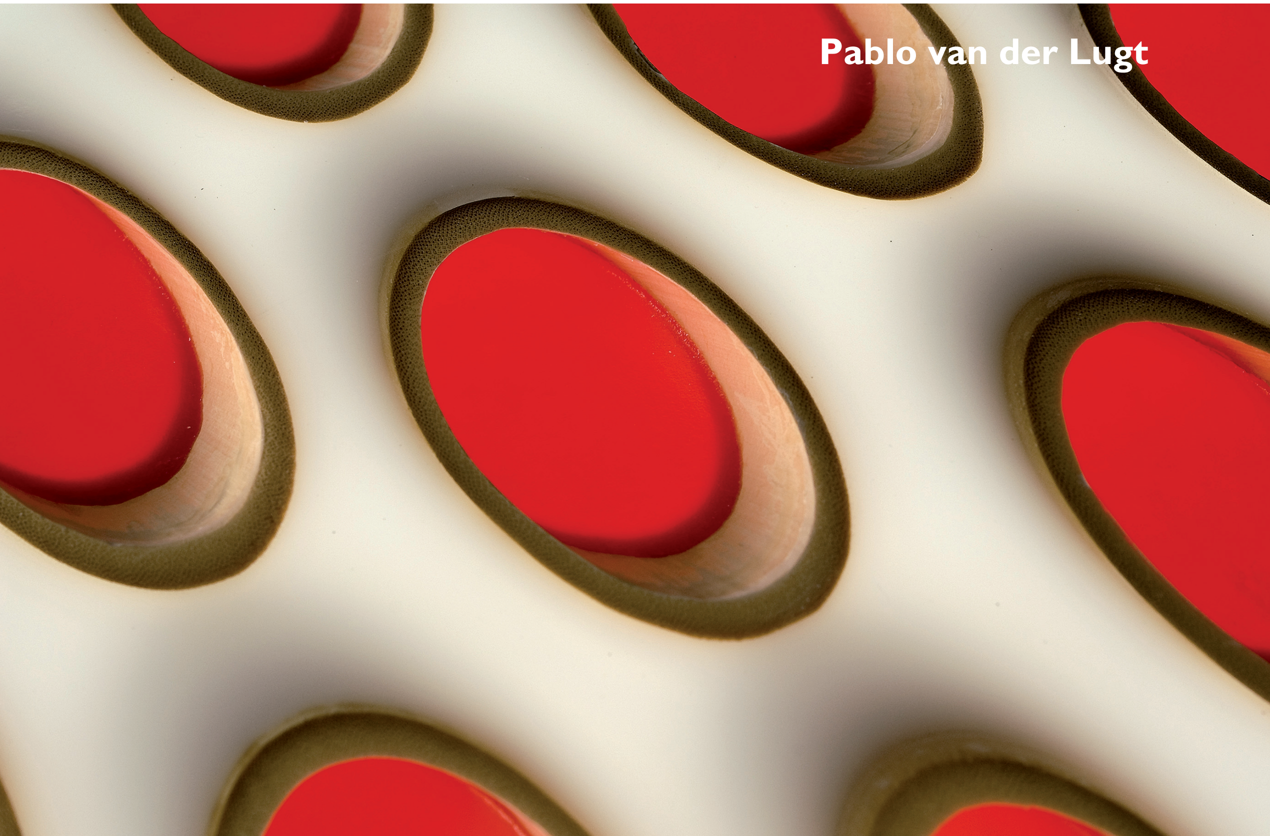
Design Interventions for Stimulating Bamboo Commercialization

Dutch Design meets Bamboo as a Replicable Model



Pablo van der Lugt

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Proefschrift

ter verkrijging van de graad van doctor
aan de Technische Universiteit Delft,
op gezag van de Rector Magnificus prof. dr.ir. J.T. Fokkema,
voorzitter van het College voor Promoties,
in het openbaar te verdedigen op dinsdag 21 oktober 2008 om 12:30 uur door

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bouwkundig ingenieur
geboren te Rotterdam

Dit proefschrift is goedgekeurd door de promotor

Prof. dr. ir. J.C. Brezet

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Design Interventions for Stimulating Bamboo Commercialization -
Dutch Design meets Bamboo as a Replicable Model
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PhD thesis Delft University of Technology, Delft, the Netherlands
Design for Sustainability (DfS) Program publication nr. 18
ISBN: 978-90-5155-047-4

Photo credentials: see colophon (back of thesis)
Published and distributed by VSSD (email: hlf@vssd.nl, website: www.vssd.nl/hlf/m015.htm)

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voor Bart

Table of Contents

PART III: CONCLUSIONS

Preface

What brings a building engineer to pursue a PhD about the commercialization of bamboo in consumer durables? For the answer to that question we have to go back to 2001, when I was in Costa Rica for an internship at the National Bamboo Project, and was first introduced to the good mechanical properties, low costs, broad applicability and especially the very high biomass production of giant bamboo stems. I was struck by the enormous potential of bamboo as sustainable raw material and at the same time wondered why bamboo was still perceived as "the poor man's timber" in Latin America, and why its use was not common in the West. It was this question which intrigued me and set me on an ongoing journey of discovery and trial & error in search of answers, which through my MSc thesis (2002) and bamboo related world trip (2003), led me to pursue this PhD research starting in October 2004 and ending exactly four years later.

Before you, in the form of this PhD thesis, lies the accumulated knowledge during this seven year-long journey, which helps to explain the background of the paradox between bamboo's potential as a fast growing renewable resource and the inability to grasp this potential, visible through the small market share of bamboo in products in the West.
During this journey for knowledge I was confronted with many changes of direction caused by new findings along the way (for an elaborate retrospective description of the seven year journey the reader is referred to the epilogue). Nevertheless, it was this pragmatic, action oriented, problem solving approach which actually provided most insights, enabling me to understand the drivers behind the aforementioned paradox, and providing the concrete tools in the form of a design intervention to actually help solve part of the obstacles causing the low market share of bamboo in products in Western Europe. Therefore, although challenging, I perceive this PhD research as a highly rewarding endeavor, which has not only contributed to new material commercialization theory in general, but unlike most academic research, has also actually made a difference in the empirical world.

As also becomes clear from the retrospective description of my PhD process in the epilogue, there are many people that have provided me with academic, financial, mental, political, organizational and other kinds of support during this PhD journey, whom I owe a lot of thanks.

First of all, I want to thank my promoter Han Brezet, who believed in me from the start, who facilitated a position as PhD researcher at Design for Sustainability (DfS), provided the optimism and encouragement to continue halfway through, and proved to be a wonderful coach at the end when writing my thesis. Han, to me, besides being my promoter you are my friend. Furthermore, I would like to thank Marcel Crul, who as daily supervisor during the first part of my research, has acted as a pragmatic, efficient and pleasant sparring partner.

Besides Han, there are a couple of people in particular that have enabled me to start my PhD research. Thank you, Hans de Jonge and Andy van den Dobbelsteen, for inspiring me and financially enabling me (Hans) to start my PhD. Thank you, Mick Eekhout, for providing me a working space and supervising me during the start of my research. Thank you, Fred Foundation, for providing me the seed money to start my research in 2004.

I am thankful to the many colleagues at the Faculty of Industrial Design Engineering (IDE) that have supported me academically during my PhD process, and in particular Joost Vogtländer for his intensive help and discussions with respect to the environmental assessments. I would also specifically like to thank Prabhu Kandachar, Henri Christiaans, Sacha Silvester, Ilse van Kesteren, Wim Poelman, Hans Dirken, Ruth Mugge, Jan Schoormans and my brother Remko van der Lugt for their academic support. Furthermore, although my attendance rate in "the aquarium" was not spectacular, I have been grateful to be part of the DfS family. Thank you (alphabetically) Ana, Daphne, Duygu, Hanna, Hitoshi, JC, Mariska, Renee, Paulson, Priscilla, Satish, Sioe-Yao, Susan, Uri and many others. At this place I would also like to thank the various students (many of which are already graduated) who have helped me in different ways during my research. Thank you (alphabetically) Mika de Bruijn, Pieter de Goede, Martijn van Loon, Eleni Soerjo, Arjan van der Vegte and Petra Veen. I would also like to thank the ladies of the Design Engineering secretariat (Astrid, Hanneke and Marijke).

I owe a lot of thanks to many persons involved in the project "Dutch Design meets Bamboo" (DDMB). Marco, it has been such a pleasure to work, discuss and brainstorm with you; I am very proud that we were able to actually materialize our "mental baby" in the form of the Bamboo Labs. José en Hanneke, thank you for taking the risk to adopt and organize the project and for the fun cooperation along the way. Arjan, thank you for multi disciplinary support during the project, and the memorable journey we had in China together. Furthermore, I would like to sincerely thank all designers that participated in DDMB for their inspirational contributions in the form of products & ideas, and their patience and cooperative attitude during the many interviews and questionnaires I forced upon them. Finally, I would like to thank the many sponsors of DDMB.

I also owe my gratitude to the dozens of persons I interviewed, or intellectually sparred with, over the past years, some of whom I would like to thank in particular. Thank you, René Zaal for your valuable and extensive contributions to my research and for facilitating my visit to China. Thank you, Jules Janssen, for having been my loyal and constructive bamboo mentor throughout my seven year journey. Thank you, Arienne Henkemans and Gerben Stegeman, for your selfless help especially in the start of my research project. Thank you, Coosje Hoogendoorn, for the inspiring discussions and realistic mindset. Thank you, Charley Younge and Pim de Blaey, for the pleasant collaboration in the beginning of my research. Thank you, Ana Cecilia Chavez and Ligia Ramirez for introducing me to bamboo….

Furthermore, I received much help during the final preparation of my thesis in the form of this book. First of all, I would like to express my gratitude to Guido van Rijn, my old English teacher and father of paranimph Paul, for proofreading and correcting my thesis. Secondly, I would like to thank Jacques Schievink and Duygu Keskin for helping me with the layout of this thesis. Finally I thank the members of my committee for the valuable suggestions they provided to improve this thesis.

At this point I would also like to thank my friends for bearing my complaints about PhD research for four years, and in particular my paranimphs Paul & Robert. Thank you, Groeneveld family, for your interest and support throughout my PhD process.

Last but not least I want to thank my fantastic family - Mank, Manu, Mara, Remko & Becky, Sam, Sarah and Ben - for always being there for me when needed, and supporting me in every possible way throughout my PhD journey. You know it has not always been easy, but your positive support has made me pull through. The same applies to you Klink; thank you for always supporting me. I am incredibly grateful to have you in my life and look forward to our future, a future in which soon you will also have your PhD, I am sure.
Finally, I want to thank my father, Bart van der Lugt, for his love, fatherhood and friendship. You always urged me to finish my PhD knowing that like for you, it will be a stepping stone toward higher goals in the future. And although I deeply regret that you will not be able to attend my defence physically, on another level I know you will be with me that day.

Bart, I dedicate this PhD thesis to you.

Pablo van der Lugt
July 16, 2008

Summary

In chapter 1 the problem analysis and main research question of this PhD research is introduced.
The importance of materials in society throughout the history of man becomes evident in the classifications provided by archaeologists for various chronological eras: the Stone Age, the Bronze Age, and the Iron Age. Each age refers to the dominant material technologies being deployed at that time, revealing the impact of materials on societal development and technological progress.
Materials also have a considerable impact on the environmental sustainability of the products in which they are used, visible through the three, interrelated, main global environmental problems: depletion of resources, deterioration of ecosystems and deterioration of human health. Due to increasing population and consumption patterns worldwide, more raw materials are consumed than can be produced globally, making especially resource depletion an urgent problem; many raw materials based on abiotic resources are expected to be exhausted within this century. Although the use of materials based on renewable resources such as timber seems a promising alternative, because of the high felling rates of available forests worldwide, especially slow growing (tropical) hardwood is under a lot of pressure and with continued unsustainable extraction can be considered a finite resource as well. Due to its good properties, bamboo - a fast growing renewable resource - could have the potential to help meet the increasing demand for raw materials, and hardwood in particular. Nevertheless, in Western Europe bamboo is still a largely unknown material with a small market share, which is caused by several obstacles found along the bamboo Production-to-Consumption System (PCS).
Due to their strategic position in the value chain, and their ability to translate a new material in a concrete value added marketable product, designers may act as champions for a material in high end consumer durable markets, such as in the interior decoration sector (i.e. furniture, interior finishing and accessories). In this action research is investigated how the commercialization of bamboo in the interior decoration sector may be stimulated through the active integration of designers as potential material champions through the main question: *To what extent can design interventions successfully stimulate commercialization of bamboo in products in the interior decoration sector in Western Europe?*

In chapter 2 the intervention proposed is further developed. Through interviews with key stakeholders in the material industry it was found that especially for small material producers, the organization of multi disciplinary design workshops, in which also other relevant value chain nodes such as material suppliers, processors, application manufacturers and retail outlets are involved, may be the most suitable strategy to actively involve designers.
The design intervention (project: "Dutch Design meets Bamboo") is divided in the core intervention (the design workshops named "Bamboo Labs," executed in Winter 2006-2007), with designers as the target group, and the extended intervention (diffusion of the results of the workshops starting in April 2007) with relevant value chain nodes downstream (at the consumption side of the PCS) as the target group. This research mainly focuses on the core intervention which targets three main obstacles found in the bamboo PCS: lack of bamboo related knowledge of designers, lack of bamboo related value chain networks around designers and lack of bamboo related design capacity, i.e. designers working with the material. The extended intervention has a broader scope and also tries to positively influence the following additional obstacles found in the bamboo PCS: lack of knowledge of additional value chain

nodes (processors, application manufacturers, retail outlets and the general public), the poor image & lack of trendiness, and the lack of value chain networks for bamboo. The overall objective of both the core- and the extended intervention is to stimulate the commercialization rate of bamboo in products, i.e. sales in final consumer markets. In the core intervention during five workshops (Bamboo Labs), 21 invited Dutch designers were challenged to develop a bamboo product with high potential for the Western European market, based on five bamboo materials: stem, Plybamboo, composite, Strand Woven Bamboo (SWB) and mats. During the Bamboo Labs the designers were supported by the Material Support System, consisting of various kinds of information material as well as interaction with experts. In the extended intervention the results of the intervention in the form of product prototypes were diffused through an exposition, publication of a bilingual book, and several activities organized around the exposition (design fair, seminar, and several lectures).

In chapter 3 the research design is introduced. Based on the elements of the intervention, and incorporating typical action research criteria, the research model was developed and operationalized into four research questions evaluating and analyzing:

1. The impact of the intervention;
2. The product prototypes developed during the intervention;
3. The bamboo materials used during the intervention;
4. The causes of the success/failure of the intervention, based on which suggestions for improvement are made.

Furthermore, the methodology used in the research is introduced in chapter 3, revealing that for data collection and analysis both qualitative and quantitative research methods were deployed.

In chapters 4 and 5 the various prototypes are evaluated.
In chapter 4 the prototypes are evaluated on their market potential and innovative character through expert appraisal. Half (11 out of 22) of the developed prototypes were evaluated by the expert panel as having a high to very high market potential, which also becomes apparent in the high number of prototypes (eight pieces) that will certainly be developed further toward commercialization. With respect to their innovative character around half of the developed prototypes were evaluated as having a high to very high level of product innovation (12 out of 22) and process innovation (10 out of 22).

In chapter 5 the environmental sustainability of the prototypes is evaluated through a thorough analysis of the bamboo materials they are made from, in terms of Eco-costs (LCA based method) at the "debit" side and annual yield at the "credit" side of the environmental sustainability balance. It was found that in terms of eco-costs bamboo materials used in Western Europe score worse than locally grown wood but in general better than wood grown in other continents (e.g. tropical hardwood) and materials made from abiotic resources (e.g. steel and plastics). In terms of annual yield (m3/ha semi finished materials) giant bamboo species such as Guadua, in general have a higher annual yield than wood (including fast growing softwood species such as Eucalyptus), a higher applicability of the yield in various applications and a higher potential for reforesting degraded land.
Although due to the higher eco-costs it is recommended to use bamboo mostly in bamboo producing countries such as India & China where demand for raw materials is growing most, in the future bamboo may also be used to help meet the demand in Western countries as well, if locally grown softwoods cannot meet the demand.

In chapter 6 the various bamboo materials used during the Bamboo Labs are evaluated by the designers participating in the intervention, based on their attitude toward the material. The evaluation showed that most bamboo materials (stem, composite, Strand Woven Bamboo and mats) are still evaluated slightly worse than softwood (Pine), and only Plybamboo can compete in terms of attitude with hardwood (Oak). However, the results did show that an increase in knowledge about the various bamboo materials leads to a significant increase in attitude toward these materials. Furthermore, many designers provided several concrete recommendations for improvement of the bamboo materials, and mentioned that several of the bamboo materials still may be optimized, and upon improvement will be evaluated better in the future.

In chapter 7 the impact of both the core intervention and the extended intervention is evaluated based on several success indicators related to the obstacles in the bamboo PCS targeted by the intervention. The results show that during the core intervention the bamboo related value chain contacts, knowledge and behavioral intention (i.e. the chance of implementation of the material within two years) of the participating designers increased significantly. The material supplier noted a strong increase in value chain contacts and generic knowledge about the various bamboo materials (Bamboo Labs functioning as "think tank") with respect to product- and process innovation. This new knowledge can be used as competitive advantage over competitors in future projects of the material supplier. Furthermore, around one third of the prototypes (eight pieces) will be further developed toward commercialization to be launched on the market in the coming years (2008-2010), while four designers already started up new design projects with bamboo individually.
The diffusion of the results (extended intervention) has led to a lot of exposure, of which a large portion was initiated by several of the participating designers themselves who turned into material champions for bamboo. Through the exposure more than one million people were reached and as a result bamboo was recognized as a trend by several acknowledged design magazines. A sample survey showed that in general the attitude and behavioral intention toward the bamboo materials increased after relevant value chain nodes downstream were exposed to the results of the Bamboo Labs. Although the extended intervention has led to a number of interested value chain contacts (mainly designers, but also some large professional clients/brands) and a couple of new design projects, the real impact of this exposure for the material supplier may only become evident in a later stage.

In chapter 8 the causes of the success of the core intervention are analyzed for the participating designers. First of all, the value of the Material Support System (MSS) for knowledge-, inspiration- and value chain contact development was evaluated, showing that depending on the personal preferences of the designer some components of the MSS were appreciated more than others, although in general the interaction component was evaluated better than the information material component. Secondly, the analysis showed that the success of the intervention in terms of an increase in behavioral intention was caused - as intended - by an increase in knowledge (through) which: 1) the attitude toward the materials increases, 2) bamboo remains more in the back of the head of the designer during material selection (mental material library), 3) bamboo is adopted in the physical material library of the designers, and 4) is perceived as a competitive advantage and time investment which the designers want to pay off. However, the analysis also showed that the increase in value chain nodes - unlike what was intended - had a small influence on the behavioral intention. The analysis revealed that existing value chain quality and a good designer - sector - material match are more important success factors toward an increase in behavioral intention, showing the crucial importance of appropriate designer selection for design interventions.

In chapter 9 the most important conclusions, recommendations and contributions of this thesis are provided. It is concluded that the intervention has been relatively successful in stimulating the commercialization of bamboo in products in Western Europe, but that the intervention has also had some additional interesting outputs besides an increase in behavioral intention. It can be concluded that the core intervention had a small reach but a high impact in terms of an increase in bamboo related knowledge, value chain contacts and behavioral intention for participating designers (of which some have turned into material champions for bamboo), and a high impact in terms of new value chain contacts, actual projects and gain in generic knowledge about the various bamboo materials for the material supplier. The extended intervention has shown that the diffusion of the results of the workshops can serve as a very strong promotion tool, generating a large amount of exposure and awareness about the potential of bamboo in the form of concrete tangible products, which leads to a small increase in attitude and behavioral intention toward the material for a large number of relevant value chain nodes. For the material supplier this exposure has yielded various value chain contacts interested in the material, some of which have already implemented bamboo in actual projects. Because of the long incubation time commercialization processes may have, the generated exposure may also result in new projects in a later stadium.

Taking into account the additional outputs of the intervention, the intervention may be evaluated as being efficient, since alternatives for the configuration of the design intervention (e.g. design competitions), with the same output requirements, were valued by the participating designers as being less effective. Furthermore, through the new material champions (designers and application manufacturers adopting the material) that have stood up as a result of the intervention, the intervention has become self propelling, showing that a one-time injection in the form of a design intervention at the right time and position in the PCS can have a sustained impact on the commercialization rate of bamboo.

Besides the general conclusions, chapter 9 sketches the theoretical contributions made through this research. The first theoretical contribution of this research lies in the greater understanding gained to what extent, and under which circumstances, designers can play a role in stimulating new material commercialization. As part of this contribution the replicability of the design intervention made in this research for other materials is substantiated. It is expected, based on the findings for the design intervention executed for bamboo, that for (small) material producers, active in the medium to high end consumer durables sector, commercializing a material that is in the development or introduction phase of the new material commercialization process, design interventions can act as an important instrument to develop (generic) knowledge, raise awareness, generate exposure and as a result stimulate the commercialization rate of a new or a lesser known material. Several suggestions are made in the recommendations on how, depending on the requirements of the commissioner, future design interventions can be configured into custom-made solutions to meet each of these outputs in the most efficient way. The second theoretical contribution of this research is in the field of research design methodology for action research based on design interventions, for which the conceptual framework developed in this research may be used as a structuring element for similar action research projects in the future.

Finally, besides the recommendations for stakeholders interested in stimulating new material commercialization in the form of custom-made scenarios, various recommendations are made in chapter 9 for further research amongst others to improve the design intervention framework in the future, including modification for use in the South. Furthermore, several recommendations are provided to the bamboo industry in general with respect to required innovations in the field of sectoral organization as well as future market development, which are suggested to be followed if bamboo is to claim its latent potential as the raw material of the future.

Pablo van der Lugt

List of Definitions

Action research	A research strategy centered around the implementation of an intervention in order to solve and understand a problem in practice in which the researcher actively participates (den Hartog and van Sluijs 1995).
Bamboo Mat Board (BMB)	A hard bamboo board made from thin bamboo strips or slivers woven into mats, pressed together with resin under high pressure and temperature.
Behavioral intention	The expected chance of implementation of a material by the designer in concrete products/projects in the near future (within two years) excluding the potential further development of the prototypes developed during the design intervention.
Carbon Footprint	The total amount of carbon dioxide attributable to the actions of an individual (mainly through their energy use) over a period of one year (Wiedmann and Minx 2007).
Commercialization	The development and successful market implementation (realization) of a new product or service by a company (Roozenburg and Eekels 1995). In this thesis product innovation is perceived as synonym for commercialization.
Composite	A material consisting of two or more different materials, which are combined to form a material that performs better than the individual components. In this thesis reference is made to bamboo composites when the resin and bamboo material are independently visible.
Consumer durables	Consumer goods that yield services or utility over time rather than those that are completely consumed at once (Baxter et al. 2003).
Corporate Social Responsibility (CSR)	A business concept whereby companies integrate social and environmental concerns in their business operations and in their interaction with their stakeholders on a voluntary basis (OECD 2006).
Ecological Footprint	A measure of how much biologically productive land and water an individual, population or activity requires to produce all the resources it consumes and to absorb the waste it generates using prevailing technology and resource management practices (WWF International 2006). The Ecological Footprint is usually measured in global hectares. Because trade is global, an individual or country's Footprint includes land or sea from all over in the world. Ecological Footprint is often referred to in short form as "Footprint".
Forest Stewardship Council (FSC)	The most important certification scheme in Western Europe for sustainably produced wood from temperate and tropical forests (Centrum Hout 2007).
Interior decoration	Categorization used in this thesis to refer to the markets of interior design, furniture and accessories.
Life Cycle Assessment (LCA)	The commonly accepted methodology to systematically test the environmental impact of a product, service or material (ISO 1997).
Material costs sensitivity	The amount of influence the material cost has on the overall cost of a product (Ashby and Johnson 2002).
Non Wood Forest Products (NWFP)	Products of biological origin other than wood, derived from forests, other wooded land and trees outside forests (FAO 2007).
North (or West)	Countries that can be categorized as developed countries (also known as industrialized countries or advanced countries), based on their industrialization level, economical development, and human development (UNDP 2006) based on the Human Development Index. These countries are usually located in the Western hemisphere.

Plybamboo	A semi finished industrial bamboo material available in various sizes, colors and thicknesses (boards, veneer) consisting of various layers of laminated bamboo strips.
Product design(er)	The whole process of the development of a new consumer product including the description of the spatial and physical-chemical form of the product and the intended means of use (Roozenburg and Eekels 1995). The product designer, referred to in this thesis as "designer", is the person who executes this process and translates requirements and needs of a commissioner into a concrete product (or service). Most product design is executed in batches or serial production using industrialized processes; therefore most product designers are "industrial designers".
Product development	The activities in which the development of the strategic course of the enterprise, the fabrication process, required machinery, product design, the production organization, logistics, marketing and the financing of the product to be developed are determined (Roozenburg and Eekels 1995). From the perspective of the designer the activity product development integrates market- and production planning with the product design activities (see above).
Production-to-consumption system (PCS)	The entire set of actors, materials, activities and institutions involved in growing and harvesting a particular raw material, transforming the raw material into higher-value products, marketing and selling the final products to consumers. The system includes the technologies used to grow and process the material, as well as the social, institutional and economic environment in which these processes operate (Belcher 1999). In this thesis the term "PCS" is used in combination with the term "value chain" (see below), which excludes the external environment that is taken into account in the PCS.
Semi finished materials	Materials in standard dimensions provided by the supplying industry, that still require some level of processing (e.g. sawing, milling) before they can be deployed in a product (Eekhout 1997).
Small and Medium sized Enterprises (SME)	Companies with up to 300 employees (Ayyagari et al. 2003).
South	Countries that can be categorized as least developed countries, developing countries or newly industrializing countries (also known as emerging economies or markets, such as India and China) based on their industrialization level (Bozyk 2006), economical development, and human development based on the Human Development Index. These countries are usually located in (sub)tropical regions.
Strand Woven Bamboo (SWB)	A very hard and dense bamboo board material made from compressed thin rough bamboo strips cast in resin.
Sustainable Development	Human development that meets the needs of the present without compromising the ability of future generations to meet their own needs (Brundtland et al. 1987).
Triple Bottom Line	The social (People), ecological (Planet) and economical component (Profit) of sustainability (Elkington 1997).
Value Chain	The full range of value adding activities which are required to bring a product or service from conception to consumption, executed by different companies during this process (Kaplinsky 2000, Porter 1985). In this thesis the term "value chain" is used in combination with the term "production-to-consumption system" (PCS), which also adds the external environment to the value chain (see above).

List of Frequently Used Abbreviations

BMB	Bamboo Mat Board
CSR	Corporate Social Responsibility
DDMB	Dutch Design meets Bamboo
DfE	Design for Environment
DUT	Delft University of Technology
FSC	Forest Stewardship Council
FU	Functional Unit
LCA	Life Cycle Assessment
MSS	Material Support System
NGO	Non Governmental Organization
NWFP	Non Wood Forest Product
PCS	Production-to-Consumption System
RIL	Reduced Impact Logging
SME	Small and Medium sized Enterprises
SWB	Strand Woven Bamboo
TRA	Theory of Reasoned Action

PART I: INTRODUCTION

1 Introduction

This chapter provides an introduction into this PhD research.
In sections 1.1 and 1.2 the problem that has led to this dissertation is explored, first focusing in section 1.1 on the relevance of renewable materials as raw material input for sustainable products, including the need to look for substitutes for (hard)wood, such as bamboo. In section 1.2 the promising potential of bamboo as a sustainable renewable material is discussed, but also the obstacles leading to the low market share of bamboo in products in Western Europe are discussed. The low commercialization rate is targeted in this research through the active involvement of designers which is explained in section 1.3. Finally, sections 1.4, 1.5 and 1.6 respectively present the classification, scope and structure of this research.

1.1 Materials and the Environment

1.1.1 The Concept of Sustainability

Sustainable Development

Because of the growing human population on our planet in combination with an increase of consumption per capita, more and more pressure is put on global resources, causing the three main interrelated environmental problems: depletion of resources, deterioration of ecosystems and deterioration of human health, and their effects (see table 1.1). Starting in the 1970s through the alarming warning from the Club of Rome, public awareness about the environment has increased drastically over the last decades. In 1987 the World Commission on Environment and Development headed by Brundtland presented the report *Our Common Future* (Brundtland et al. 1987) including the - now widely adopted - concept of sustainable development: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Although the report also emphasized the importance of decreasing the differences in wealth between developed countries in the "North" and developing countries in the "South"[1], through a better balance in economy and ecology, the term "sustainability" was first mostly interpreted in its environmental meaning.

[1] In this research, the terms "North" (or "West") and "South" refer, unless stated otherwise, to countries classified according to their industrialization level, economical development, and Human Development based on the Human Development Index as developed by the United Nations (UNDP 2006). "North" and "West" are used to refer to developed countries, also known as industrialized countries or advanced countries, and "South" is used to refer to least developed countries, developing countries or newly industrializing countries, also known as emerging economies or markets, such as India and China (Bozyk 2006).

Table 1.1: The three main environmental problems including their effects (adapted after van den Dobbelsteen 2004)

Note: There is a complex cause and effect relationship between the various problems and the effects; for more information the reader is referred to figure 4.2 in van den Dobbelsteen (2004)

Depletion of resources	Depletion of ecosystems	Deterioration of human health
Exhaustion of raw materials	Climate change	Ozone at living level
Exhaustion of fossil fuels	Erosion	Summer smog
Exhaustion of food & water	Landscape deterioration	Winter smog
	Desiccation	Noise hindrance
	Ozone layer deterioration	Stench hindrance
	Acidification	Light hindrance
	Nuclear accidents	Indoor pollution
	Eutrofication	Radiation
	Hazardous pollution spread	Spread of dust

Table 1.2: Depletion of resources - consumption and reserves of fossil energy (EIA 2007)

Resource	Fossil fuel reserves left based on most optimistic estimates (production years to go before depletion)
Oil	45 years
Gas	72 years
Coal	252 years

The Brundltand Commission also introduced the factor thinking linked to the idea of sustainable development: to give future generations the same opportunities as mankind has today, present consumption needs to be reduced by a factor of 20 compared to the reference year 1990. This number - which has been largely adopted in environmental policy making - is based on reducing the global environmental burden by half, while anticipating a doubling of the world's population and a five-fold increase of wealth per capita due to increasing consumption especially by emerging economies (van den Dobbelsteen 2004). For example, the recent targets set by the European Union for the reduction of greenhouse gases are based on a reduction by half the emissions of 1990 in 2050 (and a 20% reduction in 2020).
Although the attention for the environment is improving (see for example the EU greenhouse emission targets above), and there is a strong debate going on about strategies on the global level (e.g. Cradle to Cradle philosophy by McDonough and Braungart (2002)) about how to meet these environmental goals, the factor 20 environmental improvement has not come closer at all. In fact, environmental problems such as climate change caused by the emission of greenhouse gases such as carbon dioxide have only increased since Brundtland introduced the term sustainable development. This is caused, amongst others, by the increasing globalization including the more active involvement of new emerging economies such as India and China in the global marketplace, leading to an increase in wealth and consumption per capita of these densely populated countries. Furthermore, most environmental strategies do not yet follow an integrated approach and do not take the three main environmental problems into account in a holistic manner. For example, the acclaimed Cradle to Cradle strategy by McDonough and Braungart (2002) focuses on the re-use of raw materials, but less on energy required during this process (e.g. for recycling and transport).

In recent years, due to the increasing globalization, economical and social components - related to human rights, minimization of child labor, health & safety in the workplace, governance and management, transparency and the abolition of corruption and bribery - were integrated in the term

sustainability as well. Although globalization can potentially lead to more equality worldwide, the outsourcing of (production) activities to low income countries has in general led to the opposite, which has driven Non Governmental Organizations (NGOs), pressure groups and governments in the West to actively put sustainability in its broad form (including the social and economical component) on the agenda, resulting in an increasing emphasis on sustainable consumption and entrepreneurship.
This can be noticed in the adoption of new corporate policies by various multinationals (e.g. Corporate Social Responsibility - CSR), new business models such as the Base of Pyramid approach (Prahalad and Hart 2002), and the increasing establishment of certification schemes for products (e.g. FSC for sustainably produced wood, MSC for sustainable fish, UTZ for sustainable coffee). Companies adopting these policies and certification schemes guarantee that along the complete value chain[2] environmental, social and economical requirements with respect to sustainability are met (OECD 2006). Many cases in the media have shown that especially in the South, in which environmental and social aspects have often never been taken into account previously in business activities, it is very difficult to meet sustainability requirements (e.g. the various reports of production of clothing for the West in sweat shops in Asia).
The social, environmental and economical components of sustainability are usually referred to as "People" (the social component), "Planet" (the environmental component) and "Profit" (the economical component). These three pillars of sustainability are also referred to as "the Triple Bottom Line" (Elkington 1997).

Sustainability in Product Design

The increasing importance of sustainability has had a direct impact on product design[3] and product development[4] approaches. Every company develops products in the form of products or services that need to be sold in a profitable way to consumers who use the products. Because of the increasing importance of sustainability, new product design approaches incorporating sustainability issues have been developed in the last few decades.

Designers link the user with the product, and play a key role in the potential integration of environmental requirements over the complete life cycle in the design of their products (Charter and Tischner 2001). Products affect the environment during their complete life cycle, i.e. production, distribution, use and disposal. Unlike what was expected, in many cases, the last three phases have a larger environmental impact than the production phase. Initially, in the 1980s and 1990s this life cycle thinking was not taken into account when improving the environmental impact of products, focusing on

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[2] The value chain model was first introduced by Michael Porter (Porter 1985) to analyze the competitive position of a firm in an industry. Since then the model has been widely adopted and further developed over the decades. Kaplinsky (2000) provides the following definition: "The value chain describes the full range of activities which are required to bring a product or service from conception, through the different phases of production (involving a combination of physical transformation and the input of various producer services), delivery to final consumers, and final disposal after use." In each link of the value chain activities are deployed, which require specific knowledge and equipment that add value to the product. Value chains consist of many links that usually represent different companies.
In this thesis the term "value chain" is used in combination with the term "Production-to-Consumption System" (PCS), which also adds the external environment to the value chain (see subsection 1.2.3).

[3] Product design entails "the whole process of the development of a new product within an enterprise including the description of the spatial and physical-chemical form of the product and the intended means of use" (Roozenburg and Eekels 1995). The product designer, referred to in this thesis as "designer", is the person who executes this process and translates requirements and needs of a commissioner into a concrete product (or service). Most product design is executed in batches or serial production using industrialized processes; therefore most product designers are also referred to as "industrial designers".

[4] Besides the design of the product, product development also entails the "development of the strategic course of the enterprise, the fabrication process, required machinery, the production organisation, logistics, marketing and the financing of the newly to be developed product" (Roozenburg and Eekels 1995). From the perspective of the designer the activity product development integrates marketing (e.g. market selection) and production planning with the design activities.

end-of-pipe technologies first before shifting to new concepts such as cleaner production and eco-efficiency (Crul and Diehl 2006).
The Design for Environment (DfE) approach (also known as Eco-design) developed in the mid 1990s was the first systematic product design approach that took the whole life cycle of the product into account in order to minimize the environmental impact (Graedel and Allenby 1995). Brezet and van Hemel (1997) presented eight DfE strategies to reduce the environmental impact of products during the complete life cycle: 1) selection of low-impact materials, 2) reduction of materials usage, 3) optimization of production techniques, 4) optimization of distribution system, 5) reduction of impact during use, 6) optimization of initial lifetime, 7) optimization of end-of-life system, and 8) new concept development (functional level).
While in the beginning Eco-design focused on product improvement or redesign (Berchicci 2005), it soon became clear that with optimization on product level only a maximum factor 2 improvement of the environmental impact could be reached. In order to come closer to the required factor 20 improvement more radical changes are needed on the functional or system level (see figure 1.1).

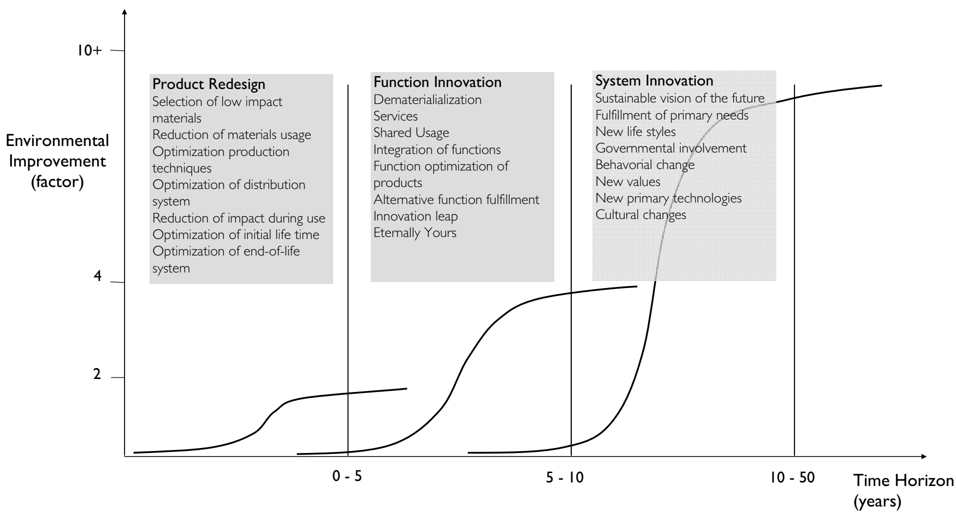

Figure 1.1: Potential level of environmental improvement in product innovation (Brezet and Rocha 2001, Crul 2003)

Innovation on the functional level not only focuses on the existing products, but zooms out to look for new products and services that can replace existing products to improve the environmental burden (e.g. shift from physical products to a dematerialized service). The Product Service System (PSS) thinking is a good example of this kind of innovation. A Product Service System can be defined as "a marketable set of products and services capable of jointly fulfilling the needs of the user" (Goedkoop et al. 1999). Various cases have shown that functional innovation can provide an environmental improvement of up to factor 4 (Mont 1999).
However, the factor 20 improvement can possibly only be reached on the system level, on the level of society as a whole. Because of its radical character, system innovation will take a lot more time than changes on minor levels, which may serve as stepping stones toward system innovation (see figure 1.1 above). System innovations can apply to different areas such as the social environment (new life styles), the infrastructure (new resource based distribution systems; e.g. the Distributed Economies philosophy) or the introduction of a new primary technology (e.g. shift to a hydrogen based energy economy) (Elzen et al. 2004).

While Eco-design has its focus on the environmental aspect of sustainability, Sustainable Product Design also integrates social and ethical considerations during the life span of the product (Charter and Tischner 2001), balancing the three elements of the Triple Bottom Line. This can be a tricky venture, because these elements can have conflicting interests; see figure 1.2.

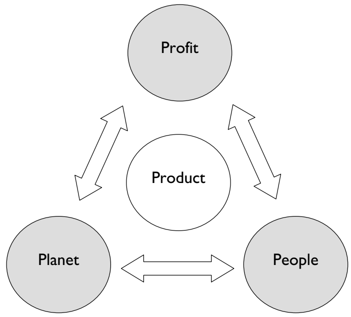

Figure 1.2: Finding the balance between People, Planet and Profit is the key issue in Sustainable Product Development (Crul and Diehl 2006)

This thesis focuses on the stimulation of a relatively unknown renewable material in the West (bamboo) because of its expected environmental sustainability for use in products in Western Europe, and does not actively take into account the potential value of the material in contributing to the socio-economic component of sustainability (Sustainable Product Design). Therefore, the subsection below about the role of materials focuses on the environmental sustainability.

1.1.2 The Impact of Materials on the Environmental Sustainability

The importance of materials in society throughout the history of man becomes evident in the classifications provided by archaeologists for various chronological eras: the Stone Age, the Bronze Age, and the Iron Age. Each age refers to the dominant material technologies being deployed at that time, recognizing the impact of materials on societal development and technological progress (Musso 2005). We may not be aware of it, but materials play a crucial role in our daily lives, or as Ashby and Johnson (2002) put it: "We live in a world of materials; it is materials that give substance to everything we see and touch." Through our senses, materials also have a large impact on the experiences people have with products (Jordan 2000). The materials used as input in products and buildings are usually referred to as "semi finished materials" or "trade materials" [5], referring to materials in standard dimensions provided by the supplying industry, that still require some level of processing (e.g. sawing, milling) before they can be deployed in a product (Eekhout 1997). Examples of semi finished materials or trade materials are glass sheets, MDF boards or steel I-beams in standard dimensions.

As seen above, the environmental impact of a product depends on all the life cycle stages of the product. Intuitively one expects that the environmental impact of a material has the most influence on the production phase of a product caused by raw material provision and factory production. However, the choice for a specific material in a product also has a strong and direct impact on other aspects of the product in other stages of the life cycle, such as the processing stage (e.g. impact on energy impact

[5] Eekhout (1997) identifies the stages a material goes through before becoming a trade material as "raw material", "material" and "composite material". A raw material is a material before purification or processing, and as such is not directly applicable in industries (e.g. ore, clay, oil, cut trees). After purification or first rough processing a "material" is ready for industrial processing (e.g. cement, sand, logs, steel). If this "material" is not homogeneous and consists of two different materials (e.g. fiber reinforced polyester, reinforced concrete) it is referred to as "composite material". After industrial processing the trade material or semi finished material is developed. When the term "material" is used in the remainder of this thesis, it refers to semi finished materials.

and efficiency of production technology), use phase (e.g. durability during life span) and the end-of-life phase (e.g. possibility of recycling or biodegradation at the end of the life span). This shows that materials are intrinsically linked to every stage of the life cycle of a product. Furthermore, materials come early in the value chain: Because they stand at the base of many kinds of applications, materials usually serve as the first competitive point for differentiation in the value chain (Musso 2005). Finally, no matter what the level of system- or functional innovation will be in the future, unless the product is a service, materials will always be needed to materialize the new product.
If we look at the three main environmental problems introduced earlier, the important role of materials on the environment also becomes evident:

Depletion of Resources
Directly, through the extraction of renewable biotic (e.g. timber) and finite abiotic (e.g. minerals, oil) raw materials, but also indirectly (fossil fuel needed for the production of materials), materials contribute to the depletion of resources. Taking into account the high raw material consumption of industrialized countries per capita, which lies in the range of 45-85 tons per year[6] [7] (Adriaanse et al. 1997, Dorsthorst and Kowalczyk 2000), and the expected population and consumption growth in the coming decades (see factor 20 explanation before) due to the transition of emerging economies (e.g. India, China[8]) into industrialized countries adopting Western production and consumption patterns, it becomes clear that resource depletion is becoming an urgent problem for society. More than 70 percent of the raw materials that are used as input for industrial processes in the Netherlands are extracted from other places in the world (Adriaanse et al. 1997), showing that depletion of resources is truly a global problem.
There are also various experts that believe that resource depletion of abiotic resources such as minerals is not an immediate concern, and can be tackled through increasing production and exploration capacity as well as through technological advances, in particular through recycling (Tilton 2002).
However, late studies (Cohen 2007, Gordon et al. 2006) in which current mineral consumption figures (based on a steady demand, an equal production- and consumption rate and including win-back percentages through recycling) are projected to the future indicate the contrary (see table 1.3), predicting depletion times of many important minerals (e.g. lead, zinc, indium) within half a century. In the figures in table 1.3 the increasing demand by emerging economies and developing countries in the future is not integrated, which suggests the urgency of the problem is even higher. Gordon et al. (2006) warn that: "Virgin stocks of several metals appear inadequate to sustain the modern 'developed world' quality of life for all of Earth's people under contemporary technology," and although recycling rates may increase in the future, a large amount of the extractable metals in the Earth's crust such as copper (26%) and zinc (19%) are already lost in non-recyclable wastes (Gordon et al. 2006).

[6] For example, in Japan 14 tons of ore and minerals need to be mined and processed per capita annually to meet demand for cars and other other metal-intensive products (Adriaanse et al. 1997).
[7] In the building industry in the Netherlands alone, 120 million tons of raw materials are required annually (Dorsthorst and Kowalczyk 2000), of which at least 86% need to be primary (van den Dobbelsteen 2004).
[8] For example, in China in the coming decade around 400 million new houses need to be built in the countryside, which if built in the traditional brick rural housing type would deplete 25% of China's top soil layer of agricultural land, not even taking into account the enormous amount of coal required for brick production (McDonough and Braungart 2002).

Table 1.3: Depletion times in years (reserve base/annual global consumption) of several minerals assuming global consumption equals global production (Cohen, 2007)

Mineral	Estimated depletion time (years)
Aluminium	1027
Chromium	143
Copper	61
Gold	45
Indium	13
Lead	42
Nickel	90
Platinum	360
Tin	40
Uranium	59
Zinc	46

Table 1.3 shows that basically man is extracting and consuming more resources than planet Earth can regenerate. A useful indicator, which makes this deficit quantifiable in numbers, is the Ecological Footprint, which is defined as "a measure of how much biologically productive land and water an individual, population or activity requires to produce all the resources it consumes and to absorb the waste it generates using prevailing technology and resource management practices" (WWF International 2006). Besides material resources, the Ecological Footprint also includes global food-, water- and energy production and consumption, including the required capacity to absorb the wastes emitted in energy generation (nuclear waste and CO_2 emissions during fossil fuel combustion) related to the environmental problem of ecosystem deterioration (see below).

In 2003 the Ecological Footprint was 14.1 billion global hectares, whereas the productive area was 11.2 billion global hectares, which means man is currently consuming more than 1.25 times the amount of resources the earth can produce. With the earlier mentioned population and consumption growth projections, the Ecological Footprint is set to double[9] by 2050 (WWF International 2006). For some time the earth can cover this global "ecological deficit" or "overshoot" by consuming earlier produced stocks. However, when these stocks run out, various resources will become scarce which may result in resource based disasters and conflicts. To bring the Ecological Footprint to a sustainable level, measures should be taken on both the demand and supply side (see figure 1.3). On the demand side the global population, the consumption per person and the average footprint capacity per unit of consumption (i.e. amount of resources used in the production of goods and services) determine the total demand of resources. At the supply side the amount of biologically productive area, and the productivity of that area, determine the amount of resources that can be produced globally to meet this demand.

[9] Note that in late studies (Nguyen and Yamamoto 2007) the Ecological Footprint is adjusted to also include consumption of abiotic resources, revealing even larger problems with respect to resource depletion than the original method.

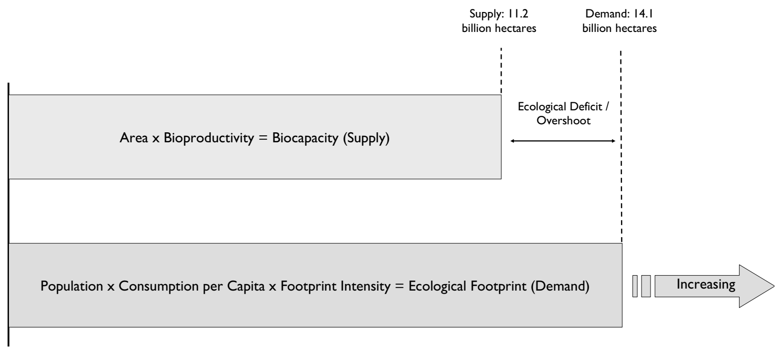

Figure 1.3: Gap between supply and demand between bioproductivity and Ecological Footprint (figure adapted after WWF International 2006)

Ecosystem Deterioration

Next to resource depletion, the high raw material requirements of industrialized countries also impact ecosystems, since these raw materials need to be extracted (e.g. landscape deterioration, erosion), processed and transported (e.g. emissions of greenhouse gases causing climate change), and ultimately disposed of as waste (e.g. toxification, acidification). Depending on the material in question the influence of the extraction and manufacturing of materials on ecosystem deterioration will differ. For example, heavy metals may have a stronger environmental impact during the use and end-of-life phase due to their toxicity and the lack of biological degradability of these materials. Also biotic raw materials such as timber will - in the case of unsustainable management - damage the ecosystem from which the wood is harvested.

Deterioration of Human Health

Some materials, such as the earlier mentioned heavy metals, can be harmful to human health. Also, biotic materials such as timber can be harmful to human health, for example, when they are impregnated with poisonous preservatives for a longer life span of the timber.

From the above it becomes clear that directly or indirectly, materials have a large influence on the environmental impact of products, now and in the future. Although the social component of sustainability lies outside the scope of this thesis, it is important to understand that many raw materials are extracted in developing countries and emerging economies and - in the case of local value addition through processing and product development - yields many opportunities for socio-economic development locally, potentially contributing to sustainable development. However, most value addition to materials still takes place in developed countries (e.g. petroleum extracted in developing countries being processed to plastics in developed countries), or in the case of local production, usually flows back to owners in industrialized countries.

1.1.3 The Potential of Renewable Materials

Above, the important impact of materials on the environmental burden of products was explored. One of the main strategies toward environmental improvement with respect to material use during product design is the deployment of renewable materials, as also proposed in the DfE strategy wheel (DfE strategy one) by Brezet and van Hemel (1997), and the Three Step Strategy[10] developed by the research group Urban Design and Environment at Delft University of Technology (DUT). Due to the increasing depletion of finite abiotic raw materials renewable resources are gaining an increasing amount of attention due to their ability to regenerate and thus help meet demand for materials in a potentially sustainable manner.

However, besides for input in raw material production, renewable resources may also be used for food or energy production (biomass, biofuel). As a result, the available 11.2 billion global productive hectares compete with each other to produce either food, energy or raw materials, which has led to much controversy worldwide. For example, using available global hectares for the production of natural crops for biofuels impedes the use of these crops for food (or raw material production), which has resulted in strong upward pressure on food prices worldwide (Worldbank 2008). Furthermore, recent studies (e.g. Searchinger et al. 2008) indicate that biofuels, stimulated until recently in various governmental policies to substitute fossil fuel because of their presumed ability to reduce emission of greenhouse gases, may even increase emission of these gases on the global level due to additional emissions caused by conversion of forests and grasslands to cropland. The example above shows that renewable resources per se are not automatically environmentally sustainable, and that global synchronized policies are required if the available productive hectares are to meet the future global human demand for food (and water), energy and raw materials.

For raw material production, wood has always been the best known renewable material. However, because of the high rate of harvesting from available forests worldwide, this renewable resource is under a lot of pressure and with continued unsustainable extraction it can be considered a finite resource as well. Below, the state of the art of available forest resources is assessed, before reviewing the potential of other renewable materials for raw material production.

Wood as a Renewable Material

Wood is derived from forests. The total area of forests worldwide is estimated to be just below 4 billion hectares, of which around 0.7-1.3 billion hectares is actively involved in wood production (FAO 2006).

For centuries, the total area of forest worldwide has decreased steadily. Although deforestation still continues at an alarmingly high rate of 13 million hectares annually, due to natural expansion, plantation development, and landscape restoration, the net loss of total forest areas in the period from 2000-2005 is "only" 7.3 million hectares per year (almost twice the size of the Netherlands). This means that the net loss of forest area is decreasing compared to the periods before, with a net loss of forest area of 15.6 million hectares annually from 1980-1990 and 8.9 millions of hectares per year from 1990-2000 (FAO 2001, FAO 2006).

[10] The Three Step Strategy entails the following steps to increase a more conscious use of our resources (Duijvestein 1997):
1. Avoid unnecessary demand for resources
2. Use resources that are unlimited or renewable
3. Use limited resources wisely (cleanly and with a large return)

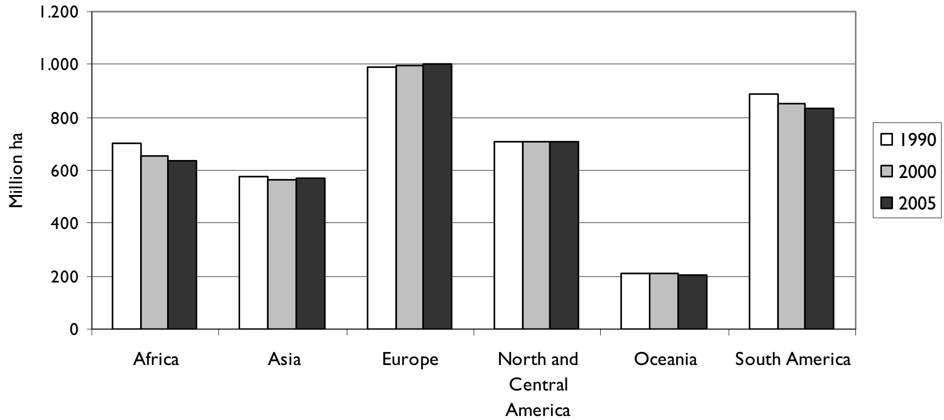

Figure 1.4: Trends in forest area by region[11] 1990-2005 (FAO 2006)

Besides the development of new plantations (+2.8 million hectares per year in 2000-2005), natural expansion, and landscape restorations, another cause of the decrease in net forest loss is the increase of sustainable forest management practices in which the forest from which the wood is derived is kept largely intact. Various schemes exist certifying the sustainability of the chain of custody of wood products. The Program for the Endorsement of Forest Certification schemes (PEFC) and the Forest Stewardship Council (FSC) schemes are most popular in the EU and the USA. The PEFC scheme mostly presumes coniferous wood, whereas FSC has a relatively large share of certified tropical forest. Demand of certified wood is strongly growing, especially in North America and the EU. This is mainly due to the strong lobby of public organizations, NGOs and governments, driven by the growing importance of sustainability. Besides the Planet component, the People and Profit elements of sustainability are also of importance in sustainable forest management certification schemes. The total area of certified forest in 2007 is estimated at just over 300 million hectares (with only 8% in (sub)tropical regions), with a growing rate of approximately 10% annually (Centrum Hout 2007).

Table 1.4: Certified forest area worldwide per certification scheme, million ha (Centrum Hout 2007)

	2000	2001	2002	2003	2004	2005	2006	2007
FSC	22.17	24.10	31.07	40.42	46.94	68.13	84.29	90.78
PEFC	32.37	41.06	46.31	50.85	54.96	185.16	193.82	196.00
SFI	11.33	22.00	32.37	41.36	45.59	> PEFC	> PEFC	> PEFC
ATFS	-	-	10.50	10.50	10.50	10.50	10.50	10.50
CSA	5.03	5.94	14.44	28.41	47.38	> PEFC	> PEFC	> PEFC
MTCC	-	-	-	-	4.74	4.79	4.73	4.73
Other	-	-	-	-	-	1.18	1.19	1.18
Total	**70.90**	**93.10**	**134.69**	**171.54**	**210.11**	**269.76**	**294.53**	**303.19**

FSC - Forest Stewardship Council; PEFC - Program for the Endorsement of Forest Certification schemes; SFI - Sustainable Forestry Initiative; ATFS - American Tree Farm System; CSA - Canadian Standards Association; MTCC - Malaysian Timber Certification Council. In 2005 SFI and CSA were integrated in the PEFC system

[11]FAO (2006) included Northern Asia in the region of Europe (see figure 1.1 on page 8 in the Global Forest Assessment 2005) explaining the high forest area in Europe as a relatively small continent in figure 1.4.

Although the total area of certified forests is growing, because of the high requirements resulting in complex logistics and management systems needed during the value chain, the availability of certified wood is low, whereas the demand is very high and is expected to remain growing, resulting in high prices of certified wood. A global market survey by FSC reported demand exceeding supply by at least 10 million cubic meters of round wood for hardwood (FSC 2005).

The Situation in (sub)Tropical Areas

From figures 1.4 and 1.5 it becomes clear that while the total forest area increases or stabilizes in more temperate regions (North America, Europe, Northern and Central Asia), in tropical regions around the equator in general the forest area still decreases. This is a problem since the forests with the most biodiversity and biomass per hectare are located mostly in this (sub)tropical area (FAO 2006). Deforestation, especially of tropical forests, is therefore also a major contributor to carbon dioxide emissions, accounting for around 20% of total emissions worldwide (Knapen 2007).

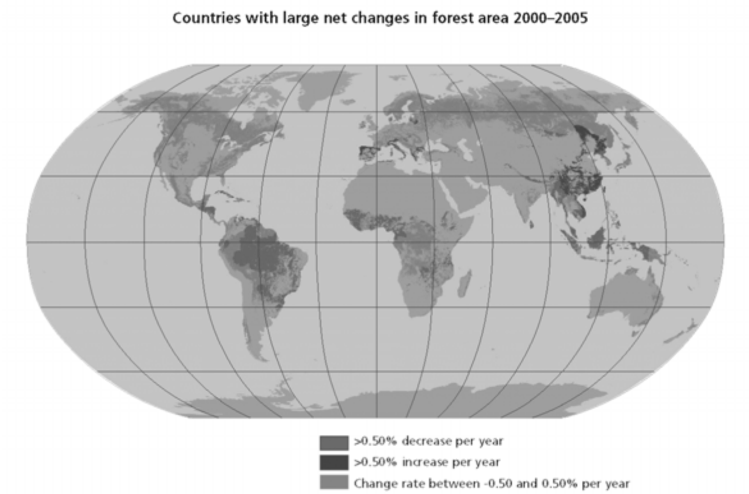

Figure 1.5: Changes in forest area worldwide 2000 - 2005 (FAO 2006)

The causes of tropical deforestation are complex and many. Various studies show that although wood production is an important factor in deforestation, deforestation is also caused by slash-and-burn agriculture by poor peasants looking for new ground and fuel wood, permanent agriculture (mainly converting forest in grasslands for cattle breeding) and the development of large civil and infrastructural projects (van Soest 1998). Depending on the region, the importance of these causes may differ. Van Soest (1998) finds that depending on the region, wood production may account for approximately 10-20% of tropical deforestation, while the conversion of forest into agricultural land is perceived as the most important direct cause of tropical deforestation, of which slash-and-burn agriculture and permanent agriculture may account for up to 40% each. The conversion of forest into crop or cattle land is a good example of the Ecological Footprint becoming too large; to fulfill demand for food, man is turning to forest land reserves (required for housing, fuel and as carbon sink).

While the total forest area in the (sub) tropics is 858,842 million hectares, only around 15% has a forest management plan, and only 4% is certified (Centrum Hout 2007, ITTO 2004). Around 65% of the total area of certified forest in the tropics falls under the FSC regime (Helpdesk Certified Wood 2008). The largest area of certified forest in the (sub)tropics can be found in Central and South America (12.45

million hectares in January 2008), followed by Asia (5.62 million hectares) and Africa (3.96 million hectares).
About 46% of the total forest area in the (sub)tropics (397.33 million hectares) is used for timber production (plantation and natural forest), of which almost 30% has a forest management plan, and 6.3% is certified (Centrum Hout 2007). Of the total productive area in the (sub)tropics, around 11% (44 million hectares) consists of plantations (FAO 2006) of which 11.1% (4.9 million hectares) is FSC certified (FSC 2008). The combination of the high biodiversity and the high decrease rate of natural forests in tropical areas, largely explains why environmental groups and governments in the West stress the need for guaranteed sustainable production of tropical timber. However, as mentioned above, supply cannot keep up with demand, especially for slow growing tropical hardwood.

The paragraph above points out that although wood is a renewable material, the sources of this material (forests) are steadily decreasing over time. Especially in tropical regions the total forest area is decreasing rapidly, a.o. due to unsustainable harvesting. The large demand of tropical hardwood because of its good mechanical & aesthetic properties and durability advantages for use outdoors, in combination with the slow growing speed of trees that provide tropical hardwood, makes depletion of especially tropical forests an urgent problem.

Alternatives for Wood: Non Wood Forest Products

Besides wood there are various other renewable resources that can be used to produce semi finished materials. These renewable materials, such as bamboo, rattan, sisal, cork and reed, fall under the umbrella of the term "Non Wood Forest Products" (NWFP). The Food and Agriculture Organization of the United Nations (FAO) defines NWFP as "products of biological origin other than wood derived from forests, other wooded land and trees outside forests (FAO 2007). The term encompasses all biological materials other than wood which are extracted from forests for human use, including edible and non-edible plant products, edible and non-edible animal products and medicinal products (e.g. honey, nuts, pharmaceutical plants, oils, resins, nuts, mushrooms, rattan, cork)." Although most NWFPs predominantly have value for local trade, some are important export commodities for international trade. Bamboo and rattan are considered the two most important NWFPs (Belcher 1999).
Still, whereas wood as a renewable material has been mass adopted in Western markets, many other renewable materials belonging to the NWFP-group are not well known and can hardly be found in products in these countries, while some of them could have considerable potential to contribute toward sustainable development, both in the country of production and in the country of consumption. In this thesis the potential of bamboo, as one of these relatively unknown renewable materials, is explored because of its high potential for regeneration and thus also for raw material production.

1.2 The Latent Potential of Bamboo

1.2.1 Introduction about Bamboo

Virtues of Bamboo

Because of its high growth rate and easy processing, bamboo is a promising renewable resource that could potentially especially substitute for slow growing hardwood. Bamboo's good mechanical properties, low costs, abundant availability in developing countries and potential use in a multitude of applications show the potential of this versatile resource for income generation through commercialization of the resource. Moreover, because of its rapid growth and extensive root network, bamboo as a plant is a good carbon fixator, erosion controller and water table preserver. The bamboo plant is an eminent means to start up reforestation, as the plant often has a positive effect on groundwater level and soil improvement through the nutrients in the plant debris. In the box below a more general introduction about bamboo as a plant is provided.

Box: Bamboo as a Plant

From a botanical point of view, bamboo belongs to the grasses, the Graminea, and is therefore not a tree. Bamboo is a collective name of all botanical species. Although the complete taxonomy of bamboo is still evolving, current estimations are that around 1000-1500 different species of bamboo exist. There are considerable differences between species (see figure 1.6) in size, color, node distribution and configuration, mechanical properties and climatic preferences. Some giant species might reach up to 30 meters with cross sections of up to 30 centimeters per stem, whereas some species might not reach above 1 meter in height and 1 centimeter in diameter. Approximately 50 bamboo species are considered to be very suitable for use as construction material.

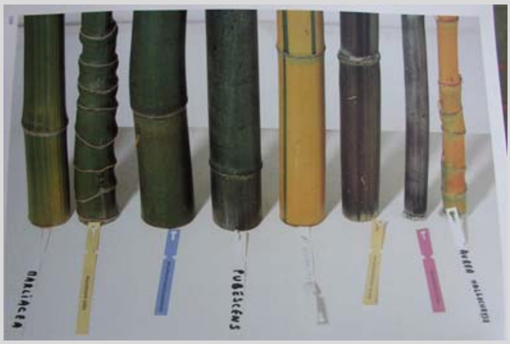

Figure 1.6: Various bamboo species

Bamboo is mainly distributed in countries with a tropical to subtropical climate. In Western countries bamboo is mostly known as a garden plant. Some smaller species can even withstand temperatures below zero, such as the species that live in the Himalaya mountains. Giant bamboo species, which have the most potential for industrial processing and economic development, mainly derive from (sub)tropical areas, usually in developing countries or emerging economies. In China and India the largest stocks of the worldwide 20 million hectares of bamboo forest can be found.

Figure 1.7: The bamboo species Phyllostachys Pubescens (Moso) can reach up to 15 meters (left) and grows abundantly in China (right), where a couple of million hectares of bamboo are available

Although the chemical compositions of bamboo and wood are practically identical (Liese 1998), the differences in anatomical composition are considerable. For instance, bamboo has no rays or knots. Furthermore, the bamboo stem is hollow compared to the solid stem of trees. In the cross section of a bamboo stem we can identify cellulose fibers (40%), vascular bundles (10%), and the in-between parenchyma tissue (50%), which largely consists of lignin (see figure 1.8). The fibers and the parenchyma tissue together function as a composite material: the cellulose fibers make the bamboo strong, functioning as the reinforcement in the matrix of the thin-walled parenchyma cells, similar to steel in reinforced concrete. The fibers run in a longitudinal direction around the vascular bundles. The outer wall of the stem consists of a thin silica layer of 0.25 mm that protects the stem. The outer and inner walls of the stem are also covered with a waxy layer. The solid patches (see figure 1.8) are the cross-sections of the cellulose fibers. The distribution of fibers increases from the inside toward the outside, where they are most needed with respect of moments of force that need to be absorbed caused by mechanical loads. After about 4 years, the walls of the fiber cells have become mature and solid. Only then is the bamboo stem ready to be felled for construction purposes. For applications in which the fiber function is less important (such as bamboo pulp for the production of paper), the stem can be felled at an earlier stage.

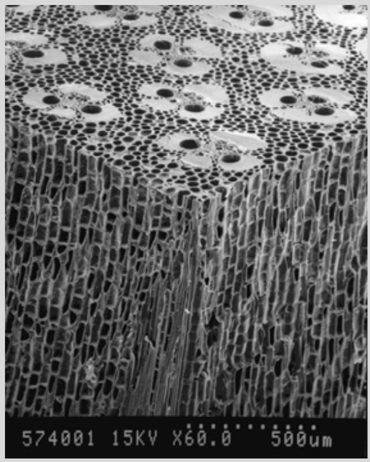

Figure 1.8: Microscopic three dimensional representation of bamboo tissue consisting of parenchyma cells, vascular bundles (black) circled by fibers (light and solid)

The greatest advantage of bamboo is undoubtedly its unparalleled growing speed. Bamboo shoots in tropical countries grow up to 30 meters within six months. The record growth speed measured for a bamboo stem is 1.20 meters per day (Martin 1996), which directly shows the potential of bamboo to substitute slower growing wood species in terms of annual yield. Due to the high growing speed of bamboo, plantations are expected to be proficient in sequestration of carbon dioxide (CO_2), one of the major contributors to the greenhouse effect, causing global warming. During their growth, plants convert CO_2 through photosynthesis into plant carbohydrates, and emit oxygen in the process. The carbon makes up approximately half of the biomass (dry weight) of the renewable raw material. There is an ongoing discussion about the question whether the carbon sequestration capacity of bamboo is larger than that of fast-growing softwood trees. In appendix J this topic is further elaborated upon.

Besides the many traditional applications for local markets and low end export markets in which bamboo in its natural form (stem) is usually used, through industrial processing a wealth of new bamboo materials, such as Plybamboo and Strand Woven Bamboo have become available since the 1990s, which can be used for applications in high end markets in the West as well. In figure 1.9 it can be seen how various kinds of bamboo products relate to each other in terms of production technology on the axis traditional - industrial/advanced (bottom of figure). For more examples of innovative and surprising bamboo applications (e.g. bamboo bikes, bamboo food, and bamboo textile), the reader is referred to van der Lugt (2007).

Figure 1.9: Range of bamboo applications possible, based on traditional and advanced technologies (Larasati 1999)

In this subsection, the potential of bamboo will be explored for giant bamboo species from (sub)tropical regions suitable for industrial processing.

Industrial Bamboo Materials

Through industrial processing of bamboo virtually anything that can be made from wood can also be developed in industrial bamboo materials. The industrial processing of bamboo and in particular the lamination of bamboo strips into boards (Plybamboo), which is mostly applied in flooring, furniture board, and veneer, started in China in the early 1990s. China is still the leading industrial bamboo producer worldwide and supplies more than 90% of bamboo flooring in Western Europe (van der Lugt and Lobovikov 2008). In the main introduction figure of chapter 5 on page 116 in the form of a collage, the production process of Plybamboo is depicted in short form (for the complete production process the reader is referred to appendix I). Besides flooring and board materials, China is also a major producer of woven bamboo mats that can be used, for example, in blinds.

Figure 1.10: Plybamboo is available in various colors and sizes

In the past few years, many innovations in the field of production technology have led to the development of new industrial bamboo materials with different properties and possibilities, such as

Bamboo Mat Board (BMB), Strand Woven Bamboo (SWB), Bamboo Particle Board, and various experiments with Bamboo Composites.
BMB is made from thin bamboo strips or slivers woven into mats to which resin has been added. Pressed together under high pressure and high temperature, the mats become extremely hard boards, which during pressing can even be put in molds to be processed into corrugated boards.


Figure 1.11 (left): Coarse woven mats form the building stones for BMB
Figure 1.12 (right): Various kinds of bamboo board material including BMB (right side of picture)

SWB is a new bamboo material made from thin rough bamboo strips that under high pressure are glued in molds into beams. An interesting feature of SWB is that there are no high requirements for input strips which means that, unlike the production of Plybamboo, a large part of the resource can be used, thereby utilizing the high biomass production of bamboo to the maximum (see for more information section 5.2). Due to the compression and addition of resin, SWB has a very high density (approximately 1080 kg/ m3) and hardness, which makes it a material suitable for use in demanding applications (e.g. staircases in department stores).

Figure 1.13: Application of SWB in a stairway

Recently, new higher resin content versions of SWB were developed apt for outside use[12], which could make SWB a suitable alternative for scarce tropical hardwood species such as Bangkirai. In table 1.5 the hardness of Plybamboo and SWB flooring are compared with various kinds of wooden flooring.

[12] The latest durability tests executed by SHR (Wood Research Foundation Netherlands) under the commission of Moso International b.v. have revealed that the outdoor version of SWB (higher resin content) falls in durability class I-II (durable - very durable outdoors), which is on par with the most durable tropical hardwood species such as Teak and Azobé. However, the tests were made in laboratory circumstances and focused on the core material and did not include tests on the resistance of the surface of the material to fungi- and UV degradation, nor on the behavior of the material during use. As a consequence more research is still needed about the suitability and competitiveness of SWB for outdoor use (Zaal and van der Vegte 2008).

Table 1.5: Janka hardness ratings for wood and bamboo flooring (after de Bruijn 2007a)

Wood/bamboo material	Janka Hardness (lbf) [13]
Douglas Fir	660
Yellow Pine	690 - 870
Teak	1000
Black Walnut	1010
Plybamboo (carbonized)	**1180**
Red Oak (Northern)	1290
White Oak	1360
Australian Cypress	1375
Plyamboo (natural)	**1380**
Hard Maple	1450
Wengé	1630
Brazilian Oak	1650
Merbau	1925
Burma Mahogany	2170
SWB	**2800**
Camaru (Brazilian Teak)	3540
Brazilian Tiger Mahogany	3840

Other new industrial bamboo materials such as Bamboo Particle Board and Bamboo Plastic Composites are still in the earlier stages of development. These materials are based on copying existing techniques from the wood industry, and are not yet widely available commercially. For an overview of available industrial bamboo materials, the reader is referred to Appendix 1 in van der Lugt and Otten (2007).

Besides the bamboo materials being based on industrial production technologies mentioned above, there is also an array of materials available based on non-industrial technologies. Well known examples of non-industrial bamboo materials are the complete bamboo stem and strips derived from the stem. In the box "Bamboo Stem as a Building Material in the West" in subsection 9.3.3 an introduction about the use of the bamboo stem as a building material can be found. Another material based on a non-industrial technology that can be seen in products in the West is the coiling technique, derived from Vietnam, in which long, thin bamboo slivers are rolled tightly by hand into a mold and then glued together.

Figure 1.14: Coiling is a non industrial processing technique that can create surprising effects; chair design (right) by Jared Huke

[13] The Janka test is a test method following ASTM (American Society for Testing and Materials) standards which is often used to establish the hardness of a wood species; it measures the force (in pounds force - lbf) required to embed a 11.28 millimeter steel ball into wood to half its diameter.

The Sustainability of Bamboo

Because of its widespread availability in developing countries, bamboo offers many opportunities for sustainable development, especially in developing countries where this development is needed most. Furthermore, bamboo can easily be processed manually or industrially, and due to its abundant availability has a low cost.

At an environmental level (Planet), due to its high growing speed, bamboo is expected to be an environmentally friendly material. Environmental impact studies based on Life Cycle Assessment (LCA) previously executed by the author have shown that the use of bamboo stems of the *Guadua spp.* species from Costa Rica used as a structural element (beam, column and rail) in a walking bridge in the Netherlands has led to a strong environmental improvement compared to common building materials such as steel, concrete and wood (van der Lugt et al. 2003). Although there is an extensive production process (many production steps), the environmental advantage for industrial bamboo materials such as Plybamboo was shown in the study to be on a similar level as most wood-based boards; due to the high resource production industrial bamboo materials may still serve as an excellent alternative compared to hardwood products (note that the environmental impact of bamboo materials will be assessed again in a more extensive manner in this research and presented in chapter 5).

An additional advantage of industrial bamboo materials is that because of the labor-intensive process much value is added. Therefore, industrial bamboo materials can make a greater contribution in terms of employment than the development of products made from the bamboo stem, usually based on handicraft techniques with less value added. The cases of bamboo stem (strong in Planet) and industrial bamboo materials such as Plybamboo (potentially stronger in People and Profit) also provide an excellent example of the conflicting character the various pillars of sustainability (the Triple Bottom line) can have (see figure 1.2).

Despite its evident virtues, bamboo is still regarded as an inferior material or as "poor man's timber" in developing countries (von Vegesack and Kries 2000). The ready availability and affordability of bamboo have had a negative effect in these countries. As many poor people live in bamboo houses, bamboo is easily associated with poverty. Although bamboo houses are very earthquake-resistant, many people in developing countries have, for reasons of social status, a preference for much less earthquake-resistant concrete dwellings.

Bamboo as an Alternative for Hardwood

In the previous subsection it was found that an increasing use of renewable raw materials may be necessary to bring down the Ecological Footprint to a sustainable level. However, we also found that at the moment, due to increasing consumption and population numbers, raw material demand is set to increase while supply diminishes. This also applies for timber, as the increasing consumption figures (see table 1.6), and the decreasing forest areas (see previous subsection), especially for tropical timber, show. Also, since emerging economies started to raise their consumption patterns (e.g. China has raised its tropical hardwood import to 7.6 million m3 in 2003, being by far the world's largest importer of tropical logs), the pressure on timber will continue to grow.

Table 1.6: Consumption figures of primary wood products in the EU in 2004, 1000 m3 (ITTO 2004)

Wood	Total	Growth % 2000-2004
Logs	285,878	+7
Sawn timber	88,994	+6
Plywood	5,694	+0
Veneer	1,753	+15

Due to the expected higher annual yields, and the ability of bamboo plantations to be established on areas of land where trees may not survive (e.g. degraded hill slopes), bamboo may be a promising alternative to help meet the increasing demand in raw materials and timber in particular. Thus bamboo may play an important role at the supply side (area x bioproductivity = biocapacity; see figure 1.3) of the Ecological Footprint, to meet future human needs for fibers and timber used as input for housing, clothing, interior finishing, furniture, household products and other consumer durables.[14]

Figure 1.15: Bamboo can also grow well on steep slopes

Because of the many hard fibers present in bamboo, industrial bamboo materials such as Plybamboo and SWB in general have competitive mechanical (see table 1.5 above) and aesthetic properties to hardwood products and better mechanical properties than softwood (coniferous wood), whereas the annual production volumes are expected to be higher because of the high growth rate of bamboo.[15] Generalizing, it seems to come down to the following: Bamboo grows faster than softwood, but has hardwood properties. Since industrial bamboo materials are still priced more or less at the same level as hardwood materials (which is higher than most softwoods), the best bet for bamboo is to initially target the markets in which hardwood is used.

In the light of the increasing demand for raw materials, including timber, and the decreasing forest area worldwide, bamboo based materials can therefore serve as an additional alternative to fill the gap between supply and demand of sustainably produced hardwoods. This may apply to both hardwood from temperate and tropical regions, although as seen above, from an environmental point of view it would be best if bamboo could help to meet the demand in tropical hardwood, especially since tropical forests from which this timber is derived are under pressure. This applies in particular to SWB since most tropical hardwood is used in applications outdoors due to its good durability. However, various tropical hardwood species are also used indoors (e.g. Teak) where Plybamboo may also serve as an alternative. In the future some cheaper industrial bamboo products, such as BMB, might be able to compete with softwood.

Besides the development of products for the local market, export markets in the West offer potential markets, especially for industrially produced bamboo materials. In view of the increasing awareness in the West with regard to the necessity of sustainable consumption, there are plenty of possibilities for bamboo to profit from this trend. Furthermore, once bamboo gains a stronger foothold as a potentially sustainable material to be used for products in the West, more trend-following emerging economies

[14] Consumer products that yield services or utility over time rather than those that are completely consumed at once (Baxter et al. 2003).

[15] The annual yield of bamboo compared to hardwood is separately investigated in section 5.2 of this thesis.

such as India and China might follow and will most likely actually acknowledge bamboo as a high end material as well, instead of perceiving it as poor man's timber. It is for these reasons that this thesis focuses on the potential of bamboo to help meet the demand for raw materials (and especially hardwood) in products in the West, and in particular on Western Europe as a consuming region.

1.2.2 The Market Share of Bamboo in the West

The annual world trade in bamboo and rattan has been estimated at $14 billion, although the current officially registered volume is $2.5 billion (Hunter 2003, Lobovikov 2003).[16] This shows that the importance of bamboo as a commodity on a worldwide scale is on par with other important commodities such as bananas ($5 billion) and cotton ($6 billion) (Hunter 2003, Lobovikov 2003). However, despite its promising potential, the market for bamboo products in Western markets like the USA and the EU is still small at the moment compared to the consumption of wood in products (Belcher 1999, Held and Manzano 2003, Klop et al. 2003, Mathew 1998). This was further amplified in an extensive market survey (van der Lugt and Lobovikov 2008) conducted by the author in collaboration with Dr. Maxim Lobovikov, chief of the Forest Product Service at FAO and former INBAR director. Some of the main conclusions of this market analysis showcasing the relatively small market share of bamboo products compared to wooden products in the West are presented below:

- Even compared to the size of only primary wood products (logs, sawn timber, veneer, and plywood), world trade in all bamboo products still pales in comparison. For example, the current value of global trade in all bamboo products is estimated at $2.5 billion, which is almost met by the value of the import of primary wood products in the Netherlands alone at $1.8 billion in 2004.
- The import of wooden furniture only for the Netherlands in 2002 ($1 billion) is almost as high as the import of bamboo and cane furniture parts (based on HS codes 9401.50 and 9403.80) over the whole world ($1.3 billion).
- With an estimated consumption of 0.67 million m2 in 2003, the bamboo flooring market represents a marginal role accounting for 0.7% of the wooden flooring market in the European Union (95 million m2). The same applies to the consumption of bamboo veneer in the EU (345 m3 in 2005), accounting for 0.019% of the consumption of wooden veneer (1,753,000 m3 in 2005).

With an estimated consumption of 0.67 million m2 in 2003, the bamboo flooring market represents a marginal role accounting for 0.7% of the wooden flooring market in the European Union (95 million m2). The same applies to the consumption of bamboo veneer in the EU (345 m3 in 2005), accounting for 0.019% of the consumption of wooden veneer (1,753,000 m3 in 2005).

Analysis of trade statistics shows that the current market size of traditional bamboo products is rather small. Only three product groups have a considerable size: (1) basketwork, (2) seats made from rattan, bamboo and similar materials, and (3) cane furniture made from rattan, bamboo and similar materials.[17] These traditional products mostly target saturated low end markets and have little growth potential, as the consumption figures over the last ten years show (INBAR 2008).

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[16] This difference between estimates and official numbers shows that the current set of the Harmonized System (HS) codes for bamboo products is insufficient for a detailed trade analysis. The existing HS codes represent traditionally plaited or cane based bamboo products and exclude new industrial bamboo materials. The new codes for industrial bamboo products, approved by the World Customs Organization, and effective since 2007, will make future bamboo trade statistics more reliable and precise (van der Lugt and Lobovikov 2008).

[17] For example, imports of basketwork between 1989-2002 in the USA were registered to be at a level of almost 300 million dollars annually ($295,793,000), while annual imports in the same period of cane furniture accounted for $231,055,000, and bamboo and rattan seats accounted for $100,824,000 (van der Lugt and Lobovikov 2008).

In contrast, new industrial bamboo products, such as flooring, veneer and board materials, show high growth potential. For example, the consumption of bamboo flooring increased approximately 25% between 2003 and 2005, while many other new materials, such as veneer, have successfully established a niche market in the West since its launch a couple of years ago (van der Lugt and Lobovikov 2008).

Although the actual market size of bamboo products is small compared to the wood market, because of their similar properties especially industrial bamboo materials could try to fill the increasing gap between supply and demand for hardwood.
However, before an intervention can be developed that may help to grasp this latent potential in practice, it is important to understand which obstacles along the value chain have caused the small market share of bamboo in products in Western Europe.

1.2.3 Obstacles during Bamboo Commercialization

Before the main obstacles causing the small market share of bamboo in the West are presented, some important concepts in new material commercialization need to be introduced first.

Obstacles in the Production-to-Consumption System; Materials in General

The commercialization[18] process is similar for most new materials and seems to follow a distinct pattern. Based on the work of Ashy and Johnson (2002) and Manzini (1986), van Kesteren and Kandachar (2004) acknowledge three sequential phases during the commercialization of a new material: the development phase, the introduction phase and the acceptance phase.
In the *development* phase, the material producer is the most important stakeholder. In this phase a new material is invented, tested and optimized by material technologists and scientists in terms of material properties, processing behavior and suitability for large scale production. In this phase the material might be tested in demonstration projects. Once the quality of the material is stabilized and the material can be produced in sufficient quantities, the material enters the *introduction* phase. During the introduction phase, designers start to use the new material for their products, and the first products become available for early adaptive consumers. During the implementation of the new material in products, knowledge is generated by the various stakeholders along the value chain (value chain nodes) with respect to the properties of the material during processing, production and use. Based on feedback from the field, the material might be further optimized by the material producer, and in the case of a positive evaluation this might result in growing adoption of the material by the other value chain nodes. Once the material becomes widely adopted in a certain market, the material has reached the *acceptance* phase in that sector.
Note that if sectors are adjacent to each other, and have similar stakeholders in the value chain with the same interests (e.g. might keep an eye on developments in the adjacent sector for example through magazines and symposia) a material might spread from one sector to another directly in the acceptance phase without a lot of additional efforts from the material producer (e.g. from the furniture sector to architecture). However, a material that is in the acceptance phase in one sector (e.g. titanium in the aerospace industry) can still be in the introduction phase or even development phase for sectors that are very different (e.g. titanium in the bike industry).
Although almost every new material goes through this process, there are large differences in time required to reach the acceptance phase (see table 1.7), while some materials might not even reach the market and will never leave the laboratories of material producers (van Kesteren and Kandachar 2004). Based on past experiences during the commercialization process for most materials, stakeholders in the

[18] The development and successful market implementation (realization) of a new product, service or material by a company (Roozenburg and Eekels 1995). In this thesis (product) innovation is perceived as synonym for commercialization.

materials industry acknowledge a typical 20-year interval between the invention of a new material and its widespread adoption in a certain sector (Musso 2005).

Table 1.7: Duration of the commercialization process from start of invention to widespread adoption for various materials (Maine and Garnsey 2006, Maine et al. 2005, van Kesteren and Kandachar 2004)

Name of material	Duration of commercialization process
Bakelite	25 years (1907 - 1932)
Nylon	4 years (1935 - 1939)
Teflon	23 years (1938 - 1961)
Polycarbonate	17 years (1953 - 1970)
Polypropylene	37 years
Kevlar	17 years
Carbon fiber	34 years

To better understand the causes of the long commercialization times of new materials one should look at the value chain of materials, which refers to the value addition through an activity in each node of the chain when bringing a product from conception (upstream[19]) to final use (downstream). The various activities in the value chain of raw materials into products are executed by different companies. As a reference in figure 1.6 in simplified form a typical value chain of a material that is being used in a consumer durable is presented. At the top of the figure the value adding activity is depicted and in the rectangles the main stakeholder that usually takes care of this activity in the value chain is represented (value chain nodes). If nodes are connected this means there is a direct interaction between nodes through material-, information- and/or money flows.

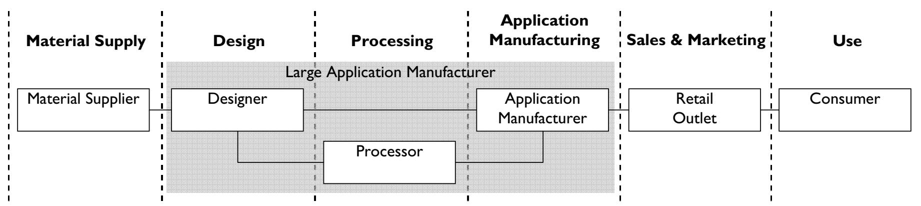


Figure 1.16: Simplified model of a typical generic value chain of a consumer durable

Although not depicted in figure 1.16, stakeholders in the external environment (e.g. government, NGOs, industry and trade organizations, etc.), that do not directly belong to the value chain, can also influence the adoption of materials in value chain nodes (e.g. through the development of regulations & policies or influencing public opinion). For this reason the Production-to-Consumption System (PCS) framework developed by Belcher (1995, 1999) was adopted in this thesis for obstacle analysis during the commercialization of new materials, including bamboo. A PCS is defined as "the entire set of actors, materials, activities and institutions involved in growing and harvesting a particular raw material, transforming the raw material into higher-value products, marketing and selling the final products to consumers." The system includes the technologies used to grow and process the material, as well as the social, institutional and economic environment in which these processes operate" (Belcher 1999).

[19] Upstream refers to stakeholders at the production side (closer to the source). Downstream refers to stakeholders closer to the consumption side of the chain.

While most materials differ in properties, many share similar problems during their commercialization process, as the influence flow model[20] in figure 1.17 shows. The model summarizes key obstacles found along the PCS during the commercialization of new materials in consumer durables in the North based on a review of relevant literature. Each obstacle adds costs directly or indirectly (e.g. time loss) to the commercialization process of the material and in the worst case can stop the commercialization of the material. For the obstacle analyses in this thesis, the use phase (including maintenance & recycling) of the consumer durable was added to the PCS. Below the model, the direct value chain nodes, which are influenced by the obstacles, are depicted. Dotted ovals can be considered obstacles on the meta level, which consist of various obstacles. For the background of each obstacle including literature references the reader is referred to appendix B.

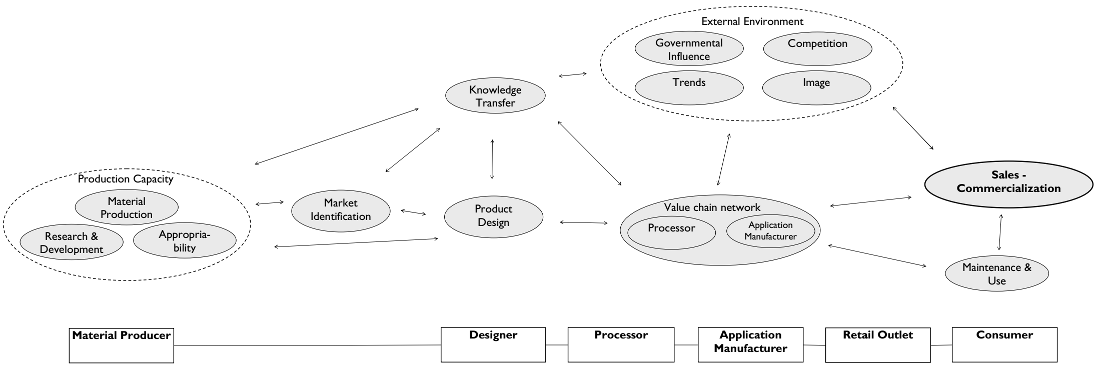


Figure 1.17: Influence flow diagram representing the main obstacles, and their relationships, over the PCS during the commercialization of new materials in consumer durables in the North

In general, the obstacles have a sequential relationship; it does, for example, not make sense to solve design related problems, if problems related to production capacity have not yet been solved. If a material is still in the development phase, the emphasis of problems will usually lie on the first part of the PCS (left side of figure 1.17), mostly related to the material producer. If a material reaches the introduction or acceptance phase, most problems during the commercialization of a new material will apply to value chain nodes downstream, on the consumption end of the PCS (right side of figure 1.17).
Furthermore, it should be noted that while some problems only apply to a certain value chain node (e.g. production capacity to the material producer), other obstacles may apply to more than one value chain node (e.g. knowledge transfer to all value chain nodes). Finally, the importance of the found obstacles may differ per material and sector (e.g. in the building industry governmental influence through codes & standards are very important for new materials to comply with).

Obstacles in the Production-to-Consumption System; Bamboo

Obstacles along the PCS during the commercialization of bamboo as a new material[21] in consumer durables (with a focus on the furnishing sector) for the Western European market are also similar to the

[20] In an influence flow diagram, qualitative relationships of a systemic nature that together influence an outcome can be depicted. The interactive nature of the relationships is shown in two sided arrows, showing the variable may operate both as cause and effect (Wolstenholme 1990).

[21] Note that especially industrial bamboo materials, due to their recent introduction and the corresponding relatively low acquaintance of value chain nodes with them, are perceived as new materials within this thesis. Furthermore, besides acquaintance of their use in low end traditional applications, knowledge about the real potential of the bamboo stem is also limited, and in a way the stem can also be perceived as a new material.

generic obstacles found in figure 1.17, as several separate field studies (van der Lugt 2005a, van der Lugt and Otten 2007) executed by the author in 2005-2006 in South East Asia (China) and Latin America (Ecuador & Colombia) as the producing region in the South, and Western Europe (the Netherlands & Germany) as the consuming region in the North, showed. In figure 1.18 the main obstacles found along the bamboo PCS based on design and production of products in the North (scope of this thesis) are summarized in an influence flow diagram. For the background of each obstacle including a more extensive explanation of the methodology used, the reader is referred to appendix C.

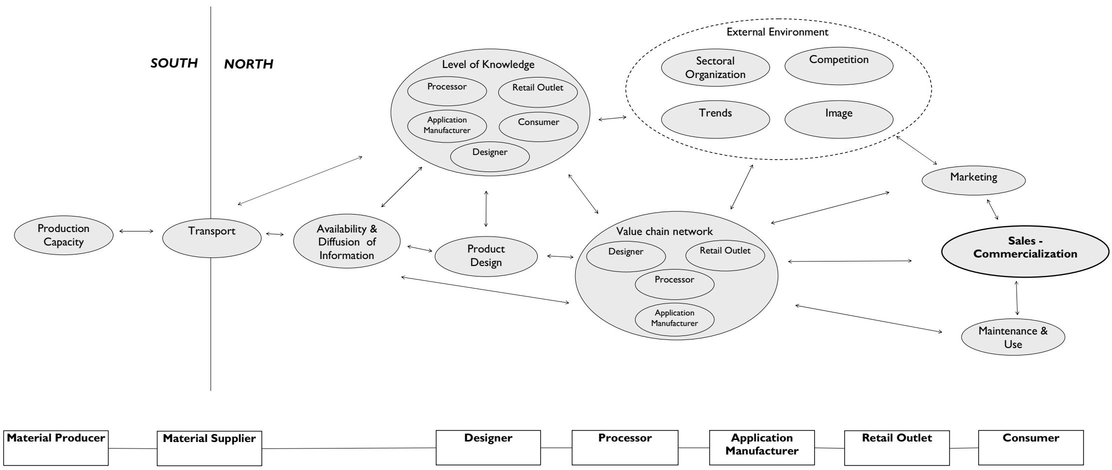


Figure 1.18: Influence flow diagram representing the main obstacles, and their relationships, over the bamboo PCS based on design & production of the products in the North

From the diagram it becomes clear that many different obstacles, related to various actors, with a complex cause and effect relationship hinder the successful commercialization of bamboo in consumer durables in Western Europe. Although there are many similarities between obstacles for generic materials and bamboo, there are also some differences. For example, for bamboo the image[22] problem is a larger issue than for most other materials (for more background information about the image problem of bamboo the reader is referred to appendices C and E). Furthermore, since bamboo is a natural resource, the production capacity obstacle has a different character than for more engineered materials such as plastics and metals, consisting of various (modified) resources.
Since the bamboo materials industry in the North is still relatively small compared to incumbent materials, obstacles for bamboo suppliers will be mostly similar to obstacles experienced by small generic material producers which have lower resources in terms of capital, facilities and client base compared to large material producers (see also subsection 1.3.1 below).

1.3 Using Designers to Stimulate Bamboo Commercialization

In the previous subsection an overview was provided about obstacles along the PCS that hamper the commercialization of bamboo in consumer durables in Western Europe, including the value chain nodes that affect these obstacles, resulting in the small market share of bamboo in products in Western Europe. This PhD thesis, deriving from the Faculty of Industrial Design Engineering of DUT, focuses on

[22] In this thesis the image of a material refers to the intangible properties of a material (Karana et al. 2008) i.e. the perceptions, associations and emotions related to a material. For more information about intangible properties the reader is referred to appendix D.

the potential role of the designer, as one of these value chain nodes, to stimulate the commercialization process.

1.3.1 The Potential Role of the Designer as Material Champion

In a social system - in this case stakeholders active in the nodes of the materials value chain - some persons have a more important role in the diffusion of an innovation than others. Rogers (2003) defines innovation as "an idea, practice, or object perceived as new by an individual or other unit of adoption." In the line of this research new materials can also be perceived as an innovation. Diffusion can be defined as "the process in which an innovation is communicated through certain channels over time among the members of a social system" (Rogers 2003).
For the adoption of a new material all the relevant members in a social system (value chain) need to be convinced before a material might make it eventually onto the final consumer market. The key persons involved in the diffusion of a generic innovation in a social network are opinion leaders or champions (Rogers 2003). *Opinion leaders* play a crucial role in the initiation of the diffusion of innovations through a social system. They are individuals that, in an informal way, have a high influence on the attitude and opinions of other individuals in a social system. *Champions* are for an organization what opinion leaders are for a community. A champion is usually a charismatic person who plays an important role in overcoming resistance in an organization toward the adoption of an innovation, or leads opposition against the adoption of an innovation (anti-champion). Since opinion leaders and champions have such similar characteristics and this thesis mostly relates to organizations, in the remainder of this thesis only the term "champions" will be used. Below, it will be explained that under some particular circumstances designers may function as a champion for the commercialization of a new material.

Although material research derives mostly from the defense and aerospace industry, it is now more directed at the consumer than before. This has provided the (product) designer a more important role in the adoption of new materials (Ashby and Johnson 2002). Designers have an important position in the value chain of most consumer durables because they link material producers with application manufacturers and potentially final consumers by translating the opportunities posed by a material in a concrete marketable product (Bas 2007, van Kesteren and Kandachar 2004).
Designers create products for various consumers who can choose from a high variety of similar products in a competitive market. For these reasons the user-interaction aspects of a product are very important as well for these consumers; besides technical and functional benefits, emotional benefits are also required to compete in the market (van Kesteren 2008). Therefore, alongside the technical and economical properties of materials, designers also integrate the environmental-, use-, as well as softer[23] sensorial- and intangible properties of materials in their designs. For more information about the role of materials in product design and an explanation of various material properties, the reader is referred to appendix D.
In industries where material costs sensitivity[24] is high (low end consumer goods, building industry) or technical constraints prevail (aerospace engineering), the role of the designer might be replaced by a production technician or engineer. In contrast, in medium to high end markets for most consumer durables (e.g. furniture, sport equipment, domestic appliances, consumer electronics) next to the

[23] Material properties that have a subjective character and depend on the perception of the beholder: sensorial properties and intangible properties of materials.
[24] Material costs sensitivity refers to the influence material cost has on the overall cost of a product (Ashby and Johnson 2002). If a lot of value is added in the processing and development of a material the product in which the material is used is material - cost insensitive (compare a golf club with a lot of added value, to a golf tee, which is a very material - sensitive product because of the low added value).

technology and functional aspects, user-interaction aspects are also of importance, facilitating a more important role of the designer as material prescriber.
In medium to high end consumer durables markets, usually small to medium sized (SME)[25] material producers are more innovative than large material producers and are the players to introduce new materials (Maine et al. 2005). Large material producers often focus on bulk low end mass markets or follow a market pull approach in medium to high end consumer durable markets in which they, based on their reputation, large resources, extensive existing client base, and marketing competences, focus on meeting the needs of existing clients through delivering service, quality and developing improvements to established materials by adding specific utilities required by the client. When large material producers do develop new materials, they are usually based on incremental innovations of established materials, pushed into the market by convincing their existing clients (large application manufacturers) of the virtues of the new material by organizing master classes in which all relevant departments that have an influence on the adoption of the material (design, production, marketing, purchasing, and management) are invited (Bogaert 2007, van Rijn 2007). However, due to the desire to match research & development activities strongly with current core competencies and the priority with many large material producers to safeguard current business, many potentially profitable markets are passed over by them (Maine et al. 2005, Neely 1998).

Figure 1.19: The Customer Innovation Center of GE Plastics houses thousands of samples of plastics

Since smaller material producers usually do not yet have the existing client base, the reputation or the in-house facilities that large material producers have (see for example the Customer Innovation Centre of GE Plastics in figure 1.19) to directly convince large application manufacturers (which usually combine the design, processing and application manufacturing nodes, see figure 1.16), they will usually first need to convince other nodes in the value chain to even consider the implementation of the new material. Due to their strategic position in the value chain (between the material producer and application manufacturer) and their ability to translate a new material in an application with potential in appropriate high end markets, designers may therefore act as material champions, especially for small material producers (Bas 2007, van Bezooyen 2007). These designers may either be independent or be imbedded in the design department of small to medium sized application manufacturers, since small material producers are usually not able to meet material quantity demands of large application manufacturers. However, as can be seen in figure 1.17, the designer also comes early in the chain and is

[25] Please note that there is no generally accepted definition for Small and Medium sized Enterprises (SMEs); some definitions are based on quantitative standards (e.g. employee number or capital value), and others on qualitative aspects (e.g. management style, method of operation). In this thesis the definition of the World Bank is adopted (Ayyagari et al. 2003): Small and medium enterprises refer to companies with up to 300 employees.

dependent on many other nodes downstream (e.g. processors, outlets, etc.) which need to be convinced before the product in which the new material is used may actually reach the final consumer market.

Designers may also be able to play a role in stimulating the commercialization rate of bamboo in consumer durables in Western Europe for two reasons. First of all, in subsection 1.2.3 it was already found that designers directly influence various obstacles found in the bamboo PCS (i.e. product design capacity, lack of knowledge and lack of value chain networks) influencing the eventual commercialization rate of the material. Secondly, due to the immaturity of the bamboo sector all bamboo material suppliers in the North belong to the SME sector for which, as seen above, the involvement of designers seems a suitable strategy to stimulate the commercialization rate. Below is substantiated which consumer durable market may be suitable to target through the involvement of designers for bamboo suppliers in Western Europe.

1.3.2 Enabler Market for Bamboo

Market Selection as Strategic Tool in New Material Commercialization

According to Musso (2005) the tiresome commercialization process of new materials (see table 1.7) may be accelerated by strategic market selection. In his PhD thesis Musso argues, based on a historic analysis of the commercialization of plastics in the USA, that choosing right initial markets for new materials may be crucial to accelerate the commercialization process. Although material producers tend to directly try to substitute incumbent materials in mass markets, Musso explains that before a new material can actually compete with established materials, first, an understanding needs to be created about the material throughout the value chain nodes. If new materials target mass markets before this understanding is created, the intensity of the obstacles mentioned in subsection 1.2.3 will most likely be higher, and will lead to higher costs and delays in the commercialization process (see for example the case of the premature introduction of Polystyrene in children's toys in appendix B). Musso argues that first understanding should be created about the new material in a value chain through "enabler applications".

In short, enabler applications in general have a *simple value chain* with a relatively *high fault tolerance* in *small markets* with a *high visibility* and a *low material - cost sensitivity*, providing *credibility* of the *unique value* of the material, while developing *knowledge* and *capability* along the value chain nodes.

After the material has proven its worth in the enabler application, it can be launched in "platform applications". Musso (2005) defines a platform application as "the first large-market application in which a material is so compelling that all application manufacturers must use it in order to be competitive, thereby creating a path for future growth of the material in other major markets." In the platform application a material can really show its value based on superior properties over incumbent materials (usually not lower cost). More importantly, the platform application serves as a spring board to other large adjacent markets in the "widespread adoption" phase. Usually platform markets are markets that value high performance, are material-cost insensitive, and can accept a degree of risk. Note that the degree of risk strongly depends on the cost of failure, which will differ per industry (e.g. unacceptable in nuclear industry). New materials are therefore mostly adopted in platform applications in material cost insensitive industries such as high end appliances, furniture, automotive, sports equipment, aerospace and biomedical equipment (Ashby and Johnson 2002).

Once sufficient knowledge has been developed over the value chain, the switching costs caused by obstacles during the commercialization of new materials are overcome and the material has shown its value in enabler- and platform applications, the new material can compete with established materials on costs and performance in the widespread adoption phase. In this phase "battles" between materials can be fierce, with many different materials targeting various market segments simultaneously (Musso 2005). Musso's study shows that the few plastics which followed the strategic enabler-platform market selection path were quicker in successfully reaching the widespread adoption phase than most material producers who directly tried to target mass markets.

Interior Decoration as Enabler Market for Bamboo

In subsection 1.2.1 it was substantiated that for bamboo it would be suitable to target markets where (hard)wood is the incumbent material. Looking at current consumption of wood in the Netherlands, one can see that wood is mostly consumed in the building industry followed by the garden sector, DIY sector, pallet industry, furniture industry and in civil engineering projects (see figure 1.20). Although in general hardwood consumption is a lot smaller than softwood consumption in Western countries (see figure 1.21 for the Netherlands as an example), the volumes are still very high, especially compared to current bamboo consumption figures.

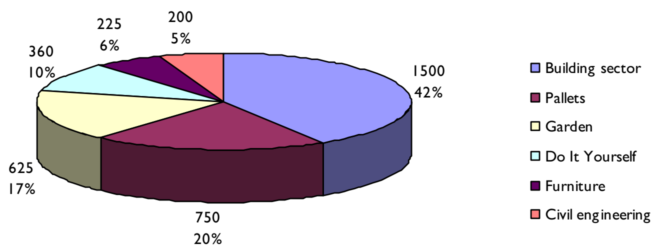


Figure 1.20: Consumption of processed wood in the Netherlands in 2001 per sector, 1000 m3 (Kuiper and Jans 2001)

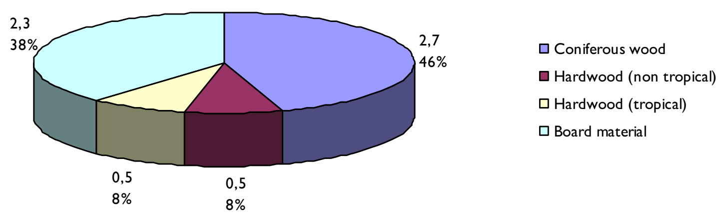


Figure 1.21: Consumption of wood in the Netherlands in 2004, million m3 (adapted from (CBS 2006)

Taking the market selection strategy developed by Musso (see above) as the point of departure, what could be a suitable enabler market for bamboo, before mass markets such as the building industry should be targeted? It should be noted that the market selection strategy developed by Musso is based on experiences with the commercialization of plastics, which was - when launched in the middle of the 20th century - a completely new material with a completely different chemical composition and properties compared to established materials. Therefore, for plastics it was easy to find an enabler application in which the unique properties of the material could be used. For bamboo in its raw form (stem) but especially in the various semi finished materials, the situation is different. The chemical composition of bamboo and wood, the incumbent material it tries to replace, is very similar; especially industrial processed bamboo resembles wood in various properties (technological, economical, and sensorial properties). Therefore, for bamboo it is more difficult to find a unique enabling application to pave the way, because unique selling points based on hard technical and economical aspects are difficult to locate compared to (hard)wood. However, softer aspects related to product experiences and emotions are becoming more important, and in this realm bamboo can also search for unique features to distinguish itself. Taking this into account potential initial target markets for bamboo were explored, based on the various enabler criteria. As a result, the *medium to high end interior decoration market*, used to categorize the combined markets of interior design, furniture and accessories, was chosen as the best initial market for bamboo to introduce itself. The choice for this particular market is explained below.

Because the bamboo industry is still relatively small (and therefore lacks economies of scale advantages) and materials have to be brought in from overseas, most bamboo materials (except the bamboo stem) cannot compete in price with most softwood and wood based board materials. Prices for most industrial bamboo materials are on a similar level as most hardwood. Therefore, especially for industrial bamboo materials it makes sense to focus on high end markets which are less material - cost sensitive, in which both the harder properties (e.g. relative hardness) and softer aspects of bamboo materials are appreciated. The high end interior decoration market is a typical material-cost insensitive market in which softer aspects are also important. In the interior decoration market bamboo can distinguish itself through softer aspects such as aesthetics and its perceived environmental sustainability, which might prove to be the strongest unique selling point for bamboo.

Furthermore, in the case of new materials - which especially industrial bamboo materials are - the identity of the material can still be "molded" based on first associations (van Bezooyen 2007). As is further explained in appendix D, if a material and its application grow up together, they are attached to each other. If the material is first introduced in a hip product, it will be associated with the characteristics of the product (see various examples in appendix D, e.g. the use of neoprene in sports equipment). Evidently, associations with high end interior decoration products will have a positive influence on the image of bamboo as a material.

Additionally, most value chains of products in the interior decoration market are relatively simple (compared, for example, with the value chains of domestic appliances), in which the same machines as deployed for wood can be used, thus avoiding high costs related to switching machines and production processes.

Likewise, most products in the interior decoration sector are relatively fault tolerant (e.g. a small deficiency in a table has a smaller impact than a small deficiency in consumer electronics). More importantly, the active involvement of designers, which is topic of research in this thesis, is only valuable in markets where designers play an active role in the development of the product features. Designers play a very important role in the medium to high end interior decoration market. Furthermore, high end interior decoration is a highly visible market, and is a very good market to show what a material can do. For example, high end design chairs have been used by many designers in the past as a useful enabler application for new materials, to show the world the technical and aesthetic performance of a new material (e.g. glass fiber composites used by Charles Eames).

Finally, it is important to select an initial enabler/platform market which has many large adjacent markets with similar characteristics, to facilitate diffusion from one sector to another, which will not happen if the sectors are too different from each other (e.g. aerospace vs. domestic appliances). The high end interior decoration market, because it is a relatively large market, combines characteristics of both enabler and platform markets, and has many attractive adjacent markets attached to it with similar characteristics. Once bamboo has proven itself in the interior decoration market, a following promising platform market to target in the West could be the medium to high end segments of the building industry (e.g. in visible building elements in architecture). Since many architects first experiment with a material in furniture, this seems a logical sequence. In architecture the role of materials to give identity to the product (in this case the building) through its intangible properties might be even more important than in consumer products (van Bezooyen 2007). However, in the building industry the fault tolerance is lower, and conservatism of some stakeholders is higher (contractors), making it important for bamboo to first prove its value in the interior decoration sector. Once bamboo has proven itself in these sectors, other mass markets in which wood is the dominant material should be attacked, which applies mostly to the building industry as a whole (including the bulk low end segments). In subsection 9.3.3 further suggestions are provided for mass markets in which the various bamboo materials can serve as an alternative to incumbent materials in the future.

1.3.3 Main Research Question

It was previously substantiated that designers could possibly contribute to stimulate the commercialization of bamboo in products in the interior decoration sector in Western Europe. To what extent this assumption is valid, and under which circumstances, is the topic of this action research which is tested by making a design intervention in practice and which can be translated in the *main question (MQ)* of this research:
To what extent can design interventions successfully stimulate the commercialization of bamboo in products in the interior decoration sector in Western Europe?

After the development and structure of the intervention is introduced in chapter 2, in chapter 3 the main question of this research will be translated into several detailed research questions.

1.4 Research Classification

Generally speaking, all existing kinds of research can be divided in theoretical research and practical research. According to Verschuren and Doorewaard (2001), theoretical or fundamental research focuses on solving problems in the general theory known about a phenomenon, while practical research focuses on solving a problem through an intervention in an existing practical situation. Of course combinations of the two also exist. This research can be perceived as being practical. Practical research usually focuses on solving one or more aspects of the intervention cycle, which is defined as "a defined series of process steps that is taken in solving practical problems" (Verschuren and Doorewaard 2001). The intervention cycle consists of the following steps: 1) problem description, 2) diagnosis, 3) design, 4) intervention, and 5) evaluation. For each step a specific research strategy with its own methods of data collection can be formulated (e.g. diagnostic research, evaluative research, etc). For reasons of feasibility, practical research usually focuses on contributing to only one step of the intervention cycle. However, some kinds of practical research do cover a bigger part of the intervention cycle, such as action research, which focuses on understanding and solving a practical problem, and starts with the description of the problem and from there on covers all phases of the intervention cycle through diagnosis, action (design & intervention) and evaluation (den Hartog and van Sluijs 1995).

This research can also be entitled action research, a research strategy which was first developed by Kurt Lewin in the 1940s (Lewin 1948, Nystrom and Starbuck 1983). Action research focuses on the implementation of an intervention in the real world in order to solve a problem in practice (e.g. in an organization), and includes the analysis of the execution of the intervention. Furthermore, contrary to traditional experiments, in action research the researcher and members of the organization in which the intervention takes place actively participate in the change process in order to bridge the gap between science and practice. Action research is problem driven, puts the client in center, questions the status quo, and results in empirical verifiable conclusions that can be used to eventually form theories that are also applicable in practical reality (Argyris 1983, den Hartog and van Sluijs 1995). Note that action research has a double meaning: it is both a research strategy and an intervention method. As a research

strategy strictly taken it can be considered a field experiment with a practical purpose, although compared to experimental research, in action research the role of the researcher is participatory.
The main advantage of action research is the high validity of the results through the problem oriented approach; because the intervention takes place in reality, actively involves participants throughout the process and continuously processes their inputs in a step-by-step manner, a high level of learning is created on the spot, custom-made for the situation (van der Zwaan 1995). Although this high validity a.o. through the active participatory involvement of the researcher is a strength of action research, it is also a weakness. Through the close involvement of the researcher as a change agent throughout the process, the researcher takes his own beliefs and values into the intervention, which could lead to biased results. This does not need to be a problem, as long as the researcher acknowledges this potential bias and is able to objectively describe his role during the process. Subsection 3.4.2 will explain how this was assured for this research. Another disadvantage of action research is the fact that the double role of the researcher as facilitator/organizer and researcher is very time consuming, and requires a lot of effort from the researcher to switch between roles throughout the process. For more background information about the main elements of action research the reader is referred to appendix F.
Since prior research on the development of design interventions to accelerate the commercialization rate for new materials including bamboo is scarce, this research has an exploratory character. In contrast with experimental research, in the evaluation of the intervention the execution process is also included since it is crucial to understand if and how the intervention works, and how the intervention can be improved for potential future interventions (van der Vall 1980). For evaluation of an implemented intervention this consists of a) measuring the intervention impact (product impact), b) monitoring of the intervention process (process evaluation), and c) the development of an advisory intervention which entails recommendations for both a) and b). Based on these various evaluation elements the various research questions 1-4 will be formulated in section 3.1.

1.5 Scope and Delimitations

The most important delimitations that determine the scope of this research are based on the main elements of the main question of this research (see subsection 1.3.3 above), which are further elaborated upon below.

Stakeholder Focus

Although there are many value chain nodes (see figure 1.16) that determine if a new material will actually be implemented in a product in the final consumer market, this thesis primarily focuses on the potential role of the *designer* (as one of these value chain nodes) to stimulate the commercialization process of bamboo. Although the primary focus of the intervention developed within this research is on the designer, some other value chain nodes downstream (closer to the consumer), such as the processor, application manufacturer, and retail outlets are integrated as secondary stakeholders in the intervention as well (for more information see subsection 2.2.1).

Regional Focus

Because of the increasing interest in sustainability in the West providing interesting potential growth markets, and the Western trend following character of emerging economies and developing countries, the focus of this research is on commercialization of bamboo in products in *Western Europe*, and in particular on the two countries in the EU which were the first to adopt and import industrial bamboo materials and still have a leading role with respect to industrial bamboo commercialization: the

Netherlands and Germany. At the moment Germany is clearly the largest industrial bamboo consumer in the EU; the German market alone accounts for more than 50% of the whole consumption of bamboo flooring and veneer in the EU (van der Lugt and Lobovikov 2008). When this research refers to "Western Europe," these two countries are meant.

Before bamboo is successfully commercialized in a consumer durable in Western Europe, it will go through various value chain nodes that have to overcome obstacles related to various activities (e.g. plantation, harvesting, processing, transport, etc.). Since giant bamboos suitable for industrial utilization grow in the South, obstacles during the PCS will relate to both stakeholders in the South and stakeholders in the North (Western Europe). However, the design intervention introduced in chapter 2 will take place at *the consumption side of the PCS, based on design and production of products in the North*, using bamboo materials from China, as the leading bamboo producer and exporter worldwide.

By choosing a particular PCS in which the obstacles in the South are already solved, only obstacles in the North will be tackled through the design intervention in this research. Note that despite the focus on the North, in various parts of this thesis results are also of direct interest for bamboo producers in the South, either because of the generic character of the results (e.g. material properties appreciated by designers; see section 6.2) or because of their potential interest to target Western export markets in the future.

Market Focus

The potential role of the designer to stimulate the commercialization rate was investigated for the use of bamboo for products in the *medium to high end interior decoration sector,* which is presumed to be a suitable enabler market for bamboo (see arguments for this choice in subsection 1.3.2).

Sustainability Focus

The choice for bamboo in this research is derived from the potential environmental virtues of bamboo, and therefore stems from the Planet component of the Triple Bottom Line. Consequently, this research focuses on the potential of bamboo as *environmentally sustainable* material in Western Europe. Obviously, this does not mean that bamboo does not have potential for the socio-economic components of sustainability. On the contrary, through its abundant availability in the South, usually in distant rural areas, bamboo has much potential to contribute to local socio economic growth and thus to sustainable development. Although it is not the focus of this research, some recommendations will be provided to take these socio economic benefits in future interventions into account as well (see subsection 9.3.2).

Resource and Material Focus

This thesis focuses on the use of bamboo materials made *from* the most commonly used and industrialized giant bamboo species in China: *Phyllostachys pubescens* (referred to as "Moso" - its local name - in the remainder of this document). Moso is perceived as being one of the bamboo species worldwide with the most commercial potential based on its availability, accessibility and potential for industrialization. Moso bamboo grows abundantly in temperate regions in China, can reach lengths of 10-15 meters and a diameter of 10 centimeters, and is very suitable for industrial processing to develop all kinds of industrial bamboo materials. Since besides Moso there are many other bamboo species (1000-1500 species), the results and findings of the design intervention in this research apply in particular to this species and similar giant bamboo species apt for industrial utilization like *Guadua spp.* (referred to as "Guadua" in the remainder of this document) and *Dendrocalamus Asper*.

Figure 1.22: Guadua is a giant bamboo which grows in clumps mainly in Latin America which may reach heights up to 25 meters

As was shown above, there is a wide array of industrially and non-industrially produced bamboo materials available in the South. The focus in this thesis is on bamboo materials that are already available in Western Europe, or bamboo materials with potential for the Western European market that are expected to become commercially available on the short to medium term (within ten years): the *stem* and *mats* as representatives for non industrial bamboo materials, and *Plybamboo (board and veneer), Strand Woven Bamboo (SWB), Bamboo Mat Board (BMB) and bamboo composites* as representatives for industrial bamboo materials. Other, mostly low-end industrial bamboo materials, such as Bamboo Particle Board, are not deemed competitive yet with wood-based boards in the West on the short to medium term. However, for the long term, if production capacity and availability of these materials are improved, they could also become competitive in the West.

1.6 Thesis Structure

This thesis consists of three parts: an introduction (part I), the results (part II) and the conclusions & recommendations (part III).

Part I consists of the problem analysis leading to the main research question in chapter 1, the development of the design intervention in chapter 2 and the research design including the conceptual framework and the operationalization of the main research question in detailed research questions in chapter 3.

Part II of the research is structured based on the main elements of action research: the evaluation of a design intervention, after which advice for improvement should be provided (as input for a possible new intervention cycle). In chapters 4-7 the complete intervention is evaluated based on the various components as distinguished by van der Vall (1980), and therefore is divided into an evaluation of developed product prototypes during the intervention based on their market potential, innovative character (chapter 4) and their environmental sustainability (chapter 5), an evaluation of the bamboo materials deployed in the intervention (chapter 6), and an evaluation of the intervention itself based on relevant success indicators measured before and after the intervention as a kind of black box indication (chapter 7). In chapter 8 the process of the intervention is analyzed and evaluated: "what happened in the black box?" Based on the findings, suggestions to improve the intervention in the future are provided. Each chapter in part II more or less follows the structure: introduction (including methodology used) - results - conclusions.

In part III (chapter 9) conclusions are provided as well as policy recommendations for the bamboo industry and recommendations for further research. Chapter 9 also explores under what circumstances the design intervention for bamboo evaluated in this research could be replicable for other materials as well. The structure of this thesis, including the research questions (RQ) which will be further introduced in chapter 3, is represented in figure 1.23 below.

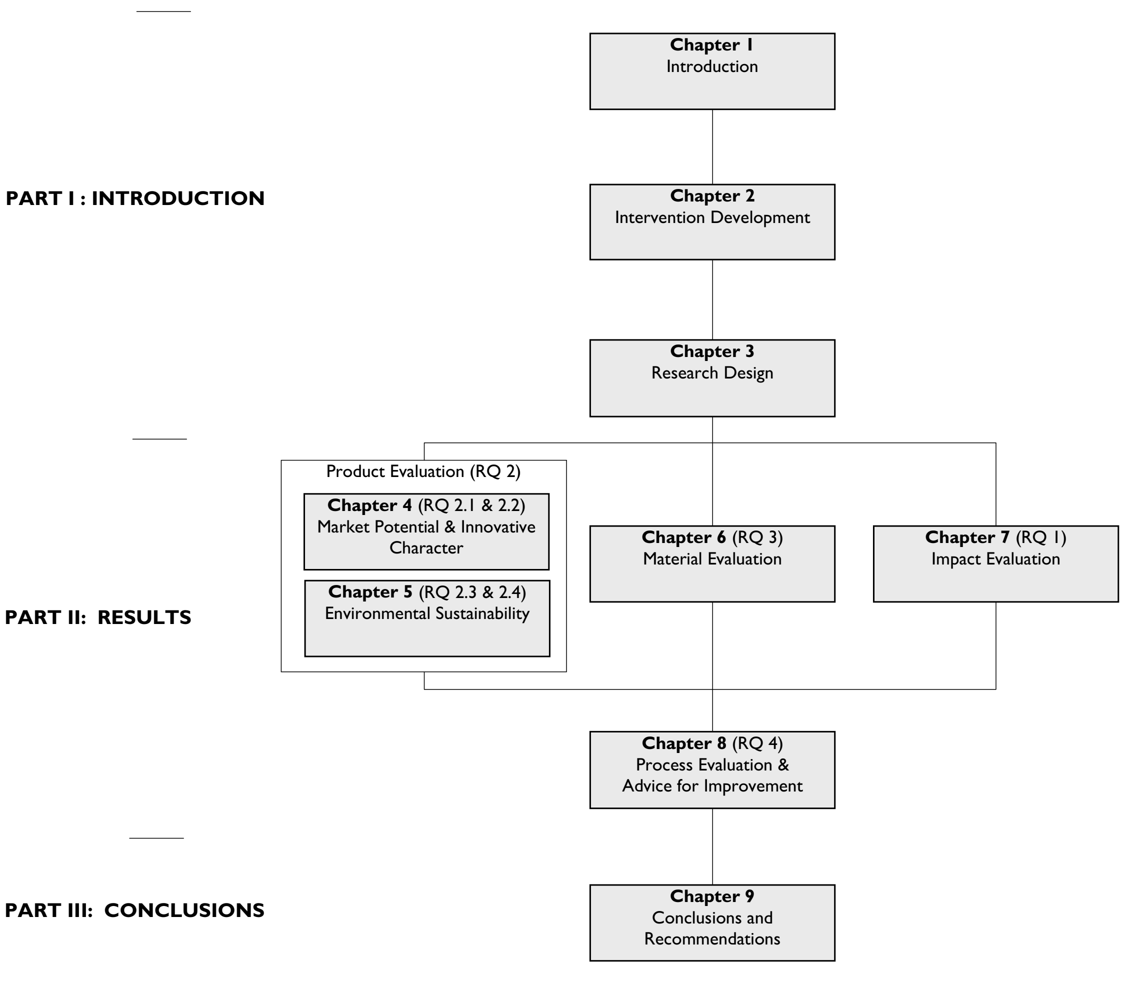


Figure 1.23: The outline of this thesis


DELL

2 Intervention Development

In the previous chapter it was found that designers can possibly play a role in stimulating the commercialization of bamboo in the interior decoration sector in Western Europe. Based on this point of departure, a custom-made design intervention is developed for bamboo in this chapter which will be tested in the remainder of this thesis.

Section 2.1 explores which strategies to introduce designers to a new material may be most efficient for bamboo. In section 2.2 the chosen strategy in the form of design workshops is further developed into a custom-made design intervention specifically targeting several of the obstacles found in the bamboo PCS in subsection 1.2.3. Furthermore, the main elements of the intervention, including its components and subcomponents, will be explained in this section.

2.1 Available Strategies to Involve Designers

In section 1.3 it was found that in the high end consumer durables market, designers could have a differentiating role as material champion, due to their strategic (and early) position in the value chain, and their ability to translate a material in a marketable product. For these reasons designers can be an important stakeholder for (especially small) material producers in order to stimulate the commercialization of their new materials in a high end consumer durable. As a result the involvement of designers could also be a promising strategy for bamboo material suppliers in the North. In this section it will be reviewed which concrete strategies material producers and suppliers can use to integrate designers, and which of these strategies may be suitable for bamboo.

Since there is not a lot of theory available about this topic, expert interviews in the empirical domain were conducted with seven key stakeholders (for names and details about respondents see appendix A) involved in the commercialization of new materials in various consumer durables industries. Expert interviews are a very suitable and efficient tool to gain understanding of the state of the art situation in a specific field (Baarda et al. 2005). To get a good overview of strategies deployed in various sectors for various materials, respondents were strategically chosen to include representatives of large leading material manufacturers in the Benelux (GE Plastics, CORUS Steel, Dow), but also from material suppliers in the SME sector (Biopearls). Finally, three representatives were selected that work for organizations in the tension field between design and material production, with material producers as clients (University Leuven/Material Science Department, Material Matters and Material Stories). Each respondent was interviewed in a semi structured, open way. Below, the most important strategies mentioned by the respondents are presented in order of impact and designer involvement, starting with strategies with the least impact and involvement. At the end of this section is explained which of these strategies could be most suitable to stimulate the commercialization of bamboo in the interior decoration sector.

2.1.1 Non- or Semi Active Involvement of Designers

Many material producers usually deploy traditional instruments to get designers acquainted with their materials in a non- or semi active manner. Table 2.1 represents the various channels mentioned by respondents, that both small and large material producers use, including the means to convey information about the properties of the material.

Table 2.1: Various channels and instruments used by material producers to inform designers about their materials

Channels/Venues	Instruments (used for the various channels)
Internet	- Commercials & Advertisements
- Digital magazines	- Live presentations
- Digital newsletters	- Brochures & flyers
- Websites	- Design guides
- Material databases	- Material data sheets
Printed Media	- Samples
- Magazines & journals	- Articles
- Newspapers	- Mouth to mouth
- Newsletters	
Materials related events	
- Fairs	
- Conferences & seminars	
Television and Radio	

Most information tools and instruments about materials developed by material producers and scientists are very technically oriented and are not synchronized toward designers as a specific target group, who also require information about softer aspects of materials (Ashby and Johnson 2002, Diehl 2005, Karana et al. 2008, van Kesteren 2008). It is for these reasons that samples are a very good means to convey the softer properties of a material, which explains the rise of various material collection centers that also offer consultancy services about material selection, as an important trend. Material suppliers need to get their materials in these kinds of libraries to be taken seriously. Another trend is the increasing importance of material databases available online (e.g. Material Explorer, Material ConneXion), which to some extent also include some softer properties of materials through pictures and descriptions of sensorial properties of materials which designers can use as a quick source of inspiration. Still, a central point for all information needs required by designers for selection of materials is lacking, which is the reason why designers use various sources at the same time to acquire information about both hard and soft properties of materials (Beiter et al. 1993, Ferrante et al. 2000, Fidel and Green 2004, Karana et al. 2008). For an overview of sources used by designers, see van Kesteren (2008). For more information on material information needs by designers the reader is referred to appendix D.

2.1.2 Active Involvement of Designers

The instruments mentioned above are suitable for information gathering, which is only the first step in the knowledge acquisition process of designers about a new material, before they might implement it in their design projects. Most designers have a strong desire to learn more about materials and gain practical hands-on experience with them. Especially in the beginning of the design process, designers require more information about visual and tactile attributes that form the associations and perceptions of a product (Ashby and Johnson 2002, Karana et al. 2008). By experimenting with a material in practice, designers first get acquainted with the softer aspects of a material (touch, texture, smell, visuals), and secondly understand the technical limits of a material during processing, finishing and use, which tells them a lot more than any technical data sheet can do.

The only way for them to gain this experience is to learn in a real life setting, by being introduced to the material and experiencing the material by working with it. However, there is a gap in follow-up curricula

for designers about materials once they have finished their studies in the Benelux. Although there is a strong demand by designers for material knowledge and opportunities to experiment with new materials, there are few courses and initiatives for designers to satisfy this need.
If designers do not get hands-on experience with a material, they most likely will keep opting for materials that they are already acquainted with. There are a couple of strategies which were mentioned by the respondents that material producers can use to actively acquaint designers with new materials to overcome thresholds, which are presented below.

A first intervention to actively involve designers is the organization of *design competitions* around a new material. In such a competition, designers are usually challenged to design a prototype of a product or project in which the potential of the new material is shown. If designers will participate mostly depends on the prestige of the competition in terms of exposure and media attention related to the competition. The danger with design competitions is that they usually have a voluntary character and therefore mostly result in very conceptual entries; there is a strong need in guidance through knowledge provision if the organizer wants to get anything out of the competition.

Material design workshops are a very efficient tool to introduce designers to new materials, teach them the opportunities and limits of the material, and thus gain hands-on experience with the material, possibly in the time frame of just a couple of days. An important requirement if material workshops for designers are to succeed is the availability of sufficient facilities to experiment with the material, including the required technical assistance and support. Good results have already been gained in the past with material workshops for designers for textiles and ceramics.
As an extra spin-off, a material workshop might deliver prototypes showing the potential of the material in actual products, which can be presented for example in *expositions*. By showing all possibilities of a new material in various concrete product prototypes, other designers, application manufacturers and customers can get inspired. For a material with a bad image, the development of expositions targeted toward a larger audience showing what the material can actually do in high end design products can be a good tool to influence the public opinion about a material. A good example of this strategy is the Proud Plastics exposition organized around 2000 in Rotterdam, showing high quality design products of plastics.
According to interviewed experts the best method to convince various value chain nodes at once is to develop an integrated solution in the form of *multi disciplinary material design workshops, centered around designers*. In this setting the other important value chain nodes besides designers are also integrated (material supplier, processor, application manufacturer and retail outlets) and the various instruments mentioned before are combined (material design workshops and exposition). Because the outcome of the workshop is usually very tangible in the form of a physical prototype instead of a hypothetical concept, showing exactly what a material can do, further development of the material is facilitated by diffusion of the results to relevant value chain nodes as part of the intervention.

Two cases in which this multi disciplinary concept has been successfully implemented are presented in the box below.

Box: Multi-disciplinary Material Design Workshops - Two Successful Cases

Composites-on-Tour

A good example of the multi disciplinary material workshop mentioned above in which various parties (material producer, university, designer, processor and application manufacturer) and various means (material design workshops, international design competition and traveling exposition) were combined is the Composites-on-Tour project, conceived and supervised by Katholieke Universiteit Leuven and by Design Flanders in Belgium. The first Composites-on-Tour project in 2002 was such a success that a second Composites-on-Tour project was executed in 2006-2007. The larger intent of the project was to inform the general public about the use of composite materials in consumer goods, and thus the primary objective was not commercial. However, through the project many designers were introduced to the material and links between material producers, designers, processors and application manufacturers were developed. Besides these value chain networks developed, the project also proved very successful exposure wise; more than 50,000 people visited the exposition and many designers applied to participate in the workshops. Furthermore, the evaluation afterwards showed the potential of this approach: both the theoretical parts (information input) and the practical parts (hands on experience with production techniques) were strongly appreciated by the participating designers (Pil and Verpoest 2006). In both the first and second Composites-on-Tour project an international design competition was organized as another element of the project. Around thirty designers in the first project and seventy in the second project from over fifteen countries submitted prototypes of products that had to be interesting from a design point of view while applying composites in an innovative manner. As a result of the success the project received two prizes from the EU: the JEC Special Award in 2003 and the Descartes Prize for Science Communication in 2004.

European Ceramic Work Center

A more permanent example of this approach is the establishment of an independent centre which has the facilities for designers to experiment with the material and has the contacts and channels to diffuse results to relevant value chain nodes downstream. Such a centre may be established by a union of material producers. An example of this permanent solution are the three-month long material workshops (so called "master classes") organized by The European Ceramic Work Centre (ECWC) located in Den Bosch, the Netherlands. ECWC provides invited designers the facilities to explore the technical and artistic possibilities of ceramics, which prevents the designers from being too dependent on demands by processors and application manufacturers. Each year the workshop focuses on a particular theme (e.g. bathroom products), which makes the workshop very focused and enables the invitation of specialist companies from the sector. Application manufacturers and retail outlets are usually inspired by the prototypes developed and may adopt the products and deployed techniques shown in their own product line. Ceramics used to be a material with a quite traditional image, but a.o. through the efforts of ECWC, has become a more trendy material through the involvement of (star) designers implementing the material in high end products.

For large material producers, who have large application manufacturers as important clients, the organization of material design workshops is usually not necessary. Since most large material producers already have an existing client base with whom they have a good reputation based on prior projects, and most of their innovations relate to incremental improvements of established materials based on requirements of these clients, it is easier for them to directly convince these large clients, without having to organize material design workshops.

2.1.3 Specific Design Intervention for Bamboo

In the previous subsections it was found that (small) material producers can use various strategies to actively acquaint designers with a new material. For bamboo, which is still a small industry in the North, the active integration of designers through the development of multi-disciplinary material design

workshops, in which other value chain nodes are also involved, may be a particularly useful strategy to stimulate the commercialization rate for two reasons. First of all, as was also found in appendix C, due to the lack of knowledge and availability, and the mediocre image of bamboo products, not many Western designers have found their way to bamboo to experiment with the material. Secondly, as an important spin-off, this method will most likely result in various prototypes that show the potential of the new material, through which other designers, but also additional value chain nodes, may be inspired.
Based on these reasons, the strategy of multi-disciplinary material design workshops - referred to as "design workshops" in the remainder of this thesis - will be used as a point of departure for the development of a custom-made design intervention to stimulate the commercialization of bamboo in products in the interior decoration sector in Western Europe in the following section.

2.2 Design Workshops as Custom-made Intervention

2.2.1 Introduction

In subsection 1.2.3 it was found that there are many obstacles with a complex cause - effect relationship that need to be solved (see figure 1.18) over the PCS in order to eventually increase the commercialization of bamboo in products. Most obstacles earlier in the PCS have a negative influence on obstacles later in the PCS, and need to be solved first. Therefore, if possible the intervention in this research should target problems at the beginning of the consumption side of the PCS: lack of availability & diffusion of bamboo based information, lack of knowledge about bamboo, lack of bamboo related value chain networks, and a lack of bamboo related product design capacity, i.e. Western designers working with the material. It is expected that lack of knowledge (due to lack of availability and diffusion of information) is one of the crucial problems that lies at the source of obstacles later in the PCS, such as lack of product design capacity and lack of value chain networks. In other words, if designers and other relevant value chain nodes do not know the potential of bamboo as a material they are not likely to implement it in their projects.
The above designers, as potential material champions, were already introduced as the *primary target group* of the intervention, which should be actively introduced to the material through the development of design workshops. Once designers have adopted the material and transfer bamboo into products with high potential, the added value of the material might become evident through concrete product examples, which eventually may be launched on the market. Through exposure of the results value chain nodes downstream might also be influenced, eventually leading to the launch of these products in final consumer markets.
However, in the previous section it was also found that only introducing designers to the material is not sufficient, and other value chain nodes downstream (application manufacturers, processors, retail outlets) should preferably be involved in such a design intervention as well, in order to improve chances of success (i.e. a higher and quicker commercialization rate). The involvement of these value chain nodes downstream, but also additional relevant stakeholders (e.g. policy makers, general public), which together form the *secondary target group* of the intervention, should be facilitated through the diffusion of the results of the design workshops. The intervention was therefore composed of two parts in which each have a different scope and target group: the core intervention and the extended intervention.

The *core intervention* consists of the design workshops and focuses on designers as the target group to tackle the bamboo related problems: lack of knowledge with designers (due to lack of availability and diffusion of information), lack of value chain networks around designers and lack of product design capacity (too few designers working with the material). Since the lack of knowledge lies at the source of these problems the design workshops require a *knowledge intensive* character. For the development of value chain contacts already during the workshops, the focus was on establishing links of designers with application manufacturers and processors because 1) they are usually the next value chain nodes to convince in the PCS, and 2) because of their (contacts with) retail outlets and therefore their power to actually introduce a material in a product on the market.

The *extended intervention* also focuses on the secondary target group of the intervention (relevant value chain nodes downstream and additional relevant stakeholders) and focuses on the *diffusion of the results* of these workshops. The extended intervention has a wider scope and also tries to positively influence additional problems on the consumption side of the bamboo PCS: lack of knowledge of producers, retailers & consumers, the poor image, lack of trendiness, and lack of value chain networks on a broader level (additional processors, application manufacturers and this time also retailers); see figure 2.1.

The focus of this research principally lies with the evaluation of the core intervention, and to a lesser extent on the evaluation of the extended intervention. Besides the choice for designers as a target group this focus was required to keep the evaluation of the intervention, based on various success indicators, feasible within the time frame of this research.
The design workshops (core intervention) were titled "Bamboo Labs", and are part of the project "Dutch Design meets Bamboo" (DDMB) which combines the core- and the extended intervention. In figure 2.1 the scope of the core- and extended intervention is depicted, based on the main obstacles found along the bamboo PCS in figure 1.18. The darker gray obstacles refer to the Bamboo Labs (centered around designers), whereas the lighter gray obstacles refer to the extended intervention. Both interventions have the overall objective to increase the commercialization rate of bamboo in products on final consumer markets (at the right side of the diagram). The bold arrows in the figure show how the obstacles during the Bamboo Labs were targeted with an emphasis on targeting the problem of lack of knowledge as the main cause of obstacles later in the PCS.

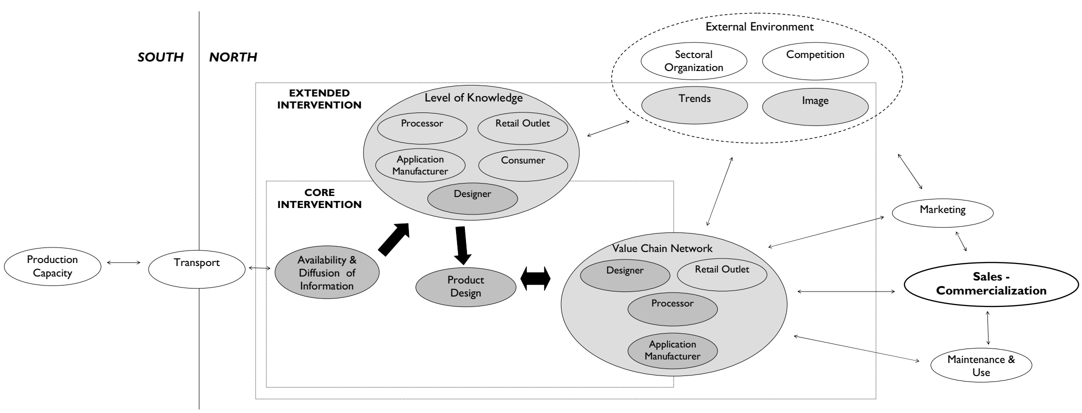


Figure 2.1: Scope of the core intervention and the extended intervention over the obstacles in the bamboo PCS

The idea behind the Bamboo Labs and DDMB is that an intervention at exactly the right spot in the PCS can result in a positive chain reaction throughout the PCS. Because of the interactive relationship between obstacles later (and earlier), obstacles in the PCS are also expected to be affected by the intervention in a later stage (depends on the location of the obstacle in the PCS). For example, if through the intervention bamboo materials are used in high end consumer durables and are therefore perceived as a high end material, adoption of Western trends by trend adopting markets in the South may result in an improved image and increased consumption of bamboo in these countries as well in the long run. However, due to obvious time limitations, this evaluation was not taken into account in this thesis.

It should be noted that the focus selected for the intervention is a choice.
First of all, obstacles in the South also will need to be solved before the bamboo materials can be successfully commercialized in the North. While the choice for a scenario in which production and design will take place in the North avoids many typical problems for bamboo in the South such as lack of local product development capacity (for more information about obstacles in the South, the reader is referred to van der Lugt (2005a) and van der Lugt and Otten (2007)), also with production and design of the products in the North, the production capacity of the bamboo materials in the South and transport to the North is usually an obstacle. However, the obstacles found in figure 1.18 apply at the sectoral level, which means that there are also exceptions on firm level of value chains in the South that have already solved these problems. For example, besides the many bamboo producers that cannot meet Western standards, there is a limited number of Chinese producers that are able to deliver industrial bamboo materials of sufficient quality to the West. Therefore, for the intervention in this research, the production capacity- and transport obstacle in the South was solved by the selection of the right supplier of bamboo material who already tackled these problems in his individual production chain in the past, and who was able to supply high quality material available in high quantities.
Secondly, additional obstacles later in the PCS that fall outside of the direct scope of this research will also have to be solved in future projects (e.g. marketing issues) to improve the commercialization rate of bamboo in Western Europe. However, it is expected that once Western designers, processors and application manufacturers adopt bamboo, they will solve these problems in-kind through their existing marketing proficiency. In INBAR Technical Report 29 (van der Lugt and Otten 2007) various recommendations are provided that also focus on these obstacles.

2.2.2 Initial Conceptual Framework

Based on the main problems stipulated in the previous subsection, the main elements of the intervention can be designed, which target each specific problem. These elements also define the initial conceptual framework of the research, which will be presented in this subsection as well. The conceptual framework helps to operationalize this research in measurable dependent and independent variables, which is necessary to be able to objectively evaluate the intervention after implementation.

The bamboo related problems mentioned in the previous subsection determine the main elements of the core intervention (Bamboo Labs). First of all, the lack of product design capacity requires *the selection and active involvement of a talented group of designers.* Secondly, the lack of knowledge (due to lack of availability and diffusion of bamboo information) & lack of value chain networks for designers requires *the development of a Material Support System* (in this case the Bamboo Support System) catered toward the needs of designers. This Material Support System (MSS) needs to provide the designers with the appropriate information and relevant value chain contacts (in this stage primarily processors and application manufacturers) for bamboo, and consists of an information material component and an interaction component. Finally, it should be remembered that the core intervention is only feasible if various preconditions are met:

- Provision of a large variety of bamboo materials in high quality and sufficient quantity

- Availability of adequate facilities (physical environment, multi media facilities, capable facilitators, etc.) during the intervention
- An adequate organization team capable of organizing and coordinating the intervention
- Sufficient financial resources to fund all activities

Taking the above into account, the first conceptual model of the research can be built (see figure 2.2), presenting the most important concepts and variables of this research, based on the baseline situation (T0), the core intervention, and post intervention situation (T1). The main elements of the core intervention were introduced above (participating designers, MSS). These elements, including their components, form the independent variables of this research. The expected improvement of the situation through the intervention is measured through performance indicators, which form the dependent variables of the research. The intervention is made in the design practice in the Netherlands and therefore designers are the research units. The intervention will be evaluated based on a comparison of the baseline situation and the post intervention situation through the following bamboo related properties of the designers (performance indicators), which are related to the main problems that the core intervention targeted: bamboo design knowledge, bamboo related value chain contacts and bamboo implementation behavior measured through the behavioral intention of the designer, defined as "the expected chance of implementation of the material by the designer in concrete products/projects in the near future (within 2 years)."
These success indicators will be further introduced in section 3.3. Besides these indicators the intervention needs to result in concrete prototypes of new innovative bamboo products with high potential for the Western European market. As was mentioned before, an improvement measured for the indicators mentioned is expected to eventually improve the commercialization rate at the end of the PCS.

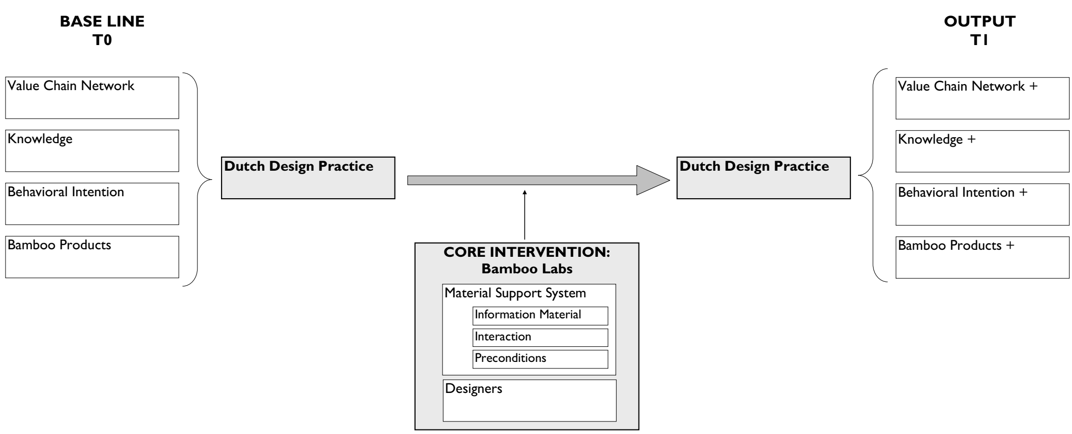


Figure 2.2: First rough conceptual framework of the research (Scope: core intervention)

Compared to the more controlled core intervention, it is more difficult to measure the success of the extended intervention, based on success indicators related to the main problems which the extended intervention targets (see previous subsection). There are two main reasons for this. First, the environment during the external intervention is less controlled than during the core intervention; during the extended intervention the results of the Bamboo Labs are diffused into the external environment, in which market forces and dozens of internal and external factors (see appendix G) determine if a product will actually be optimized and successfully launched onto the market (last phases in the product innovation process). Second, due to the long time the final stages of the commercialization process can take, and the short time span between the writing of this thesis and the start of the extended intervention, it is impossible to exactly measure the impact of the extended intervention in this stage. Based on these reasons the success of the extended intervention can only be roughly measured compared to the core intervention, and was not yet included in the first conceptual framework shown above. Nevertheless, in section 3.2 the extended intervention will be integrated in the conceptual framework.

2.2.3 Outline

Besides previous design workshops held for composites in general (the Composites on Tour project, see the box in subsection 2.1.2), and for bamboo composites (*Material Legacies: Bamboo,* executed as a student project in 1999 at the Rhode Island School of Design - RISD), there are few recorded and reviewed precedents of similar design interventions that took place in the past that could be relevant for the design of the pending intervention (core- and extended intervention). Therefore the DDMB project had to be designed almost from scratch.

To ensure the intervention was designed in an efficient way to optimize chances of positively influencing the success indicators, various sources were consulted for input in order to further shape the structure and components of the intervention. First of all, the primary target group of the intervention, the participating designers, were consulted for input before the intervention started. Secondly, previous experiences and lessons learned from the *Material Legacies: Bamboo* design workshop were taken into account through intensive correspondence with the shaper and founder of the workshop, Enrique Martinez of RISD, who was also invited as the keynote lecturer during the opening of DDMB. Besides Martinez, other leading scholars active in the field of bamboo and design/engineering were also consulted such as Dr. Jules Janssen from Technical University Eindhoven, the Netherlands and Prof. M.P. Ranjan of the National Institute of Design, India. Thirdly, the project team of DDMB, consisting of representatives from various parties active in the realm of Dutch Design (DUT Industrial Design Engineering, Design Platform Eindhoven, Architectural Firm "De Onderneming in Architectuur", Art Centre "de Krabbedans" and Moso International), held various meetings in which the best outline (i.e. best output, most efficient configuration) of the intervention was discussed. All the input from the various sources was taken into account during the development of the structure of the intervention, which is introduced below.

Structure

The core intervention (the Bamboo Labs) consists of a series of five group sessions (Bamboo Lab days), serving as knowledge input, evaluation and inspiration meetings, which are structured following the product innovation model developed by Buijs (2000). The Bamboo Labs cover the various phases of the product innovation process until and including the materialization sub phase of the development phase; see figure 2.3.

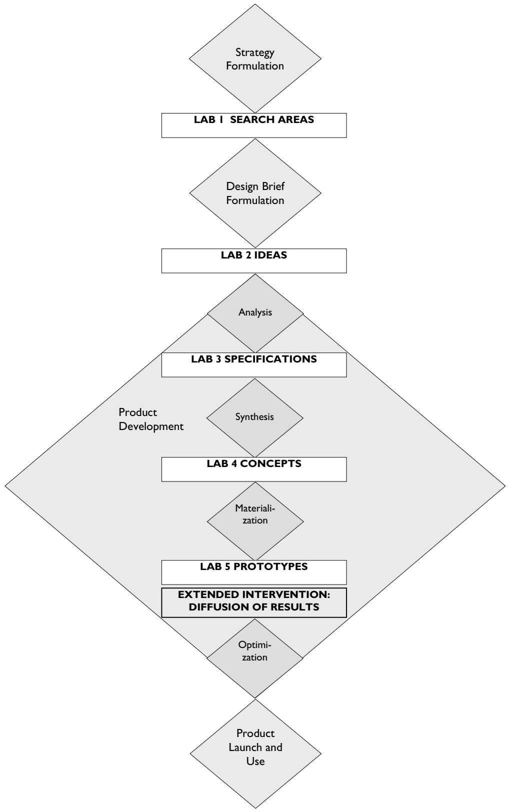


Figure 2.3: Structure of the intervention based on the product innovation model by Buijs (Buijs and Valkenburg 2000)
Note: The Product Development phase has been folded out to show the various subphases of this phase

The various Bamboo Lab days varied in character depending on the needs of the designers in the various phases of the product innovation process. For example, in the first two Bamboo Lab days the emphasis was mostly on information input for the designers to acquire the necessary start-up knowledge, which is crucial in the beginning of the design process. The first two Bamboo Lab days, including the opening of the project, were therefore organized within two weeks of each other to provide a kick start for the participating designers. In the following Bamboo Lab days the focus was on the evaluation of the developed product ideas and concepts of the designers, and the possibility to interact with experts, the other participants and processors, and application manufacturers. In between the various Bamboo Lab days the participating designers were urged to experiment in their own design studios to eventually materialize their initial product ideas into mock ups and prototypes. Therefore, the final three Bamboo Lab days were organized with a time difference of a month.
Twenty-one Dutch designers active in the interior decoration sector were selected and invited to participate in the Bamboo Labs. The design brief they received was largely based on the criteria for enabler applications which were introduced previously in subsection 1.3.2. According to the design brief the newly to be developed bamboo product should: 1) have high potential for the Western European market (be able to compete with existing products in the target market), 2) use the specific qualities and unique properties of bamboo as a material (technology oriented approach), 3) be a high end consumer durable (visible in the end product as bamboo for a long period of time), 4) be innovative,

and 5) improve the image of bamboo; if possible serve as an icon and thus fulfill an ambassador function for bamboo as high end design material in the West.
Most of these criteria are self explanatory, and only the second criterion requires some additional information. Musso (2005) and van Kesteren & Kandachar (2004) emphasize that application search which uses the unique qualities of a material is an important factor for the successful commercialization of a new material. For these reasons the designers in the core intervention were urged to explore the possibilities of bamboo from a technology oriented approach, which was also taken into account in the development of the MSS (see next subsection), and is further explained based on concrete examples in the box below. Note that these unique properties besides technological properties can also refer to soft properties (e.g. sensorial and intangible properties).

Box: The Potential of a Technology Oriented Approach for Bamboo

During product innovation in general, mainly the market side is emphasized, purely focusing on customer attributes and needs, neglecting innovation opportunities from a technological point of view. Since most product innovators mainly focus on market opportunities, there are more technological opportunities to be exploited for product innovation (Poelman 2005). The same certainly applies for bamboo based product innovation. Larasati (1999) states that exploring new processing technologies in combination with the material properties of bamboo to create new ways to use the material is of crucial importance for successful bamboo product development, especially for Western markets. Ranjan mentions that "While bamboo is one of the oldest materials exploited by man, recent developments suggest that completely new ways of using this material in an environmentally sustainable manner are possible that will put this natural material on par with the most sophisticated synthetic materials ever invented by man" (Ranjan 1999), also emphasizing the important role of a technology oriented approach in order to take advantage of bamboo's qualities.
Although many opportunities still seem present for the development of high quality bamboo products from a technology oriented approach based on industrial techniques, not many product developers, designers and consumers are aware of these possibilities. This is caused by the fact that bamboo is usually known in very traditional products using traditional processing techniques. However, using industrial processing technologies many products can be created from bamboo delivering a completely new identity and improved image to the material (see figure 2.4 and appendix E). Also, the designers Anthony Marschak, Jared Huke and Marco Groenen (see their designs in figure C3 in appendix C), who are some of the pioneering designers working with bamboo in product designs in the West, agree that once designers know their way to information about the possibilities of bamboo as a material for designers, they might be able to utilize the specific advantages of bamboo in contemporary products with higher market potential. Especially if star designers start working with bamboo and are able to create a special design functioning as an icon for bamboo, exposure related to the product can improve the image of the material. A historic example from the wood industry are the bended chairs by Thonet, functioning as an icon for the wood bending industry in the twentieth century (van der Lugt 2005b).

Figure 2.4: Examples of bamboo furniture with a completely different appearance because of different processing technologies (based on bamboo culms - left, bamboo strips - center, and laminated bamboo - right); figure made by de Goede and van Loon (2006)

Besides the existing processing technologies mentioned for bamboo above, there is room for the development of many new technologies (e.g. steaming, chipping, microwave heating, etc.) that can have potential for new bamboo applications.
For example, Pil and Verpoest (2006) found, based on their experiences with the implementation of composites in consumer goods that one of the most important steps designers should make when working with a new material is to radically let go of previous standard structural solutions used in their form language based on experiences with other materials. It took Verner Panton, for example, twenty years after the first use of composites in chairs to make this shift in thinking to develop a 100% composite chair. For bamboo the same shift of thinking could lead to new solutions as well. Since bamboo and wood resemble each other a lot, many designers tend to manipulate and process bamboo in the same way as wood. Once they let go of this prejudice potential technological breakthroughs might be feasible. For example, the composite structure of bamboo with strong fibers embedded in softer parenchyma tissue hypothetically makes it very suitable for bending. A preliminary test done by the author already showed the potential of bamboo for bending into extreme curves based on steam heating techniques (see figure 2.5 below). Furthermore, very little information is available about bending bamboo after or during microwave heating; however, the few publications (Norimoto 1980) that are available show the potential of this technique, which deserves further exploration.

Figure 2.5: bamboo strips curved after steaming procedure
Note: 1x1cm grid is photographed at the back of the sample revealing a 25 cm diameter of the curved strips

But also other technologies in other phases of the production chain could result in major breakthroughs for bamboo, like, for example, the manipulation of the form of the bamboo stem during the growth phase with molds (see figure 2.6 below), providing opportunities for many new exciting applications.

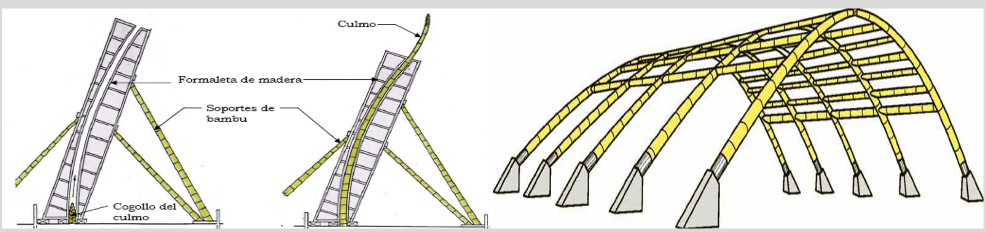


Figure 2.6: Deformation of bamboo culms during the growth phase for special applications (Hidalgo Lopez 2003)

The core intervention focuses on the first three phases of the product innovation process because, as we already saw in the previous subsection, these can be better controlled within the environment and the time frame of the core intervention, since the final phases of the product innovation process (optimization and launch, see figure 2.3) take a rather long time. As can be seen in figure 2.3, the core intervention ends with Bamboo Lab day 5, after completion of the materialization sub phase of the development phase in the product innovation process, resulting in prototypes of the products, which marks the start of the extended intervention. The extended intervention wants to stimulate the initiation of the final phases in the product innovation process. Therefore, for the extended intervention around the core of the intervention (the Bamboo Labs) various other activities were organized in the DDMB project to stimulate diffusion of the results of the core intervention in order to accelerate potential implementation of bamboo by additional designers, producers and retailers in Western Europe. The most important instruments during the extended intervention to diffuse the results of the workshops were the establishment of an exposition around which several activities were organized (seminar, design fair, etc.), the publication of an international book about the project, and press releases to stimulate exposure about the project. These elements and its components will be further introduced in the next subsection.

2.2.4 Elements

This subsection will explain how the main elements of the intervention introduced in the conceptual framework are detailed into components. Also, the main components of the extended intervention will be introduced.

Participating Designers

The active involvement of a talented group of designers is the first main element of the core intervention. In the intervention, designers from the Netherlands were chosen to represent Western designers. This choice was made out of practical reasons, but also because Dutch Design is acclaimed worldwide (Betsky and Eeuwens 2004). By choosing Dutch Designers it was expected that products with the highest potential for the Western European market, and an ambassador's function for bamboo as a design material, would be developed in the intervention. Furthermore, emphasis was put on the selection of designers that have their working field in the interior decoration sector.

Besides these similarities, because of the exploratory and novel character of this research, the selection of designers within the total population of Dutch designers was executed in such a way that a large variety of different kinds of designers participated in the Bamboo Labs, in order to gain a better and broader understanding of the relationship between the properties of the designers and various success indicators (see RQ 4.1 in subsection 3.3.4).

Besides the selection of designers, which differ in various properties, a requirement the designers had in common was their level of talent. To enhance chances of success, designers with a better than average talent were invited for the intervention. Because DDMB was sponsored by various parties with different interests, some extra constraints were added while selecting the designers (e.g. requirements of one of the subsidizers to integrate young designers from the province of Brabant). Furthermore, some furniture producers sponsored DDMB through provision of one of their in-house designers to participate in the Bamboo Labs, resulting in these designers being more constrained to a specific market and style.

Based on these criteria, the members of the organization team (who have a good overview of the population of Dutch designers), first made a long list; after various discussions they compressed it to a short list of around twenty Dutch designers or design studios who were invited to join the project. Almost all designers who were invited directly accepted the invitation to join the project. The invited designers, including their characterizations, are represented in table 2.2 below.

Table 2.2: The selected designers and their key characteristics

Designer (Studio/ company)	Sector	Professional Experience	Organizational Structure
1. Maarten Baptist (Wat Design)	Interior design, furniture and graphic design.	0 - 5 years	Independent designer
2. Nathalie Meijer (Leolux)	Furniture	> 5 years	In-house designer
3. Leonne Cuppen (Yksi)	Furniture and interior design	> 5 years	Self producing studio
4. Lara de Greef	Small user objects and textile	0 - 5 years	Independent designer
5. Ro Koster (Ro & Ad Architects)	Architecture	> 5 years	Independent designer
6. Ad Kil (Ro & Ad Architects)	Architecture	> 5 years	Independent designer
7. Maarten Baas	Furniture	0 - 5 years	Self producing studio
8. Thijs Bakker	Furniture and fair design	0 - 5 years	Independent designer
9. Patrick Kruithof (the Moment Company)	Small user objects and product experiences	> 5 years	Independent designer
10. Jacqueline Moors	Public space and street furniture	> 5 years	Independent designer
11. Ed van Engelen (Haans)	Furniture and accessories	> 5 years	In-house designer
12. Gilian Schrofer (Concern)	Interior design	> 5 years	Independent designer
13. Mette Hoekstra (Concern)	Interior design	0 - 5 years	Independent designer
14. Tejo Remy	Interior design, furniture, and public spaces	> 5 years	Independent designer
15. René Veenhuizen	Interior design, furniture, and public spaces	> 5 years	Independent designer
16. Eliza Noordhoek	Small user objects and furniture	0 - 5 years	Independent designer
17. Yvonne Laurysen (Lama Concept)	Furniture, interior design and textile	> 5 years	Self producing studio
18. Erik Mantel (Lama Concept)	Furniture, interior design, and textile	> 5 years	Self producing studio
19. Bert Jan Pot	Furniture and accessories	> 5 years	Independent designer
20. Lotte van Laatum	Furniture and accessories	0 - 5 years	Independent designer
21. Daan van Rooijen (Kiem)	Sustainable products & engineering	> 5 years	Other

Although the selection of a talented and varied group of designers is an important element in the Bamboo Labs, these designers also need to be supported, in this case through the Material Support System.

Material Support System

The development of a Material Support System (MSS) is the second main element of the core intervention which targets the earlier found bamboo related problems like lack of knowledge of designers and lack of value chain networks of these designers for bamboo. First of all, since most Western designers have no knowledge and experience in working with bamboo, they need to be supported with adequate information. Secondly, they are not acquainted with many bamboo related value chain nodes. The main components of the MSS to support the designers within the framework of the Bamboo Labs are the provision of information material, and the interaction with relevant stakeholders, which will be further elaborated upon in this subsection. The preconditions mentioned first in subsection 2.2.2 are also perceived as part of the MSS and will therefore also be covered here.

The consulted sources mentioned earlier in subsection 2.2.3 to develop the outline of the intervention were also used to further develop the various components and subcomponents of the MSS, and were supplemented with findings from interviews executed by the author with a selection of participating designers prior to the start of the intervention (T0). From these sources it became clear that first of all designers are interested, especially at the beginning of the design process, in soft properties of materials (sensorial and intangible properties), instead of the usually over emphasized harder properties of materials (e.g. technological properties). Based on these sources, and especially the interviews with the designers, the main requirements of the knowledge contents of the MSS were identified, which needed to include:

- Properties of the various bamboo materials (information about both hard and soft properties)
- Practical information; do's and don'ts during the processing and finishing of bamboo materials
- Examples of previous products made out of bamboo, based on various processing technologies

According to the designers the contents of the MSS needed to be a combination of thorough fundamental knowledge and practical hands-on knowledge, with an emphasis on the latter. In general, it could be stated that the contents preferably needed to be presented in a visually attractive manner with many examples. In table 2.3 below, the various possible general information sources that could be used for the MSS are depicted, after which the actually chosen subcomponents of the MSS are presented, based on the requirements posed by the participating designers. Note that in the selection and design of the MSS subcomponents, the lack of bamboo related value chain contacts of designers was also taken into account, which explains the relatively high importance of the interaction component.

Table 2.3: Potential means to be used for the MSS, including the actual chosen subcomponents of the MSS for the intervention

Potential Means	Actual subcomponents of the MSS (choices)
Information Material	Bamboo Information Material
1. Printed publications (Books, catalogues, magazines, etc.)	1. Printed publications - Reader - Library
2. Digital publications (Digital newsletters, CD ROMs, PDFs, etc.)	2. Digital publications - CD ROMs - Digital database
3. Internet based (Websites, online databases, etc.)	3. Internet based - Overview of relevant websites (in reader)
4. Other (Material samples, videos, etc.)	4. Other - Material library
Interaction with experts	Interaction with bamboo experts
5. Physical; face to face (lectures, meetings, etc.)	5. Physical; face to face - Lecture (opening) - Excursion (Bamboo Lab day 2) - Interaction during other Bamboo Lab days ▪ Other participants (designers) ▪ Experts in-house/tutors ▪ External experts
6. Internet based (blog, email groups, fora, etc.)	6. Internet based - Blog
7. Other (telephone, fax, etc.)	

Furthermore, as mentioned in the previous subsection (see box in subsection 2.2.3) the designers were urged during the Bamboo Labs to explore the material to its limits from a technology oriented approach, which was taken into account in the development of the MSS subcomponents, which are further presented below.

Information Material

The most comprehensive component of the MSS is the information material provided to the participating designers. As explained before, this is important since there are very few high quality publications available for bamboo that provide adequate information about bamboo as a designer's material, and if available, these publications are very difficult to find. There are hardly any standard works available that give a systematic and visually well presented overview of the existing bamboo materials and processing technologies available including their properties (especially softer properties) and product examples of the various materials.

Through the development of several subcomponents of the MSS in various media, an attempt was made to solve this gap in availability and diffusion of information for the participating designers, taking their content requirements into account. The mentioned subcomponents of the information material component will be further introduced below.

The development of a *digital database* systematically presenting available bamboo materials, processing technologies and product examples, was one of the most important information instruments developed for the participating designers. The database was envisaged as a highly user friendly and visually oriented information database for the participating designers as well as a potential on-line information portal for bamboo as a designer's material in the long run. The database (named "Bamboo Browser") was developed by Mika de Bruijn as part of his MSc thesis (de Bruijn 2007a) at the faculty of Industrial Design Engineering at DUT in collaboration with design studio Horizon Design & Development. The database was developed for the designers as a target group, taking their requirements, acquired through various interviews executed by de Bruijn, into account.

The database was structured following the manufacturing and processing technology possibilities of bamboo, in a similar manner as the acknowledged Cambridge Materials Selector material database is structured. The database presents the various technologies available for bamboo in a systematic step-by-step way, using schematic diagrams for each process step leading to the final semi finished material. To accommodate the navigation requirements of the designers, a Wikipedia style navigation system was developed showing the history of the choices in the menu at the top of the screen (see also figure 2.7). The final screens for each (semi finished) material provided many examples of previous applications in which the technology was used, by using a photo gallery of existing relevant bamboo products. For most bamboo materials, more technical, economical and environmental data was presented in a separate reader, not to affect the required visual and intuitive interface of the database.

Figure 2.7: Screen samples of the digital database by de Bruijn (2007b) with left the opening screen and right one of the hundreds of process screens of the database, explaining the various process steps of all bamboo processing technologies

The *reader,* supplementing the design tool, presented the most important bamboo articles and book sections with respect to the following topics: resource in general, anatomy, preservation, mechanical properties, processing technologies, building with bamboo, and finally bamboo marketing. Furthermore, the reader provided an overview of the best bamboo websites available (e.g. INBAR site, University of Aachen site, Bamboo Craft Forum, etc.) and relevant e-groups for bamboo (e.g. Bamboo Plantations yahoo e-group) for the designers.

Besides the reader, the *CD ROMs* Bamboo Boards & Beyond (NID 2001) and Beyond Grassroots (NID 2003), presenting the bamboo design projects executed at the National Institute of Design in India, were provided to the designers. The design projects at NID provide the best examples of bamboo product design projects found in bamboo producing countries according to the author's opinion.

These information sources were further supplemented by a *mini library* of the most important bamboo books and technical reports present (around 20 items), made available by the author and Dr. Jules Janssen. The library was available during all the Bamboo Lab days, and in between the library was accessible during the complete project at the premises of Design Platform Eindhoven. Furthermore, the designers had access to the full digital versions of all INBAR publications available through the INBAR website, and hard copy versions via the library of DUT.

A final important subcomponent of the information material, meeting the needs of many designers to directly observe and experience the sensorial properties of the bamboo materials, was the provision of a small *material library* for each designer. The library consisted of a box with samples of a wide assortment of the various bamboo (raw) materials available, such as pieces of the stem, strips, slivers, fibers and samples of all kinds of semi finished bamboo materials (Plybamboo in various colors, forms and thicknesses and Strand Woven Bamboo (SWB); for more information about these materials, see subsection 1.2.1). All the materials represented in the material library were made available to the designers in large quantities (see preconditions below).

Figure 2.8: The box with industrial bamboo material samples handed out to the participating designers Note: The provided raw materials in the material library are not depicted in this picture.

<u>Interaction with Experts</u>

The core intervention consisted of five Bamboo Lab days facilitating the MSS, which, besides the provision of information material, stimulated the interaction between the designers and several bamboo experts to enable knowledge- and value chain contact development for the designers. The various interaction components available during the Bamboo Labs are explained below.

Opening Lectures (24 October 2006) and Bamboo Lab Day 1 (25 October 2006)

The opening and official launch of the Bamboo Labs took place during the Dutch Design Week 2006 with two lectures in the Design Academy in Eindhoven. In a packed lecture hall also open to the general public, the author gave an introduction about bamboo as a resource, the various bamboo materials available, their properties and limitations, possible processing technologies, and various product examples for bamboo. The most important aspect of the lecture was to emphasize the problems over the bamboo PCS, and the key role Western designers could play to give an impulse to the commercialization of bamboo; the designers were challenged to contribute with the development of a high potential bamboo product. The second speaker, Enrique Martinez of the Rhode Island School of Design, USA had been invited by the organization because of his experiences as the organizer of the bamboo design workshop *Material Legacies* in 1999 (Martinez and Steinberg 1999). The Rhode Island bamboo design workshop also explored the potential of bamboo from a technology oriented approach, mimicking all the various industrial processes through which bamboo can be transformed in various semi finished materials. Martinez shared his experiences, and also urged the designers to explore the material to its fullest during the Bamboo Labs.

The next morning the first Bamboo Lab day took place in Eindhoven as well, in an old Philips factory at Strijp S. The design brief was provided to the designers in a very bamboo-rich ambiance (formed by large tables made from bamboo board, surrounded by bamboo plants, see also the main introduction figure of this chapter on page 38) and the previously mentioned subcomponents of the information material component of the MSS were handed out to the participating designers. At the end of the morning Enrique Martinez again provided various tips to the designers based on his experiences with earlier bamboo design workshops.

Excursion (Bamboo Lab day 2, 2 November 2006)

Similar to the opening and Bamboo Lab day 1, the second Bamboo Lab day was focused on information input to the participating designers, through a day-long excursion. The designers first visited the Bamboo Information Centre, a bamboo plantation in the Netherlands, to get acquainted with the bamboo plant, after which a visit was paid to the warehouses and premises of Moso International, importer of a wide assortment of bamboo materials. At both companies the complete production process of the various bamboo materials was explained by experienced staff members. In the afternoon, the designers attended presentations by (hands-on) experts in the Cartesius Institute in Leeuwarden, where additional information material was also handed out to them.

Figure 2.9: the designers being shown around at the premises of Moso International during the excursion

Bamboo Labs Days 3-5 (14 December 2006; 18 January 2007; 1 March 2007)

Whereas the emphasis was on information input and provision during the first Bamboo lab days, during the final three Bamboo Lab days the focus was on interaction between 1) the designers themselves, 2) designers and "in-house" experts and 3) designers and external experts.

The first important interaction subcomponent in Bamboo Lab days 3-5 was the interaction between *the participating designers.* During the project all participating designers were free to choose a certain material and product (within the framework of the design brief) and were urged to set out in different directions to experiment in various ways with the bamboo materials. As such they developed much knowledge and became hands-on experts with the various bamboo materials. To disseminate this knowledge between the designers, the third and fourth Bamboo Lab days, which each lasted one morning and took place once again at Strijp S in Eindhoven, were set up in such a way that designers could actively share and discuss first product ideas (Bamboo Lab day 3) and first product concepts (Bamboo Lab day 4) and other findings with the other participants. During these Bamboo Lab days, the designers were split up into three groups to stimulate exchange and interaction, which is usually hampered in groups that are too large. The setting in which this took place was designed to be very laid back ("coffee table concept"), in order to create an open and informal atmosphere in which the exchange of ideas and findings was stimulated. The key topics and findings of the discussions were written down on flipovers by the facilitators and presented in a summarized way in a plenary session at the end of the day to all the other designers. This summary was also sent later, including photos, as a small digital report in pdf format to the participants.

Figure 2.10: The participating designers sharing ideas during the Bamboo Lab days

The second interaction component in the Bamboo Lab days was the interaction between the designers and various experts that were present during all these days, the so called "*in-house experts*". The principal bamboo expert available throughout the complete Bamboo Labs was Dr. Jules Janssen of the Technical University Eindhoven from the Netherlands, who has lifelong experience in bamboo as a material for construction and design. Dr. Janssen was assisted by various other in-house experts, all with a different background and expertise: Marco Groenen (designer of the bamboo furniture line "Grass"; see figure 4.29), Arjan van der Vegte and Rolf Bakker of material supplier Moso International, and finally the author of this thesis. Especially during Bamboo Lab days 3-5, these in-house experts were available to answer any questions the designers would have. In between the Lab days the in-house experts were available to answer questions over the telephone or through email.

Figure 2.11: Dr. Jules Janssen as one of the in-house experts available throughout the Bamboo Lab days.

Furthermore, all the experts and designers were also united and linked to each other throughout the project through a *web blog*. In this blog the designers could ask advice and questions to invited experts on the blog. Besides the previously mentioned in-house experts, Enrique Martinez and Professor Ranjan from the National Institute of Design in India were also available as experts on the blog. The blog can be visited at http://dutchdesignmeetsbamboo.blogspot.com/.

The final interaction component during the Bamboo Lab days was the interaction between designers and *external experts.* In between the Bamboo Lab days the designers were, depending on their interest in a certain processing technology and bamboo material, linked by the project team to additional tutors in specific fields. For example, designers that saw the most potential in using bamboo for composite materials were linked to the laboratory of Aerospace Engineering of DUT, where tutors knowledgeable in natural fiber reinforced composites (Rik Brouwer, Bob van Ursum) gave an introduction about the use of natural fibers in composite materials. Besides the provision of these external contacts, the designers were also stimulated to set out by themselves to search for experts knowledgeable in their specific field of interest (depending on the design choices of the particular designer).
Furthermore, during the final Lab day (Bamboo Lab 5) in which the prototypes had to be presented, various representatives and experts from the processing and production industry in the Netherlands were invited to join the presentation. All of the invitees had signed a statement of confidentiality prior to the presentations. These invitees acted as external experts, but were also perceived as important value chain contacts to introduce to the designers and vice versa, which enhanced the probability of implementation of products developed within the framework of the project.

Figure 2.12: During Bamboo Lab day 5 the designers presented their prototypes to each other and a small number of selected invitees

Preconditions

In order for the MSS to be effective, various preconditions had to be met for the Bamboo Labs to live up to its objectives: the provision of a large variety of bamboo *materials* in high quality and sufficient quantity, the availability of adequate *facilities,* the availability of an adequate *organization team*, and the availability of sufficient *financial resources* to fund all activities. How these preconditions were met for the intervention will be explained below.

<u>Materials</u>

An important precondition within the intervention was the availability of high quality material, in sufficient quantity, and in a high variety. The material used for the design workshops was sponsored by the company Moso International which provided all the necessary bamboo raw materials and semi finished materials to maximize the freedom for exploration of the resource bamboo by the designers, and to enable the designers to hypothetically develop any product possible out of bamboo, based on all possible processing technologies. However, the choice for Moso International as sponsor also limited the choices for the bamboo species to deploy during the Bamboo Labs. Moso International derives all its bamboo products from China, where most industrially processed bamboo materials are made from the species *Phyllostachys Pubescens*, also known as "Moso" bamboo. Because most bamboos are very similar in their anatomical structure, it is expected that the findings for these Bamboo Labs also apply to other (giant) bamboo species.

As explained before, a large assortment of bamboo raw materials and semi finished materials was made available to the designers: bamboo stems, bamboo strips (including skin/excluding skin, rough planed/fine planed), bamboo mats (based on woven slivers), bamboo fibers (in the form of very thin sticks with a diameter of 2 mm, which are normally used for the manufacturing of blinds; see figure 2.13) and several industrial bamboo materials (Plybamboo, Strand Woven Bamboo) in many variations (color, thickness, side- or plain pressed, etc.).

Figure 2.13: Bamboo blinds made up of various thin bamboo sticks which were made available in their individual forms to the participating designers

In the end, five different bamboo materials, which were either a composition of the raw materials provided (e.g. composites which combined the bamboo fibers with resin) or the direct use of the materials provided (e.g. stem, Plybamboo), were used in the final prototypes of the designers: I) stem, II) Plybamboo (in many variations), III) composites[26], IV) SWB, and V) mats (orthogonally woven slivers of bamboo, used as input a.o. for Bamboo Mat Board - BMB), see figure 2.14.

Figure 2.14: Samples of the various bamboo materials used in the final prototypes of the participating designers (from left to right): I) the stem, II) Plybamboo, III) bamboo fiber based composite, IV) SWB, and V) mats

<u>Facilities</u>

Another important precondition throughout the Bamboo Lab days was the availability of adequate facilities. First of all, as the location for the Bamboo Lab days (besides Bamboo Lab day 2) the fourth floor of the monumental old Philips factory building Strijp S was chosen. This location was chosen as an informal, quiet and spacious setting which facilitated interaction and exchange between the designers, and provided enough room for them to show experiments and first concepts. In this setting all possible multi media facilities were available to further stimulate exchange between the participants and in-house experts (beamer & screen, flipover sheets with markers, etc.). The Bamboo Lab days were facilitated by designer Marco Groenen and the author, who through their style as facilitators also tried to create an open, informal atmosphere to provoke interaction and exchange between the participants about their designs and ideas, and to avoid secrecy (since theft of their ideas is a common threat for designers). In between the Bamboo Lab days the designers were expected to make use of their own processing facilities in their design studios to experiment with the various bamboo materials in order to develop their product concepts and final prototypes. In the case of complicated processing requirements the organization team and in-house experts tried to provide leads to potentially interested processors and

[26] Note that technically speaking, a composite material consists of two or more different materials which are combined to form a material that performs better than the individual components. Theoretically, bamboo materials II-IV in figure 2.14 are all composites, since they consist of bamboo tissue combined with glue/resin. In this thesis reference is made to bamboo composites when the resin and bamboo material are independently visible.

application manufacturers that could assist the designers, but the designers were also urged to search for processors & application manufacturers on their own.

Organization Team

The third major precondition for the intervention was the availability of an adequate organization team capable of the organization and coordination of the intervention. The organization of the DDMB project should not be underestimated; the various elements of the intervention required a lot of effort and expertise in various fields (e.g. fundraising, supply of sufficient material, selection and communication with designers, provision information material, arrangement facilities, development of the program and policy, invitation of speakers & facilitators, financial accounting, development of the exposition and book, etc.). Therefore, the organization team was made up of various persons from various organizations with various interests, fields of expertise and roles in the organization team: Marco Groenen (Architectural firm De Onderneming in Architectuur), Jose Vermeij (Design Platform Eindhoven), Hanneke van den Nieuwenhof (Art Centre CBK de Krabbedans), and Pablo van der Lugt (DUT). Arjan van der Vegte (Moso International) was later added to the organization team as project secretary, to organize the day-to-day activities and requirements of the Bamboo Labs. The author chaired the team meetings and tried to act as driver to keep the momentum in the project. As was found in section 1.4, this active participatory role of the researcher is typical for action research.

Financial Resources

A final major precondition which had to be met for the intervention to continue was the availability of sufficient financial resources to fund all required activities. Although the employers of the organization team members provided various in-kind contributions to the project, a substantial amount of money (over €100,000) was needed to cover all required expenses (organization costs, renting facilities, development of information material, supply of bamboo material, development of book and exposition, etc.). Almost half this amount (€2,500 per designer/design studio) was allocated to financially compensate the designers for their costs and time expenditures during the intervention. By financially compensating the designers for their time spent in the project, it was expected that a larger commitment and drive of the designers was created to meet the requirements posed in the design brief in a satisfactory manner. The additional required funding to cover these expenses was acquired through active fundraising by the organization team. Moso International provided all the bamboo material needed during the intervention. Various additional sponsors (Mondriaan Stichting, Province Noord Brabant, DUT, Cartesius Institute) financially supported the intervention. These sponsors in turn had various demands in order to support the project (e.g. the province of North Brabant demanded that young designers from this province needed to be integrated in the Bamboo Labs in order for them to sponsor the project).

Extended Intervention

Above, the various subcomponents of the main elements of the core intervention (Bamboo Labs) were introduced. Although the primary focus of the intervention is on the Bamboo Labs, the diffusion of the results of the core intervention during the extended intervention is also an important part of the total project, which has a wider scope than the Bamboo Labs and targets additional stakeholders and their problems on the consumption side of the bamboo PCS such as lack of knowledge of processors, application manufacturers, retailers & consumers, the poor image, lack of trendiness, and lack of value chain networks on a broader level (also including retailers). The most important instruments used during the extended intervention to diffuse the results of the Bamboo Labs and tackle these problems were (1) the organization of a traveling exposition with the results, (2) the organization of a seminar (Bamboo

Company Day), (3) a design fair around the exposition for interested designers, producers and retailers in the Netherlands, (4) the publication of a book presenting the results, and (5) a press release to various media (magazines, radio, newspapers, etc.) to further stimulate diffusion of the results of the Bamboo Labs. An important difference between the Bamboo Labs and the extended intervention was the fact that during the Bamboo Labs participants received the complete picture about bamboo, including its pitfalls, whereas the extended intervention had a promotional function, in which the positive properties and opportunities of bamboo as a sustainable material for product design were emphasized. In the extended intervention these traits were communicated and marketed in a smooth, compressed and visually attractive manner to have interested stakeholders develop positive schemata for bamboo in order to improve the image and trendiness of bamboo.

Figure 2.15: The opening of the DDMB exposition was organized in the form of a design fair

The results of the Bamboo Labs were exhibited in an *exposition*, designed to travel. The exposition was first exhibited for two months (May-June 2007) at Art Center CBK de Krabbedans, after which it was adopted by the materials library "Material Matters" which further facilitated the traveling exposition with a first stop at the Faculty of Architecture at DUT in autumn-winter 2007, with a second stop at the National Dutch Weaving Museum in spring 2008. The results of the Bamboo Labs were made public for the first time at the opening by former Dutch minister Laurens Jan Brinkhorst of the Dutch Design meets Bamboo exposition, which was organized as a small *design fair.* The organization of the opening of the exposition in the form of a mini design fair was done on purpose; in the interior decoration sector design fairs (especially the ones in Milan and Frankfurt) are the most important media channels for design companies to show their new product designs, and the premier venue for designers to bring their newest work to the surface. Furthermore, potential adopters are easier convinced when they can actually experience a product by all senses through a full scale prototype instead of indirectly experiencing a product by only one sense, e.g. through a photo (van Raaij et al. 2004). Based on these reasons the organization of various activities around the exposition with selected invitees seemed an excellent medium for bamboo to show its potential in concrete high end products to potential value chain nodes downstream (including retailers) in order to facilitate the development of new value chain networks.

The opening of the exposition was attended by carefully selected invitees (priorities for decision makers and other potential material champions) from processors, application manufacturers and retailers in the interior decoration sector and adjacent sectors. The organizations to be invited were selected based on their susceptibility to trends and properties which fit bamboo as high end design material well (e.g. sustainability, FSC, Innovative character). Besides companies, it was also important to invite non profit organizations such as NGOs (e.g. WWF, ICCO, NCDO) to the opening. These organizations are (public) opinion makers in the field of sustainable business and product development, and are able to influence the public opinion, and therefore also companies based on new sustainability demands in their institutional environment.

Besides the fair around the opening of the exposition, a *seminar,* called the "Bamboo Company Day", was also organized around the exposition in collaboration with Material Matters (afternoon of June 14, 2007). The target audience of the seminar was similar to the invitees at the opening of the exposition, and consisted of designers, processors, application manufacturers and retailers in the interior decoration and adjacent sectors, prioritizing sustainability in their company policies, and largely unacquainted with bamboo. Again, emphasis was only posed to invite stakeholders within companies that could act as material champions in their organizations. During the seminar, lectures were given to the participants by invited speakers (René Zaal - director of Moso International, Dr. Aart van Vuure of the University of Leuven, designer Marco Groenen, and the author), after which a guided tour through the exposition was provided to participants. In between activities there was plenty of room for networking for the development of new value chain networks for bamboo.

Besides these activities organized around the exposition, the exposition itself also provided general information about bamboo and various material samples were made available to tackle the problem of lack of knowledge with designers, producers, retailers and the general public about bamboo. The exposition was accompanied by the bilingual 160 page full color book *Dutch Design meets Bamboo*, which was designed to further spread knowledge about bamboo as a material a.o. based on the results of the Bamboo Labs. The book was published by an external publisher ([Z]OO productions) and made available for sale through the exposition as well as through various bookstores.

Figure 2.16: The Bamboo Company Day was organized to inform other relevant value chain nodes about the potential of bamboo

Besides these organized instruments to diffuse the results of the project, a lot of exposure was also created by third parties through various media (magazines, newspapers, radio, television and internet) based on press releases and mouth-to-mouth communication about the project put out by the organization team.

3 Research Design

In the previous chapter a custom-made design intervention, in the form of design workshops, was introduced as a suitable strategy to actively introduce designers to bamboo, which was further detailed into several elements, components and subcomponents. In this chapter, the research design will be introduced, and the main question of this research will be further operationalized in detailed research questions, including relevant research methodology and underlying theory used.

In section 3.1, first the research questions will be introduced, after which in section 3.2 the research model will be developed. In section 3.3 the variables determined in the research model are linked to each other and operationalized into detailed research questions. In section 3.4 the methodology of this research is introduced, including specific data collection and processing methods used, as well as the validity and reliability of this research. Finally, in section 3.5 the outline of the remainder of this thesis is explained.

3.1 Research Questions

The main question of this research was introduced in subsection 1.3.3:
To what extent can design interventions successfully stimulate the commercialization of bamboo in products in the interior decoration sector in Western Europe?
In the previous chapter knowledge intensive design workshops (Bamboo Labs) were introduced as potentially suitable instruments to actively involve designers, to be tested as custom-made design intervention within the framework of this research.

As explained in section 1.4, according to van der Vall (1980), in action research the success of an implemented program (intervention) should be evaluated through an impact evaluation (impact of the intervention measured by comparing success indicators after the intervention - T1, with the base line situation - T0), a process evaluation (monitoring of the process during the intervention) and advice for improvement. This framework to evaluate an intervention is usually applied for the implementation of a new management or communication plan within an organization (den Hartog and van Sluijs 1995). Therefore, for the evaluation of the specific intervention in this action research, consisting of knowledge intensive design workshops, two additional outputs need to be taken into account.
First of all, the output of the design workshops in the form of prototypes of bamboo products provides an additional output compared to a typical organizational intervention. Secondly, through the deployment of a new material in the intervention, new generic knowledge about bamboo will develop as an output. Understanding the experiences of the designers with the various bamboo materials, including their assessment of the new material, will provide important knowledge about the potential of bamboo, providing valuable input for further development of the material for the bamboo industry.
Therefore, to evaluate this specific intervention, besides the impact evaluation and the process evaluation, the outputs in the form of developed prototypes and experiences with the deployed materials should also be evaluated after the intervention (T1).

As seen in subsection 2.2.1, the intervention consists of the core intervention (design workshops) and the extended intervention (diffusion of the results), and focuses on the former. Therefore, unless stated otherwise, when the term "intervention" is used in the remainder of this thesis, it refers to the core intervention. Still, in this thesis the impact of the extended intervention was also measured using rough success indicators, almost one year (T2, April 2008) after the extended intervention was launched in the first exposition (May 2007).

The development of the research questions (RQ) based on the main question to evaluate this intervention then logically follows out of the typical action research elements mentioned before (impact evaluation, process evaluation and advice for improvement), added with an individual evaluation for the materials used and product prototypes developed:

Impact Evaluation (T1-T0 & T2-T1)

RQ 1: To what extent is the impact of the intervention successful?

Product Evaluation (T1)

RQ 2: To what extent are the products developed in the intervention successful?

Material Evaluation (T1)

RQ 3: To what extent is bamboo perceived by Dutch designers as a successful material for product design?

Process Evaluation (between T0 and T1) and Advice for Improvement (T1)

RQ 4: What are the causes of the success/failure of the intervention and how can the intervention be improved?

Although the intervention also wants to yield various high potential bamboo product prototypes, the research focus is not on the act of design but on the discipline of design, systematically investigating through observation and reasoning a body of knowledge about the discipline of design (Horvath 2006). Therefore, this research can be labeled "design inclusive research", and more specifically "operative design research" focusing on enhancing practical problem solving capacity in the design practice through systematic investigation into design processes in order to support designers through proper methods and tools (How to design).

The research questions will be further explained and operationalized into detailed research questions based on the variables in the conceptual model of the research presented in the section below.

3.2 Research Model

In action research, all facts and properties of the organizational setting and its context need to be gathered and structured in the diagnosis phase before the intervention takes place, in order to measure the baseline situation (Susman 1983). After the intervention, there can then again be an evaluation of the properties of the organizational setting, and the values can be compared with the baseline situation to see if the intervention was successful. In the case of this research the organizational setting refers to the part of the PCS the intervention focuses on (see scope in figure 2.1), while the properties refer to the elements of the proposed intervention (independent variables) and the problems in the PCS the intervention targets, based on which indicators can be developed to evaluate the success of the intervention (dependent variables). According to Susman (1983) both the dependent and independent variables are custom-made for each solution in action research, and their impact and relationship should be measured through the development of so-called "working hypotheses".[27] Since the first three research questions of this action research are of an evaluative nature, the most important issue therefore is to establish the indicators with which to measure the success of the impact (RQ1), the prototypes (RQ2) and the bamboo materials used (RQ3). In subsection 2.2.2 some success indicators (for RQ1), related to the main problems found in subsection 1.2.3 for the bamboo PCS, as well as the components of the intervention itself, were already introduced. The independent variables play an important role in explaining the causes of the success/failure of the intervention through RQ4. All relevant variables for the research are represented in the extended research model placed below, in which also the less elaborate evaluation of the extended intervention at T2 is included. In the following section all variables mentioned in the model will be explained.

[27] Note that these "working hypotheses" are very different from hypotheses used in theoretical and fundamental research, to either reject a theory in a certain scientific paradigm or strengthen the acceptance of this theory. Because of the exploratory, practical character of this research and the immaturity of the theoretical field this research targets (active involvement of designers to accelerate material commercialization processes), there are too few precedents of similar interventions and research efforts to form these kinds of hypotheses or propositions for this research.

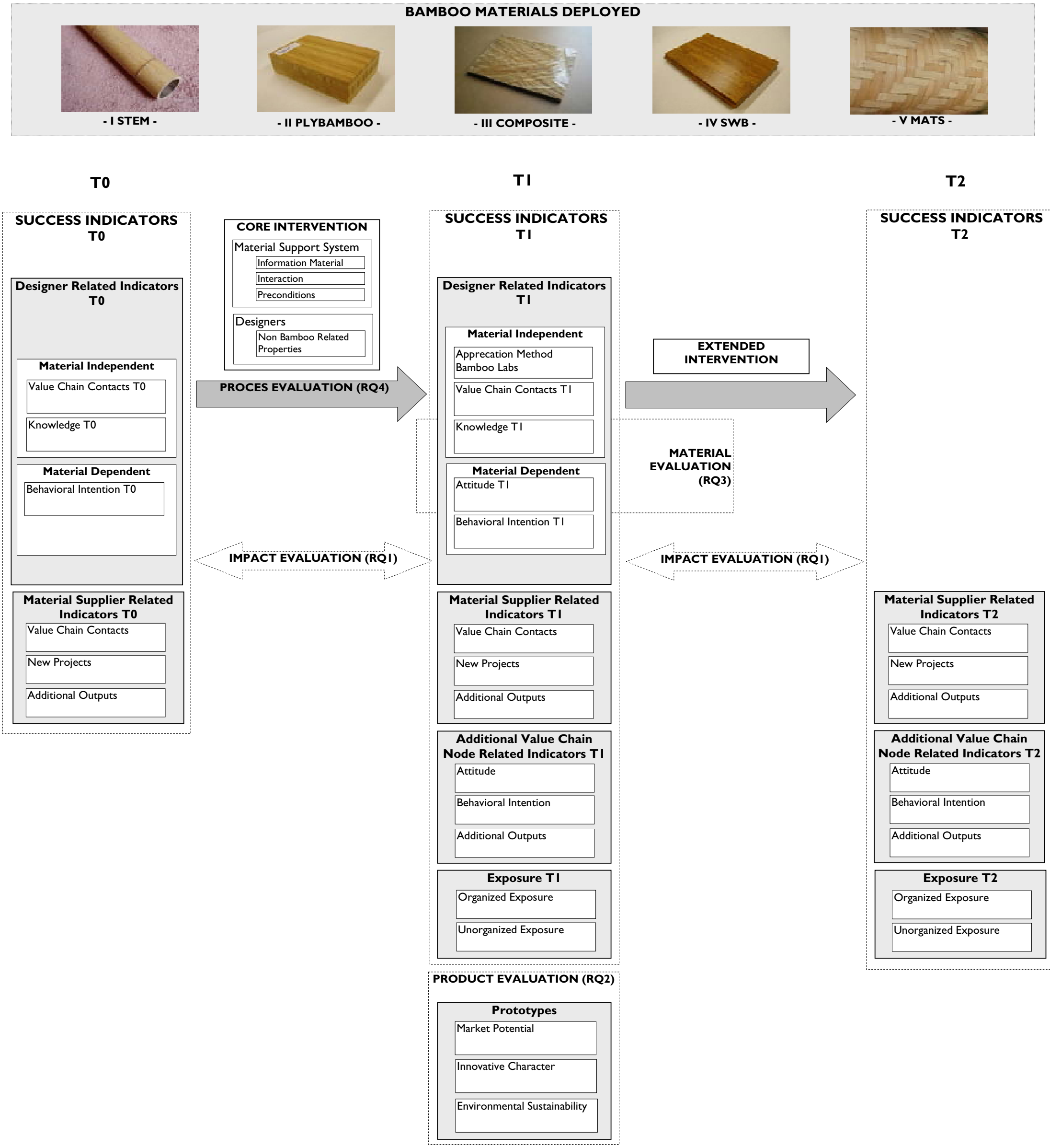


Figure 3.1: The research model presenting all relevant variables for this research

3.3 Operationalization into Detailed Research Questions

In this section especially the dependent variables found in the research model in the previous section will be explained in detail for each research question, including the underlying theory (in section 2.2 the independent variables were already introduced). Furthermore, in this section the research questions will be further operationalized into workable detailed research questions (the working hypotheses of Susman; see section 3.2 above) in which the variables presented in the research model will be connected.

3.3.1 Impact Evaluation (RQ1)

The impact of the core intervention will be evaluated in this thesis for the designers participating in the design workshops, based on the difference between T1 and T0 for the following bamboo related properties of the designers: value chain contacts, knowledge and behavioral intention (see figure 3.1). Although the focus of the impact evaluation of the core intervention lies with the designers, the impact of the core intervention will also be measured for the material supplier. Besides the evaluation of the core intervention, the impact of the extended intervention (the diffusion of the results of the Bamboo Labs) will also be measured for the material supplier, as well as for other relevant value chain nodes, making use of general success indicators at T2 compared to T1. Below, the choices for the several indicators used are explained.

Success Indicators Related to Participating Designers (Core intervention)

The core intervention is primarily focused on solving three key problems for designers determined in the PCS analysis in subsection 2.2.2: lack of knowledge about bamboo (due to a lack of availability of information and lack of diffusion of information), lack of value chain related networks around bamboo and lack of product design capacity, i.e. Western designers that implement the material. Influence of the intervention on the first two problems can be measured directly through the increase in knowledge and value chain related contacts of the designers.

Although the problem of lack of product development capacity is temporarily solved in this intervention through the active involvement of designers, the solution should preferably be durable, i.e. the designers should continue implementing bamboo materials in their future projects. However, future implementation behavior of the participating designers is more difficult to measure because it usually takes a long time before designers will actually adopt and implement a new material in their projects.

Because of this reason and the short time between the intervention and the writing of this dissertation, the implementation chances were measured through the behavioral intention toward future adoption of the material by participating designers. The behavioral intention in this research is defined as "the expected chance of implementation of the material by the designer in concrete products/projects in the near future (within 2 years) excluding the potential further development of the prototypes developed during the Bamboo Labs", and is perceived as the most important success indicator for the core intervention because it is directly linked to the future commercialization rate (main objective of this action research). As will be explained below, the attitude toward bamboo has a large influence on the behavioral intention, and is therefore added as variable to the research model. In turn, the amount of knowledge about bamboo will most likely influence the attitude toward the material, as well as the behavioral intention. Besides the knowledge, the amount of value chain contacts is also expected to have a positive influence on the behavioral intention. The intervention primarily focuses on improving the material independent indicators "amount of knowledge" and "amount of value chain contacts" for bamboo, through which is attempted to positively influence the material dependent variables "attitude"

and "behavioral intention". These variables are labeled "material dependent" in the research model in figure 3.1 because they are directly coupled to the appreciation of the material; it could be that the intervention works well and a lot of knowledge and value chain contacts are gained through the intervention (material independent indicators), but because of the material itself the attitude may decrease once designers know more about the material, negatively influencing the behavioral intention in turn. This does not mean the intervention itself cannot be successful for other materials.
Therefore, the relationship between the material independent indicators and material dependent indicators will be analyzed separately as part of RQ 3 & 4. Regardless of their relationship, the impact for RQ 1 (T1-T0) of the intervention will be measured for both the material independent indicators "value chain contacts" and "knowledge", as for the material dependent indicator "behavioral intention".
Below, the success indicators used for the impact evaluation of the designers are further explained, based on relevant theory.

<u>Bamboo Related Value Chain Contacts Gained</u>
The value chain model developed by Porter (1985) was already introduced before, and refers to "the value addition through an activity in each node in the production chain when bringing a product from conception to final use." Since the scope of this research starts with the supply of the material (see figure 2.1), for the participating designers the most important direct value chain nodes downstream to get acquainted with are especially processors and application manufacturers, but also retail outlets related to or interested in bamboo as material, since these contacts usually have the power to launch the bamboo products designed on the final consumer market. Other indirect value chain contacts that could be of value through knowledge provision or collaboration are other designers (not participating in the intervention) and knowledge institutes. As part of RQ1 the relevant new value chain contacts which the designers gained during the intervention will be measured and categorized.

<u>Knowledge Gained</u>
According to Weggeman (Weggeman 1997) knowledge can be defined as "the ability to connect external information with information that is already acquired (codified or explicit knowledge), including skills, experiences and attitudes (tacit knowledge)." In general, the acquisition of knowledge leads to new understanding or action. The process of acquiring knowledge can be defined as learning, which can take place at various levels (individual, group, organization, society). Two types of learning are commonly distinguished: operational learning and conceptual learning (Crul 2003). Operational learning refers to the acquisition of skills or know-how (physical and intellectual ability to perform a particular action), while conceptual learning refers to know-why (ability to gain a conceptual understanding of an experience). In the intervention the focus is on operational learning (know-how to use bamboo in product design) and to a lesser extent also on conceptual learning; in the first Bamboo Labs days the larger picture of the role bamboo could play in sustainable development as a renewable resource was presented, including the many contradicting interests over the PCS (e.g. mass production vs. handicraft, local consumption vs. export, etc.).
In the Bamboo Labs, acquisition of both codified knowledge and tacit knowledge is important. While codified knowledge can be transferred and communicated easily using information technologies, tacit knowledge cannot, since it is not stated in an explicit form. In contrast to explicit knowledge, tacit knowledge cannot be acquired from a book, but requires experimentation in practice in order to gain the necessary skills (e.g. learning to ride a bike). Tacit knowledge is usually internalized in a subconscious way, while explicit knowledge is consciously acquired (Polanyi 1983). Although acquiring tacit knowledge can be time consuming, it is necessary in order to gain specific skills required in some fields. Therefore, besides the required explicit knowledge (background and general information about

bamboo), in the intervention it is important for the participating designers to also acquire tacit knowledge through hands-on experience with a new material.
The success indicator "gained knowledge" of the designers should obviously relate to knowledge that appeals to the target group and is relevant during product design. In subsection 2.2.4 the bamboo related topics about which designers require knowledge were already presented: material properties (soft and hard), processing & finishing and general information such as application possibilities and additional material features (e.g. material availability), with a focus on practical, hands-on knowledge. Knowledge about the topics mentioned was used to evaluate the success indicator "gained knowledge" in RQ1.

Difference in Behavioral Intention; the Theory of Reasoned Action
In order to understand the behavioral intention better, the Theory of Reasoned Action, in which the attitude plays an important role, needs to be introduced first.

Attitude is a very important aspect in the understanding of (consumer) behavior. It can be defined in short as "the total judgment of a product, service, person, idea, material" (van Raaij et al. 2004). Three components of attitude are being distinguished (van Raaij et al. 2004): (1) thinking, the cognitive element (beliefs), (2) feeling, the affective element (feelings) and (3) behavior, the behavioral element (the intention to act based on the attitude). The concept of attitude has evolved over time from a global to a very differentiated concept, consisting of a combination of cognitive and evaluative elements. Fishbein and Azjen (Fishbein and Ajzen 1975) describe the total attitude (A) with respect to a product or service as the sum of the opinions (O) and evaluations (E) of all relevant product attributes:
$A = \Sigma\, O \times E$. The opinion, based on beliefs, is strongly dependent on the individual's perception and fore knowledge, whereas the evaluative component in which value-judgments of the individual are taken into account, can be influenced directly or indirectly by affect (van Raaij et al. 2004). The attributes that normally determine the attitude of a designer toward a material are further explained below in the introduction about RQ3.

The attitude provides an indication about the potential behavior of individuals. However, besides the attitude many other aspects play a role in predicting behavior, and therefore Fishbein and Azjen developed the Theory of Reasoned Action (TRA) (Ajzen and Fishbein 1980), which includes other elements responsible for the actual behavior of individuals: the Social Norm (SN) based on Normative Convictions (NC) and the Inclination to Give in (IG) to the socially accepted norm. The social norm, together with the attitude, defines the Behavioral Intention (BI), which may help to predict actual Behavior (B). In many studies (e.g. Miller 2005, Sheppard et al. 1988) a high correlation has been found between attitudes and social norms to behavioral intention and subsequently to actual behavior.
The weight of both components of BI, attitude and social norm, differs per person. In formula the BI for a person can be presented as: $B \approx BI = w_1 \times A + w_2 \times SN = w_1\ (\Sigma\, O \times E) + w_2\ (\Sigma_j\ NC \times IG)$, in which w_1 is the weight of the attitude for this person while w_2 is the weight of the social norm for the person in question.
However, it should be noted that although the TRA mostly provides an adequate indication of the future behavior of individuals (especially if they follow a rational procedure in their decision for a certain behavior), in various cases individuals use other decisions-rules and are influenced by additional factors such as habits, external factors based on situational influences and various personality factors (self monitoring, action orientation, etc.) (van Raaij et al. 2004). Therefore, it is impossible to exactly predict future behavior of consumers, and the actual behavior can only be measured once it has actually taken place. The same applies for the future implementation of a new material by designers. Furthermore, the

aim of the TRA is on volitional behaviors and excludes impulsive, habitual or unconscious behavior (Hale et al. 2003).

For this research focused on the adoption of a new material it is assumed that a designer has complete control over the decision to implement a material in a new design or not, which is expected to be based on reasoned action. Therefore, the perceived behavioral control is not expected to have a large influence on the actual future implementation of bamboo in products, and the TRA is adopted in this research as a structuring element for the conceptual model of the research (see figure 3.1). The TRA will not be used to calculate the attitude & behavioral intention based on the mathematical formula presented in the theory, but is used to get a general idea of the first attitudes and intentions of the designers toward the various bamboo materials used in the intervention. For RQ1 the difference (T1-T0) in behavioral intention toward bamboo as potential designers' material at T1 will be measured. In RQ 3.2 the relationship between the knowledge about the various bamboo materials and the attitude will be analyzed.

Success Indicators Related to Material Supplier (Core intervention)

Although the focus of the impact evaluation lies with the participating designers as the primary target group, the impact of the core intervention will also be evaluated for the material supplier. The material supplier is a very good point to gauge the success of the total intervention, because if there is an increased interest in the material through the intervention, it is here where this will be noticed first. Furthermore, also for other materials besides bamboo, the material supplier or producer is (besides trade organizations and NGOs related to the material) the most likely stakeholder in the PCS from which similar design interventions might be initiated in the future (see also subsection 9.3.1). Therefore, it is important to understand if the (bamboo) material supplier was satisfied with the results of the intervention.

Obviously the sales of bamboo material made available through the supplier is an important indicator. However, due to the short time between the finishing of the project and the writing of this dissertation, it is difficult in this stage to measure the impact of the project on actual sales of bamboo material, since product innovation projects in general take much time. However, a first indication of a risen interest in bamboo materials that might predict implementation in a later phase is the development of new value chain contacts and the initiation of new bamboo product development projects for the material supplier as a result of the intervention. Furthermore, additional benefits for the material supplier as a result of the core intervention were also measured.

Impact Evaluation Extended Intervention

In subsection 2.2.1 we saw that this research focuses on the evaluation of the core intervention because the extended intervention (the diffusion of the results of the Bamboo Labs) is less controlled (and therefore less measurable) and cannot yet be measured fully within the timeframe of this thesis because of the long time the diffusion, and consequent final commercialization phases of the product innovation process usually take.

However, although the time between the start of extended intervention and the writing of this thesis is short, some preliminary indications can be provided about the success of the extended intervention for various relevant value chain nodes (e.g. additional designers, processors, application manufacturers, retailers, etc.). Therefore, various rough success indicators will be introduced below that were used to measure the success of the extended intervention based on the exposure the results of the Bamboo

Labs yielded, indicators related to relevant value chain nodes downstream, and indicators related to the material supplier.

Exposure

The diffusion of the results starts with the exposure of the results of the core intervention through various (media) channels. Through the exposure, the commercialization rate of bamboo in products might eventually indirectly be positively influenced. For example, through the exposure, information about the potential of bamboo might reach various designers, processors and application manufacturers with a latent interest in the material that gives them the final trigger required to start experimenting with the material. Therefore, as a first broad indicator of the success of the extended intervention, the exposure of the results was measured based on organized exposure and unorganized exposure. The former relates to exposure actively put out in the open by the organization team such as the publication and distribution of the book *Dutch Design meets Bamboo,* and the organization of the exposition, including various activities around it (seminar, design fair during opening, etc.). The latter relates to exposure of the project results taken up spontaneously (e.g. based on mouth-to-mouth communication, press releases, previous publications, etc.) by various media (e.g. magazines, newspapers, radio & television, etc.).

Success Indicators Related to Additional Value Chain Nodes

Besides measuring solely the exposure of the results of the Bamboo Labs, it is important to get some indication of the consequences of this exposure. Therefore, some indicators were established that monitor the results of the exposure for additional relevant value chain nodes, and which are related to problems mentioned earlier within the scope of the extended intervention. First of all, it is important to assess if the exposure has improved the attitude and behavioral intention toward the bamboo materials of relevant value chain nodes besides the participating designers (e.g. other designers, processors, application manufacturers). Furthermore, additional outputs of the extended intervention, unforeseen before the intervention started, were also monitored.

Success Indicators Related to the Material Supplier (Extended intervention)

Just like for the impact evaluation of the core intervention, also for the extended intervention the impact was measured for the material supplier as well, since the material supplier represents the bamboo producing and supplying industry in this intervention. For the extended intervention the same success indicators that might lead to an increase in commercialization in the future were used for the success of the core intervention: new value chain contacts, new bamboo product development projects and potential additional benefits for the material supplier.

Operationalization in Detailed Research Questions

The main question for the impact evaluation was first established in section 3.1:

RQ1. To what extent is the impact of the intervention successful?

To be able to evaluate the impact of the intervention the research question has to be divided into detailed research questions in which the various success indicators introduced above are operationalized and linked to one another. In figure 3.2 below the research model presented earlier in figure 3.1 has been detailed for RQ1, in which the non relevant variables and components have been folded, and the detailed research questions of RQ1 linking the relevant variables are visually represented. Below the model the various detailed research questions of RQ1 are presented.

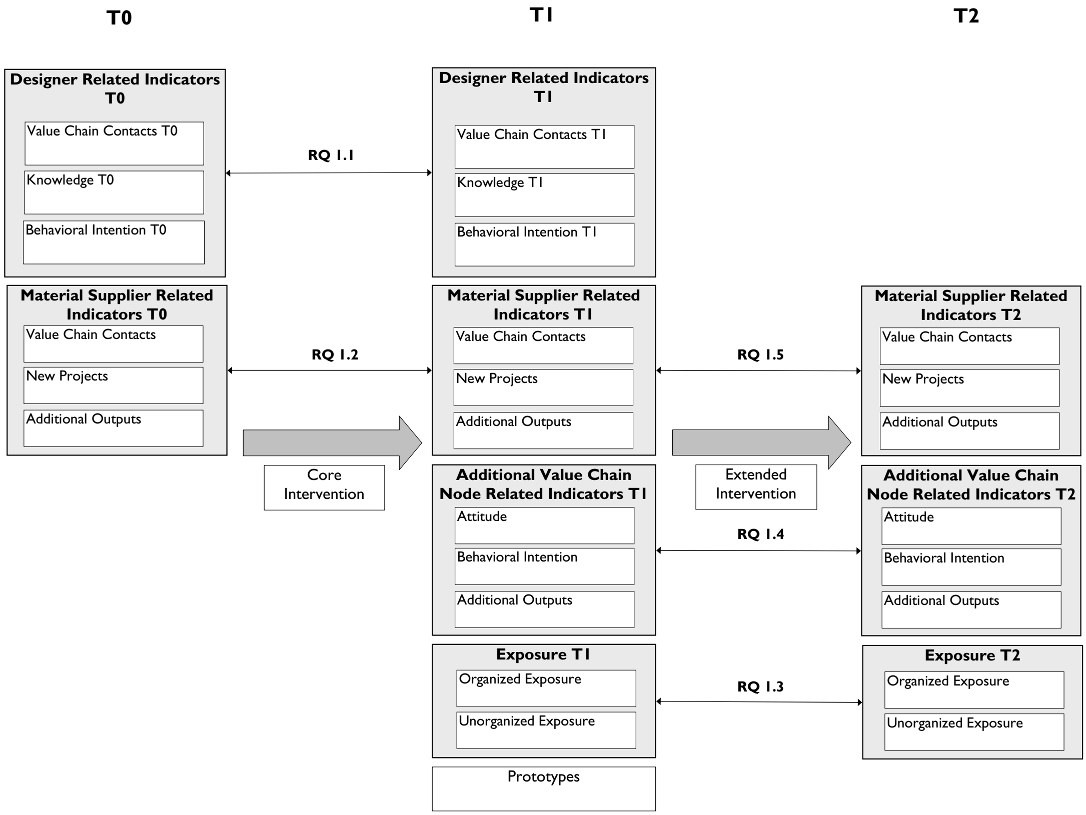


Figure 3.2: The part of the research model revealing the detailed research questions of RQ1

1.1: To what extent is the impact of the core intervention successful for the participating designers in terms of an increase in bamboo related value chain contacts, knowledge of bamboo materials I-V, and behavioral intention toward bamboo materials I-V at T1 compared to T0?

1.2: To what extent is the core intervention successful for the material supplier in terms of new value chain contacts, new projects initiated and additional outputs at T1 compared to T0?

1.3: To what extent is the extended intervention successful in terms of organized exposure and non organized exposure at T2 compared to T1?

1.4: To what extent is the extended intervention successful for additional value chain nodes in terms of an increase in attitude and behavioral intention, and additional outputs at T2 compared to T1?

1.5: To what extent is the extended intervention successful for the material supplier in terms of new value chain contacts, new projects initiated and additional outputs at T2 compared to T1?

3.3.2 Product Evaluation (RQ2)

Besides the impact evaluation of the intervention (RQ1), the success of the output in the form of prototypes of bamboo products was also evaluated based on various criteria in the second research question. The criteria deployed for the product assessment were based on existing product criteria lists, but were also linked to the design brief of the project: to develop a bamboo product which has high potential for the Western European market, uses the specific qualities and unique properties of bamboo, is innovative and improves the image of bamboo. The checklists used to develop criteria for the product assessment were the one developed by Pugh (1990) in combination with the product criteria list used by the Delft Design Institute at DUT Industrial Design Engineering for PhD students to gain their degree based on a "design proof" (design as part of thesis work). Because of the specific design brief of the intervention, the criteria distilled from the lists needed to be custom-made based on the specific requirements in the design brief. The custom-made criteria list was divided into three components on which the product assessment was based: market potential, innovative character and environmental sustainability. Each of these main components are explained below, including their division in specific criteria for the product assessment.

Market Potential

For products in general, each product has three economic dimensions: the costs, the price and the value. The producer is interested in the difference between the price and the costs, which determines his profit, while the consumer is interested in the value. If the perceived value of the product (based on product quality, service quality and image) is higher than the price, a consumer might consider buying the product. From the point of view of the customer the value equals the fair price (Gale 1994). For a producer the challenge is to optimize the value/cost ratio of a product, e.g. through better logistics, complaint management and waste & quality management (Hendriks et al. 2006). The market potential for consumers of a new product in this thesis is based on the value/price ratio of the product in the market for which the product is intended.

The price of a product depends to a large extent on the production costs (manufacturing costs and transport costs) which need to be made. Manufacturing costs are usually lower in the case of (mass) production in the South.[28] However, production in the South can compromise the manufacturing quality of the product (i.e. manufacturing of the product exactly in the way it is intended/designed), which might lower the value of the product. Furthermore, especially in the case of manufacturing in the South the transport costs can have a considerable impact on the production costs and therefore the price. More information about the background of production costs in the North and South is provided in subsection 4.1.2.

Therefore, the choice for the best producing region with respect to the manufacturing quality/production costs ratio was taken into account in the product assessment in RQ2. Assuming the manufacturing quality of the product is met, the price the consumer wants to pay for a product depends on many other aspects related to the perceived quality of a product, such as its functionality, the aesthetics, and intangible properties such as the trendiness and image of the product. The importance of the aspects mentioned may differ per market, even for segments within the same market.

The market potential (value/price ratio) of the bamboo products developed in the intervention will be assessed as part of RQ2 for their intended target market based on the commercial value mentioned (related to the product quality) and the price (related to the production costs mentioned). The framework deployed to assess the market potential of the products developed is represented in table 3.1.

[28] Although the initial focus on the intervention was on production and design of products in the North, since many application manufacturers outsource their production to the South, and many application manufacturers in the South may also be interested in developing similar bamboo products in the future, the manufacturability of the prototypes in the South was also taken into account.

Table 3.1: Criteria used to determine the market potential of the products developed in the intervention

Product Quality (value)

- Functionality & use
    - Weight
    - Sturdiness (durability)
    - Reparability & maintenance
    - Specific functionality
- Aesthetics & intangible properties
    - Aesthetic quality & trendiness
    - Originality; Strength of concept

Production costs (price)

- Transportability
- Manufacturing costs in North/South (assuming the manufacturing quality required for the target market can be met)

Market potential (value/price)

- Current market potential
- Future market potential after optimization

Innovative Character

There are many kinds of innovation. Diehl and Crul (2006) distinguish between product innovation (introduction of a new product with new characteristics compared to existing products), process innovation (new method of production), market innovation (introduction in new markets and/or through new service systems) and business & management innovation (new reward- and organizational systems). As can be noted from the design brief, the intervention focuses on product- and process innovation. It focuses on product innovation by developing high potential bamboo products for the Western European market with a new image and by using the specific properties of bamboo. It focuses on process innovation by using new processing technologies in order to manufacture the product. In the assessment the developed prototypes were evaluated based on their innovative character (product innovation & process innovation) with respect to the use of bamboo as a new material. The product innovation evaluation was based on the specific requirements posed in the design brief (improve image, use specific properties), while the level of process innovation evaluated the innovativeness of the processing technology used for bamboo to produce the prototype. As an additional criterion in the process innovation assessment, the processing technology itself was also evaluated based on its market potential, to get bamboo in high quantities on the market in the medium to long term. The main elements used to assess the innovative character of each product prototype are presented in the table below.

Table 3.2: Criteria used to determine the innovative character of the products developed in the intervention

Innovative character; use of bamboo as a new material

Product innovation

- Utilization of specific properties of bamboo
- Contribution to new image of bamboo

Process innovation

- Level of process innovation (processing and manufacturing technology) - Bamboo
- Overall future market potential of new processing technology (if applicable)

Environmental Sustainability

As seen in subsection 1.1.1 sustainability is a very broad and multi disciplinary concept. The Triple Bottom Line (People, Planet and Profit) is a useful way to distinguish the social, environmental and economical pillars of sustainability. This thesis focuses on the stimulation of bamboo for use in products in Western Europe because of its expected environmental sustainability, and does not actively take into account the potential value of bamboo in contributing to the socio-economic component of sustainability. Thus, in the product assessment only the environmental sustainability is evaluated. Since the developed prototypes are almost totally made out of bamboo, any statement about their environmental sustainability can only be made after the environmental assessment of the materials from which the products are made, which requires additional research due to the lack of knowledge available about the environmental sustainability of bamboo.

As mentioned in subsection 1.2.1 bamboo is perceived as being environmentally friendly. There are many qualitative arguments, mainly around the biomass production of bamboo, that justify this positive perception. However, many of the industrially produced bamboo materials (Plybamboo, SWB, etc.) go through many energy intensive production steps, produce a lot of waste and are supplemented with many chemical substances (glue, lacquer, etc.). Although the same applies to many wood based products, it does mean that the perceived environmental sustainability of bamboo materials should be questioned.

Therefore, in this thesis the environmental sustainability of the various bamboo materials is determined based on the three environmental problems introduced in subsection 1.1.2 at the "debit" side through calculating their environmental impact or eco-burden (negative environmental effects caused by bamboo materials during their life cycle contributing to the three main environmental problems) using the Eco-costs model developed by Vogtländer (2001), based on Life Cycle Assessment (LCA) methodology, and at the "credit" side (diminishing the environmental problems) through calculating the regenerative power of bamboo (bioproductivity; see figure 1.3) through the annual yield. Combined, the environmental impact (debit) and annual yield (credit) can provide an indication of the environmental sustainability of bamboo materials, although the environmental impact calculated through the eco-costs has a broader range than the annual yield (see table 3.3). Note that the annual yield indirectly has a positive impact on climate change through carbon sequestration (see also appendix J). For an explanation about the relationship between Eco-costs and Ecological Footprint, the reader is referred to Vogtländer (2008).

Table 3.3: Together the eco-costs and annual yield determine to a large extent the environmental sustainability of a material

Main problem	Debit (-)	Credit (+)
Depletion of resources		Exhaustion of food & water
	Eco-costs	Exhaustion of energy
	Exhaustion of food & water	
	Exhaustion of energy	**Annual Yield**
	Exhaustion of raw materials	Exhaustion of raw materials
Deterioration of ecosystems	Climate change	Climate change
	Erosion	Erosion
	Landscape deterioration	Landscape deterioration
	Desiccation	Desiccation
	Ozone layer deterioration	Ozone layer deterioration
	Acidification	Acidification
	Spread of dust	Spread of dust
	Nuclear accidents	Nuclear accidents
	Eutrofication	Eutrofication
	Hazardous pollution spread	Hazardous pollution spread
Deterioration of human health	Ozone at living level	Ozone at living level
	Summer smog	Summer smog
	Winter smog	Winter smog
	Noise hindrance	Noise hindrance
	Stench hindrance	Stench hindrance
	Light hindrance	Light hindrance
	Indoor pollution	Indoor pollution
	Radiation	Radiation

Operationalization in Detailed Research Questions

The research question for the evaluation of the products developed during the Bamboo Labs is:
RQ2: To what extent are the products developed in the design workshops successful?
As had been the case with the first research question, the second research question needs to be divided in detailed research questions in which the success indicators (market potential, innovative character and environmental sustainability) are integrated. In figure 3.3 below the research model presented earlier in figure 3.1 has been detailed for RQ2, in which the non relevant variables and components have been folded and the detailed research questions for RQ2 have been depicted. Below the model these detailed research questions of RQ2 are presented.

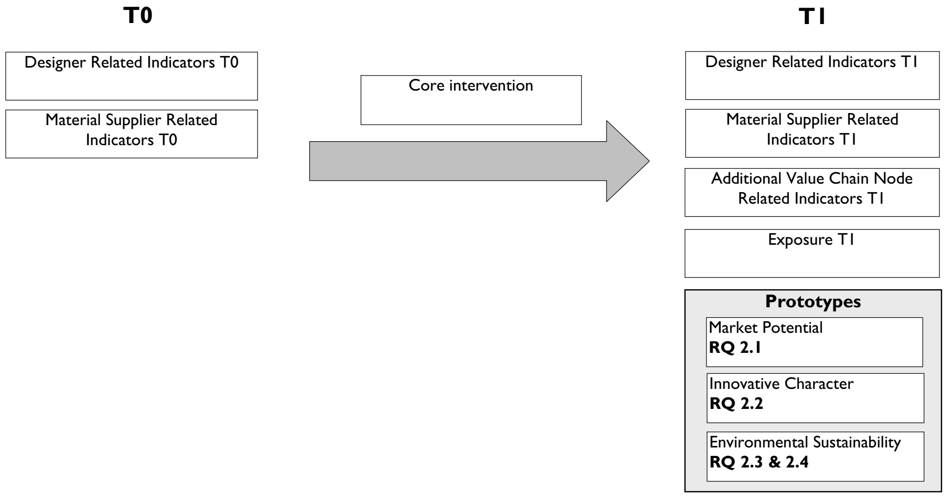


Figure 3.3: The part of the research model focusing on RQ2, including the corresponding detailed research questions

2.1 What is the market potential of the products developed?

2.2 How innovative are the products developed?

2.3 How environmentally sustainable are the products developed?

The environmental sustainability assessment of the products can only be done if the environmental impact of the bamboo materials of which they are comprised is known. Therefore, the following research question was added:

2.4: What is the environmental sustainability of the bamboo materials used in the products developed? Due to the extensive character of the environmental assessment, research questions 2.3 and 2.4 are covered in a separate chapter (chapter 5).

3.3.3 Material Evaluation (RQ3)

Although more bamboo materials were at the disposal of the participating designers, only the following five bamboo materials were actually implemented in the final products (see figure 2.14): (I) stem, (II) Plybamboo, (III) composite, (IV) SWB and (V) mats. Because the designers only gained experience with these five bamboo materials during the workshops, only these materials could be evaluated at T1 by the designers. The first part of the material evaluation was based on the assessment of the designer's attitude toward the bamboo materials deployed.

The term "attitude" was already introduced in subsection 3.3.1. The attitude toward a material depends on the evaluation of the various attributes of a material, based on beliefs. The beliefs are a result of all previous experiences in an individual's life, which can be referred to as "observational learning", and depend on factual knowledge, marketing, cultural influences, trends and memories (see figure 3.4). Beliefs are usually subjective and depend on the perception of the beholder. For example, through marketing, many companies are trying to develop as many positive associations (schemata) around a

product as possible, emphasizing only the positive aspects of a product (van Raaij et al. 2004). This fact has also been utilized for the development of the extended intervention (diffusion of the results), which emphasizes the positive aspects of bamboo as a renewable material.
Furthermore, through cultural influences additional schemata are developed around a material (e.g. Asia to bamboo), which can have both a negative or positive effect on the attitude. Finally, a special memory can be attached to a product or material (Mugge 2007) which can yield positive or negative memories and associations (e.g. a relative died in a bamboo field). Most of the subjective aspects mentioned above (marketing, cultural influences, trends and memories) will have influence on the intangible properties of a material, while factual knowledge has influence on most other material properties (for more information about material properties the reader is referred to appendix D).
Apart from the various material properties depicted in figure 3.4, interviews executed by the author with a selection of the participating designers prior to the intervention to establish criteria for the development of the MSS (see subsection 2.2.4) also showed that other material related attributes such as processing and finishing do's & don'ts, application possibilities and preconditions (e.g. the phase of the commercialization process of the bamboo materials) determine the attitude of a designer toward a material (see figure 3.4). For example, if a designer knows a material is not yet ready for actual implementation because it still needs to be further developed, this might result in a negative attitude toward the material.

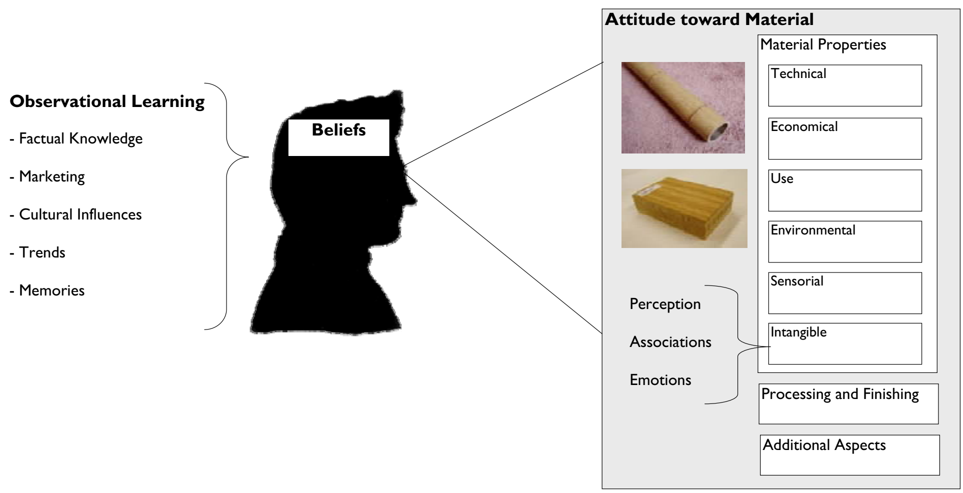


Figure 3.4: The various aspects that determine an individual's attitude toward a material (after Karana et al. 2008, van Kesteren 2008, Ashby and Johnson 2002)

Knowledge obviously is an important variable in order to influence attitude (Bettinghaus 1986, van Raaij et al. 2004); the more one knows about a product or material the better (or more objective) judgment can be made. In case knowledge is low, previous experiences and associations related to these experiences play a more important role in forming the attitude. Therefore, the attitude toward a material is very personal (e.g. some designers find environmental properties very important), and the evaluation of various material attributes will differ per product design project (e.g. for some products the material costs sensitivity is more important than sensorial attributes such as aesthetics), and can even differ in the various phases of the design process (Karana et al. 2008).
Thus, the knowledge level of a designer can influence the attitude toward the material; the more a designer receives factual knowledge about the properties of a material, the better the opinion he/she

can form about the material. In the PCS analysis in subsection 1.2.3 and appendix C it was revealed that designers and consumers in the West have many negative associations with bamboo caused a.o. by a lack of knowledge about the material, and it is therefore expected that an increase in knowledge will lead to a positive attitude change for the material. However, the relationship between the amount of knowledge and attitude can also be negative; maybe because of the knowledge gained about a bamboo material a designer is disappointed in the performance of the material and will exclude bamboo as a potential material for future projects. Therefore, it is important to better understand the relation between the amount of bamboo knowledge of a designer and the corresponding attitude toward the material, which is a material dependent property. For these reasons the relation between knowledge and attitude was measured separately as part of RQ 3. The evaluation of attributes that form the attitude (see below) can further explain the causes of the either positive or negative relationship.

As seen above, the attitude toward a material is based on various material related attributes that are important for designers (see figure 3.4). Together, all these aspects form the overall attitude toward the various bamboo materials. Both the underlying aspects and the overall attitude will be analyzed and presented as part of RQ3. Based on the results of the evaluation, recommendations can be provided that are of importance for marketing and development purposes in the bamboo industry.

Operationalization in Detailed Research Questions

The research question used for the evaluation of the bamboo materials deployed in the intervention is:
RQ3: To what extent is bamboo perceived by Dutch designers as successful material for product design?
Like before, this research question is operationalized in several detailed research questions in which the success indicators (attitude and behavioral intention) are integrated, and the variables of knowledge and attitude are linked to one another; see also the custom-made representation of the research model, with non relevant variables folded, for RQ3 in figure 3.5.

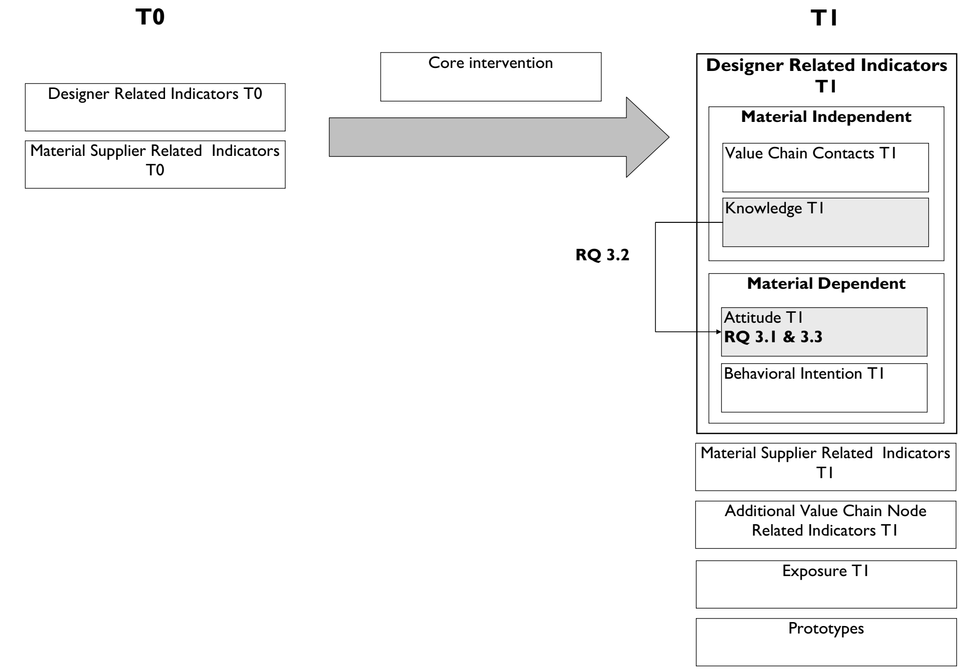


Figure 3.5: The part of the research model focusing on RQ3, including the corresponding detailed research questions

3.1: To what extent are bamboo materials I-V evaluated by Dutch designers as a promising material for product design in terms of attitude toward the materials?

3.2: What is the relation between the knowledge and the designer's attitude toward bamboo materials I-V?

Furthermore, for the bamboo industry and material suppliers it is important to understand which bamboo related attributes, that make up the attitude, are appreciated by the designers and which are not. Based on this information the materials can be improved in the future through adjustments in processing and finishing, or through marketing efforts.

3.3: Which attributes of bamboo materials I-V are evaluated by the designers in a positive or negative manner?

3.3.4 Process Evaluation and Advice for Improvement (RQ4)

In the case of action research, besides measuring the impact, it is also of importance to understand the background and the causes of the success (or failure) of the evaluated intervention. What happened in the black box of the implementation of the intervention between T0 and T1? Through the monitoring of the process and by analyzing relationships between the elements of the intervention and the success indicators, and between the success indicators themselves (material independent and material dependent indicators), better understanding about the intervention can be created, based on which the elements of this intervention can be improved for use in similar interventions in the future.

As seen before, the core intervention consists of two main elements: the participating designers and the MSS, which was designed in such a way to improve the amount of knowledge and value chain contacts for bamboo of the designers as much as possible. Through these material independent indicators the intervention hopes to positively influence the material dependent indicators attitude and behavioral intention. Because the relationship between the material independent and material dependent indicators will differ for each material (it could be that participants gain a large amount of knowledge and value chain contacts, but just do not like the material), the causes of the success/failure of the intervention for the material independent indicators are important to understand. For this reason the influence of the (sub)components of the MSS on the material independent success indicators increase of knowledge and value chain contacts will be investigated separately in RQ4.
The MSS was designed on purpose in such a way that a broad array of information tools and sources were provided to support the designers in their design process. For similar interventions in the future it is important to know which instruments were appreciated most by the designers. Furthermore, the appreciation by the designers of the MSS as a whole was measured as well.
Secondly, besides the main elements of the intervention, it is important that the earlier mentioned preconditions (see subsection 2.2.4) with respect to the material, facilities, organization team and financial resources are met in order to facilitate the success of the material independent indicators. Therefore, the preconditions are also evaluated with respect to their contribution to the success/failure of the intervention in RQ4.

Although it is important to understand the success of the intervention in terms of bamboo knowledge and value chain contacts development, the main success indicator the intervention aims to positively influence is the behavioral intention of the participating designers toward implementation of bamboo in future projects, which can be perceived as the most important success indicator for this thesis. Through the attitude, the amount of bamboo knowledge may influence the behavioral intention of the designers (see RQ 3.2). However, besides the knowledge, attitude, and the developed value chain contacts, many additional factors might influence the actual behavioral intention of a designer toward adopting the material. Since the whole intervention started with the intention to increase the future commercialization rate of bamboo (directly related to the behavioral intention), it is of crucial importance to understand all the causes of the increase (or decrease) of the behavioral intention for the participating designers. Only in this way can it be understood if the causes are directly related to the intervention and if the intervention in the form of knowledge intensive design workshops is efficient at all. Therefore, the causes of the success/failure of the intervention in terms of increase in behavioral intention will be analyzed separately as well in RQ4 (RQ 4.2).

Finally, after the evaluation of the intervention process, and understanding the deeper causes of the success/failure of the intervention, recommendations will be provided as part of RQ4 (RQ 4.3), explaining how the core intervention may be improved.

Operationalization in Detailed Research Questions

By analyzing the process during the implementation of the intervention, the background and the causes of the success (or failure) of the intervention can be better understood and improved for similar interventions in the future. The research question related to the process evaluation is:
RQ4: What are the causes of the success/failure of the intervention and how can the intervention be improved?

The fourth research question is operationalized in several detailed research questions in which the main elements and (sub) components of the intervention are linked to the various (material independent and -dependent) success indicators to help understand the causes of the success/failure of the intervention; see also the research model in figure 3.6, which is custom-made for RQ4, with non relevant variables folded. Based on the outcomes, specific and more general advice for improvement will be given. Below the model, the detailed research questions of RQ4 are presented.

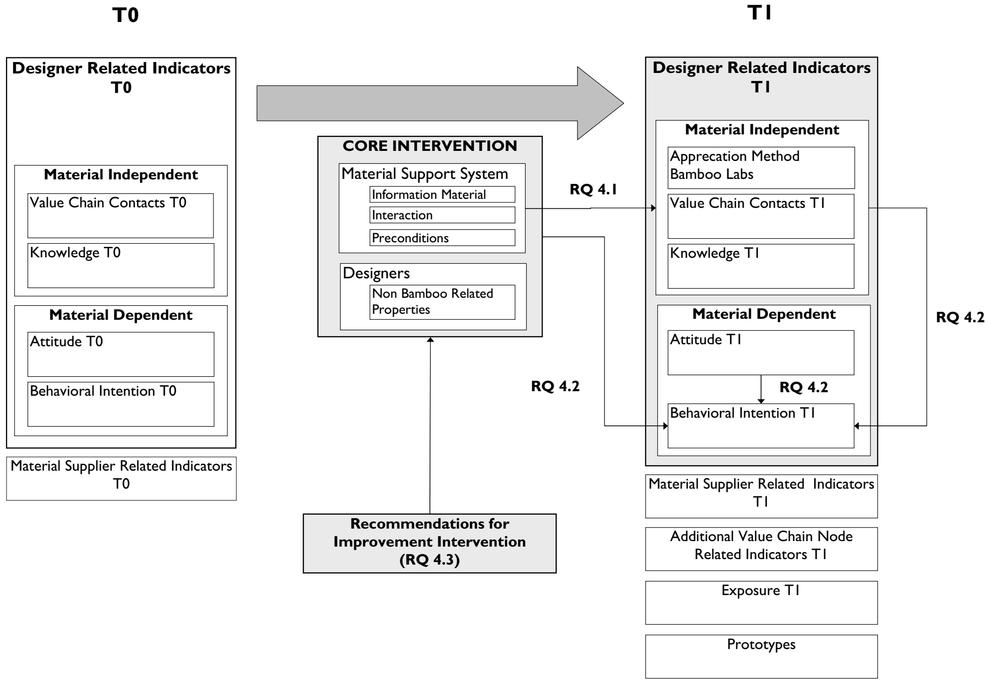


Figure 3.6: The part of the research model focusing on RQ4, including the corresponding detailed research questions

As explained above, the analysis of the causes of the success/failure of the intervention will be first analyzed for the material independent indicators, before the causes of the main success indicator behavioral intention will be analyzed.

4.1: What is the influence of the intervention on the material independent success indicators?

This question is divided into the following sub questions:
4.1.1: How are the subcomponents of the MSS valued with respect to overall appreciation, gained bamboo related knowledge, and bamboo related value chain contacts?
4.1.2 To what extent did the preconditions hamper/facilitate the intervention?

4.2: What are the key success factors toward the potential future implementation (behavioral intention) by participating designers of bamboo in new products and which of these factors is the direct result of the intervention?

4.3: How can the intervention be improved?

3.4 Methodology

3.4.1 Introduction

Although action research can be acknowledged as a research strategy, there does not exist a detailed methodology on how to execute action research (Peters and Robinson 1984). Usually in practice a broad range of various research strategies and data collection methods are combined in action research, in particular experiments, but also surveys, interviews, focus groups, questionnaires and participatory observation are commonly used instruments in action research (den Hartog and van Sluijs 1995). Choices for a particular set of strategies and data collection methods are usually dependent on the setting in which the intervention takes place and are therefore custom-made. As for most kinds of research, the combination of data from theory and practice, using various data collection methods (method triangulation) and acquiring data from various sources (source triangulation), provides the most accurate results (Verschuren and Doorewaard 2001), and is also recommended in action research.

Qualitative research focuses on depth by using only a small number of research units which are analyzed thoroughly, providing results that accurately represent the actual situation (empirical validity). This high level of accuracy compromises a lower level of generalizability due to the small amount of research units. In quantitative research this relationship is reversed. Quantitative research focuses on broadness resulting in higher generalizabilty but lower empirical validity (Verschuren and Doorewaard 2001). Because of their differences in nature, both types of research require different kinds of data collection and analysis methods. In this research both qualitative and quantitative research methods were deployed in order to try to develop conclusions that are both accurate and generalizable.
In this section a brief description is provided about the generic methods used to collect and process the research data acquired. In the chapters themselves more specific information will be provided about the methods used and the choices made with respect to the methodology.

3.4.2 Data Collection

In order to find the answers to the research questions posed in the previous sections, first, relevant information needs to be gathered (research data), which then has to be processed and analyzed. In order to guarantee a high validity in this research several methods for data gathering have been chosen that complement each other's weaknesses.

First, the methods used to acquire qualitative research data are presented.
Most research questions relate to the participating designers who were interviewed face-to-face in their design studios before (T0) and directly after the intervention (T1). The interviews consisted of several open questions and were combined with several closed questions in a questionnaire (see below). Besides the individual interviews, the designers were also interviewed by the author in group form (focus groups) during Bamboo Lab day 4 to evaluate the elements of the intervention and to provide recommendations for improvement. Apart from the participating designers, the material supplier was also interviewed face-to-face at T2, in order to acquire qualitative data.
Observations are usually more objective than the results from an interview, but do not provide the deeper insight that interviews provide, therefore they are complementary tools to deploy for data generation (Verschuren and Doorewaard 2001). Observations in this research were made by the author directly (direct notes in log book) and indirectly (through audio recordings and video recordings), and supplemented by observations of the other members of the organization team, who provided feedback about their observations in evaluation meetings which took place after each Bamboo Lab day. The role of the researcher during the intervention was also reviewed based on observations.

Objective observation of the participatory role of the researcher is crucial in action research since the researcher takes his own beliefs and value system into the intervention which holds a risk of biased interpretation. This does not need to be a problem as long as the role of the researcher throughout the intervention is observed and described in an objective way. This was done by direct observations and feedback by the supervisors of the author (Dr. Marcel Crul, Prof. dr. Han Brezet), and by a self assessment of the researcher throughout the intervention noted down in a log book. The members of the organization team, who were present throughout the whole intervention and had the best overview of the role of the author during the intervention, were requested to validate the self assessment made by the researcher. The results of the review about the role of the researcher throughout the intervention will be covered in subsection 8.1.3 as part of RQ 4.1.2.
Expert appraisal was deployed as a final qualitative data collection (and analysis) method during the intervention, in order to evaluate the developed product prototypes. Expert appraisal refers to the objective evaluation of a product or service by an expert or panel of experts that have expertise in the sector of the product or service to be assessed (Clarkson et al. 2007), but are not acquainted with the product yet. For the expert appraisal of the prototypes in this intervention, a panel of experts with a broad expertise in the field of product design was invited to evaluate the prototypes.

The main method to acquire quantitative data for this research was the use of questionnaire interviews (T0 & T1), during which the researcher directly asked several closed questions to the designers based on a questionnaire, which was simultaneously handed out to the designers. Through this procedure the main weakness of questionnaires (non-response, questions not taken seriously, etc.) due to a lack of supervision, was avoided. Furthermore, the designers could receive feedback from the researcher if they did not understand the questions which contributed to the validity of the data acquired.
Regular questionnaires were used to acquire quantitative data with respect to additional relevant value chain nodes, the material supplier and for the acquisition of production data from bamboo producers in China.

3.4.3 Data Analysis

Through the various data collection methods mentioned above a lot of qualitative and quantitative data was acquired for this research. While some of the data could be presented directly as answers to some research questions, most data needed to be processed and analyzed further, before being useful.
Qualitative research data (mostly derived from the interviews) was analyzed using labeling and categorization techniques to distil the relevant data, providing answers to the research questions (Baarda et al. 2005).
Although the sample group of research units (the participating designers) is quite small (N = 21), data was quantitatively analyzed using the statistical computer program SPSS 13.0. The results of the statistical analysis are represented in this thesis following the guidelines used by the *Journal of Consumer Behavior*. The data collected for the environmental impact assessment (RQ2.3 & 2.4) was quantitatively analyzed using the Eco-costs method (Vogtländer 2001) based on the LCA methodology (for more information, see section 5.1).
All data collection and -analysis methods used in this research for the corresponding research questions of this research are represented in table 3.4 below. For more details with respect to the operationalization of the methods used, the reader is referred to the chapters in which the research questions are covered (see before).

Table 3.4: Detailed research questions including the data collection and processing methods deployed

Research question	Kind of data (qualitative/quantitative)	Data collection method (source)	Data analysis method
1.1	Quant.	Questionnaire interview T0 & T1 (participating designers)	Statistical analysis
1.2	Quant. & Qual.	Face-to-face interview T2 (material supplier) Questionnaire (material supplier)	n/a
1.3	Quant. & Qual.	Questionnaire (participating designers, organization team, material supplier) Observations (researcher)	n/a
1.4	Quant. & Qual.	Questionnaire (participating designers, material supplier, organization team, additional value chain nodes) Observations (researcher)	Statistical analysis
1.5	Quant. & Qual.	Face-to-face interview T2 (material supplier) Questionnaire (material supplier)	n/a
2.1	Qual.	Expert appraisal (expert team)	n/a
2.2	Qual.	Expert appraisal (expert team)	n/a
2.3 & 2.4	Quant.	Questionnaire (bamboo producers, material supplier) Telephone interview (material supplier)	LCA (Eco-costs)
3.1	Quant.	Questionnaire interview (participating designers)	Statistical analysis
3.2	Quant.	Questionnaire interview (participating designers)	Statistical analysis
3.3	Qual.	Face-to-face interview (participating designers)	Labeling
4.1.1	Quant.	Questionnaire interview (participating designers) Observations (researcher & organization team) Focus group (participating designers)	Statistical analysis
4.1.2	Qual.	Face-to-face interview (participating designers) Observations (researcher & organization team)	Labeling
4.2	Quant. & Qual.	Face-to-face interview (participating designers) Questionnaire interview (participating designers)	Labeling Statistical analysis
4.3	Qual.	Face-to-face interview (participating designers) Observations (researcher & organization team)	Labeling

3.4.4 Validity

One of the main advantages of action research is the high internal validity of the results through the problem oriented approach which takes place in practice. Since the research actively integrates participants, and is embedded in a project with the primary target to use the results obtained, a connection between practice and theory is immediate. Internal validity was further secured by triangulation of data collection methods in which qualitative (interviews, observations) and quantitative (questionnaires) research methods were combined. For the interviews the data was acquired through interview rounds which included various evaluation and feedback loops by the respondents. The respondents were also supported by an open questionnaire during the individual interviews, which increases understanding of questions being asked, thus further increasing internal validity, while avoiding the main weaknesses of questionnaires (e.g. non response, questions not taken seriously). For the expert appraisal a team of three independent experts was established to verify the preliminary scores, and come up with one overall score for each criterion after elaborate discussion, thus further securing the internal validity.

Through the action research approach the external validity is also secured because of the problem oriented approach, and the fact that the typical action research diagnosis - action - evaluation cycle (see appendix F) was repeated several times during the intervention. This was done by requesting feedback from the participating designers during the Bamboo Lab days, but also during evaluation meetings of the organization team directly after each Bamboo Lab day. Thus, needs and findings in the empirical world were accurately recorded, and responded to, further facilitating external validity. Furthermore, the participating designers were chosen to be representative of the complete designer population (see subsection 2.2.4). Because of the explorative character of the research it is therefore expected that explanation building is to some extent generalizable for the wider Dutch designer population. Finally, the external validity of the results was tested during external presentations of the author in various design oriented forums.

The construct validity refers to the accuracy and correctness of the measures selected for the main concepts that are operationalized through the research questions. Since the dependent variables chosen to assess the success of the intervention are directly linked to the main obstacles over the PCS found in subsection 1.2.3 that can be influenced by designers, construct validity is expected to be high. For the product evaluation, success criteria directly derive from acknowledged product criteria lists used to assess product design trajectories.

3.4.5 Reliability

Reliability refers to the degree of consistency built in during data collection in order to reduce chances of error, i.e. can the data collection be repeated with the same results by another researcher (Hammersley 1992). In this research reliability was increased in various ways. First of all, the interview questionnaires were developed in collaboration with experts in questionnaire development, to accurately acquire data linked to the key variables. Secondly, these questionnaires were pre-tested through independent designers (not participating in the intervention) before the interviews were executed, to rule out inconsistencies and unclear questions. Thirdly, the interviews taped were directly written out and transcribed on the same day as the interview. Fourthly, observations in this research were made by the author directly (direct notes in log book) and indirectly (through audio recordings and video recordings), and supplemented by observations of the other members of the organization team, to record the actual happenings during the intervention as accurately as possible. Finally, the active participatory involvement of the researcher in action research can represent a weakness in the reliability. In subsection 3.4.2 it was already explained how reliability with respect to the participatory role of the researcher was assured for this research.

3.5 Structure of Remainder of Thesis

This chapter concludes part I of this thesis. In the following chapters the results of this action research will be presented as part II of this thesis. In chapter 4 (market potential and innovative character) and chapter 5 (environmental sustainability) the evaluation of the product prototypes is presented (RQ2), while in chapter 6 the deployed bamboo materials during the intervention are assessed (RQ3). Since the impact evaluation (RQ1) and the process evaluation and advice for improvement (RQ4) have a similar character for the intervention, they are analyzed subsequently in chapters 7 and 8. Each chapter in part II of the thesis more or less follows the structure: introduction (including methodology used) - results - conclusions.

Finally, in part III of the thesis (chapter 9) conclusions will be drawn, the theoretical contributions of this research will be discussed, and several research and policy recommendations will be provided. The model in figure 3.7 is an extended, focused adaptation of figure 1.23 in section 1.6, which shows the structure of the remainder of this thesis including the sections in which the main body of the answers to the various detailed research questions of this research may be found.

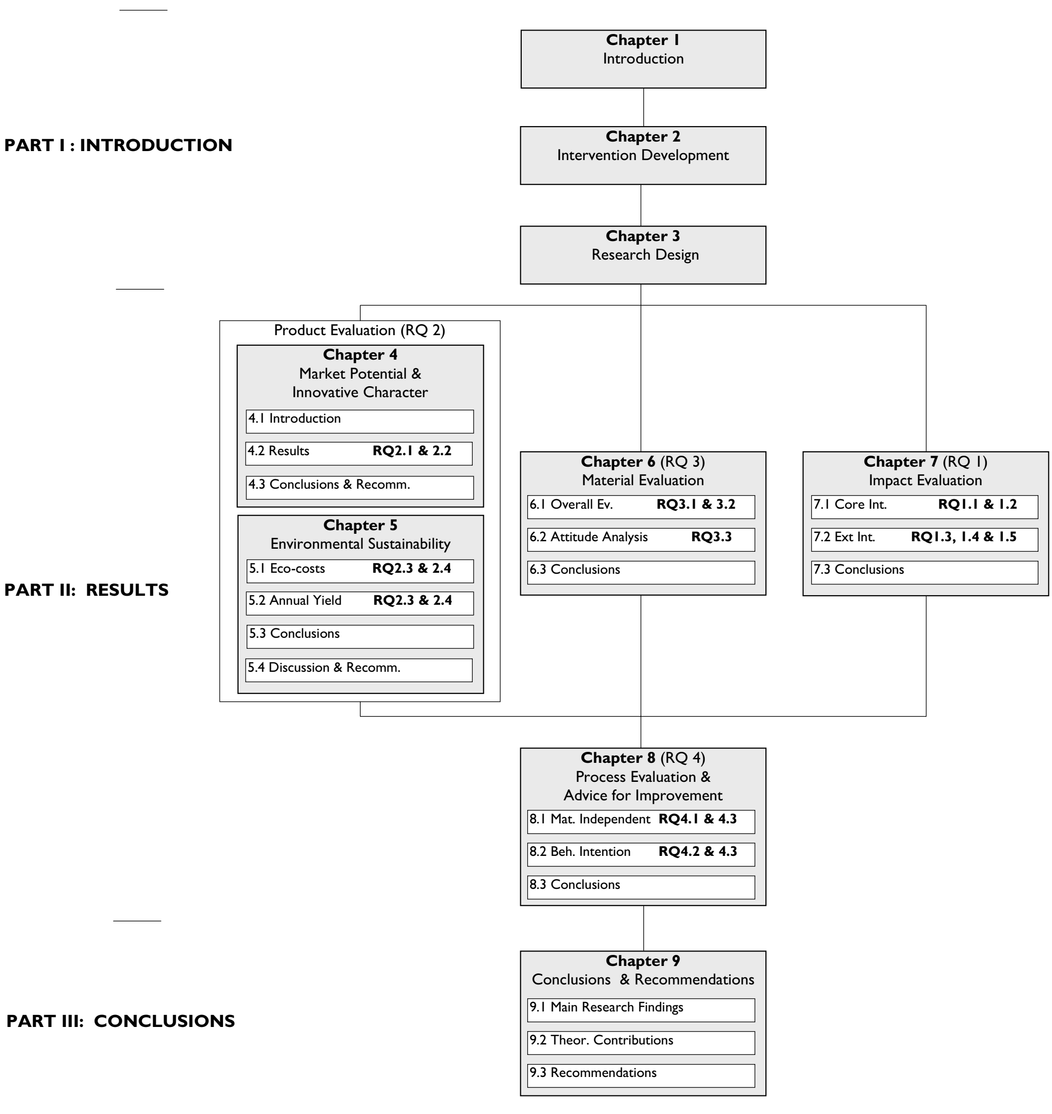


Figure 3.7: The outline in sections (subsections excluded) of the remainder of this thesis, including the detailed research questions being answered in each section

PART II: RESULTS

4 Product Evaluation; Market Potential and Innovative Character

In the previous chapter the design and operationalization of this research was explained. This chapter focuses on the second research question of this research, which evaluates the success of the developed products during the intervention. In this chapter the product evaluation will be evaluated in terms of market potential and innovative character. The environmental sustainability of the prototypes is evaluated separately in chapter 5.

In section 4.1 an introduction is provided about the prototypes that were developed during the Bamboo Labs, and the methodology used to evaluate the market potential and innovative character of these prototypes is introduced. In section 4.2, the results of the product evaluation for the market potential and innovative character are presented, after which they are analyzed in section 4.3 in order to provide lessons for successful bamboo based product innovation to bamboo producers.

4.1 Introduction

In this section the product prototypes developed during the Bamboo Labs by the participating designers are briefly introduced, as is the methodology deployed to evaluate the prototypes based on the criteria of market potential and innovative character.

4.1.1 Developed Product Prototypes

In this subsection the product prototypes developed during the intervention are briefly presented. For a more elaborate enunciation about each product prototype the reader is referred to the bilingual full color book *Dutch Design meets Bamboo*[29] (ISBN 978-90-74009-49-2, 160 pp) which was published separately with the DDMB exposition. The book serves as product catalogue with many photos of the products, and can be perceived as an appendix to this thesis. For the book each designer was interviewed about their ideas behind their product design, how they used bamboo in the product, which problems they encountered and how they perceived the future of bamboo as a high end design material for Western Europe.

[29] Besides through various (online) bookstores, the book can be ordered through the publisher [Z]OO productions: www.zooproducties.nl

Figure 4.1: The book Dutch Design meets Bamboo was launched during the opening of the exposition of the same name

The developed product prototypes including their creator, bamboo material used, processing technologies deployed, and market targeted, are also briefly presented in the figures below (in the same order as they are presented in the book *Dutch Design meets Bamboo*). As can be noted from the figures, some designers developed more than one prototype.

Figure 4.2: Coffin by Ro Koster & Ad Kil made from bamboo composite
Main processing technologies used: sawing and casting

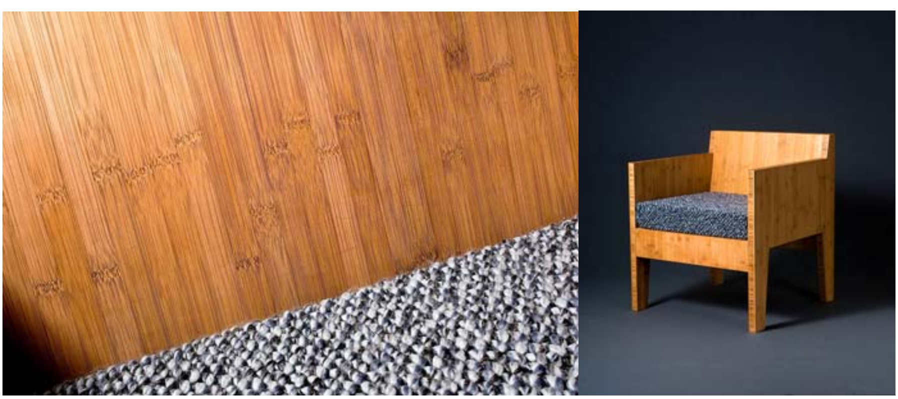


Figure 4.3: Chair by Lara de Greef made from Plybamboo and bamboo textile
Main processing technologies used: milling, weaving and varnishing

Figure 4.4: Floor tiles by Jacqueline Moors made from SWB
Main processing technologies used: sawing and sandblasting

Figure 4.5: Chair by Leonne Cuppen (Yksi) made from the stem
Main processing technologies used: sawing and sandblasting

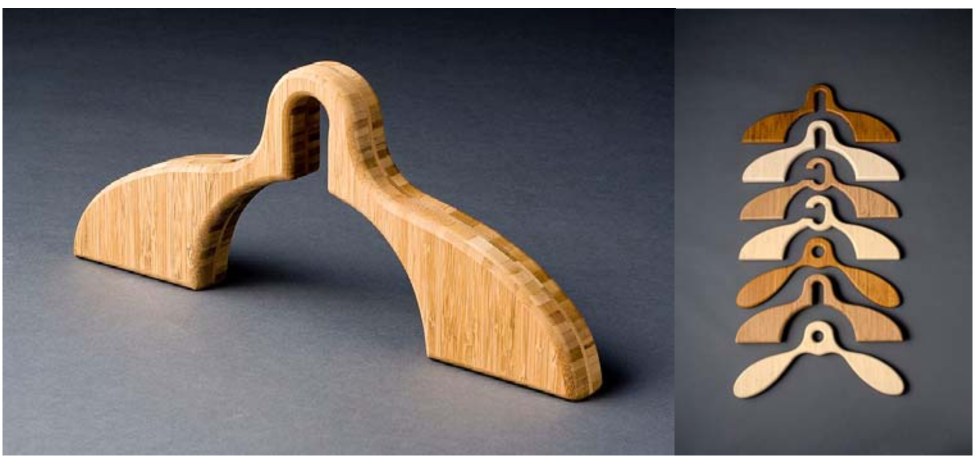


Figure 4.6: Clothing hangers by Leonne Cuppen (Yksi) made from Plybamboo
Main processing technologies used: milling and varnishing

Figure 4.7: Set of lamps by Leonne Cuppen (Yksi) made from the stem
Main processing technologies used: sandblasting

Figure 4.8: Room divider by Ed van Engelen (Haans) made from the stem
Main processing technologies used: sawing (double blade) and coating

Figure 4.9: Dinner table by Ed van Engelen (Haans) made from Plybamboo and the stem
Main processing technologies used: sawing and coating

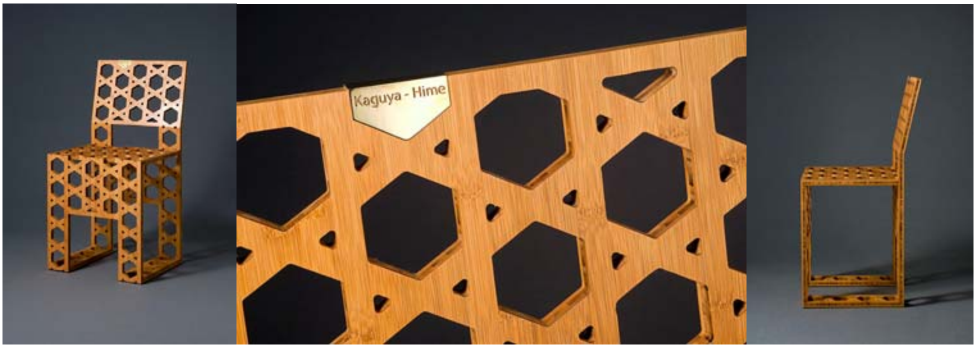


Figure 4.10: Chair by Lotte van Laatum made from Plybamboo
Main processing technologies used: milling

Figure 4.11: New board material by Bertjan Pot made from the stem, Plybamboo (veneer) and composite
Main processing technologies used: sawing, composite forming, vacuum suction and coating

Figure 4.12: Lamp by Eliza Noordhoek made from Plybamboo (veneer)
Main processing technologies used: die cutting

Figure 4.13: Vase by Eliza Noordhoek made from bamboo composite
Main processing technologies used: fiber extrusion and casting

Figure 4.14: Chair by Daan van Rooijen made from bamboo composite and the stem
Main processing technologies used: sawing and casting

Figure 4.15: New material by Yvonne Laurysen and Erik Mantel (Lama Concept) made from the stem
Main processing technologies used: sawing and casting

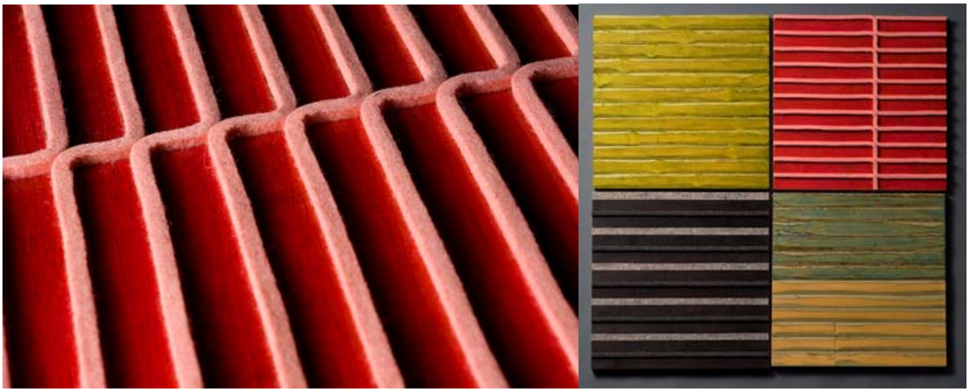


Figure 4.16: Floor/new board material by Yvonne Laurysen and Erik Mantel (Lama Concept) made from bamboo strips
Main processing technologies used: milling and coloring

Figure 4.17: Exposition system by Gilian Schrofer made from Plybamboo and the stem
Main processing technologies used: sawing, shrink sleeve application and varnishing

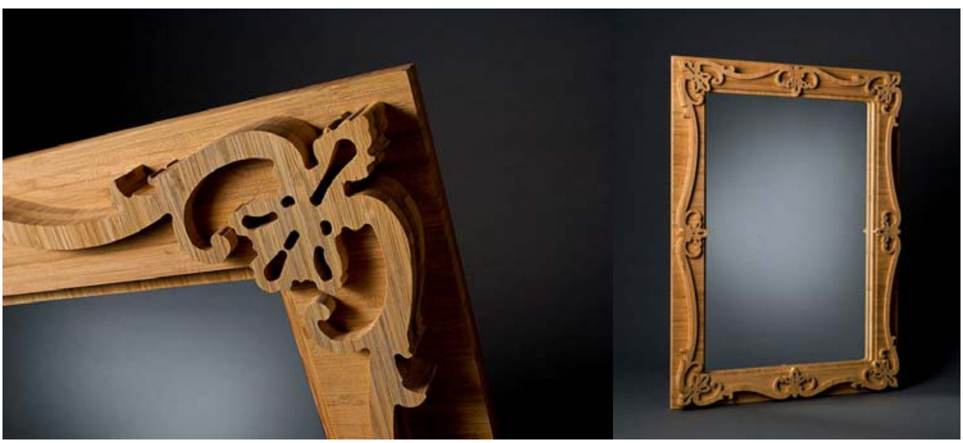


Figure 4.18: Mirror by Mette Hoekstra made from Plybamboo
Main processing technologies used: milling

Figure 4.19: Furniture set by Maarten Baas made from the stem
Main processing technologies used: n/a (no physical prototype was developed)

Figure 4.20: Chair by Maarten Baptist (Wat Design) made from mats
Main processing technologies used: molding and coloring

Figure 4.21: Floor/new board material by Patrick Kruithof (the Moment Company) made from Plybamboo
Main processing technologies used: milling

Figure 4.22: Chair by Tejo Remy & René Veenhuizen made from Plybamboo
Main processing technologies used: steam bending

Figure 4.23: Table by Natalie Meijer (Leolux) made from Plybamboo
Main processing technologies used: milling

Figure 4.24: Chairs by Thijs Bakker made from Plybamboo and the stem
Main processing technologies used: sawing

Based on the figures some initial conclusions can be drawn. First of all, the results of the prototypes are quite diverse in terms of bamboo materials deployed, aesthetics and design approach. As can be seen in the table, although Plybamboo was deployed by most designers, various other bamboo materials were also used. Furthermore, the form and style of the designs differ strongly; although eight designers decided to develop a chair (see figures above), the character of each chair is very different. Finally, while most designers decided to develop a prototype in the form of a product directly apt for the Western European market, others took the assignment differently and tried to develop new bamboo materials, based on which new products can be developed in the future (see figure 4.25).

Figure 4.25: Several designers developed a new bamboo material in the Bamboo Labs

The results of the intervention in the form of product prototypes are quite similar in terms of the kinds of products developed. Besides the new bamboo materials and the coffin developed by Ro Koster and Ad Kil, most other products are all furniture, targeting the medium to high end markets, which is not surprising taking the design brief into account. Half of these products (eight pieces) are chairs. The choice to develop a chair probably derives from the fact that the chair is a classical archetype of a product that combines many different product requirements such as mechanical performance, use, ergonomics and aesthetics.

4.1.2 Methodology

The prototypes developed during the Bamboo Labs were assessed based on their market potential, innovative character and environmental sustainability. In this subsection it will be explained in detail which methods were used to evaluate the market potential and innovative character of the developed prototypes. The sub criteria of these components were already introduced in subsection 3.3.2.

As was mentioned already in subsection 3.4.2, the product assessment was executed through an expert appraisal, a qualitative method through which a product is assessed by an independent panel of experts who are not acquainted with the product beforehand. For the expert appraisal of the prototypes in this intervention, a committee of three scientists with a broad expertise in the field of product design (Prof. dr. Han Dirken, Dr. Wim Poelman, and Dr. Henri Christiaans) from DUT was invited to evaluate the prototypes. The following procedure was used during the evaluation of the prototypes: First of all, to keep the product assessment of the Scientific Committee feasible within the time frame of an afternoon, the products were initially evaluated by Ed van Engelen, the in-house designer of furniture producer and -retailer Haans, and the author. Ed van Engelen (also a participant of the Bamboo Labs) was invited to execute the initial evaluation because of his knowledge about the current furnishing

market in Western Europe, production possibilities and constraints in South East Asia and Western Europe, and knowledge about bamboo as a material for designers.
During the evaluation, Ed van Engelen was provided with a list of criteria (see table 4.1) and guidelines to assess and validate the market potential and innovative character of each product prototype compared to similar products in the market for which the product was intended (frame of reference). Each product was evaluated for the various criteria on a five point rating scale (--, -, +/-, +, ++). Since the products were developed in a very short time they still needed optimization. Therefore, the products were evaluated taking into account a first hypothetical optimization cycle based on the ideas of the designers themselves. For example, the chair by Maarten Baptist was designed as a 100% bamboo chair. However, because the extra supply of bamboo mats arrived too late, the designer had to combine bamboo mats with wood veneer in his prototype. Nevertheless, the chair was evaluated as a 100% bamboo chair as intended by the designer.
After the scores of this first evaluation were noted and processed in evaluation sheets for each product, the Scientific Committee was invited over to the DDMB exposition in Eindhoven to validate - and if required challenge and adapt - the initial scores in order to guarantee an objective assessment of the prototypes. Throughout the evaluation and validation process the three members of the Scientific Committee were asked to first gain consensus about the score of each product in order to provide one overall score for each criterion.

Figure 4.26: The members of the Scientific Committee during the product assessment at the DDMB exposition in Eindhoven, from left to right: Henri Christiaans, Hans Dirken and Wim Poelman

The list with criteria and score levels for the components "market potential" and "innovative character" used by the assessors can be found in table 4.1. Although the criteria list largely explains itself, some additional explanations need to be made. For the criterion "manufacturing costs in North/South" it is important to understand that for the production of bamboo products in the interior decoration sector for use in Western Europe, there are crucial differences in production costs between the South (in this case South East Asia as primary bamboo product producer) and the North (in this case Western Europe) (van Engelen 2007). In the South, labor and machine costs in general are low, while material and transport costs (sea transport) are relatively high. Processing facilities and machines in general are of a lower quality than in the North, usually based on manual or semi industrial techniques, and specialized machines are usually not available (e.g. 3D molds, CNC milling machines, etc.). In general, quality control in the South is on a lower pitch than in the North. Furthermore, most (furniture) factories are specialized in the use of one material only; a combination of various materials is usually difficult. Since labor costs are low, batch size does not matter a lot in the South.

In Western Europe labor costs are high, but transport costs are lower (no sea transport required). Quality standards are usually high because of the availability of high quality specialized processing and production facilities. Because of the high labor costs and high level of industrialization, higher batch sizes can considerably lower manufacturing costs per product.

For the prototype evaluation was assessed where the developed products could best be (mass) produced (in the North or in the South) for the lowest manufacturing costs while retaining the required manufacturing quality. Together with the criterion of "transportability" (see table 4.1) this largely defines the production costs of the product prototypes. Note that although the production costs are usually only a part of the final retail price of a product, which is usually doubled (wholesale/low end outlets) and in high end markets can rise to six times the production costs in the final store, they are still an important indicator to estimate the price of a product. Basing themselves on the scores for the various criteria of the "product quality" and the "production costs" (see table 4.1) the experts were asked to estimate the market potential, based on the value (based on product quality)/price (based on production costs) ratio in the market for which the product is intended.

Table 4.1: Criteria list including scales used to evaluate the product prototypes developed in the Bamboo Labs

MARKET POTENTIAL		
Product Quality (value)		**Scale used to evaluate aspect**
Functionality & use	Weight	Performance on weight -- very bad - bad +/- reasonable + good ++ very good In general (depends on product) very bad means: very heavy and therefore difficult to use/move.
	Sturdiness (life span)	Performance on sturdiness -- very bad - bad +/- reasonable + good ++ very good
	Reparability & maintenance	Performance on reparability -- very bad - bad +/- reasonable + good ++ very good In general very good means: very easy to repair
	Specific functionality	Performance on specific functionality; does the product do what it should do? -- not at all - a little bit +/- reasonably + well ++ very well
Aesthetics & intangible properties	Aesthetic quality & trendiness	-- very bad - bad +/- reasonable + good ++ very good
	Originality; Strength of concept	-- very bad - bad +/- reasonable + good ++ very good
Production Costs		
Transportability		Potential efficiency of transport in containers (space consumption in containers, demountability, flat pack potential) -- very bad - bad +/- reasonable + good ++ very good In general very bad means: not demountable, lots of space consumption in containers, and very good means: very well demountable, transport possible in small packages; flat pack.
Manufacturing costs in North/South		-- very high (manufacturing costs) - high +/- reasonable + low ++ very low The manufacturing cost evaluation is based on the most economic producing region (North/South)[30].
Market Potential (value/price)		
Current market potential		-- very low - low +/- reasonable + high ++ very high
Future market potential after suggested improvements		-- very low - low +/- reasonable + high ++ very high
INNOVATIVE CHARACTER		
Utilization of specific properties of bamboo		-- not at all - a little bit +/- reasonably + well ++ very well Very bad means: No specific bamboo properties utilized at all, very good means: excellent use of bamboo specific properties (the product cannot be developed the same way in any other material).
Contribution to new image of bamboo		-- very low - low +/- reasonable + high ++ very high Very low means: bamboo still has a cheap/old fashioned image in this product, very high means: bamboo is used in this product as a trendy, high end, innovative material.
Level of process innovation (processing and manufacturing technology) for bamboo		-- very low - low +/- reasonable + high ++ very high Very low means: the processing technology is not new at all, very high means: the processing technology used is completely new (for bamboo).
Overall future market potential of new processing technology (if applicable)		-- very low - low +/- reasonable + high ++ very high Only if a new processing technology is developed: Future potential of the used technology to get bamboo in high quantities on the market as high end material in the medium to long term.

[30] In the product evaluation sheets in appendix H is explained for each prototype where each product can be produced in the most economical way.

It should be noted that although the criteria list was developed to be very comprehensive, some of the designs might have value on another level than the practical criteria depicted in the table. For example, the chair by Leonne Cuppen (see figure 4.5) was not evaluated very well by the committee in terms of market potential or innovative character (see table 4.2 below). However, the chair does have value as an icon and/or art object and as such can have a positive promotional function for the bamboo stem as material (see for example figure 7.20).

Finally, it should be remembered that in assessments and validations like these, there is always a large subjective factor involved which is observer dependent, that can be influenced (as we saw in the Theory of Reasoned Action; see subsection 3.3.1) by previous experiences, connotations and perceptions that the various assessors have had with the material. Therefore any evaluation will be colored by the personal subjective values of the observer who evaluates the product. It is important to take this into account when reading the results of the product evaluation in the next section, which should therefore not be perceived as the hard truth, but as a subjective evaluation by experts in the product design field.

4.2 Results

In this section the results of the product evaluation are presented. For the motivation behind the scores for each criterion, including points for improvement and recommendations for each product, the reader is referred to appendix H, in which the product prototypes are evaluated in the same order as they are presented in the DDMB book. In table 4.2 below the results of appendix H are represented in a compressed manner. All scores depicted are supported by the complete expert panel (Scientific Committee, Ed van Engelen and the author). If this is not the case the adjusted score of the Scientific Committee (SC) is depicted in the table beside the initial evaluation by Ed van Engelen and the author. For the market potential evaluation, the future market potential is perceived as the most important criterion, which takes into account all relevant criteria related to product quality and production costs, and is therefore highlighted in light gray for the products that scored an average score of "high" for the future market potential, and darker gray for the products that scored an average score of "very high".
For their innovative character, the products were evaluated on the level of product innovation for bamboo (based on the average scores of the criteria "specific bamboo properties deployed" and "contribution to the image of bamboo" combined into one overall score for product innovation, rounded up), and the level of process innovation for bamboo. As relevant background information, the market potential of the deployed process technology was also assessed. The overall criterion "product innovation" and the criterion "level of process innovation" are highlighted in the table in the case of a high level (light gray) and very high level (darker gray) of innovation.

Table 4.2: The scores for the assessment of the market potential and the innovative character of the developed product prototypes during the intervention

											
MARKET POTENTIAL											
Product Quality											
Functionality & use											
- Weight	+	-	+	-	-- SC: -	+/-	+	+/- SC: +	+ SC:+/-	++	+
- Sturdiness (life span)	+	++ SS: +	+	+ SC: -	+	--	-	+	-	+	-
- Reparability & maintenance	n/a	+	+	+	n/a	+/-	- SC: --	+/-	-	-	-
- Specific functionality	-	+/-	+/-	- SC: --	+	-	+ SC:++	+	-	+ SC:++	++ SC: +
Aesthetics & intangible properties											
- Aesthetic quality & trendiness	+/- SC: +	+	+	+	+/-	+/- SC:--	+ SC:++	+	+ SC:++	++	+ SC: +/-
- Originality; strength of concept	+ SS: ++	+/-	+/-	+/-	+/-	+/- SC: -	+ SC:++	+ SC: +/-	+/- SC:+	++	++ SC: +
Production costs											
Transportability	+	+	+/-	+/-	- SC:+/-	-	+	++	-	+	++
Manufacturing costs in North/South	-	+	-	+/-	+/-	-	+	+	+/-	+/- SC:+	++ SC: +/-
Market potential (value/price)											
Current market potential	--	+/-	-	-	- SC:+/-	- SC:--	+ SC:++	+/- SC: +	- SC:+	+/- SC:+	+
Future market potential after optimization	-	+	+	- SC: +/-	- SC:+/-	-	+ SC:++	+	- SC:+	+	++
INNOVATIVE CHARACTER											
Utilization of specific properties of bamboo	+/-	+/-	+	+	-	+/- SC:-	++	+	- SC:+/-	++	++ SC: +
Contribution to new image of bamboo	-	+	+/-	-	+	- SC:--	+ SC:++	+	+	++	++ SC: +/-
Product innovation	+/-	+	+	+/-	+/-	-	++	+	+/-	++	+
Level of process innovation for bamboo	++	+/-	+	--	+/- SC: -	+/-	+/-	+/-	+/-	++	+
Overall future market potential of new processing technology	+	+/-	+	n/a	+/-	+/-	+/- SC:++	+/- SC: +	+/-	+	+

											
MARKET POTENTIAL											
Product Quality											
Functionality & use											
- Weight	+/-	+	+/-	+/-	+/-	+/-	+/-	+/-	+	+/-	-
- Sturdiness (life span)	+	+/-	+/-	+	+	-	+/-	+/-	+/-	+/-	++
- Reparability & maintenance	n/a	--	-	+/-	+	-	+/-	+/-	-	+/-	--
- Specific functionality	+	+/-	++	+	+	+	+	+/-	+ SC: -	+	+ SC: -
Aesthetics & intangible properties											
- Aesthetic quality & trendiness	+/-	-	++	+ SC:++	+/- SC: +	-	+	+ SC:++	++ SC:+	+ SC:++	+
- Originality; strength of concept	+	+/-	++	+ SC: ++	+/- SC: +	-	+/-	+/- SC:+	+	+/- SC:+	+/-
Production costs											
Transportability	+/-	-	+	+	+	+	+	+	+/-	+	--
Manufacturing costs in North/South	-	-	- SC: +/-	+	+/-	+/-	+	-- SC: -	+	+/-	-
Market potential (value/price)											
Current market potential	-	--	+/-	+	-	-	+/-	--	+ SC:+/-	+/- SC: +	+/-
Future market potential after optimization	+/-	-	+ SC:++	+	+/-	-	+	- SC: +/-	++ SC: +	+/- SC:+	+/-
INNOVATIVE CHARACTER											
Utilization of specific properties of bamboo	- SC:+	+	+	+/-	+/-	+/-	+	+	++	+	+/-
Contribution to new image of bamboo	-	-	++	+	+/-	+/-	- SC:+	+/- SC: +	++ SC:+	+/- SC: +	+/-
Product innovation	+/-	+/-	++	+	+/-	+/-	+	+	++	+	+/-
Level of process innovation for bamboo	+	++	+	+/-	+/- SC: +	+/-	+ SC:++	-	+	-	+/-
Overall future market potential of new processing technology	+	+	+	+/-	+/-	+/-	+	-	+	-	+/-

As can be noted from table 4.2, the Scientific Committee challenged and adjusted the initial score in only 21% of the cases (70 of the 330 scores). In 18% of the scores (60 scores) the committee adjusted the score one point on the five point scale; in the remaining 3% of the scores (10 scores) the difference between the initial score and the committee score was two points. In 65% of the scores (46 scores) that were challenged, the SC scored higher than the initial evaluation. The above shows that the initial evaluation by Ed van Engelen and the author was quite accurate. The committee chair, Hans Dirken, acknowledged that the initial assessment was deemed realistic by the Scientific Committee, and that both assessments (primary assessment and the validation by the committee) have value since the expertise of the committee and first reviewers is complementary.
However, as can be noted from the table, for some products the committee consistently scored lower for most criteria, while for other products the committee consistently scored higher. For example, the committee scored the room divider by Ed van Engelen, the chair by Lotte van Laatum and table by Natalie Meijer higher on various aspects than Ed van Engelen and the author. In contrast, Ed van Engelen and the author evaluated, for example, the lamp by Eliza Noordhoek and the chair by Tejo Remy & René Veenhuizen higher on various product criteria. This shows the subjective character of these kinds of evaluations; if an individual just likes a product overall he/she tends to evaluate the various product criteria in a more positive manner. In order to diminish this effect, the scores of the initial evaluation and the evaluation by the Scientific Committee were added up and divided by two in order to establish average scores for the criteria “future market potential”, “product innovation” and “process innovation”. Based on these average scores (which were rounded up) the product designs that scored best for these criteria were selected and presented below.

Market Potential

As can be seen in table 4.2 (light gray cells), according to the expert panel (Scientific Committee + Ed van Engelen & the author), the chair by Lara de Greef, the floor tiles by Jacqueline Moors, the table by Ed van Engelen, the board material by Bert Jan Pot, the flooring by Yvonne Laurysen & Erik Mantel, the chair by Maarten Baptist and the table by Natalie Meijer have a high market potential in the markets for which they are intended, once they will have been optimized. After optimization, the room divider by Ed van Engelen, the lamp by Eliza Noordhoek, the new material by Yvonne Laurysen & Erik Mantel and the chair by Tejo Remy & René Veenhuizen even have very high potential for their intended target markets, according to the expert panel.

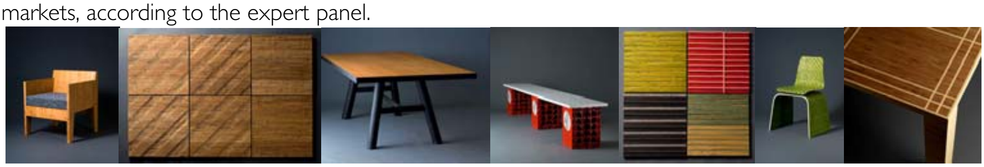


Figure 4.27: Products with high market potential after optimization according to the expert panel

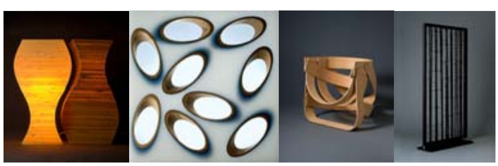
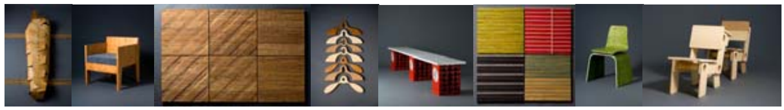


Figure 4.28: Products with a very high market potential after optimization according to the expert panel

While the product evaluation by the expert panel took place in June 2007, at the time of the writing of this thesis (autumn 2007- spring 2008) already more information was available about the further development toward potential future commercialization of the prototypes. It is interesting to compare this information with the assessed market potential, to see if the first assessment by the expert panel seems accurate. For this purpose, the author inquired with the designers in April 2008 what the plans were for further optimization and commercialization of their designs (see table 4.3).

Table 4.3: Prospects of further development toward potential future commercialization of the prototypes (state of the art situation, April 2008)

Certain further development	
Possible further development in the future	
No further development	
Unknown	

Most designers whose bamboo products will be further developed toward possible commercialization mentioned that this first step was made because stakeholders (consumers and producers) in the intended target market provided positive feedback about the product, after the prototypes were presented during the opening of the exposition DDMB in May 2007. Some of the designs were already launched successfully on the market in spring 2008 (e.g. table and room divider by Ed van Engelen), of which the room divider is most successful with requests for 1000 pieces already. Various other designs (e.g. chair Tejo Remy & René Veenhuizen, new material by Yvonne Laurysen and Erik Mantel) are set to be introduced to the market by fall 2008. Some designers mentioned that they have the prototype still waiting "on the shelf"; they take it with them in their portfolio and mention it to producers, but it is unclear if their product will be further commercialized (these designs were categorized as "possible further development in the future" in table 4.3).

As can be seen in table 4.3, all the products that the expert panel assessed to have a very high market potential will indeed be further developed toward commercialization. Furthermore, all products mentioned by the expert panel with high market potential will either certainly be further developed, or the further development toward commercialization is still possible. The comparison in table 4.3 shows that the market potential assessment by the expert panel seems very accurate. However, it should be noted that the optimization- and launch phase of the product innovation process takes time. Although the fact that various designs are further optimized and developed is a good sign, it will probably take until 2009 before a product might end up in final retail outlets (or might not make it after all; see the many factors of success and failure that could disturb this process in appendix G). It is interesting to see that most products that will be developed further are made from Plybamboo. The reasons for this will be further analyzed in section 6.2.

Box: Best Designs According to the Members of the Scientific Committee

It is always very difficult to say which design is best because many criteria are involved, of which many have a subjective character. For each reviewer and for each market segment other criteria may prevail and have a different weight. Product designs that do not score well on functionality can still be winners because of their aesthetic quality or simply because they have some intangible quality that makes the product appealing. Taking this subjectivity into account, each of the committee members was asked to select his overall top three of the results from the project for the categories "products" and "materials", since, as seen in subsection 4.1.1, some designers decided to make a new bamboo material (see figure 4.25) and some decided to make a final product.

Products

	Hans Dirken	Wim Poelman	Henri Christiaans
1.	Room divider by Ed van Engelen	Expandable table by Natalie Meijer	Room divider by Ed van Engelen
2.	Table by Ed van Engelen	Chair by Lara de Greef	Expandable table by Natalie Meijer
3.	Chair by Maarten Baptist	Chair by Maarten Baptist	Chair by Lara de Greef

Materials

	Hans Dirken	Wim Poelman	Henri Christiaans
1.	Flooring by Yvonne Laurysen & Erik Mantel	Everything (flooring and new material) by Yvonne Laurysen & Erik Mantel	Everything (flooring and new material) by Yvonne Laurysen & Erik Mantel
2.	Flooring by Patrick Kruithof	Material used for room divider by Ed van Engelen	Floor tiles by Jacqueline Moors
3.	New board material by Bert Jan Pot	Floor tiles by Jacqueline Moors	New board material by Bert Jan Pot

Furthermore, it should be noted that the committee members were very positive about the chair designed by Marco Groenen (furniture line "Grass"), one of the initiators of the project DDMB, which was also shown at the exposition. According to the committee the chair uses bamboo specific qualities because it is slim, yet strong. Furthermore, the concept is very clear; the chair could have an icon function for bamboo furniture in the future. The dowel connections are subtle and innovative. The chair was perceived as one of the best designs in the exhibition. However, because it was not developed during the intervention, it was not taken into account for the top three classifications above.

Figure 4.29: "Grass" furniture line designed by Marco Groenen

Innovative Character

As was mentioned before, the innovative character was assessed separately for the overall level of product innovation and level of process innovation. First, the products with the highest level of product innovation, based on the utilization of the specific properties of bamboo and their contribution to a new high end image of bamboo, will be presented. According to the expert panel (see light gray cells in table 4.2) the chair by Lara de Greef, the floor tiles by Jacqueline Moors, the table by Ed van Engelen, the lamp by Eliza Noordhoek, the flooring by Yvonne Laurysen & Erik Mantel, the chair by Maarten Baptist, the flooring by Patrick Kruithof and the table by Natalie Meijer represent a high level of product innovation. The room divider by Ed van Engelen, the board material by Bertjan Pot, the new material by Yvonne Laurysen & Erik Mantel and the chair by Tejo Remy & René Veenhuizen scored even better, and had a very high level of product innovation according to the expert panel. In other words, according to the expert panel the products mentioned above, and depicted in figures 4.30 and 4.31, use the specific properties of bamboo well and have provided a trendy new image to bamboo in their products. The members of the Scientific Committee noted that they would have liked to see more examples in which the specific properties of bamboo were deployed based on mechanical characteristics, such as the elasticity, longitudinal strength, the hollowness or the flexibility. An example of a product that did utilize these properties was the chair by Tejo Remy & René Veenhuizen.

Figure 4.30: Products with a high level of product innovation according to the expert panel

Figure 4.31: Products with a very high level of product innovation according to the expert panel

Besides the level of product innovation the products were assessed on their level of process innovation based on the processing technology deployed. Because it is interesting information for the bamboo industry in general, the market potential of this technology to get bamboo in high quantities on the market in products on the medium term to long term was assessed separately (final row in table 4.2).

According to the expert panel the products that scored high with respect to the level of process innovation were the floor tiles by Jacqueline Moors, the lamp and vase by Eliza Noordhoek, the new material by Yvonne Laurysen & Erik Mantel, the exposition system by Gilian Schrofer and the chair by Tejo Remy and René Veenhuizen. The chair by Daan van Rooijen, the coffin by Ro Koster & Ad Kil, the chair by Maarten Baptist and the new material by Bertjan Pot scored very high with respect to their levels of process innovation.

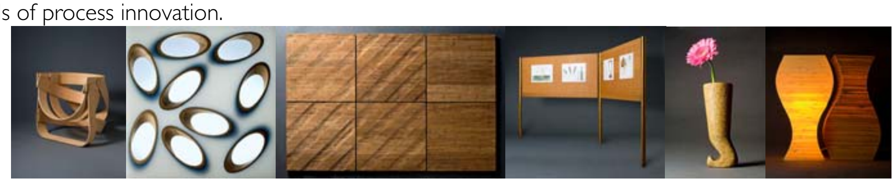


Figure 4.32: Products with a high level of process innovation according to the expert panel

Figure 4.33: Products with a very high level of process innovation according to the expert panel

Although for a more elaborate motivation the reader is referred to appendix H, the largest process innovations had to do with the use of new bamboo semi finished materials (SWB, composites, veneer) in an actual product (floor tiles by Jacqueline Moors, coffin by Ro Koster & Ad Kil, vase by Eliza Noordhoek, chair by Daan van Rooijen), the use of die-casting- (lamp by Eliza Noordhoek) and bending techniques (chair by Maarten Baptist and chair by Tejo Remy & René Veenhuizen), or the development of new bamboo materials based on casting- (new material by Yvonne Laurysen & Erik Mantel) and vacuum suction techniques (new material by Bertjan Pot).

4.3 Conclusions & Recommendations

This chapter has answered part of the second research question (RQ2: To what extent are the products developed in the intervention successful?) through answering research question 2.1 (What is the market potential of the products developed?) and research question 2.2 (How innovative are the products developed?), introduced earlier in subsection 3.3.2. This chapter has proven that in terms of market potential and innovative character the product prototypes have been quite successful: 11 of the 22 prototypes were evaluated by the expert panel as having high to very high market potential. This also became apparent in table 4.3, which showed that eight of the prototypes will certainly be further developed toward commercialization. In terms of innovative character the products also scored well; 12 of the 22 evaluated prototypes were rated by the expert panel as having a high level of product innovation, while 10 of the 22 prototypes were evaluated as having a high level of process innovation.

In this section some concluding remarks will be made to synchronize and combine the results from the market potential and innovative character evaluation, which can provide valuable lessons to stakeholders in the bamboo industry in the South[31] with an interest to target Western export markets in the future. Although some examples relating to the developed products will be provided, for more elaborate information the reader is referred to appendix H.

From table 4.2 it can be concluded that a couple of products developed during the Bamboo Labs combine a high level of process- and product innovation with a high (future) market potential of the product (see the frames in table 4.2: floor tiles by Jacqueline Moors, new material by Bertjan Pot, lamp by Eliza Noordhoek, new material by Yvonne Laurysen & Erik Mantel, chair by Maarten Baptist and chair by Tejo Remy & René Veenhuizen). The high scores for the floor tiles by Jacqueline Moors and the lamp by Eliza Noordhoek are partly based on the innovative character and the market potential of the new materials (SWB, veneer) these products are based on. The chairs by Maarten Baptist and Tejo Remy & René Veenhuizen, and the lamp by Eliza Noordhoek combine a high market potential with a high level of process innovation through deploying bending techniques very suitable for processing

[31] However, through the obstacle of lack of availability and diffusion of information (see appendix C) many bamboo producers in the South are unable to access this kind of information. Although this dissertation and the book Dutch Design meets Bamboo might provide a small contribution to making this kind of information available, more substantial information diffusion mechanisms are required. In subsection 9.3.3 more concrete recommendations are provided to tackle this issue (recommendation 1: development of an information portal).

bamboo. Although the level of process innovation of these kinds of technologies is quite high for the various bamboo materials, they do not necessarily have a radical character and do not require very large changes in production facilities, since these technologies already exist for processing wood (bending, die-cutting). Therefore, these techniques have the potential to be replicated in the South as well.
Bertjan Pot and Yvonne Laurysen & Erik Mantel (new material) have combined several existing processing technologies (e.g. casting and vacuum suction) to develop a completely new bamboo material with high market potential, once the required production facilities can be developed to manufacture the materials in an efficient way. This shows that a smart combination of existing processing technologies can also result in products with high market potential.
However, from the table it can also be seen that a high level of process innovation does not always correlate with a high market potential. Although the products that were based on the use of bamboo fibers in combination with bio resins to form composites probably have the most radical character (Ro Koster & Ad Kil, vase by Eliza Noordhoek, Daan van Rooijen), and therefore might have a higher impact on the long term (economically and ecologically), they require large, time consuming shifts in infrastructure and demand significant investments (which is characteristic for radical innovations; see also figure 1.1). For these reasons the future market potential of these products is still relatively low. Note, however, that the use of bamboo fibers in combination with bio resins to form natural fiber based composites scores well for the long term market potential of the technology itself (due to the increasing importance of sustainability), once the necessary preconditions mentioned are met.

The table also shows that for several products only a small process innovation can result in a large improvement in image and market potential. Besides bending and molding (which were assessed before as being large process innovations for bamboo), the designers used various simple technologies to improve the image and market potential of their bamboo products: (1) creating new surface patterns through milling Plybamboo, (2) sawing the bamboo stem from different angles, (3) coloring the bamboo material, (4) other surface treatments such as sandblasting, and (5) combining bamboo with other materials. These technologies will be reviewed below.

Through high quality milling (which is not a very new processing technology), there are many possibilities to process Plybamboo in a trendy high end product with a high market potential (see for example the designs by Lara de Greef, Lotte van Laatum and Natalie Meijer). Another example of a simple twitch in processing is sawing the bamboo stem in a different angle than the prevailing transversal manner. For example, in the room divider by Ed van Engelen (longitudinal sawing the stem) and the new material by Yvonne Laurysen & Erik Mantel (diagonal sawing the stem), products with a completely new and improved image are created based on this technique. Furthermore, both in his room divider and his table, Ed van Engelen gives the bamboo strips and stems a black coating, which is again a simple measure which completely changes the image (and the corresponding market potential of the product) in a positive manner. Many other designers also used coloring to positively change the image of the bamboo materials such as Maarten Baptist, Bertjan Pot, Yvonne Laurysen & Erik Mantel (flooring). Other designers used similar ways to change the surface of the bamboo materials (especially the bamboo stem) in order to improve the image of the developed product, such as Gilian Schrofer (shrink sleeve around bamboo stem) and the lamps by Leonne Cuppen (sandblasting). Another simple, but effective means to enhance the market potential and image of a bamboo product is combining bamboo with other materials such as with textile (chair by Lara de Greef, flooring by Yvonne Laurysen & Erik Mantel) or colored resin (new material by Yvonne Laurysen & Erik Mantel).

Figure 4.34: By cutting the stem in a diagonal or transversal way Ed van Engelen and Yvonne Laurysen & Erik Mantel created bamboo products and materials with a completely different visual appearance

The above is a valuable lesson for bamboo producers in the South to understand: Once the needs and trends in the target market are understood, in many cases small adjustments in processing bamboo (i.e. incremental innovations requiring only small changes to existing production facilities), are sufficient to completely enhance the market potential of bamboo products that target Western export markets. To avoid a competitive response (e.g. through copying of products by the wood industry), it is advised to try to develop products that take advantage of the specific properties of bamboo. Examples are the products developed by Bert Jan Pot, Ed van Engelen (room divider), Yvonne Laurysen & Erik Mantel and Tejo Remy & René Veenhuizen, which can hardly be copied in wood.

It is also good to mention here that sometimes the innovation might lie in unexpected places. For example, the product designs by Bertjan Pot and Maarten Baas consisted of the utilization of parts of the bamboo stem that are usually regarded as rest material. Bertjan Pot used short transversal slices of the bamboo stem (rest material) combined with veneer, which through the application of vacuum suction created a high end board material with a unique pattern. Maarten Baas applied crooked bamboo stems, which are generally not regarded as suitable for high-quality product applications, as unique elements in his design (see figure 4.35). More specific recommendations with respect to relevant processing technologies specifically attuned to the various bamboo materials used in the Bamboo Labs will be reviewed in chapter 6.

Figure 4.35: For his design (right) Maarten Baas was inspired by the crooked bottom part that some bamboo species have (left)








5 Product Evaluation; Environmental Sustainability

In the previous chapter the results of the product evaluation for the criteria market potential and innovative character were presented. In this chapter the products will be evaluated for the final main criterion of the product evaluation, the environmental sustainability. This can only be done if the environmental sustainability of the bamboo materials of which they are comprised is known - which is the main focus of this chapter - after which the environmental sustainability of the prototypes can be estimated. The environmental sustainability of bamboo materials is determined by combining the environmental impact in eco-costs at the "debit" side and annual yield at the "credit" side (see also table 3.3).

In section 5.1 the environmental impact of the various bamboo materials will first be evaluated in eco-costs using Life Cycle Assessment (LCA) after which in section 5.2 the annual yield of the various bamboo materials will be calculated. In section 5.3 conclusions are provided about the overall environmental sustainability of bamboo compared to various material alternatives. Finally, in section 5.4 several recommendations are provided based on the key findings in this chapter.

5.1 Environmental Impact in Eco-costs

5.1.1 Introduction

Although bamboo materials are marketed (and therefore usually also perceived) as environmentally friendly, few quantitative environmental impact assessments using LCA methodology are available for bamboo. The only available studies known to the author are a study executed by Dr. Richard Murphy (Murphy et al. 2004) and another study executed by the author for his MSc thesis (van der Lugt 2003) published in various journals (van der Lugt et al. 2003, van der Lugt et al. 2006). The study by Murphy et al. (2004) focuses on the use of bamboo stems (Guadua) in combination with sand/cement (based on the traditional Baharaque technique) as a structural material for social housing in Colombia compared to a similar house executed in masonry and concrete. The environmental impact of the bamboo house was approximately half the impact of the concrete house. Besides the use of the bamboo stem, the study excluded other (industrial) bamboo materials and was based on local consumption of bamboo.
Another LCA study, based on the TWIN 2002 model, was executed by the author. Besides the bamboo stem, the study assessed one version of Plybamboo board (10 mm plain pressed Plybamboo). However, part of the input data in the study was not completely reliable. Therefore, it was decided to execute a new environmental impact assessment within the framework of this research in order to determine the environmental impact of the various relevant bamboo materials deployed by the designers in the intervention. Based on the outcomes, some statements about the environmental burden of the various prototypes developed in the design workshops can also be given. Below, an introduction will be provided about LCA and the models used in this research to analyze the LCA output data to a single indicator for the environmental impact.

LCA

LCA is the commonly accepted methodology to systematically test the environmental impact of a product, service, or in this case, material. Principally, in an LCA, all environmental effects relating to the three main environmental problems (see table 1.1 in subsection 1.1.1) occurring during the life cycle of a product or material are analyzed, from the extraction of resources until the end phase of demolition or recycling (from cradle till grave). The LCA-methodology developed by the Centre of Environmental Studies (CML, in Leiden, Netherlands) was presented in 1992 (Heijungs et al. 1992) and was internationally standardized in the ISO 14040 series (ISO 1997). A standard LCA provides an outcome of different effect scores; a weighing method is not included, and an overall judgment of products is therefore not possible. Furthermore, a standard LCA is very complicated to understand and communicate, which is the reason why various additional models have been developed to be used in combination with a standard LCA in order to indicate the environmental burden of products through a single indicator. The validity of the models is always subject to discussion, mainly about the weighing method applied, but also about the environmental effects included/excluded as well as allocation issues (van den Dobbelsteen 2002). For an overview of available models the reader is referred to van den Dobbelsteen (2004). At DUT either the damage based models Eco-indicator 95 and Eco-indicator 99, or the prevention based model Eco-costs 2007 are used as single indicator models (Vogtländer 2008). In this research the Eco-costs 2007 model is used to identify the environmental burden of the bamboo materials through a single indicator.

It is important to understand that the outcomes of an LCA based calculation should not be perceived as the hard truth, but only as a rough indicator to predict the environmental impact of a product or material. First of all, LCA is a relatively new methodology which is continuously being improved, and is based on which new models continue to emerge on the market. Secondly, the factors *time* and *place* are not incorporated into an LCA, which means that any LCA based calculation is full of assumptions and estimations which may differ per calculation. For example, for the factor place, even for exactly the same product or material, production data may differ depending on the country of production (e.g. regulations with regard to emissions of production facilities), or the country of consumption (e.g. transport distance). The production context may also differ, which can be best- or worst practice or something in between (e.g. recycling, waste treatment, incorporated at production site), which can cause differences in environmental impact for exactly the same product. Besides these main reasons even more place related aspects may play a role such as the environmental effects of pollution, e.g. some regions are more prone to acid rain than others (Potting 2000).
Furthermore, the time aspect can play a crucial role; if an LCA is based on older data, it may differ considerably from calculations based on current data, based on newer and more efficient production technologies. Also, due to the time factor, annual yields and carbon sequestration by renewable materials such as timber and bamboo are not taken into account in an LCA, and are therefore calculated separately in this thesis in section 5.2.
Summarizing: an environmental impact assessment based on LCA is often lacking exact data and only provides a rough overview of the environmental impact of a product or material.

Eco-costs

The Eco-costs model is based on the concept of marginal prevention costs (Vogtländer 2008), which refers to costs in technical measures that would need to be made to prevent or compensate for resource depletion and pollution by the product or material, in order to bring the environmental burden to a sustainable level (e.g. through investments in sustainable energy) (de Jonge 2005). As such, the eco-costs are virtual costs, since they are not yet integrated in the real life costs of most production chains (Life Cycle Costs). According to Vogtländer (2008), eco-costs should be perceived as hidden obligations, and should not be confused with external costs which are damage costs and therefore only appropriate for damage based LCA-models. In practice, prevention based- and damage based LCA models seem to give similar results (Vogtländer 2008). The Eco-cost model is based on the sum of the marginal prevention costs during the life cycle of a product (cradle till grave) for toxic emissions, material depletion, energy consumption and conversion of land, and includes labor (the environmental impacts related to aspects such as office heating, electricity and commuting) and depreciation (e.g. vehicles, equipment, premises) related to the production and use of products (de Jonge 2005, Vogtländer 2001). The advantage of eco-costs is that it is expressed in a standardized monetary value which can be easily understood, and may be used in the future for the establishment of justifiable eco-taxes and/or emission rights. Although calculation of the prevention based eco-costs is complex, the calculation is feasible and transparent compared to damage based models which have the disadvantage of subjective weighting of the various aspects contributing to the overall environmental burden (Vogtländer 2001). For further examples of the differences between calculations in prevention- and damage based models the reader is referred to the ecocostsvalue.com website (Vogtländer 2008).

System Boundaries and Data Collection for LCA

Since almost every product or material goes through different production activities with different parameters, it is important to make very clear in any LCA based calculation which aspects are and which aspects are not included in the data used for the calculation. Only if these system boundaries are clear, results can be compared with other LCA based calculations, which are based on similar boundaries. In this subsection the most important assumptions and system boundaries used for this environmental impact assessment are provided, as well as the procedure and sources for data collection and -processing for the assessment.

<u>Points of Departure and Basic Assumptions</u>

The environmental impact assessment was executed for the various bamboo materials used during the intervention (Plybamboo in various variations, stem, fibers[32] (for use in composites), SWB and mats). Because the aim of DDMB was to promote bamboo as a sustainable alternative to wood and especially tropical hardwood, the bamboo materials were compared to relevant wood species. In the Eco-costs 2007 database, available via www.ecocostsvalue.com, the eco-costs of various materials, including various wood species, are provided.

The environmental impact assessment for bamboo was based on a so called "Cradle till Site" scenario, which includes all environmental effects until the point of use of the material (Hammond and Jones 2006). Although this is different from a Cradle till Grave scenario, which includes the use and end-of-life phase of a product or material, it is assumed that there are no major differentiating factors between bamboo and wood in these phases, because of the similar life span and chemical composition (same dump or recycle mechanisms deployed) of both materials in the applications in which bamboo was compared with wood (Functional Unit, see below). Thus, an environmental impact assessment based on a Cradle till Site scenario should suffice to compare the eco-costs of bamboo with wood. The assessment for bamboo was based on their use as a semi finished material (excluding additional finishing such as lacquering) in various applications in the Netherlands. From the production side the calculation was based on the use of bamboo resources (Moso species) derived from sustainably managed plantations[33] in the Anji region (province Zhejiang) in China, for which no primeval forests were recently cut. Finally, for the comparison of material alternatives in a certain function, a general basis of comparison needs to be determined. This basis is called the "Functional Unit" (ISO 1998, van den Dobbelsteen 2002). For a correct comparison, the Functional Unit (FU) is of vital importance: sizes of

[32] Only assessed in a qualitative manner due to lack of data for a complete LCA.

[33] It should be noted that most Chinese plantations originally used to be natural forests from which other vegetation has been removed. This initial loss of biodiversity is not taken into account in this calculation.

the alternatives are determined by their technical and functional requirements. Depending on the application these requirements may differ considerably. For example, for a supporting beam, strength might be the crucial criterion while for a floor, hardness and aesthetics might be the most important requirements that should be met, that determine the amount of material required. In the subsections below for the calculation of each material the FU also will be explained.

Data Collection and Analysis

Evidently, the key to any LCA based calculation is to acquire reliable data about the production process of the products or materials assessed. For this reason extensive inquiries were made in summer 2007 through questionnaires and telephone interviews with the material supplier of the intervention (Mr. René Zaal, director of Moso International BV) and the suppliers of Moso International in China (DMVP and Dasso, Mr. Xia; Hangzhou Dazhuang Floor Co, Ms. Isabel Chen). Furthermore, data used for the LCA calculation executed by the author in an earlier study (van der Lugt et al. 2003) based on the TWIN 2002 model, was also used as input for an adjusted calculation for the stem based on production in China instead of in Costa Rica (production region for the earlier LCA study by the author). During the environmental impact assessment of the bamboo materials for each production- and transport process step the environmental effects were noted (mostly based on energy consumption and addition of chemicals), and translated into eco-costs by Dr. Joost Vogtländer, architect of the Eco-costs model, who assisted the author in processing the data. Dr. Vogtländer also translated the TWIN 2002 data (which is based on the LCA calculation program Green Calc) of the earlier LCA study executed by the author into eco-costs, including the modification of the effect of the emission of greenhouse gases based on data from the ICE database of the university of Bath (Hammond and Jones 2006). The density used in the calculations for all alternatives was based on Wiselius (Wiselius 2001) and Ashby and Johnson (2002). The outcomes of the eco-costs calculation for the bamboo materials, based on the added sum of all process steps, was compared with the data for various alternatives mostly in wood. The Eco-costs database derives its data from various other acknowledged databases such as Simapro and IDEMAT.

Below, the results of the environmental impact assessments for the various bamboo materials will be presented and compared to various wood based materials. In appendix I all the activities calculated during the chain (Cradle till Site scenario) are covered for the various bamboo materials in various forms (e.g. carbonized, bleached, etc.), including all the assumptions made during this process, which shows the complexity of the data collection and -analysis procedure during environmental impact assessments.

5.1.2 Wood Based Materials

The eco-costs per kilogram of various wood species and wood based panels are represented in table 5.1 below. The data for wood species was derived from the Eco-costs 2007 database (Vogtländer 2008) and IDEMAT database (DfS 2008) and are based on sawn timber in dried state ready for sale in wholesale outlets in the Netherlands derived from sustainably managed plantations, dried and processed into sawn timber in the Netherlands (based on a Cradle till Site scenario, thus including all processing and transport steps). Data for wood based board materials was derived from the TWIN 2002 database and the ICE database from the university of Bath (Hammond and Jones 2006), and were modified to Eco-costs 2007 for the same parameters as mentioned above for wood.

Table 5.1: Eco-costs per kilogram of various wood (based) materials

Category	Material/species	Data source	Total Eco-costs (€)/kg, including material depletion[34]
Wood	Pine	Eco-costs 2007 database	0.096
	European Beech	Eco-costs 2007 database	0.166
	Walnut	Eco-costs 2007 database	0.178
	Teak (natural forest; RIL)	Eco-costs 2007 database	4.97 (4.65)
	Teak (FSC certified)	Eco-costs 2007 database	1.25 (0.93)
	Teak (plantation)	Eco-costs 2007 database	0.322
	Scotch Pine	Eco-costs 2007 database	0.180
	Poplar	Eco-costs 2007 database	0.032
	European Oak	Eco-costs 2007 database	0.173
	Robinia	Eco-costs 2007 database	0.148
	Azobé (natural forest; RIL)	Eco-costs 2007 database	4.83 (4.65)
	Azobé (FSC certified)	Eco-costs 2007 database	1.11 (0.93)
	Azobé (plantation)	Eco-costs 2007 database	0.184
Wood based board material	Chipboard (100% waste wood)	TWIN 2002- and ICE (v.1.5 beta) database	0.116
	MDF (plantation)	TWIN 2002- and ICE (v.1.5 beta) database	0.176
	Hardboard (100% waste wood)	TWIN 2002- and ICE (v.1.5 beta) database	0.236
	Chipboard (100% new wood)	TWIN 2002- and ICE (v.1.5 beta) database	0.196
	Plywood (Pine; plantation)	TWIN 2002- and ICE (v.1.5 beta) database	0.295
	Plywood (tropical hardwood; plantation)	TWIN 2002- and ICE (v.1.5 beta) database	0.786

From table 5.1 it can be seen that due to material depletion, the differences in eco-costs between the various wood (based) materials are considerable. The eco-costs for material depletion are based on degradation of biodiversity, caused by the conversion of land (i.e. the difference in biodiversity before and after the harvest) (Barthlott and Winiger 1998). In the case of a sustainably managed plantation, material depletion is zero because the biodiversity (species richness) remains the same, resulting in zero eco-costs. Since most wood from Europe comes from sustainably managed plantations nowadays, the material depletion factor is not much of an issue for most European based wood.

In the case of wood deriving from tropical areas (see for example Teak and Azobé in table 5.1) the situation is different, since a lot of timber is derived from natural forests (in subsection 1.1.3 it was found that only 11% of timber from (sub)tropical regions is derived from plantations). Thus, for wood from tropical forests material depletion can have a large impact on the eco-costs. Because of the high biodiversity in most tropical countries the value for eco-costs of species richness is estimated at an average of 11.3 € per m2 of nature in 2008 (Barthlott and Winiger 1998).

In the case of Reduced Impact Logging (RIL) of timber from a tropical forest (Rose 2004), a 50% loss of eco-value because of the harvest is assumed, resulting in eco-costs of 4.65 €/kg sawn timber

[34] Contribution of material depletion in brackets; if none mentioned, the material depletion is zero (wood from sustainably managed plantations).

(Vogtländer 2008); see table 5.1. As a result, tropical hardwood RIL harvested from a natural forest is not competitive with European grown wood with respect to the eco-costs/kg.

In the case of tropical hardwood sustainably harvested from natural forests under the FSC certification scheme, the compensation costs because of material depletion are considerably lower. The FSC certification scheme guarantees - to some extent - a sustainable and socially responsible chain of custody when harvesting, transporting and processing trees into sawn timber. FSC practices, however, differ from country to country; local customs are adhered to. FSC more or less guarantees RIL. One may hope that areas with high biodiversity are therefore preserved to a larger extent by RIL harvesting under the FSC regime.
Due to the higher expected biodiversity preservation in logging under the FSC regime, in combination with the fact that 35.4% of FSC certified productive forest area in the tropics consists of plantations (FSC 2008), Vogtländer (2008) assumes a 10% loss in eco value caused by harvesting FSC wood (instead of a 50% loss assumed for RIL), corresponding with 0.93 €/kg sawn timber (see table 5.1).

In case tropical timber derives from sustainably managed plantations the material depletion costs are neglectable, as is the case for the other wood species in the table derived from sustainably managed plantations in temperate regions. A problem with tropical timber is that it is usually difficult to ascertain if it is sourced from a plantation or a natural forest, which is a relevant issue since only 11% of the total amount of productive forest area in the (sub)tropics consists of plantations.

For more details of the impact in eco-costs of all other activities along the production chain based on a Cradle till Site scenario for the various wood species the reader is referred to the IDEMAT database (DfS 2008).

Below, the eco-costs for the various wood based materials will be compared to the results of the eco-costs for the bamboo based materials assessed in this research.

5.1.3 Plybamboo

Plybamboo materials exist in many sizes, colors, layers and patterns. The most common differences are the thickness, ranging from 0.6 mm (veneer) to 40 mm (5-layer Plybamboo panel), the texture (plain pressed or side pressed) and the color (the most commonly used colors are bleached and carbonized; see figure 5.1).

Figure 5.1: Plybamboo is available in various colors, textures and sizes; in the left picture Plybamboo flooring (from left to right: bleached side pressed, bleached plain pressed and carbonized plain pressed) is depicted, in the right picture a sample of a 3-layer carbonized Plybamboo panel is shown

For the environmental impact assessment, the environmental impact of 3-layer Plybamboo board (bleached and carbonized), 1-layer Plybamboo board (bleached and carbonized, plain pressed and side pressed) and veneer (bleached and carbonized, plain pressed and side pressed) were calculated. The standard dimensions of most Plybamboo boards are 2440 (length) x 1220 mm (width), which was used as a base element for the eco-costs/kg calculations for Plybamboo. In appendix I all the calculated activities during the chain of these Plybamboo materials are presented, including all the assumptions made during this process. In the tables below the results of these elaborate calculations in appendix I are depicted in the form of the final eco-costs/kg of the various Plybamboo boards.

Table 5.2: Eco-costs per kg of 3-layer Plybamboo board

Product	Eco-costs (€)/kg
3-layer bleached Plybamboo board	0.393
3-layer carbonized Plybamboo board	0.358

Table 5.3: Eco-costs per kg of 1-layer Plybamboo board in several variations

Product	Eco-costs (€)/kg
1-layer plain pressed Plybamboo board (bleached)	0.367
1-layer side pressed Plybamboo board (bleached)	0.399
1-layer plain pressed Plybamboo board (carbonized)	0.332
1-layer side pressed Plybamboo board (carbonized)	0.364

Table 5.4: Eco-costs per kg of Plybamboo veneer in several variations

Product	Eco-costs (€)/kg
Plain pressed veneer (bleached)	1.21
Side pressed veneer (bleached)	0.70
Plain pressed veneer (carbonized)	1.10
Side pressed veneer (carbonized)	0.63

Please note that these figures do not say a lot yet. Only when a material is used as an element in a product in which it fulfils a function (FU), the required amount of kilograms of the material can be calculated, and it can be compared with other materials based on the eco-costs per FU. Depending on the form or density of the material, this may result in completely different outcomes with respect to the eco-costs. For example, while the eco-costs per kilogram of steel at 0.41 €/kg (Vogtländer 2008) is almost as high as for the Plybamboo boards, because of the high density of steel (7850 kg/m3), a lot more kilograms of material will most likely be required (depending on the function). The potentially confusing character of the eco-costs/kg is also the reason why the results for the various Plybamboo materials were represented in separate tables above. Later in this section the eco-costs for bamboo materials for several FUs will be compared to other materials.

However, analyzing the production process steps (see appendix I) that have led to the eco-costs/kg figures can already provide insight into the contribution of each process step to the environmental impact for each individual material. Furthermore, this process step analysis can further pinpoint causes of the difference in eco-costs/kg for bleached and carbonized Plybamboo material (see figure 5.2), and the difference in side pressed and plain pressed Plybamboo (only applicable for the 1-layer board). Note that the production process of Plybamboo is also depicted in short in the introduction photos of this chapter on page 116.

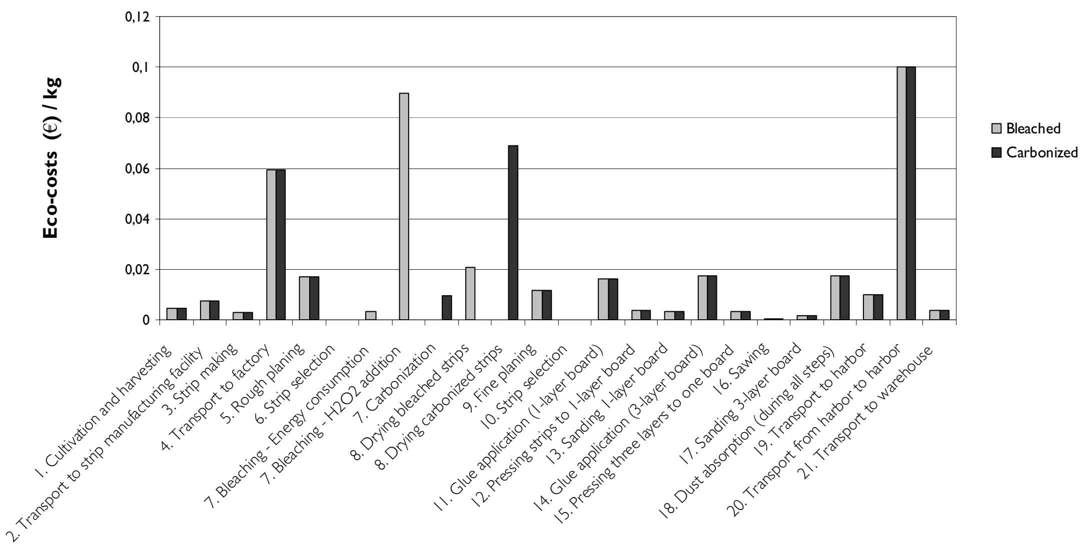


Figure 5.2: Environmental impact in eco-costs (€/kg) of the various process steps during the production and transport of 3-layer Plybamboo board to the Netherlands

From figure 5.2 some conclusions can be drawn. First of all, the figure shows that there are many process steps that bamboo as a resource has to go through until it ends up in the final board material in the warehouse in the Netherlands. Secondly, the figure shows that transport (dispersed over various process steps) has a large influence on the environmental impact of Plybamboo. For precise numbers and percentages of each process step, the reader is referred to the tables in appendix I. Finally, figure 5.2 tells us that the preservation and drying phase has a relatively large impact on the eco-costs for

Plybamboo, and is also the differentiating factor causing the difference in eco-costs per kilogram between the bleached and carbonized version of Plybamboo. Whereas the addition of H_2O_2 has a large impact on the environmental impact of bleached Plybamboo, for carbonized Plybamboo the longer and more drying cycles required (total of 240 hours) levels out the smaller environmental impact carbonization has as a preservation method. Similarly, the differences between plain pressed and side pressed Plybamboo can be assessed, which is differentiating in the case of a 1-layer board (see table 5.3 above), caused by the larger amount of glue required in side pressed bamboo (for details see tables I3-I7 in appendix I).

Based on these kinds of analyses, Plybamboo material producers can see where they should focus their attention if they want to lower the environmental damage the production and transport of their material inflicts. This can be done, for example, by finding more environmentally friendly preservatives/chemicals for bleaching, or finding less energy consuming ways to dry carbonized bamboo strips (e.g. solar powered drying chamber; see figure 5.3 for a low-cost example used in Colombia).

Figure 5.3: Low cost solar powered drying chamber for bamboo strips in Colombia developed by Jörg Stamm

Eco-costs per FU

As mentioned above, the eco-costs/kg figures of Plybamboo do not say a lot compared to other materials; it is only when they are used in a certain application which determines the required amount of kilograms per material to satisfy needs in this FU that the eco-costs of materials can be properly compared. Usually a material will be deployed in an application in which the specific advantages of the material can serve as an added value. The competitive advantages of Plybamboo lie in the hardness and aesthetic qualities of the material, which can be utilized in applications such as flooring or tabletops. Compared to most wood based materials in these applications, there will not be many differences in volume used to satisfy needs for the application. Since this research focuses on the interior decoration sector, Plybamboo was compared with various wood materials for a piece of furniture, in the function of a tabletop (see an example in figure 5.4). Later in this subsection Plybamboo is compared in a lounge chair with wood alternatives based on its bendability.

Tabletop as FU

Depending on the market segment targeted, different wood based alternatives can be used as tabletop. In general the aesthetic properties may be the most important product attribute for wood species selection in this application. Furthermore, in tabletops wood species are usually used that are sufficiently hard (so deciduous trees like Pine are not eligible), and combine this feature with a warm color and beautiful distribution of rays, such as European Oak, Teak, or Walnut. Besides some exceptions (e.g. "Slim Table" by Bertjan Pot), the size (and especially thickness) of the tabletop will usually be chosen based on dimensions of the semi finished material to facilitate an efficient production. For this particular environmental assessment will be calculated with a dimension of the tabletop of 1220 x 1220 x 20 mm. In the case of medium to high end markets, customers tend to prefer a solid tabletop. In the case of low end markets to reduce costs, producers usually opt for the use of a wood based board, such as MDF, chipboard, hardboard or plywood, as carrier, and a layer of veneer of the same wood species with nice aesthetic properties as mentioned above (European Oak, Walnut and Teak). Based on these parameters the eco-costs per FU were calculated for both the medium-high end market (based on solid material) and low end market (based on a wood based board material as carrier); see the tables below. For Plybamboo it was calculated with the eco-costs/kg of the 3-layer panel. In the final column the eco-costs/FU of the most environmentally friendly 3-layer panel (carbonized) was compared to the various wood alternatives. Note that in the calculation, the life span, maintenance and end-of-life scenario is assumed not to be differentiating for the various alternatives in this application.

Figure 5.4: Plybamboo board used as a tabletop

Table 5.5: Eco-costs per tabletop of 1220 x 1220 x 20 mm (0.0298 m3) based on solid material

Material	Density (kg/m3)	Eco-costs/kg	Kg/FU	Eco-costs (€)/FU	Eco-costs/FU (ratio)
3-layer Plybamboo carbonized	700	0.358	20.9	7.5	100%
3-layer Plybamboo bleached	700	0.393	20.9	8.2	109%
European Oak	700	0.173	20.9	3.6	48%
Walnut	600	0.178	17.9	3.2	43%
Teak (natural forest; RIL)	700	4.97	20.9	103.9	1384%
Teak (FSC certified)	700	1.25	20.9	26.1	348%
Teak (plantation)	700	0.322	20.9	6.7	90%

Since the eco-costs/kg numbers for wood relate to sawn timber, for the eco-costs/kg for veneer production these figures need to be adjusted since in general veneer production has higher material losses due to the thin character of the material. As calculated in appendix I material input during the production of the highest quality (zero defect), bamboo veneer is due to these material losses 1.38 times (side pressed bamboo) to 2.35 times (plain pressed bamboo) higher compared to the 1-layered Plybamboo board. For the production of the highest quality wood veneer it is assumed that material input is twice as high compared to the production of sawn timber, which means that the eco-costs/kg are doubled compared to the eco-costs/kg for sawn timber in table 5.5. To calculate the eco-costs for a tabletop for the low end market based on veneer and an inexpensive wood based board as carrier (see table 5.8), first the eco-costs for the veneer and wood based board are calculated separately (see tables 5.6 and 5.7). For the veneer calculation, in the final column the eco-costs of the various alternatives are compared with the bamboo alternative with lowest eco-costs (side pressed carbonized). For the carrier board calculation and the total tabletop (carrier + veneer) in the final column the ratio compared to the most environmental friendly bamboo material (3-layer carbonized Plybamboo) derived from the solid material calculation (see table 5.5 above) is depicted.

Table 5.6: Eco-costs per 1220 x 1220 x 0.6 mm (0.00086 m3) veneer sheet used for a tabletop

Material	Density (kg/m3)	Eco-costs/kg	Kg/FU	Eco-costs (€)/FU	Eco-costs/FU (ratio)
Plain pressed veneer (bleached)	700	0.86	0.60	0.52	172%
Side pressed veneer (bleached)	700	0.55	0.60	0.33	110%
Plain pressed veneer (carbonized)	700	0.78	0.60	0.47	156%
Side pressed veneer (carbonized)	700	0.50	0.60	0.30	100%
European Oak	700	0.35	0.60	0.21	69%
Walnut	600	0.36	0.52	0.18	61%
Teak (natural forest; RIL)	700	9.94	0.60	5.98	1988%
Teak (FSC certified)	700	2.50	0.60	1.51	500%
Teak (plantation)	700	0.64	0.60	0.39	129%

Table 5.7: Eco-costs per 1220 x 1220 x 20 mm (0.0298 m3) of wood based board material used as carrier in a tabletop

Material	Density (kg/m3)	Eco-costs/kg	Kg/FU	Eco-costs (€)/FU	Eco-costs/FU (ratio)
MDF	750	0.176	22.35	3.93	52%
Plywood (Pine)	600	0.295	17.9	5.28	71%

Table 5.8: Eco-costs per tabletop consisting of a 1220 x 1220 x 20 mm carrier finished with veneer (accumulation of tables 5.6 and 5.7)

Material (carrier + veneer)	Eco-costs (€)/FU	Eco-costs/FU (ratio)
MDF + Plain pressed veneer (bleached)	4.4	59%
MDF + Side pressed veneer (bleached)	4.3	57%
MDF + Plain pressed veneer (carbonized)	4.4	59%
MDF + Side pressed veneer (carbonized)	4.2	56%
MDF + European Oak	4.1	55%
MDF + Walnut	4.1	55%
MDF + Teak (natural forest; RIL)	9.9	132%
MDF + Teak (FSC certified)	5.4	73%
MDF + Teak (plantation)	4.3	58%
Plywood + Plain pressed veneer (bleached)	5.8	77%
Plywood + Side pressed veneer (bleached)	5.6	75%
Plywood + Plain pressed veneer (carbonized)	5.7	77%
Plywood + Side pressed veneer (carbonized)	5.6	74%
Plywood + European Oak	5.5	73%
Plywood + Walnut	5.5	73%
Plywood + Teak (natural forest; RIL)	11.3	150%
Plywood + Teak (FSC certified)	6.8	91%
Plywood + Teak (plantation)	5.7	76%

In figure 5.5 the results of table 5.5 (solid material) and table 5.8 (veneer on carrier) are visually represented. In the figure alternatives based on a wood based board material and a veneer carrier (low end market) are depicted in black, while the solid wood alternatives are depicted in gray and the solid bamboo alternatives in light gray.

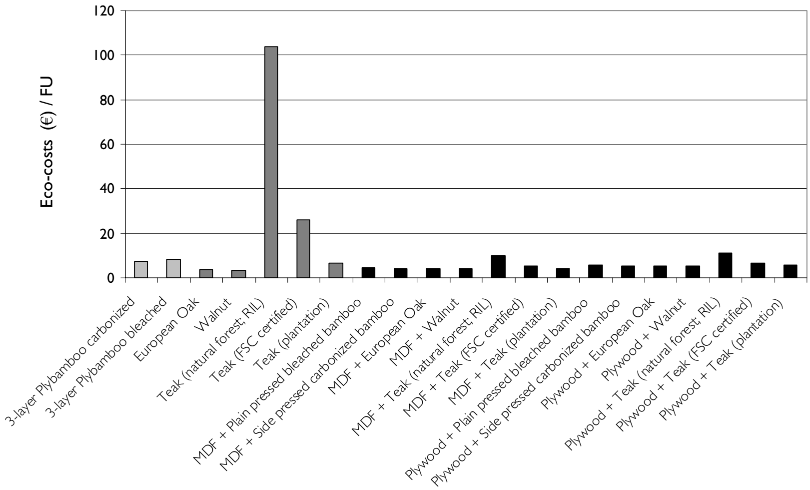


Figure 5.5: Eco-costs for a 1220 x 1220 x 20 mm tabletop for various wood- or bamboo based alternatives (including alternatives harvested in natural forests)

From figure 5.5 it becomes immediately clear that from an environmental point of view the use of tropical hardwood harvested from a natural forest has a very large environmental burden, and should preferably be avoided. In the case of FSC certification (for which is not clear if the wood derives from a plantation or natural forest), the environmental burden is lower, although still considerable. Since the bamboo assessed in this evaluation was derived from a sustainably managed plantation, it is fair for the comparison with wood to focus on the eco-costs figures for wood also sourced from a sustainably managed plantation. Therefore, to better understand nuances between alternatives sourced from sustainably managed plantations, in the graph below the environmental costs of alternatives from natural forests were excluded (see figure 5.6).

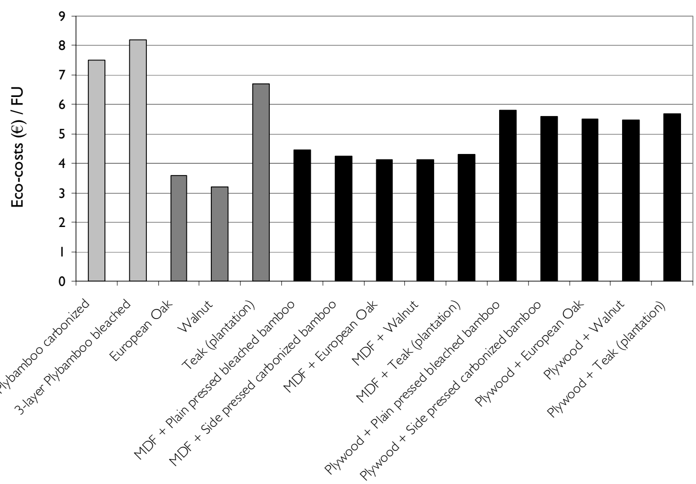


Figure 5.6: Eco-costs for a 1220 x 1220 x 20 mm tabletop for various wood- or bamboo based alternatives (excluding alternatives harvested in natural forests)

From figure 5.6 several conclusions can be drawn. First of all, it can be seen that tabletops made from solid wood which is grown and harvested in the same continent as where it is used (Walnut, European Oak), have the lowest environmental burden. In case the tabletop is made from a wood based material (MDF or plywood) with a veneer layer, the environmental burden seems higher than for solid alternatives from locally grown wood, but lower than for solid alternatives from alternatives grown in other continents (Teak, bamboo). Furthermore, figure 5.6 shows that Plybamboo has a larger eco burden in this application than all wood alternatives that derive from plantations. However, in the case of tropical timber, including FSC certified timber, is often not clear if the wood is derived from a natural forest or a plantation. Plybamboo does score better than tropical hardwood which is derived from natural forests and FSC certified wood (see figure 5.5 before). The table also shows that in terms of eco-costs, it is better to use bamboo veneer on a wood based board as carrier than Plybamboo in solid form[35] since in terms of eco-costs/kg, Plybamboo veneer, and especially the most popular version (side pressed carbonized veneer), is competitive with local wood species in eco-costs/FU (see table 5.6).

To better understand the differences in eco-costs between the various alternatives one should analyze and compare the environmental impact of the various production process steps for bamboo (see figure 5.2 for Plybamboo) and for wood (see the IDEMAT database (DfS 2008)). In figure 5.2 it was found that for Plybamboo, transport and drying (carbonized version) or bleaching through H_2O_2 (bleached version) contributed most to the eco-costs. Depending on the species and location of sourcing for various wood species material depletion (especially from natural tropical forests; see above), transport and drying are the process steps which are most harmful in terms of eco-costs for wood.

It should be noted that sea transport from China to the Netherlands has a large impact (25-28%; see tables I1 and I2 in appendix I) on the environmental burden of Plybamboo. If Plybamboo is used locally (in China) the eco-costs will therefore be considerably lower, and Plybamboo might be competitive in terms of eco-costs with locally grown wood species. A new LCA based calculation comparing Plybamboo with locally grown wood (based materials) would be required to further analyze this hypothesis.

Lounge Chair as FU

Through the Bamboo Labs (Lounge chair designed by Tejo Remy and René Veenhuizen) it was found that the bendability can also be acknowledged as a competitive advantage for Plybamboo. Therefore, this chair was chosen as another FU to compare the eco-costs of bamboo with wood.

Figure 5.7: Bamboo chair by Tejo Remy and René Veenhuizen

[35] Note: Additional eco-costs of adhesives required to glue the veneer onto the wood based carrier were not taken into account in this calculation.

The chair consists of seven slabs of 1-layer carbonized, side pressed Plybamboo (three slabs of approximately 2.25 x 0.15 x 0.005 m, four slabs of 1.25 x 0.15 x 0.005 m; in total 0.0088 m3 of material). For bending, Beech is usually chosen as the most appropriate wood species. As an additional alternative plywood topped with a layer of 0.6 mm thick veneer of an aesthetic wood species (e.g. Walnut) may be used in this application. For both the Beech and plywood alternatives it is assumed that the same volume of material is required as for Plybamboo. In table 5.9 and figure 5.8 the eco-costs/FU for Plybamboo and the various alternatives are represented.

Table 5.9: Eco-costs per year for 1-layer Plybamboo (carbonized) and wood alternatives used in the bended lounge chair

Material	Density (kg/m3)	Eco-costs/kg	Kg/FU	Eco-costs (€)/FU	Eco-costs/FU (ratio)
1-layer Plybamboo carbonized	700	0.364	6.16	2.24	100%
European Beech	670	0.166	5.90	0.98	44%
Plywood + Walnut veneer	600/600	0.295/0.36	5.28	1.58	71%

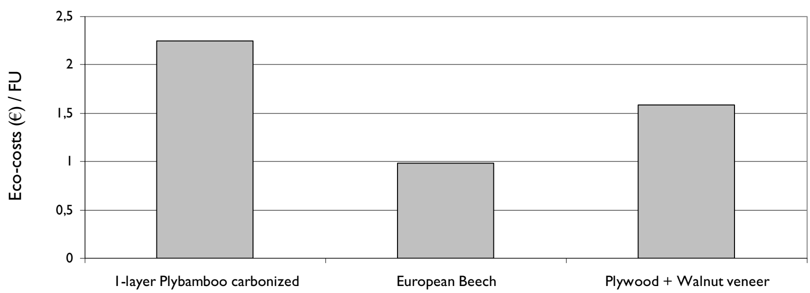


Figure 5.8: Eco-costs per year for 1-layer Plybamboo and wood alternatives used in the bended lounge chair

From figure 5.8 it becomes clear that also in this application the Plybamboo alternative scores worse in terms of eco-costs compared to relevant wood based alternatives for this particular application. Here also applies that the eco-costs for Plybamboo will be lower if it is not exported and sea transport eco-costs can be avoided (28.3% for carbonized side-pressed 1-layer Plybamboo board; see appendix I).

5.1.4 Stem

Figure 5.9: Bamboo stem of the Moso species

The bamboo stem, used as input for the production of Plybamboo in the previous calculation, can also be used directly as a material in various applications. Therefore, in this environmental impact assessment the bamboo stem was also compared with alternatives in wood. The environmental costs per kilogram during the production and transport of the bamboo stem were calculated for a 5.33 m long bamboo stem from the Moso species. For the calculations the reader is referred to appendix I. In table 5.10 the eco-costs per kilogram of a Moso stem are depicted. In figure 5.10 the contribution of each process step to the eco-costs per kilogram is presented.

Table 5.10: Eco-costs per kilogram of a 5.33 m Moso stem

Product	Eco-costs (€)/kg
Moso stem	0.88

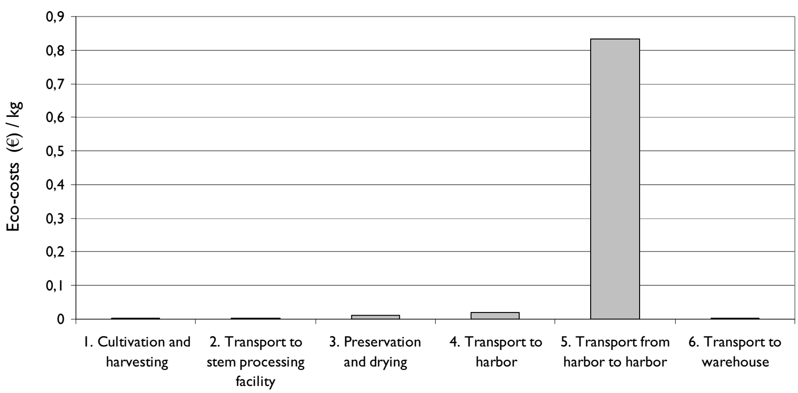


Figure 5.10: Environmental impact (eco-costs in €/kg) of the various process steps during the production and transport of a Moso stem

From figure 5.10 two important conclusions can be drawn: 1) the bamboo stem goes through very few processing steps; besides the transport steps, after harvest and preservation bamboo can directly be used as input for applications, which shows the efficiency of the material (e.g. a tree is almost never used in its natural form in applications); and 2) almost all the environmental costs of the bamboo stem (95.2%; see table I7 in appendix I) are caused by the sea transport of the stems from China to the

Netherlands. Due to the large volume bamboo stems occupy in the container, the transport of the material to a very large extent determines the eco-burden of the material, since for low weight sea transports the eco-costs are calculated based on the eco-costs per m3.km of the boat used (see for more details appendix I).

Eco-costs per FU

As mentioned before, the eco-costs/kg do not say a lot unless a material is compared with other materials in a certain FU, in which both materials fulfill requirements for the same function. The unique properties of the stem are mainly its lightness and distinct aesthetic look. Since this research focuses on the interior decoration sector, a leg of the table developed during the Bamboo Labs by Ed van Engelen (not taking into account coating), was chosen as a FU.

Figure 5.11: Bamboo table designed by Ed van Engelen

In this particular application the size of the leg is determined by the aesthetics of the table. Only for very thin legs, buckling and compression strength may become the critical property. Therefore, in this FU bamboo was compared with various softwood and hardwood species (Poplar, Pine, European Beech, European Oak and Teak) based on similar dimensions as the bamboo version: round legs of 0.8 m long with a diameter of 9 cm, resulting in a volume of the leg of 0.0051 m3. The weight of the bamboo stem was calculated with the average weight per m^{1} of a 5.33 m long stem based on table 5.20 in subsection 5.2.2: 1.44 kg/m^{1}, which equals 1.15 kilogram for a 0.8 m long segment. The results of the eco-costs per FU of bamboo compared to wood are represented in figure 5.12 and table 5.11, with in the final column of the table the ratio of eco-costs of the wood alternatives compared to bamboo. Note that in the calculation the life span, maintenance and end-of-life scenario is assumed not to be differentiating for the various alternatives in this application.

Table 5.11: Eco-costs per table leg for various wood- or bamboo based alternatives

Material	Density (kg/m3)	Eco-costs/kg	Kg/FU	Eco-costs (€)/FU	Eco-costs/FU (ratio)
Bamboo stem	700	0.88	1.15	1.01	100%
Pine	450	0.096	2.295	0.22	22%
European Beech	670	0.166	3.417	0.57	56%
European Oak	700	0.173	3.57	0.62	61%
Poplar	440	0.032	2.244	0.07	7%
Teak (plantation)	700	0.322	3.57	1.15	114%
Teak (FSC certified)	700	1.25	3.57	4.46	441%

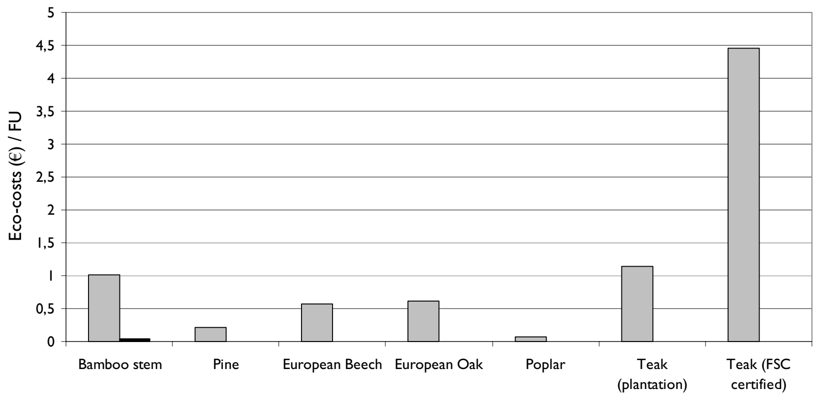


Figure 5.12: Eco-costs per table leg for various wood- or bamboo based alternatives

From figure 5.12 and table 5.11 several conclusions can be drawn. First of all can be seen that despite the low weight of the hollow bamboo stem (1.15 kg) compared to the solid legs made from wood (2.3 - 3.6 kg), due to the high eco-costs/kg caused by the sea transport, the bamboo stem has a higher environmental burden than almost all wood alternatives (except tropical hardwood). In case the bamboo stem is used locally (in this case in China), the eco-costs/FU will be drastically lower (see black column in figure 5.12), and the bamboo stem performs even better than locally grown wood species.

Although it may not be the best application in which to use the bamboo stem, in the box below, another comparison of the eco-costs was made between the bamboo stem and wood, this time for the use as a structural element in a walking bridge.

Box: The Eco-costs of the Bamboo Stem and Wood in a Walking Bridge

Figure 5.13: The bamboo walking bridge in the Amsterdam Woods

In this box the FU used by the author in a earlier LCA calculation based on the TWIN 2002 model (van der Lugt et al. 2003) was executed again based on the eco-costs 2007 method. In this calculation the use of bamboo and wood in a transversal supporting beam (2.1 m) in a walking bridge in the Amsterdam Woods in the Netherlands was taken as FU (see figure 5.13 of the actual bridge executed in steel and bamboo). Bamboo was compared with two hardwood species (one European species and one tropical species) known for their suitability for outdoor use in these kinds of applications due to their durability outside: Robinia and Azobé. For the TWIN 2002 calculation the exact dimensions of the beam were already calculated by an engineer to meet strength requirements (0.1 × 0.2 × 2.1m for Azobé, and 0.12 × 0.225 × 2.1m for Robinia). In the original calculation Guadua stems from Costa Rica were used for bamboo. Since the eco-costs calculation is executed for Moso, and Moso is a smaller and in general weaker species than Guadua, for the current calculation it is assumed that two Moso poles of 2.1 meters and a diameter of 9 cm are required with an average weight of 1.44 kg/m[1], instead of one Guadua stem. Since in this particular application the durability outside differs for the various materials, the life span needs to be taken into account for a just comparison (Azobé 25 years, Robinia 15 years, Bamboo 10 years) (van der Lugt et al. 2003). Furthermore, as a reference a steel beam (IPE 100, 22.3 kg, life span of 50 years) was also taken into account in this particular calculation. The results of the eco-costs per FU of bamboo compared to the alternatives are represented in figure 5.14 and table 5.12, with again in the final column the ratio of eco-costs of the alternatives compared to bamboo.

Table 5.12: Eco-costs per year for bamboo and wood used as a transversal beam in a walking bridge

Material	Density (kg/m3)	Eco-costs/kg	Kg/FU	Eco-costs (€)/FU	Eco-costs (€) per FU per year	Eco-cost per FU per year (ratio)
Bamboo stem	700	0.88	6 (2 stems)	5.28	0.53	100%
Robinia	740	0.148	42.18	6.24	0.42	79%
Azobé (plantation)	1060	0.184	44.52	8.19	0.33	62%
Azobé (FSC certified)	1060	1.11	44.52	49.42	1.98	372%
Steel	7850	0.41	22.3	9.143	0.18	35%

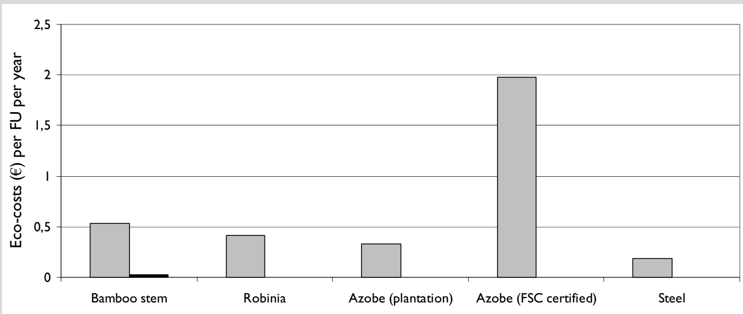


Figure 5.14: Eco-costs per year for bamboo and wood used as a transversal beam in a walking bridge

From the figure and table it can be concluded that although the weight of the two bamboo stems combined in the function of transversal beam is the lowest of all alternatives, the eco-costs per FU per year are higher than all alternatives, except FSC certified Azobé (and Azobé from natural forests). In case bamboo is used locally (in China), the eco-costs of the bamboo stem are drastically lower (see black column in figure 5.14). Finally, it is interesting to see that steel (with high eco-costs/kg) is the most environmental alternative in this particular application due to the relative low weight of the I-profile compared to the massive wooden beams, and the long life span of steel (50 years).

5.1.5 Fibers

Small bamboo sticks (diameter 2mm) as, for example, used in blinds (see figure 2.14), were used as reinforcement in natural fiber reinforced composites during the intervention, as seen in the products developed by Daan van Rooyen en Ro & Ad architects. The environmental impact of these sticks was not assessed, since in regular projects instead of sticks, fibers would be used (see figure 5.15), which were not available during the Bamboo Labs. To provide some indication of the energy consumption during production of glass fibers (most often used in composites), carbon fibers and cellulose fibers, the reader is referred to table 5.13.

Figure 5.15: Bamboo micro fibers

Table 5.13: Energy consumption during production of several fibers (Kavelin 2005)

Fiber	Energy consumption during production (MJ/kg)
Cellulose	4
Glass	30
Carbon	130

Note that in this table the density of the materials and the FU is not yet taken into account; however, independent of these features, natural fibers seem to score quite well. Nevertheless, compared to other popular natural fibers (e.g. sisal, flax, hemp, jute, various wood species), bamboo needs to go through more processing steps before the fiber is distilled and/or has to be transported from further away. Therefore, it may be questionable if bamboo will be very competitive compared to other natural fibers in terms of eco-costs for use in Western Europe. This might be different for production of natural fiber based composites for local use, especially if researchers are able to efficiently distill the bamboo fiber from the stem without too many material losses, in order to utilize the large annual increase in biomass (see section 5.2).

5.1.6 Strand Woven Bamboo

Figure 5.16: Samples of Strand Woven Bamboo (SWB)

Strand Woven Bamboo (SWB) is a relatively new industrial bamboo material that can be used indoors and outdoors, with a high hardness (2800 lbf, see table 1.5) and density (1080 kg/m3) due to the compressed bamboo strips used in combination with a high resin content. The eco-costs calculation was based on the outdoor version (with a higher glue content and higher compression level) in a carbonized color. The eco-costs per kilogram calculation was based on the production and transport of one SWB plank of 1900 x 100 x 15 mm (0.00285 m3). For the complete calculation the reader is referred to appendix I. The eco-costs per kilogram for SWB are presented in table 5.14. In figure 5.17 the contribution of each process step to the eco-costs per kilogram is presented.

Table 5.14: Eco-costs per kilogram of SWB

Product	Eco-costs (€)/kg
SWB (carbonized)	0.654

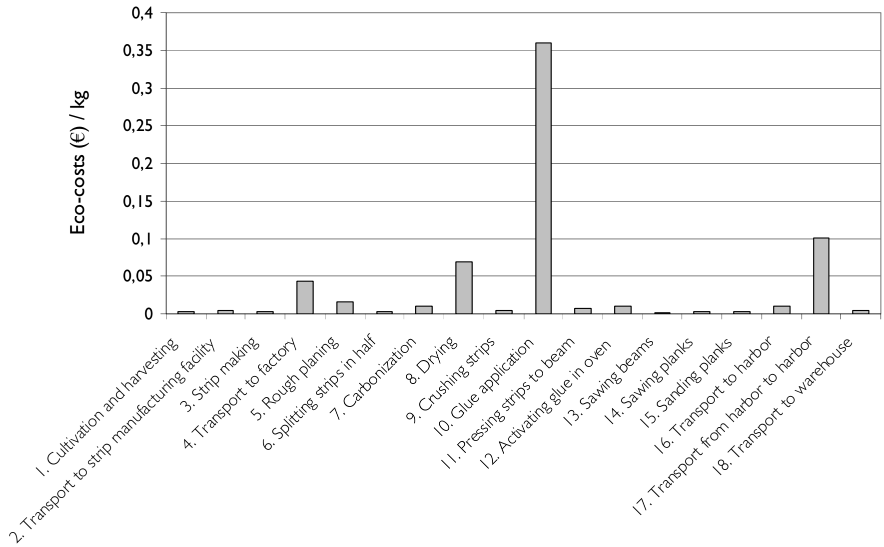


Figure 5.17: Environmental impact (eco-costs in €/kg) of the various process steps during the production and transport of a SWB plank

From figure 5.17 it can be concluded that the Phenol Formaldehyde resin used (23% in the final product) has a large impact on the eco-costs/kg of SWB, accounting for 54.9% of the environmental burden. For more background information, the reader is referred to appendix I.

Eco-costs per FU

One of the unique features of SWB is that, unlike other industrial bamboo materials, it seems suitable for use outdoors (van der Vegte and Zaal 2008); for more information see footnote 12 in subsection 1.2.1. For this reason, the eco-costs of SWB were compared with wood alternatives in the function of terrace decking (FU) for outside use with dimensions of 1900 x 100 x 15 mm (0.00285 m3). In this application, besides aesthetics, the durability outside is the most important criterion for material selection, based on which alternatives for comparison with SWB were selected. Various tropical hardwood species (e.g. Teak, Azobé, Bangkirai) are well known for their durability outside. For the eco-costs calculation SWB was compared with Teak. Since tropical hardwood is often used in outdoor applications, and it often is unclear if this wood is sourced from natural forests or plantations, the eco-costs for various scenarios (plantation, FSC certified, RIL harvested from natural forest) were calculated for Teak. Furthermore, a wood-plastic composite was also taken into account for this calculation; Tech-Wood® is a material which consists of 70% of Pine fibers and 30% of polypropylene (Tech-Wood 2008). As such the eco-costs/kg of the Pine fiber input for Tech-Wood accounts for 0.096 x 0.7 =

0.067 €/kg. The eco-costs/kg of the Polypropylene part are 0.3 × 1.066 = 0.32 €/kg. In total the eco-costs/kg for Tech-Wood are then 0.387 €/kg.

In table 5.15 and figure 5.19 the eco-costs per FU of the various alternatives are depicted. In the final column of the table the ratio of the alternatives compared to SWB is provided. The eco-costs/FU are calculated based on the same dimensions of the decking plank as for SWB (1900 × 100 × 15 mm = 0.00285 m3), except in the case of Tech-Wood. Since Tech-Wood profiles are made through a "push-trusion" process, around 40% less material is required (see figure 5.18) than for a solid alternative. The density of Tech-Wood was based on the density and volume percentage of Pine (500 kg/m3) and Polypropylene (900 kg /m3).

Figure 5.18: Sample of a Tech-Wood decking profile

Table 5.15: Eco-costs per year for SWB and alternatives for outside terrace decking

Material	Density (kg/m3)	Eco-costs/kg	Kg/FU	Eco-costs (€)/FU	Eco-costs/FU (ratio)
SWB	1080	0.652	3.08	2.01	100%
Teak (plantation)	700	0.322	2.00	0.64	32%
Teak (FSC certified)	700	1.25	2.00	2.49	124%
Teak (natural forest; RIL)	700	4.97	2.00	9.92	494%
Tech-Wood	620	0.387	1.06	0.41	20%

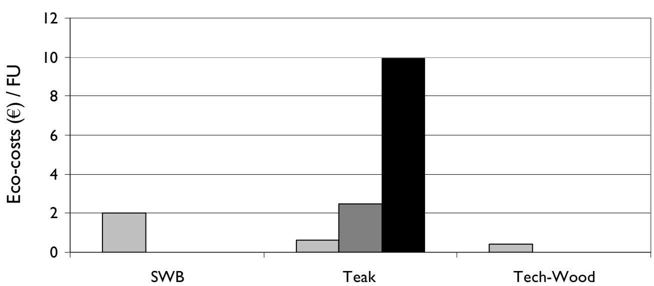


Figure 5.19: Eco-costs per year for SWB and alternatives for use in outside terrace decking

From figure 5.19 it can be concluded that SWB has an environmental burden that is higher than for Tech-Wood and tropical hardwood (Teak) from plantations (light gray bar), but that it has a lower environmental impact than FSC certified Teak (dark gray bar) and Teak harvested from natural forests (black bar).

If SWB is used locally, the eco-costs will be somewhat lower, since sea transport accounts for 15.4% of the total environmental burden. For inside applications it would be worthwhile to investigate to what

extent the Phenol formaldehyde resin in SWB could be replaced by completely biodegradable resins such as PLA (eco-costs/kg at €0.059 instead of at €1.56). As such, the eco-costs/kg of SWB would be cut by half to 0.306 €/kg.
It can be concluded that in terms of eco-costs the use of SWB is only recommended to help meet the demand in tropical hardwood sourced from natural forests, although better performing alternatives from an environmental impact point of view (Tech-Wood, tropical hardwood from plantations) are available.

It should be noted that in the eco-costs comparison for SWB, modified softwood (impregnation, thermal modification, acetylation) was not included. Impregnation is only functional if heavy metals (e.g. chrome, copper, arsenic) are used, which are poisonous for humans and will be released in the environment once the wood is disposed of. Impregnated wood has therefore received a lot of resistance in the West ("poison wood") and is increasingly being replaced by supposedly more eco-friendly techniques to modify softwood. For this reason impregnated wood was not taken into account in this calculation.
Thermal modification is one of these new modification techniques; through cooking or baking wood in exactly the right circumstances the durability of softwood can improve considerably (e.g. Plato® wood). Acetylation is another method that is currently being commercialized, that can be used to modify the durability of softwood. In this chemical process wood reacts in kettles with acetic anhydride, through which free hydroxyls in the wood are formed into acetyl groups. According to Titan Wood (Titan Wood 2008) the process is 100% recyclable and non-toxic. Since no exact and complete production data was available, these alternatives were not included in this environmental impact assessment. It is recommended to perform new environmental impact assessments in the future for outdoor applications in which these alternatives are included for a more comprehensive overview. [36]

5.1.7 Mats

Figure 5.20: Bamboo mats are available "on the roll"

[36] Just before this thesis went to the printer, the author received LCA data from Titan Wood about acetylated wood, and found LCA data with respect to energy use during thermal modification of Plato Wood. Conversion of the data found in Classen and Caduff (2007) to eco-costs showed that the acetylation process results in extra eco-costs of €0.23 per kilogram wood. For Plato wood the energy required to transform regular wood into Plato wood was based on Nypels et al. (1998), who found an additional energy consumption of 2,8 MJ/kg for Plato wood, which corresponds with an additional 2,8 x 0,0231€/kg (see Vogtländer 2008) = extra eco-costs of 0.065€ per kilogram wood. This means that for the FU chosen in subsection 5.1.6 (terrace decking), acetylated locally grown softwood seems to have slightly higher eco-costs / FU compared to the best scoring alternatives in figure 5.19 (Tech-Wood and plantation grown teak), while Plato wood based on locally grown softwood seems to perform considerably better from environmental point of view compared to the best scoring alternatives in figure 5.19.

In Asia thin bamboo slivers and strips are commonly woven into large mats, which can serve as input for the production of various boards which can be pressed into molds of various shapes (including corrugated boards). In the Bamboo Labs, Maarten Baptist used bamboo mats glued and pressed together for the development of a chair (see figure 5.21), which is actually the same process the semi finished bamboo material Bamboo Mat Board (BMB) goes through.[37] Since the production and density (1030 kg/m3) of BMB (BMTPC 2002) and SWB are very similar and both materials use a large amount of resin, it was assumed for the calculation that the eco-costs/kg of both materials are similar.

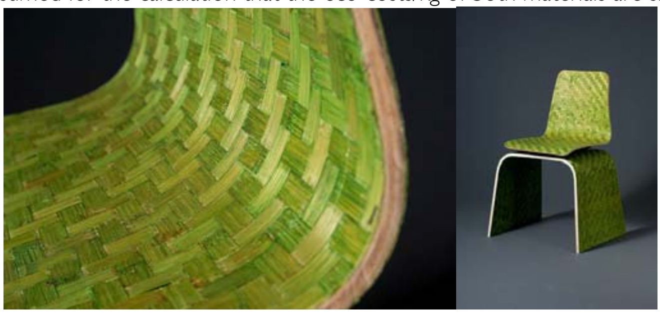


Figure 5.21: Chair made from bamboo mats, designed by Maarten Baptist

To compare BMB with alternatives on eco-costs, the molded seating as used by Maarten Baptist was chosen as FU. Since one of the unique properties of BMB is that it can be molded in three directions at the same time to form 3D structures, it was assumed that the seating was executed as a bowl (instead of the 2D bended seating in figure 5.21). It is assumed that for the seating a piece of 0.4 x 0.4 x 0.015 m (0.0024 m3) BMB is required. Since BMB is meant for use outside, a hypothetical version of BMB with biological degradable resin (PLA) for indoor use was also added to the calculation. Since 3D bending is not possible in wood, as a reference the calculation was also executed in ABS, a high end polymer suitable for this use in 3D bowls. For the calculation it was assumed that the ABS alternative can be produced in a slimmer version than the bamboo alternative: 0.4 x 0.4 x 0.003 m (0.00048 m3). In table 5.16 and figure 5.22 the eco-costs/FU for BMB and the various alternatives are represented.

Table 5.16: Eco-costs per year for BMB and alternatives used in a 3D molded seating

Material	Density (kg/m3)	Eco-costs/kg	Kg/FU	Eco-costs (€)/FU	Eco-costs/FU (ratio)
BMB	1030	0.652	2.47	1.61	100%
BMB (PLA)	1030	0.306	2.47	0.76	47%
ABS	1100	1.526	0.53	0.81	50%

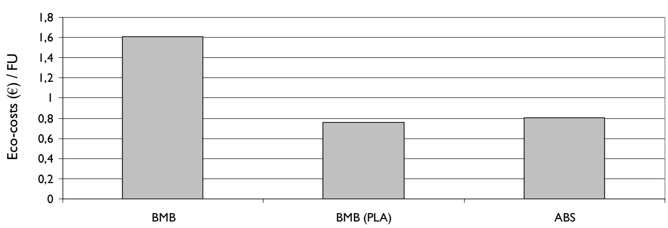


Figure 5.22: Eco-costs per year for BMB and alternatives for use in a 3D molded seating

[37] According to Zhang Qisheng et al. (2003) the BMB production process is as follows: Strip making > weaving > glue application (usually phenol formaldehyde) > drying > hot pressing (in mold) > sawing.

From figure 5.22 it becomes clear that in this particular application BMB has an even higher environmental burden than ABS, which is one of the least environmentally friendly polymers. In the case of the use of PLA instead of Phenol formaldehyde as resin, BMB does score slightly better than ABS. For local use the eco-costs might also be lower since sea transport will not play a role in that scenario. In the case of PLA based BMB this would save an extra 33% in eco-costs. Note that in the case of 2D bending, Beech, Plywood and Plybamboo are also eligible, which, due to the lower density and eco-costs per kilogram will have lower eco-costs when used in molded seatings.

In the box below, an example is provided about an eco-costs comparison of corrugated BMB roof sheets based on use in China.

Box: Eco-costs of BMB Corrugated Roof Sheets Based on Use in China

BMB is often also used in China and India as corrugated roof sheet. The production process is similar to the production process of regular BMB with the exception that the material is hot pressed in a mold (Zhang Qisheng et al. 2003). Furthermore, for the eco-costs per kilogram the eco-costs of transport (sea- and land transport to the Netherlands, see appendix I) should be deducted to acquire eco-costs for the local situation resulting in eco-costs/kg of € 0.547.
Corrugated BMB targets the low cost housing market in India and China and should therefore be compared with other low cost alternatives often used in these countries: corrugated steel sheet or corrugated PVC sheet. The alternatives were compared based on 1 m2 of roof sheet (FU). Corrugated sheets in steel (thickness 0.6 mm) and PVC (thickness 2 mm) are thinner than BMB (thickness at 3.7 mm, see BMTPC 2002), thus a smaller amount of material is required for these alternatives. In table 5.17 and figure 5.24 the eco-costs per FU are represented. Note that in the calculation it is assumed that all alternatives have the same life span.

Figure 5.23: Corrugated board made from BMB

Table 5.17: Eco-costs per year for BMB and alternatives for use for in a corrugated roof sheet

Material	Density (kg/m3)	Eco-costs/kg	Kg/FU	Eco-costs (€)/FU	Eco-costs/FU (ratio)
BMB	1030	0.547	3.81	2.08	100%
PVC	1450	1.243	2.90	3.60	173%
Steel sheet	7850	0.679	4.71	3.20	153%

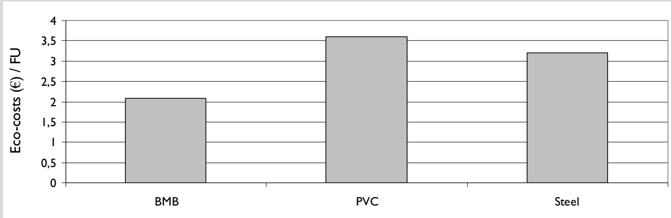


Figure 5.24: Eco-costs per year for BMB and alternatives for use for in a corrugated roof sheet

The figure and table show that if used locally, and if no plantation based wood alternatives are around for a particular application, industrial bamboo materials such as BMB can compete on eco-costs with non-wood alternatives in applications such as corrugated roof sheets.

5.1.8 Prototypes Developed

Above, the environmental burden in eco-costs of the various bamboo materials used by the designers in the product prototypes developed during the Bamboo Labs was assessed. Based on the eco-costs found, some judgments can be made about the environmental impact of the products themselves, based on consumption in the Netherlands.

First, it should be noted that for a complete environmental impact assessment of the prototypes, the complete production and lifecycle of each prototype would need to be evaluated in a similar way as was done for the individual bamboo materials. Taking into account the magnitude of such an endeavor (see appendix I), and the absence of direct relevance (we are more interested in the eco-costs of bamboo as an input material), the prototypes were only assessed on eco-costs based on material use. This means that for the product evaluation the production process of the products themselves (e.g. milling, painting, additional materials, etc.), was not taken into account.
As mentioned before, the initial idea of DDMB was to promote bamboo as a promising material to substitute (tropical) hardwood. However, it should be noted that several of the prototypes developed in bamboo could also be executed in softwood. For the environmental impact assessment the products were therefore qualitatively assessed based on the eco-costs found for the various bamboo materials in the calculations above for appropriate FUs, and compared with relevant alternatives in wood. For the comparison a similar scale was used as for the evaluation of the market potential and innovative character of the prototypes, which can be defined as "the performance on sustainability compared to alternatives": -- very bad (eco-costs > twice as high), - bad (eco-costs 1.25-2 times as high), +/- reasonable (eco-costs 0.75-1.25 times as low/high), + good (eco-costs 1.25-2 times as low), ++ very good (eco-costs > twice as low).
It should be noted that on some occasions the products developed during the Bamboo Labs cannot be executed in the same manner as in wood (e.g. chair by Leonne Cuppen, new material with bamboo ovals by Yvonne Laurysen & Erik Mantel), making it difficult to compare bamboo in these products with wood. This actually means that these designers did a good job in meeting one of the objectives in the design brief: using the specific qualities of bamboo.
In the case products developed during the Bamboo Labs were based on the bamboo stem meant for use inside, such as the lamps by Leonne Cuppen (see figure 4.5), the eco-costs are higher than alternatives executed in locally (Western - Northern Europe) grown softwood such as Poplar or Pine (- -), or hardwood such as European Oak (-), but at a similar level (+/- plantation grown Teak) or even considerably lower (++ FSC certified Teak, Teak from natural forests) in the case of tropical hardwood.

In the case products were based on Plybamboo materials, such as the chair by Lara de Greef (see figure 4.3) and Tejo Remy and René Veenhuizen (see figure 4.22), the eco-costs are higher than alternatives in locally grown wood such as Beech and European Oak (--), MDF (including veneer layer) (-), but in most cases similar (+/-) to Plywood (including veneer layer), plantation grown tropical hardwood such as Teak, and considerably lower (++) than FSC certified Teak and Teak from natural forests.

In the case of the use of bamboo sticks in natural fiber reinforced composites, as used in the coffin by Ro Koster & Ad Kil (see figure 4.2), no assessment can be made since the eco-costs/kg of the sticks were not evaluated because in normal product development project fibers would be used instead. Therefore, the sustainability of the coffin compared to a version in wood fibers cannot be provided. However, as substantiated above in the evaluation for the fibers, it does not seem likely that bamboo fibers grown overseas can compete on eco-costs with locally grown natural fibers (e.g. hemp, Pine).

For SWB, as used by Jacqueline Moors in her floor tiles for outside use (see figure 4.4), the eco-costs are considerably higher than alternatives executed in wood-plastic composites such as Tech-wood (--), and plantation grown tropical hardwood (--), but at a similar level (+/-) as FSC certified Teak, and considerably lower (++) than Teak sourced from natural forests.

Finally, in the case of the use of bamboo mats in the form of BMB, like Maarten Baptist used in his chair (see figure 5.21 above), the eco-costs of bamboo mats are higher than well moldable plastics such as ABS (-/--).

From the above it can be concluded that in most cases the products developed during DDMB score worse in terms of eco-costs than alternatives executed in wood. It is important to remember that this applies to the scenario in which these products are consumed in the Netherlands; if these products were produced and consumed locally in bamboo producing regions, the situation would be different and in most cases bamboo products are expected to be competitive in eco-costs with alternatives executed in wood (see also subsection 5.3.2).

5.2 Annual Yield

5.2.1 Introduction

In the previous section the environmental impact (in eco-costs) of various bamboo materials was calculated determining the debit side of the environmental sustainability of these materials. As seen in subsection 1.1.2, due to the increasing population and consumption per capita the Ecological Footprint is growing, resulting in more hectares required to produce the required resources compared to the biocapacity planet Earth offers. Due to the high growing speed of bamboo, the annual yield per hectare of bamboo could be higher than for wood, which would mean from a global point of view it would be more efficient in the future to plant bamboo on a hectare of vacant land as compared to trees to help to meet the increasing global resource demand. Therefore, in this section the annual yield of bamboo compared to wood will be investigated as the environmental sustainability component at the credit side of the total environmental sustainability balance (see table 3.3).

As was also the case for the eco-costs calculation, many assumptions need to be made for the annual yield calculation and -evaluation for bamboo, compared to wood. The annual yield comparison was based on bamboo- and wood plantations. For the calculation it was assumed that the annual yields of these plantations are used in industries with a high consumption of renewable materials: the building industry and the interior decoration industry. The annual yield and production efficiency calculation is based on current practices in the most advanced regions for processing both for wood and bamboo: the wood industry in Europe and North America, and the bamboo industry in China.
For wood, the raw material that is sourced from a plantation annually (logs), is processed into sawn timber, veneer or various wood based boards (e.g. Plywood, MDF, chipboard, composites, etc.), which are the semi finished materials used as input in the industries mentioned. For giant bamboo species the annual yield of a plantation will be used for the production of semi finished materials such as Plybamboo, SWB, BMB, stems, taped mats (mostly for the interior decoration industry) as well as similar board materials as available in wood (MDF, chipboard, composites, etc.). Taped mats are made from thin bamboo strips that are woven or taped together to form mats that can be used, for example, as flooring or wall coverings (see figure 5.25). Since no designers worked with taped mats during the intervention they were not included in the eco-costs evaluation, although it may be expected that the eco-costs/kg for taped mats will be somewhat lower than 1-layer Plybamboo board (no glue application, less processing steps).
Although some additional material losses will take place during the transformation of the various semi finished materials into the final consumer product, it was assumed that material losses during the process semi finished material > final consumer durable for both bamboo and wood are similar, and therefore not differentiating.

Figure 5.25: Taped mats are available in various colors

For wood, the annual yield was calculated for the following species that are commonly used in the industries mentioned: Teak, European Oak and Eucalyptus. For Teak, the annual yield was calculated for both fast growing "baby Teak" and traditional Teak. Eucalyptus is commonly used in the paper industry (Wiselius 2001) and only in rare occasions in the interior decoration industry, but is used as an interesting reference in this annual yield calculation due to its reputation as one of the fastest growing tree species. The value of the density used for the various wood species in this section was derived from Wiselius (2001).

For bamboo, the annual yields were calculated for the giant bamboo species Moso from China, and Guadua from Latin America, based on a density for both species of 700 kg/m3.[38] Guadua is a giant clumping bamboo species which grows abundantly in Latin America. Guadua may reach heights up to 20-25 meters and diameters up to 22 cm (Riaño et al. 2002). Like most bamboos it reaches its final height in the first half year of its growth (with a growing speed up to 21 cm a day), and will come to maturity in the following 4-5 years (Riaño et al. 2002). It should be noted that currently, production of industrial bamboo materials such as Plybamboo in Latin America is negligible compared to China. Thus, the annual yield of Guadua in terms of semi finished materials is only included as a reference for the future potential of Guadua for this purpose. The calculation for both wood and bamboo will be based on numbers for average plantation sites. Note that depending on geographical and climatic circumstances (e.g. soil, precipitation, elevation, etc.), yields may be considerably higher or lower, so data is only meant to be indicative of the average yields of the specific species in question. Data is based on interviews with experts in wood growing and processing (Mr. Leen Kuiper of Probos Foundation, and Mr. Hessel van Straten of NIBO N.V.) and bamboo growing and processing (Mr. René Zaal of Moso International), and supplemented where necessary with findings from key literature.

[38] Note that depending on the local circumstances even for exactly the same bamboo species the density can differ.

5.2.2 Results

Before the results of the annual yield calculations for wood and bamboo are presented in this subsection, the production efficiency of both renewable resources needs to be introduced.

Production Efficiency

In essence, the production process of wood- and bamboo resources to semi finished materials (sawn timber for wood, boards for Plybamboo, and beams for SWB) is similar. For wood the resource (the tree) will be cut in the field, after which the bark, sapwood and branches will be removed to acquire so-called "logs". After processing (e.g. sawing, drying) semi finished materials (sawn timber, board materials) are acquired. For bamboo the harvested stems, once the branches are removed, are in a similar processing stage as the logs for wood. As seen before, just like wood, these stems may be further processed into all kinds of semi finished materials as well. If a large portion of the original harvested natural material on the plantation (harvestable standing volume) ends up in the semi finished material this means the production efficiency is high, and material losses in the production process are low.

A processor or material producer will in general manufacture the semi finished materials with the highest turnover per hectare, which for wood, depending on the species, may result in the production of wood based boards (usually less added value but higher quantities per hectare) or sawn timber (usually higher added value but lower quantities). Suitability for the production into a certain semi finished material will differ per wood species. In the building and interior decoration industry, in general, hardwood will be used in applications with higher quality requirements than softwood, and will therefore to a larger extent be processed into sawn timber (higher added value) than softwood (to a larger extent used in wood based boards). For bamboo, Plybamboo boards may offer most added value, followed by SWB, taped mats, BMB, the stem and various board materials also available in wood (e.g. MDF). Table 5.18 summarizes which semi finished materials wood and giant bamboo species may be processed into, with the materials with most added value represented first (A-quality).

Table 5.18: Semi finished materials into which wood and bamboo may be processed as input for the building or interior decoration industry, ranked in categories with most added value

Quality	Wood	Bamboo
A (highest added value)	Sawn timber	Plybamboo
	Veneer	Veneer
		SWB
		Taped mats
B (low - medium added value)	Various board materials (Plywood, MDF, chipboard, etc.)	Same board materials as in wood (MDF, chipboard, etc.)
	Composites	Composites
		BMB
		Stem
C (lowest added value)	Biofuel (may be used as energy source for production of semi finished materials above)	Biofuel (may be used as energy source for production of semi finished materials above)

Since the annual yield of bamboo and wood may differ depending on the kind of semi finished materials produced, the annual yield was calculated for various production scenarios:

A: The annual yield is completely allocated to the production of A-quality semi finished materials

B: The annual yield is completely allocated to the production of B-quality semi finished materials

Depending on the local socio economic situation (e.g. prevalent species, trends in demand, etc.) either scenario A or B will be most realistic.
Below, the production efficiency for both wood and bamboo are estimated based on these production scenarios A and B, starting with wood.

For production scenario A (production of sawn timber), for wood, as a general rule of thumb, it is assumed that 80% of the total standing volume of a plantation ready for harvesting may end up in logs. When sawing the logs into timber it is assumed that over half of this volume is lost in saw mill residues, and a little less than half will end up in sawn timber (30-40% of standing volume in the plantation); see figure 5.27 (Kuiper 2006, van Straten 2006). It should be noted that this rule of thumb is very rough and may be lower or higher depending on the dimensions of the semi finished material (and eventual final application) in which the resource will be used, as well as the diameter and straightness of the trunk, which is species and site dependent. Although rest material (saw dust, etc.) may be used as input for B-quality materials (e.g. MDF), in most saw mills the rest material that is produced during processing logs into sawn timber is used as biofuel (C-quality application; see figure 5.27) to power the various machines (saws, kilns, etc.) (Bergman and Bowe 2008).

For production scenario B the annual yield calculation for both wood and bamboo is based on the production of MDF as a typical B-quality material. MDF is produced by chipping logs into fine fibers which in combination with resin are pressed into stiff boards. Since the input material is chipped to small fibers, there are hardly any input requirements for the raw material. For the production from the logs (80% of standing volume; see before) to the final boards an additional material loss during processing of 20% is assumed, resulting in a production efficiency of 64% (see figure 5.27).

Production scenario A for bamboo is different than for wood due to raw material allocation. In general, for wood, due to the large sizes and heavy weight of logs, the annual yield will be completely processed into one kind of semi finished material (e.g. sawn timber or wood based boards). In general, for bamboo, due to the smaller size and lower weight per stem the annual yield per hectare in stems can be more easily divided after quality control and sold in separate bunches to various processors and manufacturers depending on the quality of the stems (best stems go to the Plybamboo industry; the other stems go to the taped mats and/or SWB industry) (Zaal 2008). Therefore, the yield from a bamboo plantation is used as input for various A-quality materials; see figure 5.27. During processing of the harvested mature stems (around age 4 for Moso, around age 5-6 for Guadua) from the plantation (harvestable standing volume) to the debranched and topped stems a 20% loss is assumed.[39]
Of the harvested stems only a portion meets quality requirements for use as input for the production of Plybamboo boards (see complete production process of Plybamboo in appendix I). Due to the high requirements posed to the input strips in Plybamboo during the production process of selected stems into Plybamboo an additional 60% of the material is lost (Zaal 2008), which is commonly used as biofuel in the same factory, corresponding with a production efficiency of around 32%.
For the production of taped mats, the efficiency is higher since the input strips may be smaller (meaning that more strips may be derived from the upper segments of the stem with lower wall thickness), and quality requirements are lower. According to Zaal (2008) during the production of mats from the debranched and topped stems an additional 40% of the material is lost (used as biofuel), resulting in an efficiency of taped mats production of 48%.

[39] Note that in the Chinese bamboo industry even this top may be used, for example, for the production of handicraft or broomsticks.

For SWB, quality requirements of input strips are even lower since the strips are compressed in the final product, resulting in a lower material loss of 30% (Zaal 2008) than for the taped mats and Plybamboo boards, which corresponds to a production efficiency of 56%.
If is assumed that 50% of all annually harvested stems are apt to produce Plybamboo, and the other half is divided for use in the taped mat industry (25%) and SWB industry (25%); the total production efficiency during the conversion of the harvestable standing volume in a bamboo plantation to A-quality bamboo materials can be determined at 42% (Plybamboo: 50% x 32% = 16%; taped mats: 25% x 48% = 12%; SWB: 25% x 56% =14%); see figure 5.27. This shows that efficiency for the production of A-quality materials is higher for bamboo than for wood (35%). As a result, during the production process of sawn timber more rest material is produced, which is used as biofuel during the production process, which results in lower eco-costs in energy use for the production of sawn timber compared to the production of industrial bamboo materials such as Plybamboo, since this internal system use of biofuel prevents the consumption of additional electricity.

For production scenario B the efficiency for the production of bamboo based MDF is similar to the production of wood based MDF board production (64%).

Figure 5.26: Low quality bamboo material used as input (left) for the production (center) of bamboo based MDF (right)

In figure 5.27 below the production efficiency of both a bamboo plantation and a wood plantation is depicted visually for scenario A and B. Note that although not depicted in the figure, the high quality bamboo stems used as input in the Plybamboo industry can also be used directly as a B-quality material, obviously with low material losses, which depends on the quality requirements of the application in which the stem is used (e.g. scaffolding versus high end country house). For the production of A-quality materials for both bamboo and wood, it applies that rest material and waste can hypothetically be used as input in B-quality materials (e.g. MDF) but in practice is usually used as biofuel in the factory itself (C-quality).

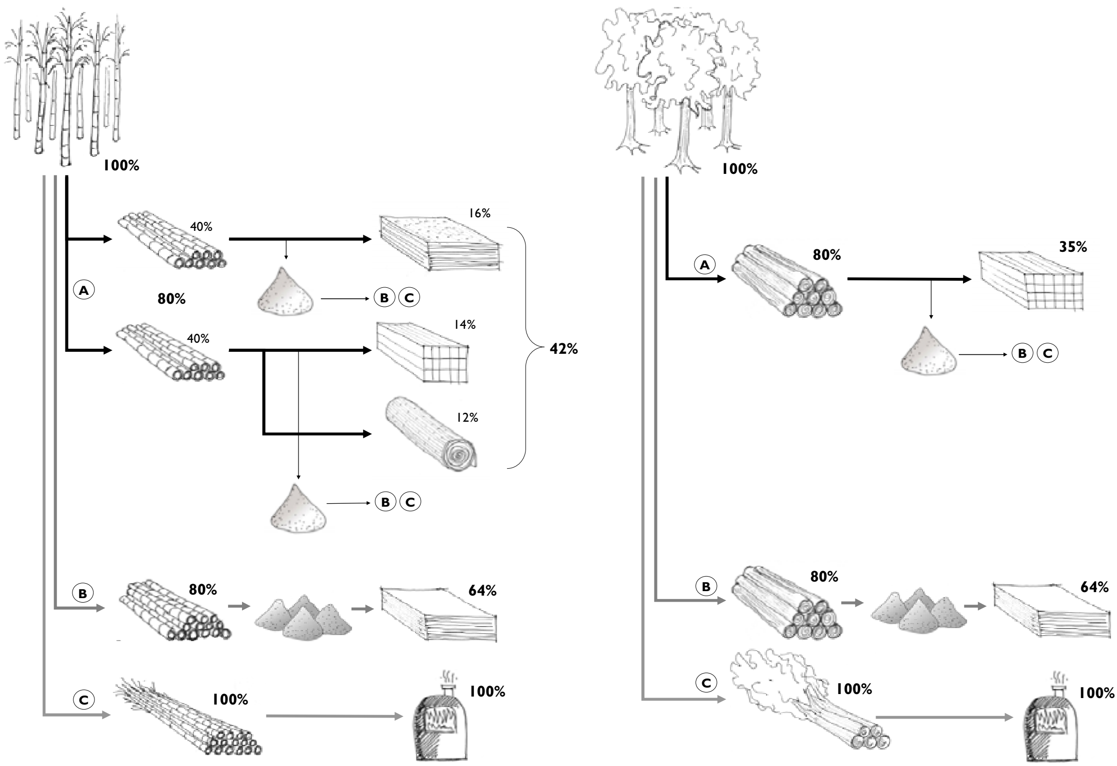


Figure 5.27: Efficiency during the conversion of bamboo (left) and wood (right) resources to semi finished materials; all percentages related to harvestable standing volume (100%)

Annual Yield

<u>Wood</u>

First, the average figures of the annual yield in terms of cubic meters of semi finished materials are presented for a hectare of sustainably managed wood plantation for both production scenario A and B. Although wood is usually harvested in multi year cycles (e.g. 15 years), this figure can be used as a base of comparison with bamboo. Again, it should be stressed that the figures mentioned may be considerably higher or lower depending on the climatic and geographic conditions of the plantation. It should be noted that in practice, due to the lower annual yields and low input requirements, fast growing softwoods will be used for the production of MDF and hardwood will not. Therefore, in table 5.19 only the annual yields of MDF in softwood are depicted. Note that for MDF, the wood fibers are combined with resin and compressed 1.5 times.

Table 5.19: Estimates of the annual yield of semi finished materials sourced from a wood plantation (Kuiper 2006, van Straten 2006, Wiselius 2001)

Wood species	Annual increase in standing volume (m3/ha)	Annual yield in logs (m3/ha)	Scenario A: Annual yield in sawn timber (m3/ha)	Scenario B: Annual yield in MDF (m3/ha)
Baby Teak	12.5	10	4.4	N/A
Regular Teak	6	4.8	2.1	N/A
European Oak	5	4	1.8	N/A
Eucalyptus	25	20	8.8	10.7

Bamboo

The annual yield calculation for A-quality bamboo materials is based on the number of bamboo stems that can be annually harvested in a sustainable manner from a Moso and Guadua plantation. While the harvest of a wood plantation is often based on multi year rotation cycles, since one bamboo plant consists of various stems and reproduces new stalks each year, for maximum yields a bamboo plantation is harvested every 1-2 years. During this harvest only the mature culms (4 years for Moso, 5-6 years for Guadua) should be felled for sustained maximum annual yields.

According to Riaño et al. (2002) a typical Guadua plantation houses 3000-8000 stems, which can be considered a conservative estimation. For this calculation an average of 5000 stems per hectare was assumed. Since Guadua stems mature in 5-6 years, was calculated with an annual harvest of 1/6 of the stems which results in an annual yield of 833 stems/ha. According to Zaal (2008) a typical Moso plantation in China used for board and flooring production will contain approximately 3000 stems, with an annual harvest of 1/4 of the stems; this will result in an annual yield of 750 stems. For the calculation it was assumed that for the production of A-quality materials half of these stems (417 stems/ha for Guadua and 375 stems/ha for Moso) are used for industrial processing into Plybamboo boards, while the other half will be evenly divided as input in the taped mats- and SWB industry (2 x 209 stems/ha for Guadua and 2 x 188 stems/ha for Moso).

In the beginning of appendix I it was explained that industrially produced bamboo materials from China are based on the 2.66 m measure; based on an 8-meter long Moso stem, three segments can be cut that can be used as input for the strip- and board producing industry. Due to the tapering character of bamboo, the diameter and wall thickness of these three segments decreases from bottom to top, which means that from the bottom part more material can be sourced than from the middle- and top part. Guadua is a bigger bamboo species than Moso. Therefore, for Guadua it is assumed that four segments can be derived from a stem: 4 x 2.66 m = 10.66 m, assuming a similar production process as in China. Note that for the production of strips the uppermost part of the stem (above 8 m for Moso, above 10.66 m for Guadua) is not suitable and is assumed to be used as input for low value applications (e.g. biofuel, broomsticks, banana props).

As a rule of thumb, the wall thickness of most bamboos can be found with the formula d = 0.82 * D, with d = the internal diameter of the cavity of the bamboo and D = the external diameter. Since the diameter of Moso and Guadua stems was measured by the author on various field studies in China and Latin America, the corresponding wall thickness was calculated with this formula for the various stem segments, based on which the material volume was calculated per stem with (π (=3.14) * (D^2- d^2)/4) in order to determine the cross section of a bamboo stem, multiplied by the length (2.66 meters).

Table 5.20: The diameter, wall thickness, volume and weight of the various segments of a harvested Moso stem

Segment in the stem	Diameter (cm)	Wall thickness (mm)	Volume (m3) of solid material per segment (2.66 m)	Dry weight (kg) per segment (2.66 m)*
0 - 2.66	10	9	0.0068	4.79
2.66 - 5.33	8	7	0.0040	2.86
5.33 - 8	6	5	0.0027	1.87
Total stem			**0.0136**	**9.52**

* based on a density of 700 kg/m3

Table 5.21: The diameter, wall thickness, volume and weight of the various segments of a harvested Guadua stem

Segment in the stem	Diameter (cm)	Wall thickness (mm)	Volume (m3) of solid material per segment (2.66 m)	Dry weight (kg) per segment (2.66 m)*
0 - 2.66	12	11	0.0098	6.91
2.66 - 5.33	10	9	0.0068	4.79
5.33 - 8	8	7	0.0040	2.86
8 - 10.66	6	5	0.0027	1.87
Total stem			**0.0235**	**16.43**

* based on a density of 700 kg/m3

Based on the amount of stems, the production efficiency (see above) and the material volume per stem the annual yield of bamboo in cubic meters semi finished materials can be established (see table 5.22). Note that for SWB, the bamboo strips are combined with resin and compressed 1.54 times into a composite material with a density of 1080 kg/m3 (see full production process in appendix I). For bamboo based MDF it is assumed that mature stems are required, while the compression rate is assumed to be 1.5 times. Besides scenario A and B, also a scenario is calculated in which all material deriving from a plantation is used for the production of SWB. Due to the increasing demand for tropical hardwood and the relative high added value of SWB this may be a realistic production scenario in the future.

Table 5.22: Estimates of the annual yield of semi finished materials sourced from a bamboo plantation

Bamboo species	Annual yield of suitable stems for semi finished material production (stems/ha)	Volume per stem[40] (m3/stem)	Efficiency in processing stems to semi finished material (%)	Annual yield semi finished material (m3/ha)
Moso: A-quality materials	Plybamboo: 375 Taped mats: 188 SWB: 188	0.014	Plybamboo: 40% Taped mats: 60% SWB: 70%	Plybamboo: 2.0 Taped mats: 1.5 SWB:1.2 **Total: 4.7**
Guadua: A-quality materials	Plybamboo: 417 Taped mats: 209 SWB: 209	0.024	Plybamboo: 40% Taped mats: 60% SWB: 70%	Plybamboo: 3.9 Taped mats: 2.9 SWB: 2.3 **Total: 9.1**
Moso: SWB	750	0.014	70%	4.6
Guadua: SWB	833	0.024	70%	8.8

[40] Applies to the debranched and topped stem, directly ready for input in the bamboo processing industry.

Moso: B-quality materials (MDF)	750	0.014	80%	5.4
Guadua: B-quality materials (MDF)	833	0.024	80%	10.3

Bamboo vs. Wood

In figure 5.28 the results of the annual yield in cubic meters A-quality semi finished materials per hectare found in the tables above is summarized for various bamboo and wood species.

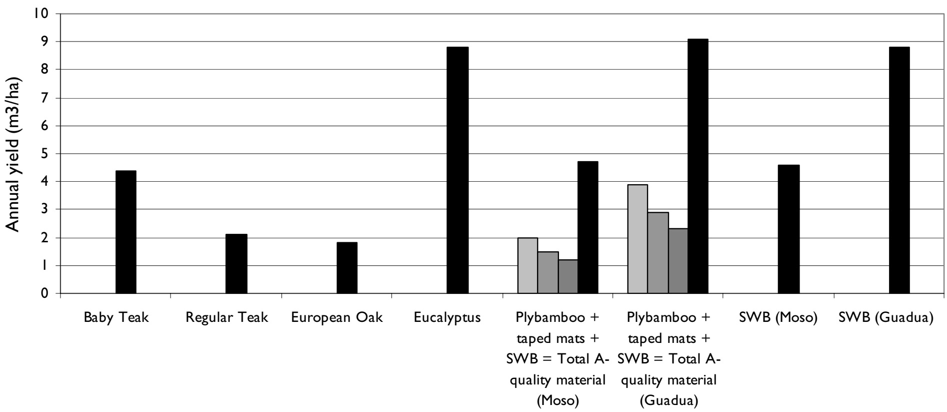


Figure 5.28: Estimates of the annual yield per hectare in cubic meters of bamboo- and wood based A-quality semi finished materials sourced from plantations
Note: For a just comparison of the total annual yield/ha for the various alternatives, the black bars should be compared

From figure 5.28 various conclusions can be drawn. For use in indoor applications all wood and bamboo species and materials depicted in the figure are applicable. Although in terms of A-quality materials Moso bamboo has a lower annual yield than Eucalyptus, due to its relatively low hardness, Eucalyptus will most often not be used in similar high end applications as Plybamboo, taped mats and SWB (e.g. flooring, tabletops), and may not serve as a good reference for these kinds of applications. Note that in the hypothetical (future?) situation that when these materials are made from Guadua the annual yields are almost twice as high as for Moso, and even higher than Eucalyptus.
Compared to one of the fastest growing hardwood species that is used in high end interior decoration (e.g. flooring), baby Teak, Moso has a slightly higher annual yield in terms of A-quality materials, while the hypothetical yield of Guadua is more than twice as high. Compared to other, slower growing hardwood species such as European Oak and regular Teak, the annual yields of A-quality materials made from Moso and Guadua are even higher, up to a factor five (Guadua compared to European Oak).

In the case of outdoor use, only some alternatives from figure 5.28 can be used due to their high durability outdoors (see figure 5.29 below). For bamboo only SWB is suitable for use outdoors, whereas in wood several tropical hardwoods such as Teak, but also modified Eucalyptus or Pine (e.g. thermally modified or acetylated wood) may be used outdoors. From the table it becomes clear that the annual yield from a Guadua plantation, transformed into cubic meters SWB is competitive to modified softwood (but has a hardness and density which is considerably higher), and is almost two times as high compared to baby Teak and over four times higher than regular Teak. In the case of a

Moso plantation the annual yield in cubic meters of SWB is around half the annual yield of modified softwood, but at a similar level as baby Teak, and over twice as high as regular Teak.

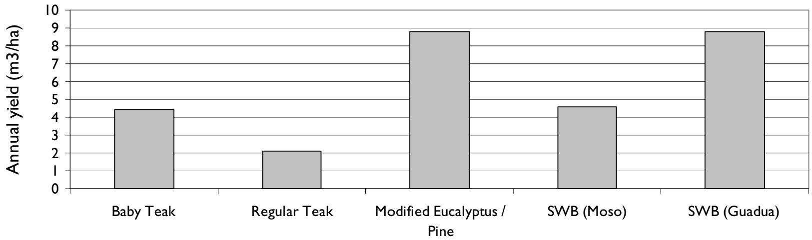


Figure 5.29: Estimates of the annual yield per hectare in cubic meters of bamboo- and wood based materials sourced from plantations apt for outside use

In figure 5.29 the annual yield of a bamboo or wood based plantation processed into B-quality materials (in this case MDF) is depicted. In practice for MDF production based on wood only fast growing softwood species will be used due to the relative low value added character of the material. The figure shows that Moso based MDF has an annual yield which is around half the yield of fast growing softwoods such as Eucalyptus and Radiata Pine, while Guadua based MDF is competitive in annual yields with MDF based on fast growing softwood. Note that the density of Radiata Pine and Eucalyptus (500 kg/m3) is lower than the density for bamboo (700 kg/m3). Taking into account a similar compression rate (factor 1.5) the bamboo based MDF will have a higher density (1050 kg/m3), and possibly better mechanical properties, than softwood based MDF (750 kg/m3).

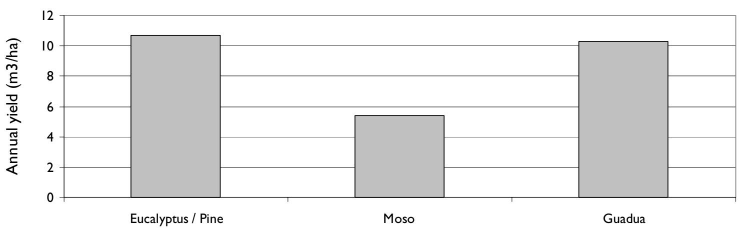


Figure 5.30: Estimates of the annual yield per hectare in cubic meters of bamboo- and wood based MDF sourced from plantations

Note that due to the comparison in annual yield in cubic meters, the bamboo stem was not integrated in the annual yield comparison because of its form. However, if a bamboo stem can substitute a solid wooden beam (see for example the FU walking bridge in the box in subsection 5.1.4) then a hectare of bamboo plantation can meet the demands of more FUs than a wood plantation. For example, if the 417 high quality stems harvested annually from a Guadua plantation are used in construction, and thus substitute a 0.05 x 0.1 x 8 m (0.04m3) long wooden beam each, they substitute 417 x 0.04 = 16.7 m3 of wooden material, which alone (not taking into account what happens with the other 417 lower quality stems from the Guadua plantation) is an amount which is twice as high as Guadua yields if processed into semi finished materials, showing the mechanical efficiency of the bamboo stem.

5.2.3 Conclusions & Discussion

The results in the previous subsection show that giant bamboo species such as Guadua may produce more cubic meters of semi finished material per hectare than any plantation grown hardwoods and most softwoods, and is only matched in annual yield by the fastest growing softwood species such as Eucalyptus and Radiata Pine. However, in general, (modified) softwoods (Eucalyptus, Pine, Poplar, etc.) have less aesthetic qualities and a lower hardness than hardwood alternatives, and are therefore to a larger extent used in applications where these properties are less required (e.g. for outdoor applications in markets such as garden wood and wall cladding). Therefore, in high end applications where hardness and aesthetic quality are of importance, such as flooring (indoors) and terrace decking (outdoors), SWB (also outdoors), taped mats and Plybamboo made from Guadua is the most efficient alternative in terms of annual yield. Moreover, also in the case of processing to B-quality materials, Guadua based MDF is competitive with the fastest growing softwood alternatives. No matter what the application is (either high end or low end) in which giant bamboo species such as Guadua are used, they are always competitive or better than wood alternatives in terms of annual yield, showing the potential of giant bamboo species for the future. However, currently almost all A-quality bamboo materials consumed in the West derive from China and are based on Moso bamboo. Due to the lower annual yield (around half of Guadua), Moso based bamboo materials have a lower annual yield compared to the fastest growing softwoods, but an annual yield which is competitive to the fastest growing hardwood species and more than twice as high as many other commonly used hardwood species (e.g. European Oak, regular Teak) in high end applications.

Due to the increasing pressure on our resources, it is important to use the hectares of land available globally in an increasingly efficient manner. Since humanity requires different resources for different needs (cropland for food, forests for materials, etc.) in combination with the increasing deforestation, it may be of importance to reforest degraded land in the future with a crop with high yields. In this section it was found that for the production of materials used as input in the interior decoration and building industry, bamboo may be the best alternative in terms of annual yield. The most interesting fact is that due to the combination of a relative high hardness and strength (like hardwood) and high growing speed (like softwood), one and the same giant bamboo species may be converted into both A-quality materials that can compete in high end markets with the highest quality tropical hardwoods (e.g. SWB with Teak) and B-quality materials that may be used in low end markets (e.g. MDF). For both markets bamboo is competitive or scores better in annual yield. This supports the proposition posed in subsection 1.2.1 that "bamboo grows faster than softwood but has hardwood properties." Furthermore, due to its long fiber bundles and specific mechanical and physical properties, bamboo may be converted into additional semi finished materials with certain competitive advantages over wood (e.g. use of BMB for the production of corrugated sheets; see box in subsection 5.1.7). This multi-functionality of bamboo is very different from wood, for which each application requires a specific species (e.g. tropical hardwood for decking outside, fast growing softwood for MDF production, etc.). Due to this versatility bamboo has a higher flexibility to meet possible shifts in demands for resources by different industries, and may prove to be the ideal reforestation crop for the future.

Some additional remarks are required at this point. In subsection 1.1.2 it was found that in order to fill the gap between demand (biocapacity) and supply (Ecological Footprint), demand should be diminished (e.g. lower consumption and footprint capacity) while supply should be increased (see figure 5.31 below).
First of all, as found in this section, bamboo may play a role by increasing the supply of raw materials through the high annual yield per hectare (high bioproductivity).

A second benefit of bamboo as a resource is that it can thrive on pieces of land where wood may not (e.g. degraded land on slopes, see figure 1.15), and due to its extensive root network may help to prevent erosion and facilitate the restoration of a healthy water table (Billing and Gerger 1990, Tewari and Kumar 1998), potentially diminishing the environmental effects of erosion, landscape deterioration and desiccation relating to the environmental problem of ecosystem deterioration (see table 1.1). The features mentioned above make some bamboo species very suitable for reforestation of deserted land which is not useful (anymore) as agricultural land (e.g. over exploited land created by the clear cutting of tropical rain forests). Therefore, bamboo in the future may be able to increase the biocapacity by simultaneously increasing the area of fertile global hectares that is able to supply resources (see figure 5.31).

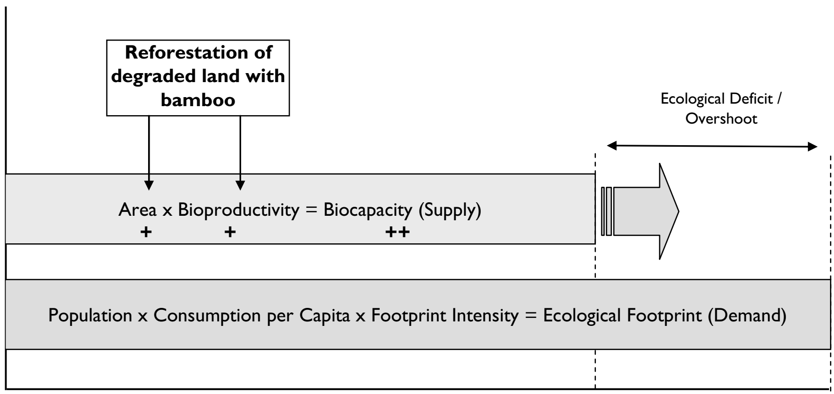


Figure 5.31: Gap between supply and demand between Biocapacity and Ecological Footprint and the potential role of bamboo at the supply side (figure adapted after WWF International 2006)

A final benefit of bamboo as a reforesting crop compared to wood is the low establishment time of a bamboo plantation. While the establishment time of a plantation of tropical giant bamboo species such as Guadua to come to maturity will not take longer than 10 years (Suarez 2006) and can be even less (see figure 5.32), the establishment time of a wood plantation to maturity may range from 15 years (Eucalyptus), 30 years (baby Teak), 70 years (regular Teak) to 80 years (European Oak) (Kuiper 2006, van Straten 2006). This means that a bamboo plantation will be able to deliver the annual yield of a mature plantation faster than any wood species can.

Figure 5.32: 3-year old plantation of Dendrocalamus Asper in Ecuador

Although the focus in the annual yield comparison was on the utilization of bamboo in the interior decoration and building industry, bamboo is also suitable as input in other high resource consuming industries such as the paper, biofuel, composite or textile industries, further highlighting the versatility of bamboo (e.g. wood is not suitable for the production of textile).

Figure 5.33: The bamboo micro fiber is increasingly being used in textile, such as in these socks

In the box below the annual yield of bamboo is compared with wood for the production of pulp (as input in paper) and biofuel. The results show that due to the fact that also younger bamboo stems can be harvested, annual thinning and therefore harvesting volumes may double for these kinds of applications, making the annual yield of bamboo compared to wood even higher, showing the high potential of bamboo in terms of annual yield for these industries as well.

Box: Annual Yield of Bamboo for Use in the Paper or Biofuel Industry

For pulp production, used as input in paper, logs (wood) or debranched and topped stems (bamboo) are processed by shredders to saw dust and fibers (additional 10% material loss assumed for both wood and bamboo). Since only cellulosic materials are required for pulp production, through mechanical pulping (pulping yield of approximately 90%, but lower quality) or chemical pulping (pulping yield of approximately 50%, but higher quality) non-useful components (e.g. lignin) are removed. Since bamboo and wood have a similar chemical composition pulp yields for both resources are similar (Dhamodaran et al. 2003).

In the case of pulp production for paper the annual yields per hectare for bamboo may be even higher than for the building and interior decoration industry since bamboo used for paper does not have to be mature (4-6 years old); rather, depending on the species it should be harvested at age 1 (Bambusa Vulgaris) or age 2 (Moso) (Dhamodaran et al. 2003), facilitating a yield per hectare that is twice as high as for the production of semi finished materials.
For paper the fiber characteristics determine the quality of the paper. Dhamodaran et al. (2003) provide an overview of bamboo species suitable for paper production, of which Bambusa Vulgaris seems one of the most promising species, although giant species such as Moso and various subspecies of Dendrocalamus (including Giganteus and Asper) are also reported. Due to its coarse fibers Guadua is not expected to be useful as input in the paper industry. Therefore, for the annual yield comparison besides Moso, Dendrocalamus Asper is included in the comparison. For Dendrocalamus Asper the annual yields of Guadua are adopted, since both are clumping tropical giant bamboo species.

Since unlike bamboo, trees do not acquire their full length in their first year, but grow and expand in size gradually, harvesting young trees does not result in higher yields per hectare. Eucalyptus is the most commonly known wood species used for paper production and was chosen as the representative wood species for the comparison. In figure 5.34 the annual yields in terms of cubic meters of wood based and bamboo based fibers/saw dust, used as input in the pulping process, are depicted. The annual yield for Moso is based on a yield of 1500 (2x 750) stems/ha x 0.0136 m3 (see table 5.20) x 90% efficiency = 18.36 m3. The annual yield for Dendrocalamus Asper is based on a yield of 1666 (2 x 833) stems/ha x 0.0235 m3 x 90% efficiency = 35.2 m3. The annual yield for Eucalyptus is based on the annual yield in logs (20 m3) x 90% efficiency = 18 m3. Note that in the comparison it is assumed that the yield is determined by the amount of cubic meters fibers/saw dust that can be produced, and not by the weight. Due to the higher density of bamboo this will result in heavier paper.

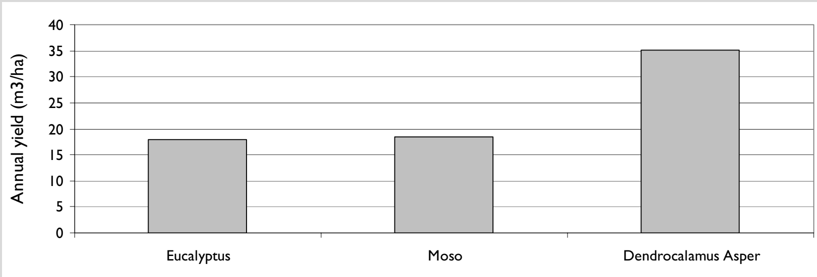


Figure 5.34: Annual yield of material sourced from a bamboo- and a wood plantation suitable for pulp production

Figure 5.34 shows that the for pulp production the annual yield of even subtropical bamboo species such as Moso is competitive with the fastest growing wood species Eucalyptus. If giant tropical bamboos such as Dendrocalamus Asper are used for pulp production, the annual yield for pulp production may be twice as high. Since the cellulose fibers in pulp may also be used as input in the textile or composite industry (although different processes are required), figure 5.34 shows the high potential of bamboo in terms of annual yield in these industries as well.

For biofuel production instead of calculating in volume (cubic meters), the total dry weight that can be produced annually from a plantation should be used as a base of comparison. Due to the relative high density this is an additional advantage for bamboo in this application compared to softwoods. For the annual yield calculation the same figures are used as for pulp production above plus the branches, leaves and top of the stem (for bamboo), which results in an additional 20% biomass. For this low added value application for wood Eucalyptus may be used, which will be compared with Moso and Guadua.

In figure 5.35 the annual yields in terms of dry tons of wood and bamboo biomass for biofuel are depicted. The annual yield for Moso is based on a yield of 1500 stems/ha x 0.0136 m3 per debranched stem x 1.25 (1/0.8) to include additional biomass in form of branches and leaves x 700 kg/m3 = 17.9 dry tons. The annual yield for Guadua is based on a yield of 1666 stems/ha x 0.0235 m3 x 1.25 x 700 kg/m3 = 34.3 dry tons. The annual yield for Eucalyptus is based on the annual yield in logs (20 m3) x 1.25 x 500 kg/m3 = 12.5 dry tons.

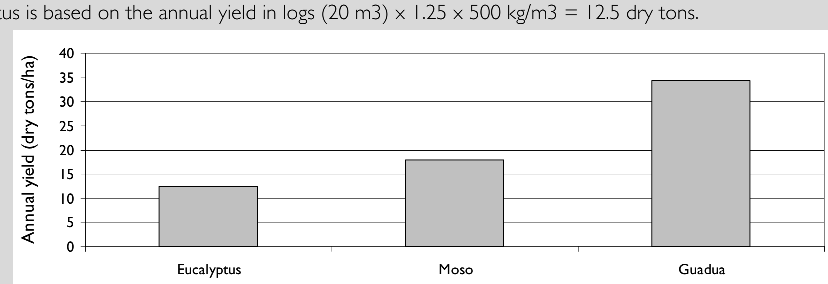


Figure 5.35: Annual yield of biomass available as input for biofuel

Figure 5.35 shows that due to the higher density of bamboo compared to softwood, the annual yield in terms of dry tons per hectare for both Moso and Guadua is considerably higher than even the fastest growing wood species.
It should be noted that for biofuel production also the caloric value of the various species should be taken into account.

Although the high biomass production of bamboo is indicative of carbon sequestration in durable products, carbon is also stored in the trees and stems (including the roots) that remain standing in a sustainably managed plantation. Since carbon sequestration is such an important issue at the moment, in appendix J a hypothetical calculation is executed in which is calculated how much carbon a permanent hectare of bamboo plantation sequesters compared to a wood plantation. Note that there is a lot of discussion if carbon sequestration by renewable resources should be taken into account since it is usually only a temporal solution. Chances are high that the carbon stored in a new planted forest will be released in the atmosphere at a later stage in the future when these wood resources (or the land on which they are standing) are felled or consumed. In the opinion of the author better solutions are available to reduce carbon emissions, such as substituting fossil fuel based energy by energy based on sustainable sources (e.g. solar and wind energy).

5.3 Conclusions

This chapter answers part of the second research question (RQ2: To what extent are the products developed in the intervention successful?) through research question 2.3 (How environmentally sustainable are the products developed?) and research question 2.4 (What is the environmental sustainability of the bamboo materials used in the products developed?), introduced earlier in subsection 3.3.2.

The environmental sustainability of a product or material is determined in this thesis through the eco-costs (environmental impact) at the debit side (negative environmental effects caused by bamboo materials during their life cycle contributing to the main environmental problems) and the annual yield at the credit side (effects diminishing the main environmental problems), calculated in the previous sections for bamboo and various alternatives. Whereas the prototypes developed during the intervention were assessed on eco-costs in subsection 5.1.8, for a more elaborate overview of the environmental sustainability of the various bamboo materials it may be more interesting to assess them on a broader level for all applications in the interior decoration industry in which bamboo may be suitable, instead of solely focusing on furniture. Therefore, in this conclusion the environmental sustainability (eco-costs and annual yield) of the various bamboo materials will be compared with alternatives in applications in the interior decoration sector in which the specific properties of bamboo can be utilized: bendability (Plybamboo, BMB), aesthetics (stem, Plybamboo, SWB) and durability outdoors (SWB) based on current use in Western Europe. Since bamboo composites seem not yet ready for commercialization, they are excluded in this comparison. Again it should be emphasized that the eco-costs calculation is based on LCA, which is a methodology still under development and full of assumptions and estimations, meaning that the environmental impact outcomes only function as a rough indicator.

After the comparison of the environmental sustainability for the Western European market, a similar comparison will be executed for bamboo materials used locally in bamboo producing countries, where also the price and mechanical properties (stem, BMB) may serve as an additional unique property of bamboo. Finally, based on the findings for the comparisons, the future potential of bamboo and wood for sustainable development will be reviewed in this section.

5.3.1 Current Use in Western Europe

In table 5.23 below the markets in which the various bamboo materials may be used, based on unique differentiating properties, are summarized. For each market a certain bamboo material is compared with suitable, mostly wood based, alternatives, based on the findings in section 5.1. Note that the target markets mentioned are exemplary; more markets may be suitable for each unique property. For the comparison of the environmental sustainability of bamboo to alternatives the following scale was used: -- very bad (eco-costs > twice as high; annual yield > twice as low), - bad (eco-costs 1.25 - 2 times as high; annual yield 1.25-2 times as low), +/- reasonable (eco-costs 0.75-1.25 times as low/high; annual yield 0.75-1.25 times as high/low), + good (eco-costs 1.25-2 times as low; annual yield 1.25-2 times as high), ++ very good (eco-costs > twice as low; annual yield > twice as high). For the annual yield component the figures for Guadua were also included as a hypothetical reference to evaluate the future potential of Guadua, since production of Guadua based semi finished material is still very low. Furthermore, for the annual yield component was assumed that Beech (European hardwood) has a similar annual yield as European Oak, and that plywood made from Pine has a similar annual yield in logs as Eucalyptus, but halved, due to the higher material losses of veneer production (thus calculating with 0.5 x 20m3 = 10 m3). Finally, the annual yield evaluation in table 5.23 and the remainder of this subsection is based on the total production of A-quality materials per hectare (see subsection 5.2.2). Only for SWB the annual yield component is based on a scenario in which the complete annual yield from a plantation is used as input in the SWB industry. Since the eco-costs and annual yield have a different scope (see table 3.3) and character, they cannot be added up one on one. However, together they do provide a good indication of the environmental sustainability of bamboo materials.

Table 5.23: The current environmental sustainability based on eco-costs and annual yield for various bamboo materials in suitable markets in Western Europe, compared to relevant alternatives

Unique feature	Bamboo material	Possible target market	Competing alternatives	Eco-costs compared to alternative	Annual yield (Moso) compared to alternative	Annual yield (Guadua) compared to alternative
Bendability	Plybamboo	Curved seatings (indoors)	European Beech	--	++	++
			Plywood & veneer	+/-	-/--	+/-
	BMB	3D molded seatings (indoors)	ABS	-/--	++[41]	++
Aesthetics	Stem	Chair, table, lamp component	European Oak	-	++	++
			Pine	--	++	++
			Teak (plantation)	+/-	++	++
			Teak (FSC certified)	++	++	++
Aesthetics & hardness	Plybamboo	Tabletops, flooring	European Oak	--	++	++
			Teak (plantation)	+/-	++ (regular Teak), +/- (baby Teak)	++ (regular Teak), ++ (baby Teak)
			Teak (FSC certified)	++	++ (regular Teak), +/- (baby Teak)	++ (regular Teak), ++ (baby Teak)
			Plywood & veneer/top layer of hardwood	+/-	-/--	+/-
			MDF & veneer/top layer of hardwood	-	--	+/-

[41] Since ABS (and Polypropylene used in Tech-Wood) is based on oil, it is not a renewable resource that can provide an annual yield. Therefore, the annual yield factor for ABS is negative compared to bamboo.

Aesthetics & outdoor durability	SWB	Decking	Tech-Wood	--	++ (see footnote 41)	++ (see footnote 41)
			Teak (plantation)	--	++ (regular Teak), +/- (baby Teak)	++ (regular Teak), ++ (baby Teak)
			Teak (FSC certified)	+/-	++ (regular Teak), +/- (baby Teak)	++ (regular Teak), ++ (baby Teak)
			Teak (natural forest)	++	++ (regular Teak), +/- (baby Teak)	++ (regular Teak), ++ (baby Teak)

From table 5.23 the following conclusions can be drawn about the competitiveness of the various bamboo materials in terms of environmental sustainability (eco-costs + annual yield) based *on the current situation* (therefore, based on bamboo materials made from Moso bamboo since Guadua based materials are not sufficiently available) and use in Western Europe.

Stem

In all applications where the bamboo stem may be used, European grown wood scores better in terms of eco-costs. Due to its efficiency in form and processing, and the high growing speed, in annual yield the stem scores significantly better than even the fastest growing softwood species (including all other bamboo materials). However, due to the irregular form and high transport costs, the market potential of the stem for mass applications in the West is limited which makes this high annual yield of limited use (which is not the case in bamboo producing countries; see below).

Plybamboo

In applications where Plybamboo is typically used (flooring, tabletops), it performs worse in terms of eco-costs than locally grown hardwood and MDF based alternatives (with hardwood top layer), and is competitive with plywood based alternatives (with hardwood top layer). In terms of annual yield Plybamboo performs better than almost all hardwoods (only baby Teak is competitive), but worse than MDF and Plywood based on fast growing softwood species. Therefore, from an environmental point of view, if Plybamboo is to be used in these applications in the West, it is recommended to use Plybamboo veneer on a local wood based carrier such as Plywood or MDF (e.g. engineered flooring), since Plybamboo veneer is competitive in terms of eco-costs even with local grown wood species (see table 5.6).

SWB

For outdoor applications outside most softwoods are not eligible due to their low durability, and tropical hardwood is often used. In high end applications (e.g. decking), SWB has higher eco-costs than plantation grown Teak. However, for tropical timber, including FSC certified timber, it is often not clear if the wood derives from a natural forest or a plantation (only 11% of productive forest area in the tropics), whereas demand for tropical hardwood is growing.[42] SWB does score better in eco-costs than timber which is derived from natural tropical forests and has similar eco-costs as FSC certified tropical hardwood.

Therefore, if SWB can replace tropical timber from natural forests (e.g. a portion of 64.6% of all FSC tropical timber derives from natural forests) it may be considered an environmental friendly alternative in terms of eco-costs, although better performing wood based alternatives (e.g. Tech-Wood, acetylated wood) are available. Although the annual yield of baby Teak is competitive with Moso based SWB,

[42] This also shows the need to establish more plantations for tropical hardwood production.

SWB does have a higher annual yield than most other tropical hardwoods. Therefore, especially due to the high annual yield, SWB can serve as a relatively environmentally friendly alternative to meet the demand of (FSC certified) tropical hardwood in the West, and help in the prevention of the clear cutting of tropical forests, perceived as important carbon sink. Note that modified softwood (e.g. thermally modified, acetylated) was not included in this assessment, and could be a suitable alternative as well, especially for applications in which hardness is not of utmost importance (e.g. cladding, garden wood).

Bamboo Mat Board (BMB)

Due to its specific characteristics BMB may be used in applications in which wood alternatives cannot (e.g. grid matrices, 3D bowls). However, in terms of eco-costs BMB scores worse than ABS in these kinds of applications, but better in terms of annual yield since ABS is based on finite resources (oil).

5.3.2 Current Use in Bamboo Producing Countries

In case the bamboo materials are used in applications in the bamboo producing countries themselves (in this case, China), the eco-costs of the various materials will be reduced due to lower eco-costs for transport. While the annual yield figures will remain the same, the eco-costs of Plybamboo will be reduced by 25-28% (depending on the color and structure), SWB by 15.4% and the stem by 95.2%. Looking at the same markets as reviewed in table 5.23, in case of use in China, one can conclude that Plybamboo and SWB become increasingly competitive with locally grown wood species in terms of eco-costs (although most locally grown wood species due to a shorter production process will remain slightly better). In combination with the often high annual yields, this makes the various industrial bamboo materials a competing alternative in terms of environmental sustainability compared to locally grown species, and even more if the production efficiency and application of less environmental harmful resins can be increased.

In the case of the bamboo stem, differences in eco-costs are especially high between use in China or in Western Europe due to the high space occupation during transport of the stem. Furthermore, due to the low costs, high local availability and lower input requirements for housing, furniture and household products compared to the Western European situation, the applicability and market potential for the stem is considerably higher in most bamboo producing countries. In these markets, due to the short production process, the bamboo stem becomes the most environmentally friendly alternative (both in terms of eco-costs and annual yield), even better than locally grown softwood alternatives (see for example the black bar in figure 5.12).

Since bamboo is especially available in China and India (millions of hectares of bamboo forest and plantations are available), where population and consumption is particularly increasing, and large areas of land are degraded, it is here where the bamboo stem can make the most advantage of its high bioproductivity and area use (see figure 5.13) to help meet local resource demand, especially for housing. For example, in China in the coming decade around 400 million new houses need to be built in the countryside (McDonough and Braungart 2002). In combination with earth or mud very strong, earthquake resistant low cost housing can be created based on bamboo (see figure 5.36). Due to the higher annual yield, this applies even more for housing made from giant bamboo species such as Guadua.

Figure 5.36: Low cost bamboo housing in Latin America
Note: in terms of durability the mud/mortar clad housing (right) is strongly preferred over the version in which all the bamboo is directly exposed to climatic circumstances (left)

Also other coarse materials such as BMB may have a higher applicability in resource consuming sectors such as the building industry, in bamboo producing countries themselves. Although compared to wood based materials (Plywood, MDF, chipboard, etc.) BMB scores worse in terms of eco-costs, if the competitive advantages of BMB compared to wood based materials are utilized (e.g. bendability), BMB might be the best alternative from the eco-costs point of view. For example, as seen in the box in subsection 5.1.7, BMB based on multi directional woven mats can be pressed into strong and cheap corrugated boards with good durability outdoors, that cannot be produced in the same manner as wood. Compared to other alternatives (steel, PVC) for low cost corrugated board, BMB is therefore the best alternative from an environmental point of view in bamboo producing countries (see also figure 5.24).

5.3.3 Future Use of Bamboo

If we look at our future needs, taking into account the increasing pressure on the environment and our remaining resources, how and where should bamboo be utilized as a renewable resource?

In terms of eco-costs it can be concluded that the further away the bamboo stem is industrially processed, the more artificial resins are added, and the further it is transported, the higher the eco-costs of the bamboo materials are, and the less competitive it becomes in eco-costs compared to locally grown wood alternatives. If the bamboo stem is used directly in appropriate applications in bamboo producing countries, it is the most environmentally friendly material around because of the very short production process; no wood species can be harvested and after drying be directly used without further processing. However, if the stem is industrially processed into boards and transported to Western Europe, this environmental edge compared to locally grown wood species is lost, and the various bamboo materials are only competitive with Plywood or plantation grown tropical hardwood, and score better than FSC tropical hardwood and tropical hardwood derived from natural forests.
Nevertheless, although various bamboo materials used in Western Europe score worse from an environmental impact point of view than locally grown wood species, compared to various other materials, especially those based on finite resources (e.g. metals, plastics), the renewable character of bamboo makes it an environmentally sustainable alternative compared to many other materials, also when used in Western Europe.

In terms of annual yield it was found that the bamboo stem was the best performing renewable resource around if used as a semi finished material in a durable application (e.g. housing). In the case giant tropical bamboo species such as Guadua are used for the production of industrial materials (e.g. Plybamboo, SWB), they have a higher annual yield than all hardwood and softwood alternatives; only wood based boards (MDF, Plywood) based on the fastest growing softwood species may perform slightly better in terms of annual yield. However, due to the higher processing efficiency and the even shorter harvesting time (1-2 years) the high annual yield of bamboo is utilized the best in pulp and fiber demanding industries, such as the paper-, textile- and composite industry.

Different resources are required for different needs (cropland for food, forests for materials, etc.). Due to the increasing pressure on the remaining hectares of land globally and the increasing deforestation, it may therefore be necessary to reforest degraded land in the future with a crop with high yields. The kind of crop required may depend on the highest needs and priorities locally.

In (sub)tropical areas in most cases giant bamboo species such as Guadua will be the ideal contender, not only because it can be planted on land which is difficult to reforest with wood and has a very short establishment time compared to wood, but also because it combines a high annual yield with a large versatility. In the building- and interior decoration industry depending on which semi finished material it is transformed into, bamboo may be deployed in the most demanding high end applications but also in low-cost low-end applications, and still be competitive. If transformed into pulp or fibers, the same giant bamboo species may also be used for the production of paper, textile or natural fiber reinforced composites. Furthermore, various bamboo species can also be used for charcoal and even as food (young bamboo shoots), further highlighting the versatility of bamboo compared to wood.[43] Above, it was found that the applicability of especially B-quality bamboo materials (including the stem) may be higher in the bamboo producing countries. Taking into account the increasing consumption patterns and the population growth in the main bamboo producing countries of India and China, bamboo should first be deployed as a tool toward a sustainable society in the countries where it grows, and not be transported over thousands of kilometers to Western markets where local grown renewable resources may perform better in terms of eco-costs. However, if demand cannot be met by local sources, due to its versatility and high annual yields, bamboo is the best alternative to help meet this demand from an environmental perspective, especially if it can be sourced from a closer distance in the future (e.g. from Africa for Europe, and from Latin America for North America) which should be further stimulated in the future by the establishment of additional bamboo production nuclei in the future.

[43] A nice overview of applications in which bamboo is used is provided in *The Book of Bamboo* (Farrely 1984)

5.4 Discussion & Recommendations

The author hopes that through the environmental sustainability assessment executed in this section the debate about the status of bamboo materials as being the greenest alternative for Western and local markets will be strengthened and further investigated through similar calculations, executed in different production sites around the world. Taking this into account the following recommendations can be made.

LCA Based Research for Bamboo

To get a better understanding of the environmental impact of bamboo much more LCA based research should be executed for different production to consumption scenarios based on:

- Different countries and factories based on different technology levels of production sites (manual, semi industrial, industrial facilities).
- Different countries of consumption, with a larger emphasis on the environmental competitiveness of bamboo when used locally, in bamboo producing countries.
- Different FUs with a broader base of comparison. For example, for outdoor applications, modified softwood (impregnation, thermal modification, acetylation, see also footnote 36) should be included as an alternative in future calculations as well.
- Different bamboo based materials and fabrics, and especially the use of bamboo fibers for the production of:
    - Natural fiber bases composites, preferably in combination with an environmentally friendly biodegradable resin (e.g. PLA);
    - Pulp for paper and cardboard production;
    - Bamboo textile, which is a new hype in Western countries as a presumably eco-friendly alternative. However, taking into account the findings in this thesis, and the knowledge that the production of bamboo fibers apt for textile follows a lengthy industrial process similar to the production of viscose, also the eco "friendliness" of bamboo textile in terms of eco-costs may be questioned.
- Different life cycle scenarios in which also the maintenance and end-of-life scenario is taken into account, including the potential use of disposed bamboo- and wood based materials for energy production, and the consequences for the eco-costs calculation (potential deduction because of the prevention of an additional amount of fossil fuel being consumed).

Annual Yield Research for Bamboo

To get a better understanding of annual yield (indirectly also carbon sequestration) by bamboo resources compared to wood, it is recommended:

- To execute similar annual yield calculations for other giant bamboo species such as *Dendrocalamus Asper* or *Giganteus*, including the applications in which they may be used.
- To execute annual yield calculations for the production of the bamboo fiber for the development of natural fiber reinforced composites, including the appropriate age required for the input material. It is likely that younger stems may be used as input for this material resulting in a yield that may be up to 2-3 times higher as for the production of other semi finished bamboo materials such as Plybamboo.
- To execute additional or new annual yield calculations for bamboo species apt for other resource demanding markets such as for textile, paper, biofuel or charcoal (also based on their appropriate felling age, see directly above), compared to suitable wood species for this application. For biofuel

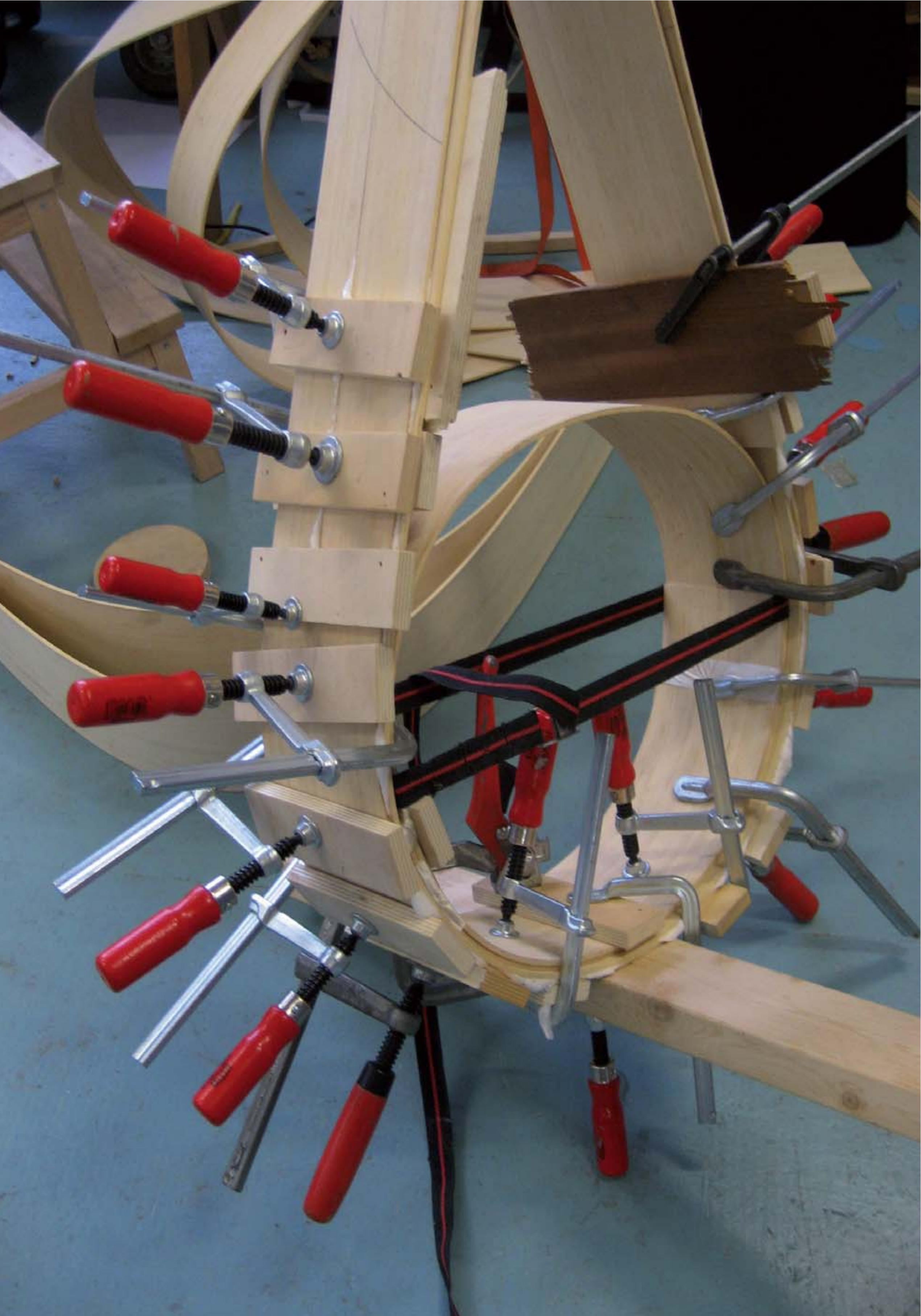
calculations the bamboo species should be chosen with the highest caloric value, for which additional research is also required.

- To execute the annual yield calculation again in various parts in the world with different geographical, climatic and soil conditions (e.g. temperate versus tropical climate, fertile versus infertile land, etc.), calculating with various local species of bamboo and wood that seem most suitable to use under the specific circumstances of the selected site.
- To execute new annual yield calculations based on future consumption scenarios and the role reforestation by bamboo may play in meeting growing resource demands.

Recommendations for the Bamboo Industry

In order to improve the environmental sustainability of their products, industrial bamboo material producers are recommended:

- To execute similar environmental impact assessments as the ones executed in section 5.1 in order to better understand which steps in the production process are most harmful to the environment and should therefore receive priority if the environmental impact of the materials is to be reduced (see for example figure 5.2). For example, industrial bamboo producers could use less harmful additives during the production process of their materials (e.g. preservatives, resins), either by reducing the amount of resins and chemicals used, but preferably by opting for more environmental friendly or biodegradable resins and chemicals.
- To make their materials lighter. For example, Tech-Wood saves a lot of material by extruding profiles instead of making a solid product.
- To develop take-back procedures, and recycling processes in which the materials at the end of their lifetime are 100% reusable in the same function (Cradle till Cradle strategy).
- To further increase the efficiency of the transformation process of the bamboo resource in semi finished materials, including the search for more high end and durable materials and applications in which the rest material can be used (e.g. similar to Tech-Wood panels).
- To increase the establishment of plantations of high yielding giant bamboo species suitable for the production of fibers and materials.
- To further develop new industrial bamboo materials, like corrugated BMB boards, in which the competitive advantages and specific differences of bamboo compared to wood are utilized. For example, if the bamboo micro fiber is chosen in natural fiber based composites because of its mechanical performance, it might be worthwhile to do research into processes to extract bamboo fibers in an efficient and environmentally friendly way from the stem, including space efficient ways of transportation to the composite material production site (e.g. compressed bags through vacuum suction).



6 Material Evaluation

In the previous chapters the various product prototypes developed during the Bamboo Labs were evaluated according to various criteria. In this chapter the various bamboo materials used in the prototypes - stem, Plybamboo, composite, SWB and mats - are evaluated by the participating designers for their suitability as a material for product design, based on their experiences during the Bamboo Labs.

First, in section 6.1 the overall attitude of the participating designers toward the various bamboo materials will be evaluated (subsection 6.1.2), as will be the relationship between the amount of knowledge and the attitude toward the same material for each designer (subsection 6.1.3).
Secondly, in section 6.2 the background of the attitude toward each bamboo material is explored, by analyzing the various positive and negative attributes related to each material. Based on this analysis, several recommendations are made for each material deployed during the Bamboo Labs.
Finally, in section 6.3 several conclusions will be drawn.

6.1 Overall Evaluation

6.1.1 Introduction

In this section the overall attitude of the participating designers toward the various bamboo materials will first be evaluated. As seen before, designers largely base their attitude toward a material on 1) the various material properties (see figure 3.4), 2) processing- and finishing possibilities and constraints, and 3) various additional features such as the quality and availability of the material, or the commercialization phase the material is in (for more information see subsection 1.2.3). The more factual knowledge a designer has about these material related attributes, the better the opinion he/she can form about the material. In subsection 2.2.1 it was substantiated that a lack of knowledge by designers is perceived as one of the key problems in the PCS in the North hampering the commercialization of bamboo materials that the design intervention in this action research targets. However, it is important to understand if the knowledge acquired will lead to a better (or possibly lower) attitude toward the material. The relation between the amount of knowledge and the attitude is therefore analyzed separately in this section.
For the material evaluation we are interested in the level of knowledge and the attitude of the designers at T1, which was distilled from the quantitative data acquired during the questionnaire interviews (see subsection 3.4.2). For the determination of the overall attitude, the designers were asked to fill in a 7-point semantic differential scale for each bamboo material (see example for the bamboo stem in figure 6.1 below). Semantic differential scales are often used in surveys and are an effective method to process attitudes statistically (Loudon and Della Bitta 1993). The evaluation was based on the overall attitude about bamboo as material for designers, with other natural materials (e.g. wood) as reference. To make this frame of reference clear, the designers were asked to also provide their attitude about the most commonly used wood species for furniture design in the Netherlands: Oak (hardwood) and Pine (softwood).

Stem: very negative 1..........2...........3...........4...........5...........6...........7 very positive

Figure 6.1: Semantic differential scale used during the questionnaire interviews to determine the attitude of the designers toward a bamboo material (in this case bamboo stem)

Furthermore, the designers were asked to evaluate their knowledge about the various bamboo materials at T1, with respect to the material properties and processing & finishing do's and don'ts. The evaluation was based on a 10-point scale, as commonly used in the Dutch educational system (1. very bad, 2. bad, 3. very insufficient, 4. insufficient, 5. almost sufficient, 6. sufficient, 7. amply sufficient, 8. good, 9. very good, 10. outstanding.) with the average Dutch designer as frame of reference. The relationship between the amount of knowledge about each material and the attitude was then analyzed in SPSS 13.0 through correlation- and regression analysis.

In the subsections below the results of the attitude evaluation, and the knowledge - attitude relation analysis, will be presented. It should be noted that the attitude analysis is based on the opinions of the designers that participated in DDMB, and is therefore subjective. Based on the background (beliefs, values, cultural background, etc.) the personal preferences of a designer may strongly differ from other designers. Since the sample group is quite small (N = 21), the results therefore only provide a rough impression about the attitude of Dutch designers toward the various bamboo materials.

6.1.2 Attitude

In table 6.1 below the average attitude (mean) of the designers is presented based on a 7-point semantic differential scale with 1 = very negative and 7 = very positive, including the standard deviation for each material, and the amount of designers (N) that evaluated the material. Note that in some cases (e.g. SWB, N = 18), some designers did not acquire sufficient information about the material during the Bamboo Labs to give a score with respect to their attitude toward the material.

Table 6.1: Attitude of the participating designers toward the various bamboo materials including two commonly used soft- and hardwood species

Material	N	Mean (ranking)	Standard Deviation
Stem	21	3.52 (7)	1.721
Plybamboo	21	5.24 (2)	1.640
Composite	20	4.20 (4)	1.436
SWB	18	4.06 (5)	1.798
Mats	20	3.65 (6)	1.565
Pine	21	4.29 (3)	1.521
Oak	21	5.48 (1)	1.030

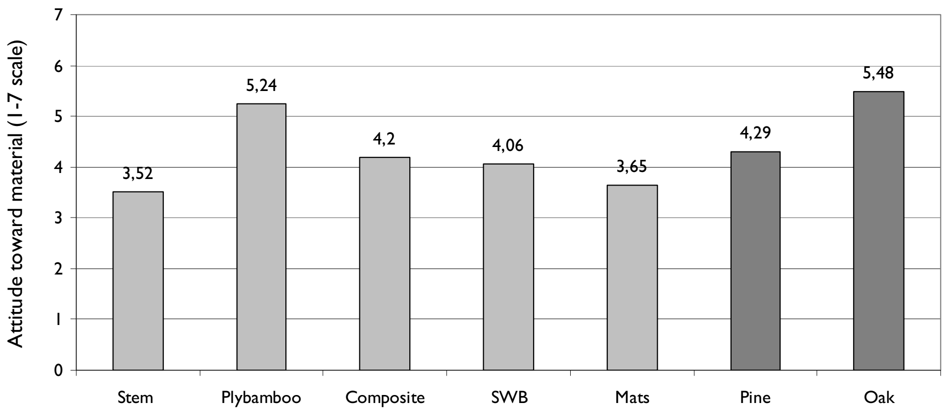


Figure 6.2: Attitude of the participating designers toward the various bamboo materials including two commonly used soft- and hardwood species (in dark gray)

From table 6.1 and figure 6.2 several conclusions can be drawn.

First of all, we see that both Oak and Plybamboo are evaluated quite positively, with Oak being the best scoring material. Secondly it can be concluded that the attitude toward Pine, bamboo composite and SWB is on a similar, slightly positive, level. Furthermore, it can be concluded that both the bamboo mats and the stem have a slightly negative score with respect to the attitude of the designers toward these materials.

Finally, it can be concluded that the standard deviation is quite high, revealing considerable differences in attitude between the participating designers. The background of these differences is analyzed in section 6.2. In the next subsection the relation between the attitude and the amount of knowledge is analyzed.

6.1.3 Relation between Knowledge and Attitude

The relation between the amount of design knowledge and the attitude was statistically analyzed for the various bamboo materials. In the case of three of the five bamboo materials analyzed through correlation analysis, a significant ($p < .05$; stem) or marginal significant ($p < .10$; Plybamboo and mats) relation between the variables was found. The nature of the relationships for these materials will be analyzed in this subsection through regression analysis, starting with the bamboo stem.

Correlation analysis revealed a significant relation between the knowledge about the stem and the attitude toward the stem at T1 ($r = .54$, $p < .05$). Regression analysis (see table 6.2) showed that this relation is very positive (Attitude T1 = -3.77 + 1.04 * Knowledge stem T1, with $\beta = .49$), meaning that a higher level of knowledge about the stem results in a significantly higher attitude toward the material.

However, taking into account the very negative value of the constant (-3.77) and the maximum score of 10, the maximum score that can be acquired is 6.63 (between sufficient and amply sufficient). This shows that although the attitude does increase if more knowledge is acquired, the attitude toward the stem remains quite low.

Table 6.2: Regression analysis for the stem; Knowledge T1 (independent variable) & Attitude T1 (dependent variable), with SE = Standard Error

	B	SE B	β
Constant	-3.77	2.99	
T1 Knowledge stem	1.04	0.42	.49*

R = 0.24; * p<.05, **p<.10

Between the knowledge about Plybamboo and the attitude toward the material a marginal significant relation was found at T1 ($r = .42$, $p < .10$). Through regression analysis (see table 6.3) it was found that this relationship is quite positive (Attitude T1 = -0.11 + 0.70 * Knowledge Plybamboo T1, with $\beta = .39$), meaning that a higher level of knowledge about Plybamboo results in a higher attitude toward the material.

Table 6.3: Regression analysis for Plybamboo; Knowledge T1 (independent variable) & Attitude T1 (dependent variable)

	B	SE B	β
Constant	-0.11	2.88	
T1 Knowledge Plybamboo	0.70	0.38	.39**

R = 0.16; * p<.05, **p<.10

A marginal significant relation was also found between the knowledge about bamboo mats and the attitude toward the material at T1 ($r = .37$, $p < .10$). The relationship between these entities is somewhat positive for bamboo mats (Attitude T1 = 1.12 + 0.42 * Knowledge bamboo mats T1, with $\beta = .37$), meaning that a higher level of knowledge about bamboo mats results in a somewhat higher attitude toward the material.

Table 6.4: Regression analysis for bamboo mats; Knowledge T1 (independent variable) & Attitude T1 (dependent variable)

	B	SE B	β
Constant	1.12	1.56	
T1 Knowledge mats	0.42	0.25	.37**

R = 0.13; * p<.05, **p<.10

No significant relationship ($p > .10$) could be found through correlation analysis for the other two bamboo materials deployed during the intervention, composite ($r = .22$) and SWB ($r = .20$).
Taking into account the small sample group ($N = 21$), finding a significant relation between the amount of knowledge and the attitude for three of the five bamboo materials used can be perceived as a satisfactory result.

In this section the attitude was only analyzed in a quantitative way. In the following section the qualitative background behind these scores will be analyzed.

6.2 Analysis of Attitude Attributes

6.2.1 Introduction

In the previous section the attitude of the designers toward the various bamboo materials was evaluated. Besides the hard figures found, it is important to understand the background of the attitude score, by finding out which aspects of the material contributed in a positive manner to the evaluation and which in a negative manner. Since through their experiences in the Bamboo Labs the designers have in some way become experts about the bamboo materials deployed, their findings and recommendations might be very interesting for the bamboo industry.

To better understand the background of the attitude evaluation, the designers were interviewed in an open way (open questions) in their design studio, and were urged to share all the positive and negative aspects, including points for improvement, for each bamboo material based on their experiences during the intervention. To acquire all opinions about the various material aspects of the various materials, the researcher kept asking questions about positive and negative aspects of the materials until the designers had mentioned all aspects in their mind. The qualitative research data acquired through the recorded interviews was subsequently written out, analyzed, and finally summarized and categorized through labeling techniques (Baarda et al. 2005), into the categories "material properties" (divided into technical, economical, use, environmental, sensorial and intangible properties; see figure 3.4), "processing- and finishing" and "other".

Although most qualitative data for the material attitude analysis was derived from the participating designers, for the recommendations about the various materials, recommendations made by the expert panel during their evaluation of the prototypes (see chapter 4) were also added in this section. For recommendations on sectoral level the reader is referred to subsection 9.3.3.

It should be noted that the attitude evaluation, and therefore also the attribute evaluation, is based on the personal opinions of the designers and therefore has a subjective character. Furthermore, it should be understood that the attribute analysis and recommendations provided are based on the experiences of the designers with bamboo materials based on the species Moso. Although the attribute analysis and recommendations may prove to be replicable for similar giant bamboo species, such as Guadua, for some bamboo species that have very different characteristics such as the *Chusquea Gigantea* (a solid bamboo species), they may not be.

For each bamboo material the positive and negative attributes are presented separately below, with a list of recommendations for each bamboo material at the end of each subsection.

6.2.2 Stem

The bamboo stem was evaluated slightly negatively (Mean: 3.52) in subsection 6.1.2. In this subsection the background behind this score is analyzed by reviewing the positive and negative aspects with respect to material properties, processing- & finishing opportunities and constraints, and other additional aspects, that together form the attitude toward a material. In table 6.5 and figure 6.3 below, the results of the inquiries with the designers are presented.

Table 6.5: Attitude forming attributes of the bamboo stem which were evaluated positively and negatively by the participating designers

	Positive aspects (number of responses)	Negative aspects (number of responses)
Material properties	Technical Very efficient from mechanical point of view; light & strong at the same time (5) High flexibility and elasticity (3) Hard (1) Strong (1) Economical Inexpensive (4) Environmental Environmentally friendly (4) Sensorial Unique - in some ways beautiful - natural tube (5) Beautiful color, texture and shine (1) Intangible Strong personality; rough and pure (5)	Technical Lack of dimensional stability (14) Difficult shape (6) Use Vulnerability for cracking in dry circumstances (5) Low durability outside (5) Environmental Not efficient during transport due to high space occupation (2) Sensorial Ugly in form and color (3) Intangible Cheap, corny, colonial image (13)
Processing and finishing	Good processability with existing wood working machines (1)	Vulnerability for splitting, cracking and splintering during processing (10) Difficulty to make connections due to form (6) Poor adhesion of lacquer and paints on outside layer (2) Wears saw blades down quickly during processing (2)
Other	High potential for use in developing countries (6) Due to strong character and difficult form the ultimate designer's challenge (8)	Low applicability in contemporary products (6) Lack of legislation and codes, especially in the building industry (2)

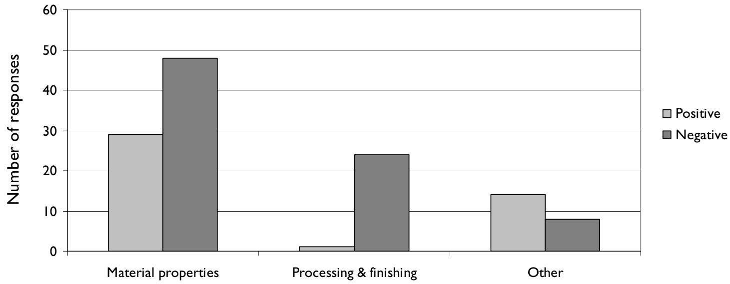


Figure 6.3: Accumulated responses with respect to positive and negative attributes forming the attitude toward the bamboo stem

From figure 6.3 it can be concluded that in total there are more aspects of the bamboo stem that are evaluated negatively than positively. In terms of material properties there are more negative evaluations (48) than positive ones (29). Figure 6.3 also shows that the bamboo stem is a difficult material to process, with 24 negative evaluations opposed to 1 positive evaluation. However, there are several additional aspects that are evaluated positively (14) compared to negative evaluations (8). Below, these positive and negative attributes are further commented upon, based on feedback from the designers.

Material Properties

From the attitude analysis it can be concluded that some of the designers really appreciated the authenticity of the bamboo stem; the fact that the bamboo stem grows directly into a strong, yet flexible and light tube which is very efficient from a mechanical point of view, was valued in a positive manner; no other material directly grows into this form (e.g. compare with plastic and steel tubes). Due to the short processing (the raw resource = the final material) and the efficient form, the stem was also perceived as being very environmentally friendly.[44] Since the natural character of the stem is evident, this could work well for the material with respect to the increasing importance of sustainability. The strong form language of the stem was appreciated by several designers as being "pure", and as "a material with character".

However, the fact that the resource is at the same time the final material also has various negative consequences, such as the lack of dimensional stability (in diameter, thickness, length, etc.) and the difficult shape of the material (round, hollow, tapering, extruding rings, etc.), which were perceived as two important negative attributes. Due to the fact that every stem is different, the material is difficult to deploy for product development based on mass production or production in series.

Another negative aspect is the fact that the stem tends to crack in dry circumstances, which is not uncommon in buildings in Western Europe, warmed by central heating systems. For example, several of the lamps designed by Leonne Cuppen, based on the stem, cracked during the exposition. Although this vulnerability for cracking could be diminished by making a thin longitudinal cut across the length of the stem[45], tensions created by different shrinkage rates within the stem may still result in risks of cracking. When used outdoors and exposed to the natural environment and direct climatic circumstances (sun & rain), the stem will also lose quality. When directly exposed to the sun, the stem might crack for the same reasons as when used inside in too dry of circumstances. When directly exposed to moisture (e.g.

[44] In subsection 5.1.4 it was found that the environmental friendliness of the stem is considerably lowered if the stem is used in the Netherlands due to the high environmental impact caused by the inefficiency of the stem during transport.

[45] To prevent their stem based furniture from cracking, the company High Touch in Indonesia cuts a strip from the stem and carefully replaces it, by which dilatation joints are developed.

rain or direct soil contact) the bamboo stem will decay and deteriorate due to the vulnerability to molds and micro organisms.

Figure 6.4: The bamboo stem is vulnerable to splitting and biological degradation when used outdoors, directly exposed to climatic circumstances (sun & rain)

According to the designers, more research should be executed about appropriate drying and preservation techniques to diminish the risk of bamboo materials deteriorating due to biological degradation. In the wood industry preservation and drying are important areas of research; for bamboo the same priority should be made. However, the best prevention is the use of the stem in locations and applications in which it is not exposed to circumstances in which it might crack or deteriorate: inside in buildings which are not heated such as in countries in (sub)tropical regions, or outside but not directly exposed to sun and rain, and off the ground (e.g. under the roof).

Finally, the image of the stem was evaluated as a negative aspect by most of the participating designers. Especially when used in smaller products and in furniture the stem, due to the particular form, was labeled as being "old fashioned", "corny" and "colonial". Some designers mentioned the Asian connotation of bamboo, which makes it difficult to use the material in Western markets.

Processing & Finishing

From the attitude analysis it can be concluded that the bamboo stem is a difficult material to process (e.g. sawing, cutting, etc.). One of the main problems of the bamboo stem mentioned by several designers is that during processing the material splits, cracks and splinters quickly due to the unidirectional fiber structure. In combination with the hardness of the outer layer of the stem this wears saw blades down at a high rate. The hard waxy outside layer also makes it difficult to paint or lacquer the stem. However, this can be solved by sanding the stem before applying coatings. Because of the form (hollow, round, tapering) and irregularity, making joints with the stem in products or housing is difficult. Standardized means to connect materials (e.g. nails, screws, etc.) are usually not appropriate to make connections with the stem, which requires an alternative solution. As an example the joints developed by Daan van Rooijen for his biodegradable chair can be mentioned; by splitting the ends of the bamboo stem and combining it with bio resin and jute textiles, a strong joint is developed which is very efficient in terms of absorption of loads, yet facilitates flexibility with respect to the exact dimensions and position of the joint in the product (or building).

Figure 6.5: Joints developed by Daan van Rooijen consisting of bamboo stems split at the end, wrapped with jute fibers

Other

Many designers saw potential for the use of the stem; however, opinions differed about the best application and market in which the stem should be used. Most designers saw potential for the stem in housing and scaffolding in developing countries and emerging economies, and not in the West due to the difficult image of the stem. In the South designers saw the most potential for the bamboo stem in low-cost housing (abundant availability, cheap, light yet strong), but also for large scale high end buildings (e.g. structures by Simon Vélez; see figure 9.14 in subsection 9.3.3), in which the giant stems can create a "majestic look" as one of the designers put it. In smaller products the bamboo stem quickly gives a corny feeling to a product.

For use in Western Europe, it is therefore more difficult to find a suitable application due to the very specific looks, difficult form and all the connotations the stem brings along based on a centuries-long tradition. If the characteristic bamboo stem will remain visible in an application in the West, then it is recommended to use the material in applications in niche markets in which its connotations can provide an added value, such as the toy industry (using the friendly almost fairy-tale like character of the stem, see also figure 9.9), or in applications in which an exotic (e.g. beach pavilions) or Asian (e.g. wellness center) feeling is actually required.

However, according to various designers the distinctly obstinate archetypical character of the stem can also be perceived as a positive attribute of the stem; it provides the ultimate designers challenge. The key to success is to make the strong character of bamboo work to your advantage, and utilize the unique features of the stem in a product design. Although the focus of this chapter is on the bamboo materials, and not on products, the prototypes developed during the intervention provide several interesting lessons about how the strong character of the stem can be made to work to the advantage of the designer. In section 4.3 it was found that a small process innovation (e.g. sawing the stem in different angles, coating or sandblasting the stem, or combining the stem with other materials) can already give a completely new feeling to the stem. Some designers that did not work with the stem were positively surprised by the various stem-based prototypes developed during the Bamboo Labs. A nice example of turning a disadvantage (round, hollow, irregular form) into an advantage is the new material designed by Yvonne Laurysen and Erik Mantel. They diagonally cut the stem to acquire various unique ovals (the aesthetics of the cross cut section of bamboo was valued highly by several designers), cast in a resin, which forms perforations used for acoustics and light penetration. Another example is the chair by Maarten Baas, who makes the irregularity of the stem work as a unique element in his furniture design. A final example of a small process innovation which gives a completely different image to the stem and simultaneously prevents the visual and mechanical effects of cracking of the stem (see above), is the shrink sleeve put over the stem in the exhibition system of Gilian Schrofer. This system could have a lot of potential facilitating the use of the stem in more difficult circumstances (e.g. dry indoor, wet outdoor) both for the furniture, scaffolding and the building industry. For more examples of (small) process innovations providing a leap in market potential by utilizing the distinct form of the stem, the reader is referred to section 4.3.

Figure 6.6: Yvonne Laurysen and Erik Mantel use the diagonal cross cut section of the stem as a unique element in their new material

Figure 6.7: Gilian Schrofer put a shrink sleeve around the bamboo stem to improve the look of the stem and prevent visual and mechanical deficiencies caused by cracking

Another recommendation is to use the bamboo stem as a building stone for new materials, which in its turn can be used for new applications. A very good example is the material developed by Bertjan Pot, which is based on several small pieces of the bamboo stem, used as the middle part of a unique sandwich panel. Since the stem absorbs the glue very well in a transversal direction through the available vessels, in this way a very strong connection is formed between the stem and the veneer at the outside of the panel. Through vacuum suction the material actually utilizes the natural irregularity of each stem through the creation of a unique pattern in the new material itself.

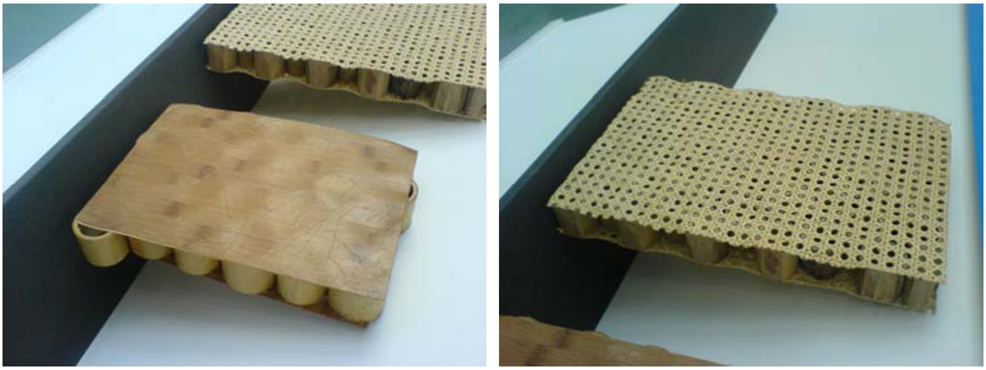


Figure 6.8: Experimental sample of the sandwich material developed by Bertjan Pot (before finishing)

Various designers mentioned that bamboo as a resource is very versatile, and that besides Moso, there are many other species with different colors, sizes and additional features that provide other unique opportunities for product development. As an example, for massive bamboo species such as *Chusquea Gigantea*, conventional joining means (e.g. nails) and milling are possible facilitating serial production to provide dimensionally stable sticks usable as input for the furniture or building industry (see figure 7.5).

6.2.3 Plybamboo

Plybamboo was evaluated quite positively (Mean: 5.24) in subsection 6.1.2. In this subsection the background behind this score is analyzed. In table 6.6 and figure 6.9 below, the results of the inquiries with the designers are presented. Note that Plybamboo is available in various sizes and thicknesses; therefore, in the table some separate evaluations posed by the designers about Plybamboo veneer were included as well.

Table 6.6: Attitude forming attributes of Plybamboo that were evaluated positively and negatively by the participating designers

	Positive aspects (number of responses)	Negative aspects (number of responses)
Material properties	Technical High hardness (6) Strong & sturdy (6) Good bendability (6) High wear resistance (1) High stability (1) Veneer: Transparency (2) Economical Good value (1) Environmental Environmentally friendly image (2) Sensorial Beautiful structure and color (10) Clean, professional look (6) Aesthetic quality of multi layered-ness (2) Good tactile properties (1) Intangible Surprising material, looks like a new wood species, yet bamboo can be recognized in a subtle way (2) Modern image (2)	Technical Veneer: Weaker and more vulnerable than wood veneer (1) Economical Expensive (3) Environmental Less environmentally friendly than stem (7) Sensorial Available colors not beautiful (2) Boring, non-surprising structure (2) Multi layered-ness (1) Intangible Illogical material (5) Mimic of wood, limited added value of bamboo (4) Too prefabricated and finished (1)
Processing and finishing	Good processability with regular wood working machines (7) Multi layered-ness provides design opportunities (3) Room for innovations in production process (1) Suitable for finishing with lacquer, wax, etc. (1)	Processing takes longer than wood (3)
Other	Availability in many different thicknesses, modular sizes, structures and colors (5) High applicability in furniture industry (2) Homogeneous quality (1) Veneer: Due to thinness and high quality, more opportunities than wood veneer (2)	

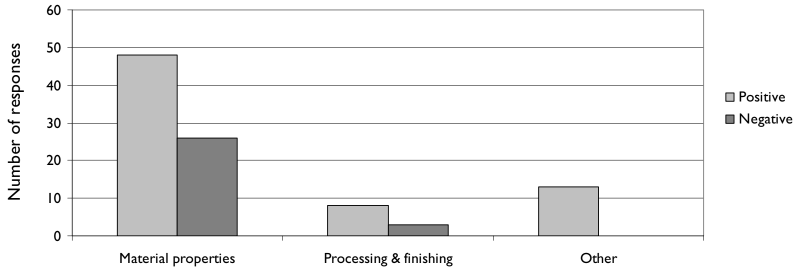


Figure 6.9: Accumulated responses with respect to positive and negative attributes forming the attitude toward Plybamboo

From figure 6.9 it can be concluded that in total Plybamboo is evaluated in a positive manner. In all categories more positive than negative attributes are mentioned for Plybamboo (material properties 48 vs. 26, processing & finishing 8 vs. 3, other 13 vs. 0). Below, these positive and negative attributes are further commented upon, based on feedback from the designers.

Material Properties

Various designers acclaimed the good mechanical properties of Plybamboo; the high hardness, strength, wear resistance and stability are appreciated. The high stability is caused by the structure of the material, made up of many small strips in which the glue seams act as a dilatation joint in the case of shrinking/swelling due to moisture and temperature changes. In contrast to the board, in the form of veneer the material is so thin that it is quite vulnerable to break and tear during processing and use. However, this thinness provides an added value to the material because it makes the material transparent, which is a property which can, for example, be utilized in lamps (see, for example, the lamp by Eliza Noordhoek).

Figure 6.10: Lamp designed by Eliza Noordhoek, taking advantage of the transparency of Plybamboo veneer

Another property which was appreciated by various designers was the high bendability of the material. By heating the material (e.g. through steaming or cooking) the lignin between the fibers becomes soft, facilitating the bending of the material in angles which only the best bending wood species (Beech) can match. Since bamboo is longer linear elastic than wood, it breaks less quickly. In their latest experiments, Tejo Remy and René Veenhuizen showed that if thin bands of Plybamboo (e.g. 3 mm thickness) are deployed, heat treatment may not even be necessary to bend the material, as long as it is fixated in its final bended position (see their lounge chair in figure 4.22). The bendability of bamboo therefore seems a unique property for bamboo which can be utilized very well as a competitive advantage for bamboo in product design over wood.

Figure 6.11: Sample of a bended seating at Moso International made from several layers Plybamboo veneer

These good mechanical properties of Plybamboo come with a price; a couple of designers found Plybamboo quite expensive. An alternative to cut costs is to use Plybamboo veneer on an inexpensive carrier (e.g. plywood). In subsection 5.1.3 it was found that besides cost reductions, this also results in a lower environmental burden. Due to the many process steps and glue application, Plybamboo was perceived[46] by most designers as a less environmentally friendly alternative than the bamboo stem. Actually the transition from a very mechanically efficient and environmentally friendly tube, through dozens of process steps in a rectangular, less environmentally friendly and less mechanically efficient material did not make sense to various designers. As a result they labeled Plybamboo as "an illogical material".

With respect to the sensorial properties Plybamboo scores well. Most designers appreciated the color (especially carbonized) and structure (especially side pressed) of Plybamboo, and many liked the clean, posh, professional look of Plybamboo. Here again it becomes clear that taste is very personal; there were also (a smaller number of) designers that actually found the available colors ugly, and the structure of Plybamboo too regular and therefore boring as compared to wood (which often has a more "flamy" structure). The aesthetic effect the multi layered-ness of Plybamboo provides was appreciated by a number of designers. Actually, this multi layered-ness stimulated designer Patrick Kruithof to develop a small cube meant as a tactile and visually interesting user object; see figure 6.12.

[46] In section 5.1 we found that perception to be right.

Figure 6.12: The small Plybamboo cube named "Cube 444" designed by Patrick Kruithof has good tactile and interesting visual features

In the same project Patrick Kruithof found that Plybamboo, after sanding, at some point becomes a very tactile material, and simultaneously gets a nice warm shine, possibly caused by brushing the silica in the material itself.

With respect to intangible properties, the opinions of the designers differed. In the line of the illogical character of the material mentioned above, some designers found that the added value of bamboo is lost in Plybamboo, and the material holds no challenge anymore. They found Plybamboo to just mimic wood, and that bamboo is not recognizable anymore in Plybamboo. Other designers actually found Plybamboo a surprising material, because one can see it is not wood, but by looking carefully one can recognize bamboo in a subtle way. As such, it was appreciated by some designers as a modern material which fits well in sustainability trends in the current Western market.

Processing & Finishing

Most designers were quite satisfied with the processability of Plybamboo. In general the same machines as those deployed for wood can be used. Some designers found that due to the hardness of Plybamboo, processing (e.g. sawing, sanding, drilling, etc.) takes longer than for wood.

As was already mentioned in section 4.3, several process innovations can provide opportunities for the use of Plybamboo as well. Some designers found that through high quality milling (CNC, water cutting, etc.) Plybamboo can yield interesting possibilities due to its specific structure. One such process innovation was found for veneer. Veneer seems very suitable for die-cutting, providing many interesting opportunities for lighting but also in other industries such as the high end packaging industry. Another example are the complex patterns and clean taut edges very well possible in Plybamboo (see for example design by Patrick Kruithof in figure 6.14). Also, the multi layered-ness of Plybamboo provides design opportunities, as the different reliefs in the mirror of Mette Hoekstra show (see figure 6.13). It should be noted that although these techniques seem promising, they are still expensive since it is too technically complicated for most bamboo producers in China, requiring the costly labor intensive processing to be executed in Western Europe.

Figure 6.13: Mette Hoekstra has taken advantage of the multi layered-ness of Plybamboo in the design of her mirror

Figure 6.14: New flooring/board material designed by Patrick Kruithof, taking advantage of clean edges of Plybamboo in its in-lays

Other

Various designers appreciated the versatility in sizes, thicknesses, textures and colors in which Plybamboo is available, which was perceived as an added value compared to wood. It should also be mentioned that the base material of Plybamboo, the bamboo strip, may in itself also be perceived as an interesting semi finished material. Although not included in the attitude assessment in subsection 6.1.2, Yvonne Laurysen and Erik Mantel performed several satisfactory experiments with the material and used rough bamboo strips in their flooring. They found that especially the rough bamboo strip (which still includes the skin of the stem) remains recognizable as bamboo, but loses the awkward image of the stem. Their color experiments (see figure 6.15) with ink and wax in case of semi-skinned strips revealed that the skin absorbs color less quickly than the inside of the bamboo, which gives interesting aesthetic effects in which the structure of bamboo is more recognizable. This coloring effect is different for wood and could be executed in an industrial way, and could therefore serve as a competitive advantage in future product innovation projects for bamboo as compared to wood. Furthermore, similar to the thinner Plybamboo bands mentioned above, the bamboo strips are also very bendable after heating.

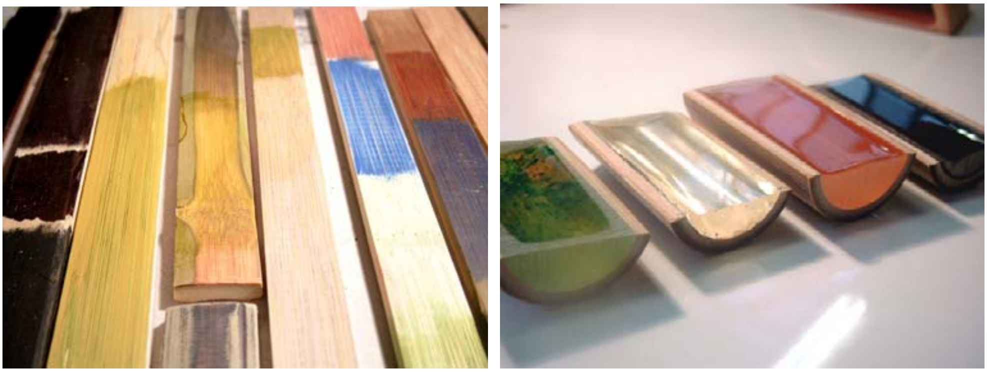


Figure 6.15: Samples of coloring experiments with strips executed by Yvonne Laurysen and Erik Mantel

Figure 6.16: Sample of a bending experiment with strips executed by Yvonne Laurysen and Erik Mantel

It can be concluded that the use of the bamboo strip, especially the rough strip, still holds a lot of unseized potential for product innovation since it combines virtues of both the stem (environmentally friendly, bamboo still recognizable) and Plybamboo (industrial production possible, good image), while avoiding the downfalls of both materials.

6.2.4 Composite

In this subsection the background behind the attitude of bamboo composite will be analyzed. Bamboo composite was evaluated in subsection 6.1.2 as being neutral to slightly positive (Mean: 4.20). In table 6.7 and figure 6.17 below, the positive and negative attributes contributing to this score are presented.

Table 6.7: Attitude forming attributes of bamboo composite that were evaluated positively and negatively by the participating designers

	Positive aspects (number of responses)	Negative aspects (number of responses)
Material properties	Technical Strong & efficient material (4) Unidirectional character of the bamboo fiber (1) Use Long durability as compared to other bamboo materials (2) Environmental Environmentally friendly alternative in case bio resins are used (10) Sensorial Smooth surface (1)	Technical Low tensile strength of the bamboo sticks (2) No uniform quality of the fiber (intrinsic feature of natural fibers) (1) Economical Expensive (1) Environmental Not very environmentally friendly in case regular resins are used (7) Sensorial Ugly (7) Poor tactile properties, does not feel well (1) Intangible Dull distant technological material with no character of its own (6) Alternative, corny image (2)
Processing & finishing	Versatility in processing possibilities resulting in large freedom of form (8)	Specific processing equipment required, demanding large investments in money and knowledge (3)
Other	High potential for the future (11) Casting fibers in transparent resin provides many aesthetic design opportunities (8) High applicability in various industries (8)	Added value of bamboo is unclear (13) Material is not yet ready for commercialization (12)

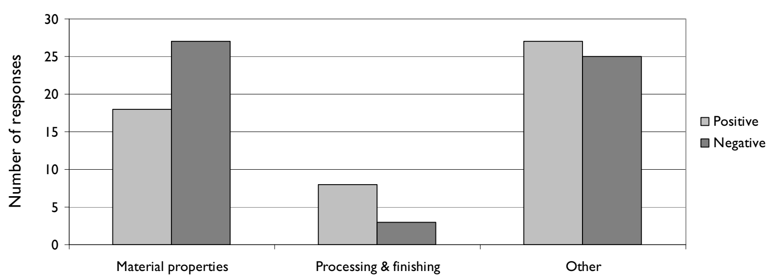


Figure 6.17: Accumulated responses with respect to positive and negative attributes forming the attitude toward bamboo composite

From figure 6.17 it can be concluded that bamboo composite is a controversial material for the designers. In some areas bamboo composite is evaluated in a positive manner (e.g. processing and finishing: 8 vs. 3), while in other areas more or less the same amount of positive and negative attributes were mentioned (other: 27 vs. 25), or more negative attributes were mentioned (material properties: 18 vs. 27). Below, these positive and negative attributes are further commented upon, based on feedback from the designers.

Material Properties

From a mechanical point of view a composite material is efficient since it combines the virtues of two materials. In case the bamboo fiber is used as a reinforcing material in a resin in the form of small sticks (see figure 6.18), the unidirectional character may be an added value, although some designers found the tensile strength of the sticks rather low, which could be caused by extensive drying of the sticks making them too brittle.

Figure 6.18: Small bamboo sticks commonly used for blinds can also be used in composite materials

The use of resin commonly provides a longer durability to a bamboo composite as compared to regular bamboo materials, and may even facilitate use outdoors. However, the same resin which makes the material more durable makes the material as a whole less environmentally friendly. According to several designers using the bamboo fiber out of environmental sustainability incentives, using polluting synthetic resins in composites does not make sense. According to them, only when the fiber is cast in biological degradable resins made from natural substances such as corn (bio resins) can bamboo composite be perceived as an environmentally benign alternative. It should be noted that the efficient material use of composites and higher durability does help to lower the environmental impact (see for example the use of BMB for corrugated sheets in the box in subsection 5.1.7). The concept of a completely biodegradable composite material (thus based on bio resin) which returns to its source after use, and fits well in the Cradle to Cradle concept of Mc Donough and Braungart (2002), was appreciated by several designers as an environmentally friendly solution. However, many designers did not like the aesthetics and corresponding image of bamboo composite, describing it as an ugly material that is so technologically adjusted that it turns into a fake, faceless, unrecognizable material that lacks any character. As such, the material is difficult to utilize for designers in high end products in which aesthetics play an important role, and seems to hold more potential in material cost sensitive and technically oriented industries such as the building- or automotive industries.

Processing & Finishing

Despite the perceived character-less image of bamboo composite, it holds many advantages during processing since it can be processed in many additional ways as compared to other bamboo (and wood based) materials. For example, through 3D-molding and injection-molding, bamboo composite provides a lot of freedom of form for designers in their product designs. A downside is that the production of bamboo composites, and products made from bamboo composites, requires specific processing facilities that demand high capital and knowledge investments. Due to the complexity of this process, outsourcing production to the South is also not an option since the average producer in the South is not able to produce nor process the material in a proficient manner.

Other

Although many designers were of the opinion that bamboo composite is still in the development phase (see also below), many also saw the future potential of the material - if based on bio resins - after improvements will have been made. This perceived potential is based on the good processability, control and stability of the properties, and subsequent high applicability of bamboo composites in industries with a high resource and material consumption, such as the building-, automotive- and packaging industries. In case of a completely biodegradable material, bamboo composites - and actually natural fiber based composites in general - could be a good alternative from an environmental point of view. Since it fits very well in the sustainability trend, many subsidies should be open to provide bamboo composites with the required boost in development that is still needed (see also subsection 9.3.3). Although most designers do not directly see potential for the use of bamboo composite in high end product design, some mentioned that casting the bamboo sticks in transparent resin could hold promising aesthetic effects by allocating the sticks in such a way that they may provide an impression of depth ("frozen grass"), or follow directly the force flows in a product, which besides the aesthetic quality could also be positive from a mechanical point of view.

Figure 6.19: Casting the bamboo fiber in the form of small sticks in a transparent resin provides interesting visual effects, such as these samples developed by Ro Koster & Ad Kil (left) and Daan van Rooijen (right) demonstrate

Although various designers saw the potential of bamboo composites, many also admitted that in its current state the material is not yet ready for commercialization in the Western European market. For example, the isolated bamboo fibers are not yet commercially available in high quantities and in sufficient quality. The same applies to bio resins; they are still expensive and cannot compete yet in quality with synthetic resins. To be able to actually compete in demanding industries such as the building industry, bamboo composite will need to be thoroughly tested and optimized so that the exact properties and tolerances are known, in order to be able to guarantee the performance of the material. For all these aspects additional research is required.

Another important aspect for bamboo composite which was evaluated in a negative way by most designers is the fact that the added value of bamboo in the material is unclear. A couple of designers wondered if bamboo is not worth more than just as a filling material; in the form of fiber, bamboo as a resource is completely unrecognizable. Furthermore, various designers doubted if bamboo is the best fiber to use in natural fiber based composites, and expected that other, possibly European grown alternatives such as hemp, could be more environmentally friendly. Besides the lower transport distance, this could also be caused by the fact that it takes many process steps to distil the bamboo fiber from the tissue in the stem. However, a potential advantage of using the bamboo fiber for composites is the high annual biomass production (see box in subsection 5.2.3), and subsequent high availability and low costs. It should be noted that the bamboo fiber will function best if the micro fiber is isolated from the parenchyma cells. In the form of sticks (used as reinforcement in the intervention) the bamboo micro fibers are not isolated, and parenchyma cells may weaken the tissue. However, the sticks can be accurately positioned in the composite material and can simultaneously be used as filling material, while the production of sticks is easily done in bamboo producing countries. If the bamboo micro fiber could be isolated, the mechanical quality of the fibers would be higher, and could be competitive with most other natural fibers (hemp, flax, sisal, etc.). The challenge is thus to extract the fiber in a cost-, environmentally- and mechanically efficient manner. Besides the need for efficient extraction methods, a lot of other additional research is also required before bamboo fiber based composites can compete with incumbent materials. Much emphasis should be placed on finding the right, economically competitive biodegradable resin to perfect the bond between the bamboo fiber and the resin. Furthermore, it should be investigated which bamboo species have the most suitable fiber for use in composites.

As seen in subsection 5.3.2, it would be best if bamboo composites would be developed and used locally, preventing the environmental burden of transport. If simple building products are developed based on bamboo composites (e.g. I-beams), the material could hold potential for the local building industry. If bamboo fibers are to be used in composite material in the West, it is recommended that the bamboo resource is processed into fibers locally, and then transported in a compressed manner to the composite manufacturer in the West.

6.2.5 Strand Woven Bamboo

Strand Woven Bamboo (SWB) was evaluated in a neutral way in subsection 6.1.2 (Mean: 4.06). In table 6.8 and figure 6.20 below, the positive and negative attributes, as perceived by the designers, contributing to this neutral score are presented. It should be noted that not many designers decided to focus on SWB during the Bamboo Labs. As a result not all designers could remember the material during the interviews, causing the lower number of responses for SWB.

Table 6.8: Attitude forming attributes of SWB that were evaluated positively and negatively by the participating designers

	Positive aspects (number of responses)	Negative aspects (number of responses)
Material properties	<u>Technical</u> Very hard (2) Very strong & sturdy (2) <u>Use</u> Good durability outside (3) <u>Environmental</u> Potentially environmentally friendly alternative for tropical hardwood (3) <u>Sensorial</u> Nice material (5) <u>Intangible</u> Bamboo unrecognizable; tropical hardwood look (1)	<u>Technical</u> High weight (5) <u>Economical</u> Too expensive (2) <u>Environmental</u> Not very environmentally friendly (5) <u>Sensorial</u> Visually uninteresting, boring material (3) Not beautiful (2) Coarse material (1) <u>Intangible</u> Character-less material (8) Bamboo unrecognizable (5)
Processing and finishing		Difficult processing due to very high hardness (3) Splinters quickly during processing (1)
Other	High potential if it can actually be used outdoors as an alternative for tropical hardwood (10) Potentially available in large massive sizes (1)	Further optimization and research required (7) Unclear added value as compared to modified softwood (4) Availability in sufficient quantity & quality (2)

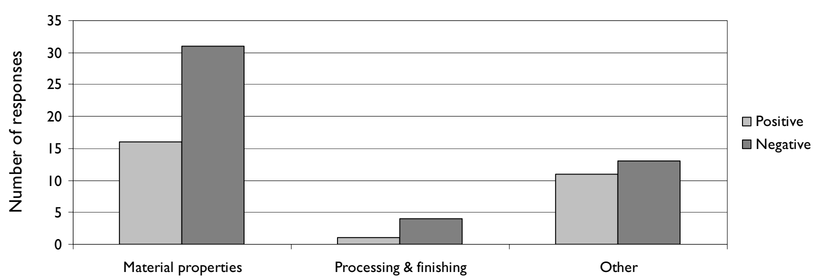


Figure 6.20: Accumulated responses with respect to positive and negative attributes forming the attitude toward SWB

From figure 6.20 it can be seen that for all categories there are more negative attributes mentioned by the designers than positive aspects (material properties 31 vs. 16, processing & finishing 4 vs. 1, other 13 vs. 11). Since only one designer (Jacqueline Moors) actually worked with the material, few attributes with respect to processing & finishing were found. Below, the positive and negative attributes are further commented upon, based on feedback from the designers.

Material Properties

Since SWB is compressed, it is very hard, strong and sturdy, which were perceived as positive attributes. However, due to the compression, the material is also very heavy, which was perceived as a negative attribute by several designers. First of all, during use (e.g. in garden furniture) this high weight can make handling difficult. Furthermore, the high weight also makes transport less efficient. Because of this reason, but especially because of the high resin content, various designers had doubts about the actual environmental friendliness of SWB.[47] If the harmfulness and amount of resin can be reduced, some designers still perceive SWB as a sustainable alternative to tropical hardwood for use outdoors. The latest (spring 2008) versions of SWB seem to have a good durability outside (see footnote 12 in subsection 1.1.2), while SWB seems to be less susceptible to graying than wood, due to UV radiation.
The opinions about the aesthetics of the material differ; some designers found the texture and looks of SWB nice, while other designers found it not beautiful but coarse or even boring. Various designers found bamboo unrecognizable in SWB. This can be perceived as an added value, since the material resembles tropical hardwood, but for most designers it was not. Some designers did not understand why a light, efficient material (the bamboo stem) should be converted into a compressed, solid, heavy, inefficient material. Several designers found SWB to be a character-less material, which does not have any appeal; it is so far engineered and combined with other materials that it is no longer clear what it really is; bamboo, wood or plastic. Finally, it should be mentioned that the name of Strand Woven Bamboo was also not considered to be very appealing. The name does not give a direct sense of the added value of this product, and does not sound trendy.

Processing & Finishing

Due to its high hardness, SWB is not easily processed. It demands drills, saws and other processing facilities of premium quality and will be more time consuming than wood processing. Furthermore, the material tends to splinter during processing.
A promising aspect of SWB is that the material is produced in molds, and can potentially be produced in a solid way in massive sizes, unmatched by wood. For example, the large size of the floor tiles for use outdoors designed by Jacqueline Moors (see figure 6.21) was appreciated by many designers. However, more research should be executed in this area, to further investigate the boundaries of manipulation of the form of SWB through compression in molds.

[47] In subsection 5.1.6 this concern was found to be partly right.

Figure 6.21: Detail of the SWB floor tiles designed by Jacqueline Moors

Other

Various designers did perceive SWB as having potential as an environmental alternative to tropical hardwood if the durability outside and resin content is optimized. However, several designers doubted if SWB would actually be a better alternative from an environmental point of view as compared to thermally modified or acetylated softwood.[48] Furthermore, various designers mentioned that in its current state the material is not yet ready for full commercialization and still needs to be further tested in terms of mechanical properties, tolerances and actual durability outside. Once these aspects will be known and quality is controlled, the material should be made available in sufficient quantity and in reliable quality.

[48] In subsection 5.1.6 was found that these designers were right.

6.2.6 Mats

Bamboo mats were evaluated in a slightly negative way in subsection 6.1.2 (Mean: 3.65). In table 6.9 and figure 6.22 below, the positive and negative attributes, as perceived by the designers, contributing to this score are presented. It should be noted that not many designers decided to focus on bamboo mats. As a result not all designers remembered the material well during the interviews, causing the lower number of responses for bamboo mats.

Table 6.9: Attitude forming attributes of bamboo mats that were evaluated positively and negatively by the participating designers

	Positive aspects (number of responses)	Negative aspects (number of responses)
Material properties	<u>Technical</u> Flexible & bendable (3) Multi directional strength (2) <u>Economical</u> Inexpensive (3) <u>Sensorial</u> Nice look (1) <u>Intangible</u> Good, pure material (3) Bamboo recognizable, yet completely different character (1) Strong cultural connotation (1)	<u>Use</u> Sensitive to humidity (1) <u>Environmental</u> Environmental friendliness unclear due to resins used (1) <u>Sensorial</u> Ugly (1) Coarse and splintery material (5) <u>Intangible</u> Corny, alternative, cheap image (7)
Processing and finishing	Freedom of form through processing (10) Weaving facilitates many interesting design opportunities (7)	Lack of processing facilities in South (1) Vulnerable material; thin strips break easily (1)
Other	Challenging material with potential (7) High applicability for a new set of applications (6) Potential for local value addition in rural areas (5)	Not yet ready for commercialization (1) Difficult applicability in Western products (1)

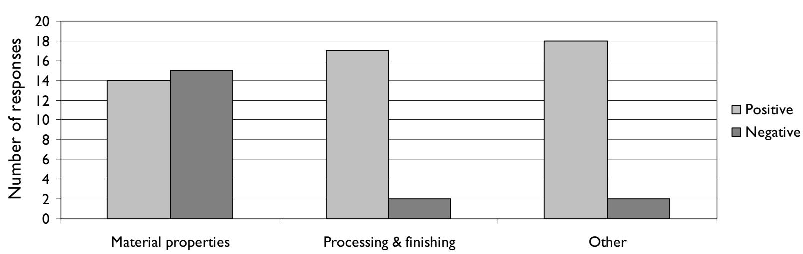


Figure 6.22: Accumulated responses with respect to positive and negative attributes forming the attitude toward bamboo mats

From figure 6.22 it can be concluded that despite the low current attitude score (Mean: 3.65), mostly caused by various negative attributes related to the material properties (15 vs. 14), designers do see potential in bamboo mats for the future especially because of processing possibilities (17 positive vs. 2 negative), and the potential of these techniques for use in new applications; see category "other" (18 positive vs. 2 negative). Below, these positive and negative attributes are further commented upon, based on feedback from the designers.

Material Properties

Since the bamboo resource in the form of thin strips is woven into mats, the semi finished material this produces is flexible, yet strong in various directions due to the multi directional weaving patterns. However, like most bamboo materials, the material is sensitive to humidity and susceptible to mold and decay, which can be diminished by drying and preserving it well, or by casting the material in resin (creating Bamboo Mat Board in the process). For the latter option, which is also used to fixate the mats in case the material is used to form 3D forms (bowls and grid matrices), the environmental friendliness may be in jeopardy depending on the resin used. A positive attribute is that the bamboo mats are an inexpensive base material. However, various designers found that the material ventilates this through its image, which was also perceived as cheap and as an alternative. This image is caused by the fact that bamboo mats have been used for ages in very traditional products. On the other hand, various other designers found the material authentic and pure, a material in which bamboo is clearly visible.

Processing & Finishing

Above, it was found that one of the positive assets of the bamboo mats is their flexibility and strength in various directions. This asset facilitates their processing in various forms, including complicated 3D forms, resulting in a high level of freedom of form which was strongly appreciated by most designers. This freedom of form could prove to be an added value for bamboo mats compared to other bamboo and wood materials. However, it should be noted that facilities required for 3D bending are limited in the South, and therefore processing should most likely be executed in the North.

Another asset evaluated positively is the variation possible in the base material by deploying different weaving patterns. The bamboo mats are based on thinly woven strips, which can be woven in many different ways and patterns, providing many opportunities from an aesthetic, but also a mechanical point of view, facilitating efficient load resistance and force flows. For example, while hexagonally woven bamboo mats were often used in various chairs in the 1960s and 1970s (see figure 6.23), they are now often neglected, even though they provide many interesting design opportunities. In the future weaving could potentially also be done in an industrial manner.

Figure 6.23: Woven bamboo patterns used in a traditional stool

Bamboo strips may also be used in the building industry and in architecture, for the development of giant woven structures and grid matrices, based on traditional weaving techniques. Designers Tejo Remy and René Veenhuizen executed experiments with weaving bamboo strips and longitudinal pieces of Plybamboo. However, if the thickness of the strips in such a structure is too thick, the strips are lifted too far from the surface of the matrix, resulting in high tensions at cross-overs which could lead to the cracking of the material. In case the matrix is cast in resin or by using thinner strips this problem can be avoided. However, more research should be executed about the potential and limitations of bamboo strips for use in woven matrices for various small (furniture) and large (building structures) applications.

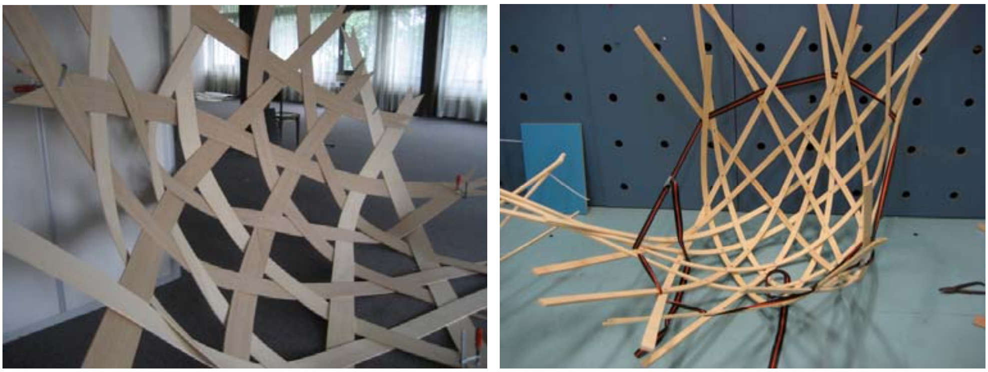


Figure 6.24: Various experiments by Tejo Remy and René Veenhuizen with structures based on woven strips and Plybamboo bands

Other

Many designers see potential for the bamboo mats once the material has been further developed and will become available to the Western market in good quality and in high quantities. One of the attributes which several designers appreciated was the fact that production of bamboo mats can be executed locally (in the bamboo producing countries) in a manual or semi-industrial way. In this way local craftsmen may profit from the value addition, and new employment opportunities may be generated.

Various designers found that the material, due to its freedom of form and processing possibilities (see above) has more potential in a different range of applications in the furniture and building industry (see examples of grid matrices above) than regular bamboo and wooden board materials. Even compared to bendable wood species (e.g. Beech), the mats may provide additional design opportunities. Some designers also saw potential for the use of Bamboo Mat Board in the building- and pallet industry as an alternative for low cost wooden board materials, but also for interior decoration due to its rough, retro look fitting in current styling trends.

Finally, in a similar way as for the bamboo stem, the bamboo mat was perceived as a challenging material for designers, with still plenty of room for exploration and innovation (in contrast to completely finished materials such as Plybamboo and SWB). Despite its flaws and the strong connotations of the material, many designers found that more experiments should be done by designers to find out how to make the strong character of the bamboo mats work to their advantage. Various designers found Maarten Baptist's chair a very good example of how to translate the initial mats with their cheap image and rough look into a contemporary product in which the specific character of the mats is utilized as a competitive advantage (texture, 3D bending).

6.3 Conclusions

This chapter focuses on answering the third research question (RQ3: To what extent is bamboo perceived by Dutch designers as a successful material for product design?).

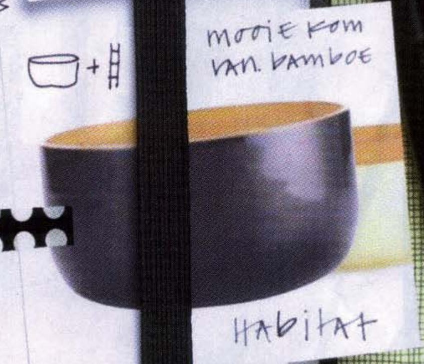
Based on the findings in the previous sections it can be concluded that at the moment the attitude of the participating designers toward the various bamboo materials is slightly lower than toward their soft- and hardwood competitors. Of all bamboo materials, only Plybamboo scores better than softwood (Pine); however, it scores lower than hardwood (Oak).

The background analysis of the various attitude scores found in section 6.2 provides a better insight into the attitude scores. If the focus would be solely on the attitude scores, one would expect that bamboo mats and the stem were evaluated in such a negative way that they could almost be neglected for future product development in the West. However, the background analysis showed that the attitude scores were evaluated by the designers based on the current situation, and that most designers did not include the future potential of the material in their overall attitude evaluation. In section 6.2 was found that most designers see a lot of potential for bamboo materials such as the stem, mats, composite and SWB, once the material is optimized and utilized in the right applications. Thus, in the future - after optimization - the attitude scores for these materials could most likely be higher. Based on the experiences of the designers it was also found that they see the most potential for improvement in bamboo materials in which the unique features of bamboo can be utilized. If bamboo tries to mimic wood in materials (board materials such as Plybamboo and SWB), it is very difficult to really ventilate the added value of bamboo, while for the other materials (especially bamboo mats and stem), the unique characteristics of the material provide opportunities for differentiation compared to wood (see for example the example of corrugated roof sheets made from BMB in the box in subsection 5.1.7).
Plybamboo is the only bamboo material which has already reached the introduction phase of the material commercialization process, and it is available in sufficient quality and quantity to really compete with wooden alternatives. Since it is expected that there is not much room for further optimization of Plybamboo, it is expected that the current attitude score (5.24) will remain more or less the same in the future.

Maaike Koorman is conceptdesigner en geïnteresseerd in hoe trends tot stand komen. Ze is altijd op zoek naar nieuwe dingen.

Back to bamboe

Goed nieuws: bamboe als woontrend! Dit duurzame en ecologische materiaal is een prima alternatief voor hardhout. Bamboe is bovendien gemakkelijk te buigen. We zullen steeds meer meubels zien met prachtige gebogen vormen. Wég dus met het stoffige imago van bamboe. De nieuwste ontwerpen zijn vooral mooi en spannend. Dat was al te zien op het bamboo-lab van de Dutch Design Week Eindhoven, vorig jaar. Op de tentoonstelling 'Dutch Design meets Bamboo' werd ook al duidelijk wat je allemaal met bamboe kunt doen. En dat is veel, vernieuwend en verbluffend! Dit jaar wordt er weer een Dutch Design Week Eindhoven gehouden, van 20 t/m 28 oktober. De moeite waard! Verder zijn ook de merken Artek, Leolux en Auping bezig met het ontwikkelen van bamboe meubels. Ten slotte: Rixt Reitsma gaat voor Dutch Design in Development naar Indonesië om een interieurcollectie met bamboe te ontwerpen. Ik ga hem zeker volgen op: **www.lidewijenrixtinindonesie.blogspot.com**



7 Impact Evaluation

In the previous chapter the various bamboo materials used by the designers during the intervention were evaluated for their suitability as a material for product design. In this chapter the impact of the intervention is evaluated by comparing various relevant success indicators before (T0) and after (T1) the core intervention, and before (T1) and after (T2) the extended intervention.

First, in section 7.1, after an introduction (subsection 7.1.1), the impact of the core intervention (Bamboo Labs) is evaluated for the primary target group, the participating designers (subsection 7.1.2) and for the material supplier (subsection 7.1.3). In section 7.2 the impact of the extended intervention is evaluated based on various rough indicators categorized in exposure (subsection 7.2.2), indicators related to additional value chain nodes (subsection 7.2.3) and material supplier related indicators (subsection 7.2.4). Finally, in section 7.3 several conclusions will be drawn with respect to the impact of the intervention as a whole (core- and extended intervention).

7.1 Impact Evaluation Core Intervention

7.1.1 Introduction

This section evaluates the impact of the core intervention based on various indicators at T1 compared to T0 relating to the participating designers (value chain contacts, knowledge and behavioral intention) and the material supplier (new value chain contacts, new projects and additional outputs).

For the impact evaluation of the participating designers the value of these indicators was distilled from the quantitative data acquired during the questionnaire interviews executed with the participating designers at both T0 and T1 (for more information see subsection 3.4.2). For the determination of the value chain contacts gained, the designers were asked to fill in a diagram similar to the value chain diagram in figure 1.16 (subsection 1.2.3) in which they had to depict all the new relevant bamboo related value chain contacts they had acquired for the categories "material supplier", "designers", "processors", "application manufacturers", "retailers" and "consumers". Besides these direct value chain nodes, they were also asked to mention relevant contacts not directly linked to the value chain, such as bamboo related knowledge institutes and platform organizations.
As was already mentioned in chapter 6, the designers were asked to evaluate their knowledge about the various bamboo materials, with respect to the material properties and processing & finishing do's and don'ts. The evaluation was based on a 10-point scale, as commonly used in the Dutch educational system (1. very bad, 2. bad, 3. very insufficient, 4. insufficient, 5. almost sufficient, 6. sufficient, 7. amply sufficient, 8. good, 9. very good, 10. outstanding.), with the average Dutch designer as a frame of reference.
For the determination of the difference in behavioral intention at T1 compared to T0, the designers had to assess the chance of implementation (in percentages) of the various bamboo materials in concrete products/projects in the near future (within 2 years), excluding the potential further development of the prototypes designed during the Bamboo Labs.

To measure the impact of the core intervention for the material supplier (Moso International B.V., in the remainder of this section referred to as “material supplier”) several questionnaires were posed to the material supplier through email before a final face-to-face interview was executed by the author with the director of the material supplier (Mr. René Zaal) and in-house designer Arjan van der Vegte. It should be noted that the impact of the core (and extended) intervention has been considerably greater than expected, which was the reason the material supplier was initially not included as the primary target group in the core intervention (see subsection 2.2.1).

To evaluate the impact, the quantitative data related to the success indicators “knowledge” and “behavioral intention” acquired at T0 and T1 by the participating designers was statistically analyzed in SPSS 13.0. The impact evaluation of the other success indicators was evaluated by counting and categorizing the various contacts mentioned by the participating designers at T0 and T1.

7.1.2 Participating Designers

The impact of the core intervention (Bamboo Labs) for the participating designers was evaluated based on the following bamboo related indicators of the participating designers: value chain contacts gained, knowledge gained, the difference in behavioral intention at T1 compared to T0, and some additional unexpected outputs.

Value Chain Contacts Gained

In figure 7.1 the combined amount of bamboo related value chain contacts, gained by all the 21 participating designers in the intervention, are depicted. Note that there will be a considerable overlap in contacts; most of the participating designers have gained similar contacts. For the value chain node “designers”, the participating designers in the intervention were also included in the count, while for the value chain contact category “knowledge institutes and platform organizations” the various tutors were also included. Finally, it should be noted that some of the new contacts have more than one value chain node under one umbrella, e.g. the furniture company Leolux combines the value chain nodes of processing, application manufacturing and retail.

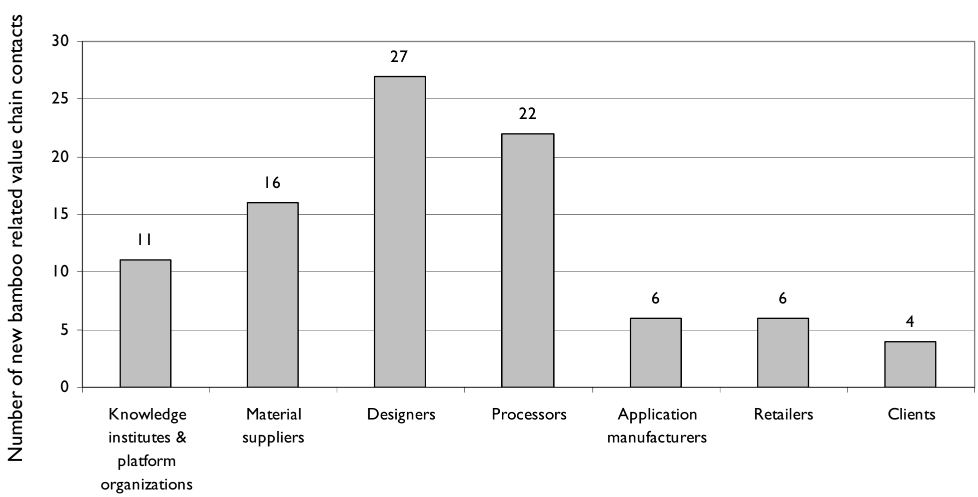


Figure 7.1: Number of new bamboo related value chain contacts gained by the participating designers at T1 compared to T0

In total, 92 new bamboo related value chain contacts were gained by the participating designers. Most of the 11 knowledge institutes and platform organizations, relate to universities where bamboo related research is taking place (e.g. DUT, Technical University Eindhoven, University of Leuven, National Institute of Design, Rhode Island School of Design). Most other gained contacts in this category relate to material or design related platform organizations (e.g. Design Platform Eindhoven, Material Sense, Material Matters). Besides the main material sponsor Moso International, various bamboo materials and additives were derived from other material suppliers (e.g. bamboo textile and fibers from the Dutch Textile Museum). For the category "designers", most contacts consisted of the group of participating designers themselves. Some of the designers actively collaborated during the intervention outside of the Bamboo Lab days, especially the ones that worked on bamboo composites (Ro Koster, Ad Kil, Daan van Rooijen and Eliza Noordhoek). A relatively large number (22 contacts) of new contacts was acquired by the participating designers in the processing industry ranging from wood benders (e.g. de Smet, van Drenth) and millers (e.g. CMC de Waal) to composite processors (e.g. Wolvega Panelen) and sandblasters (e.g. Strabeco). Furthermore, many contacts in wooden furniture processing were gained (e.g. Henk van Pelt, Harold van den Bosch). A relatively small number of application manufacturers (e.g. NPSP, Leolux, Itoki) and retailers & clients (e.g. Wood Works, Gelfort, Haans, Music Theatre Amsterdam) were acquired by the participating designers during the Bamboo Labs. There are two reasons for this. First of all, the foundation Things Design, acting as broker between designers, processors, application manufacturers and retailers, soon recognized the potential of bamboo for CSR based business practices. Things Design adopted several of the prototypes developed during the intervention, which, in collaboration with Moso International, it is trying to commercialize through its network (these contacts are not included in figure 7.1). Secondly, a lot of the designers work independently and on demand (e.g. Lara de Greef, Bertjan Pot) or are self producing (e.g. Leonne Cuppen for Yksi, Yvonne Laurysen and Erik Mantel for Lama Concept) and therefore, in case of small batches, they are not always dependent on application manufacturers and retailers to reach clients and get their products on the market.

With almost a hundred new bamboo related value chain contacts gained, the core intervention can be perceived as relatively successful for this indicator. In section 8.2 it will be analyzed to what extent this increase in value chain contacts (and also for other impact indicators such as knowledge) has influenced the overall purpose of the intervention: to stimulate the commercialization rate of bamboo in products in Western Europe. Here it will become clear that for a successful intervention the choice for participating designers with a strong value chain network may be more efficient than facilitating an increase in material related value chain contacts through the design workshops.

Knowledge Gained

In figure 7.2 below the average knowledge of the participating designers about the various bamboo materials deployed during the intervention at T0 and T1 are represented based on a 10-point scale. The knowledge at T0 about SWB was scored as "1" (lowest score possible) because none of the designers knew the material at T0. Below, in table 7.1, the average difference in knowledge between T1 and T0 of the various bamboo materials is depicted as well.

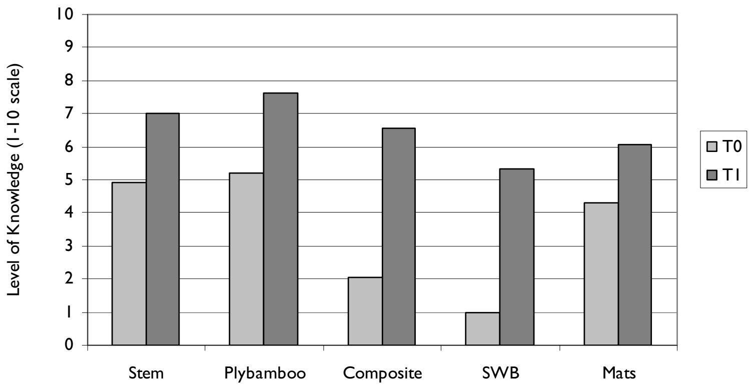


Figure 7.2: Average knowledge of the participating designers about the various bamboo materials used during the Bamboo Labs at T0 and T1

Table 7.1: Difference in average knowledge of the participating designers at T1 and T0 about the various bamboo materials used during the Bamboo Labs

	N	Mean	Std. Deviation
Knowledge stem T1-T0	21	2.12	1.448
Knowledge Plybamboo T1-T0	21	2.43	1.469
Knowledge composite T1-T0	20	4.50	2.439
Knowledge SWB T1-T0	19	4.34	1.684
Knowledge mats T1-T0	20	1.75	2.106

The descriptive statistics in table 7.1 and figure 7.2 above show that the knowledge about the various bamboo materials is considerably higher at T1 compared to T0. Through the Dependent t-test (Plybamboo and mats) and the Wilcoxon Signed Rank Test (stem, composite and SWB) it was found that this difference was also statistically significant:
Plybamboo T1 (M=7.62, SE=-.20) versus T0 (M=5.19, SE=0.21, t(20)=-7.58, p<.05, r=.64)
Mats T1 (M=6.05, SE=0.31) versus T0 (M=4.30, SE=0.43, t(19)=-3.72 p<.05, r=.65)
Stem T1 (Mdn=7.00) versus T0 (Mdn=5.00), T=0 , p<.05, r=-.86
Composite T1 (Mdn=7.00) versus T0 (Mdn=1.00), T=0, p<.05, r=-.88
SWB T1 (Mdn=5.00) versus T0 (M=1.00), T=0, p<.05, r=-.88.

From the table and figure it can be concluded that the increase in knowledge between T1 and T0 is around two points on a 10-point scale for the materials with which the designers were already acquainted at T0 (stem, Plybamboo, mats). For the other materials (composite, SWB) with which the designers were not or were only slightly acquainted, the increase in knowledge is even more than four points. With respect to the increase in knowledge the impact of the core intervention can therefore be evaluated as successful. Furthermore, it can be concluded that after the core intervention, at T1, the average knowledge level of the designers is more than sufficient (more than a score of "6" on the 1-10 scale) for all bamboo materials, except SWB. This is probably caused by the fact that SWB is still a new material which was covered to a lesser extent in the MSS, and about which the tutors also did not know a lot yet.

Difference in Behavioral Intention

In figure 7.3 below the average behavioral intention (in %) at T0 and T1 of the participating designers toward the various bamboo materials is represented. The average behavioral intention at T0 toward SWB is zero because none of the designers knew the material at T0. Below, in table 7.2, the average difference in behavioral intention between T1 and T0 of the various bamboo materials is depicted as well.

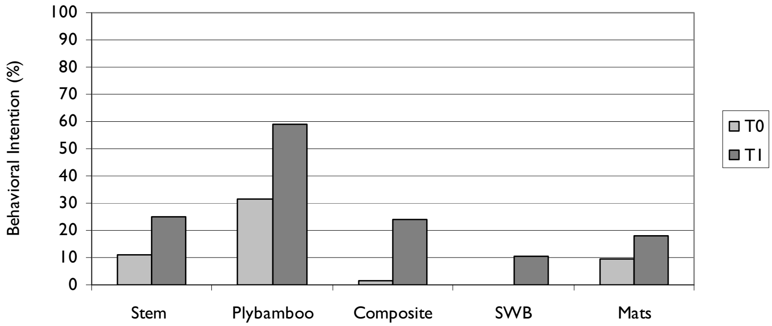


Figure 7.3: Average behavioral intention of the participating designers toward the various bamboo materials used during the Bamboo Labs at T0 and T1

Table 7.2: Average difference in behavioral intention of the participating designers between T1 and T0 toward the various bamboo materials

	N	Mean	Std. Deviation
Behavioral intention stem T1-T0	21	13.67	28.526
Behavioral intention Plybamboo T1-T0	21	27.14	27.639
Behavioral intention composite T1-T0	20	22.50	22.213
Behavioral intention SWB T1-T0	19	10.26	14.090
Behavioral intention mats T1-T0	20	8.25	24.935

The descriptive statistics table 7.2 and figure 7.3 above show that the behavioral intention toward the various bamboo materials is considerably higher at T1 compared to T0. Through the Wilcoxon Signed Rank Test it was found that this difference was also statistically significant for the stem, Plybamboo, composite and SWB (not for mats):

Stem T1 (Mdn=10.00) versus T0 (Mdn=10.00), T=29.5, p<.05, r=-.44
Plybamboo T1 (Mdn=70.00) versus T0 (Mdn=10.00), T=0, p<.05, r=-.72.
Composite T1 (Mdn=10.00) versus T0 (Mdn=0.00), T=0, p<.05, r=-.82
SWB T1 (Mdn=5.00) versus T0 (Mdn=0.00), T=0, p<.05, r=-.64

From the table and figure it can be concluded that the behavioral intention at T1 compared to T0 increased most for Plybamboo (27.1%) and bamboo composite (22.5%). Furthermore, it can be noticed that compared to other materials the behavioral intention for Plybamboo was already higher at T0 (31.7% compared to stem at 11.2% and mats at 9.8%), and has held this lead at T1 (58.5% compared to 24.9% for the stem and 24.0% for bamboo composite). These outcomes correlate well with the findings in chapter 6.

With respect to the increase in behavioral intention the impact of the intervention has increased in all cases ranging from 8.3% (mats) to 27.1% (Plybamboo). As such, the intervention can be evaluated as quite successful. Note that the causes of the increase in behavioral intention of the participating designers will be analyzed in the following chapter 8.

While the T1 evaluation took place in May-June 2007, at the time of writing of this dissertation (winter 2007-spring 2008), besides the products developed during the Bamboo Labs that will be further developed toward commercialization (see table 4.3), some of the participating designers had actually already started new design projects with bamboo (state of the art situation in April 2008): Lara de Greef, Thijs Bakker, Ed van Engelen and Tejo Remy & René Veenhuizen (see box below). This correlates well with the behavioral intention prospects provided by these designers at T1 (70% for Plybamboo for Tejo Remy & René Veenhuizen, 40% for stem and 90% for Plybamboo for Thijs Bakker, 80% stem and Plybamboo for Ed van Engelen).

Box: New Bamboo Projects Initiated by the Participating Designers (April 2008)

Ed van Engelen, in-house designer for Haans, found bamboo to fit excellently with the corporate identity of Haans (Asian, natural materials, sustainability). Through his experiences during the Bamboo Labs he decided to increase the number of bamboo products in his design portfolio for Haans. Besides the products developed during the Bamboo Labs (room divider and table), which have already been successfully launched on the market, he designed various new furniture sets (outdoor and indoor; see figure 7.5), as well as a shelf cupboard based on bamboo veneer, which was inspired by the distribution of the nodes in the bamboo stem (see figure 7.4).

Figure 7.4: Bamboo shelf cupboard designed by Ed van Engelen, inspired by the distribution of the nodes in the bamboo stem

Figure 7.5: New furniture sets designed by Ed van Engelen

Tejo Remy and René Veenhuizen used their experiences about bending Plybamboo, gained with the lounge chair designed during the Bamboo Labs, for a new interior design project in which they had to develop a new coffee corner in the atrium of a school (see figure 7.6). They noted that "without the experiences gained during the Bamboo Labs, we would never have come up with a design in bamboo" for this project.

Figure 7.6: Scale model (left) and one-on-one experiment (right) for the coffee corner in the atrium of a school made out of bended Plybamboo by Tejo Remy and René Veenhuizen

Based on her experiences with the Plybamboo chair developed during the Bamboo Labs, Lara de Greef received a commission of a music theater in Amsterdam to develop new chairs and tables from bamboo (see figure 7.7).

Figure 7.7: New Plybamboo chair designed by Lara de Greef

Based on his experiences during the Bamboo Labs, Thijs Bakker decided to develop a new and improved version of the chairs designed during the Bamboo Labs, which are still under development (see prototype in figure 7.8).

Figure 7.8: Bamboo chair designed by Thijs Bakker, inspired by his design made during the Bamboo Labs, combining the stem and Plybamboo

Additional Outputs

Besides the impact indicators established before the intervention took place, through the interviews with the designers and observations made by the author, various additional outputs were found that should also be mentioned. Several of the participating designers noted that they gained a lot of inspiration through the Bamboo Labs as additional output. For example, Ed van Engelen mentioned that he had gained more than thirty new ideas for bamboo products during the process of the Bamboo Labs. In the box above we have seen that he is already materializing several of these ideas. Other designers noted that after having seen the process of other participating designers working with other bamboo materials, they also got inspired and interested in experimenting with these materials. For example, Yvonne Laurysen & Erik Mantel gained interest in the use of bamboo textile inspired by the work of Lara de Greef (bamboo textile cushion, see figure 7.9), and as a consequence are working on a new bamboo textile based product design.

Figure 7.9: Bamboo yarn used by Lara de Greef in her design

Furthermore, it should be noted that especially for young designers with fewer than five years of professional design experience, the Bamboo Labs functioned for them as a very useful master-class as an introduction into the professional design practice. Most of these young designers found it very educational to experience the work- and design approach of other designers. This aspect of the Bamboo Labs can be perceived as an unexpected additional (positive) knowledge spin-off of the core intervention.

7.1.3 Material Supplier

In this subsection it is evaluated what the impact of the core intervention has been for the material supplier, measured by several rough indicators: new value chain contacts, actual projects and additional outputs.

Value Chain Contacts

The material supplier experienced the core intervention as a very inspirational and educational experience which has helped the company to shift and broaden its strategic product innovation course. First of all, as a result of the intervention, the company has broadened its product portfolio (product innovation) to also include design furniture and accessories. Secondly, as a result of the various prototypes developed, the experiments executed and questions posed during the core intervention, the company has turned into the road of process innovation: Several new processing technologies already available for other materials have been tested for various bamboo materials which have provided promising possibilities for product innovation for bamboo (e.g. die-casting, folding and/or laminated bending for bamboo veneer, using extrusion techniques for bamboo fiber based composites, combined use of bamboo with other materials such as glass and plastics, etc.). This process of process innovation was largely fuelled by the Bamboo Labs, functioning as a think tank (see below in this subsection under the heading "Additional Outputs"). As a result, the company has broadened its (production) activities, including the production of some of the newly designed furniture and accessories.

As a result of this new portal of innovation the company entered, the material supplier gained dozens of new value chain contacts mostly in the realm of process innovation (e.g. processors specialized in die-casting for the packaging industry, extrusion experts, bio resin suppliers, testing institutes for durability, water resistance, fire safety, etc.), but also in the realm of furniture and accessories (e.g. furniture producers and manufacturers).

Some of these new contacts represent a dormant collaboration (possibly active in the future), while with other value chain contacts an active collaboration has already been initiated. For example, in the realm of product innovation the furniture manufacturers Haans and Leolux can be perceived as two important new business partners for the material supplier in the interior decoration field. For both companies Moso International serves as the material supplier, while for Haans the company also manufacturers some of the furniture in China, and takes on the role of producer. Above, we have seen that in its turn Haans has developed itself to become a material champion for bamboo toward potential clients. Finally, garden furniture and beach house manufacturer Gelfort has gained much interest, especially in the application of SWB in its future products & projects, and may develop into an important business partner in the future.

Projects

The material supplier will play a role in the commercialization of several of the products developed during the Bamboo Labs. As found in table 4.3, eight of the products designed during the Bamboo Labs will be further developed toward potential commercialization. Since the bamboo stem is normally not a material sold by the material supplier, the room divider by Ed van Engelen and the new material by Yvonne Laurysen and Erik Mantel are projects for which the material supplier will most likely not provide the material. For the material supplier this is too bad especially since the room divider appears to turn out as very successful with already about 1000 requests by retailers in spring 2008. Since the dividers are produced in Vietnam, the local bamboo industry over there will benefit most from this success.


Figure 7.10: The room divider designed by Ed van Engelen is one of the most successful products produced during the Bamboo Labs in terms of short-term commercialization

Furthermore, the material supplier will most likely provide the material for the new design projects initiated by Ed van Engelen, Tejo Remy & René Veenhuizen, Lara de Greef and Thijs Bakker (see box in subsection 7.1.2). As was mentioned already above, the development process for these products has also led to new projects with potential for future commercialization. For example, the lamps made from Plybamboo veneer, designed by Eliza Noordhoek, required die-cutting techniques. As a result the material supplier is investigating if through this technique bamboo veneer can be used in the high end packaging industry (e.g. luxury gift wrapping for wine bottles or shoes; see figure 7.11).

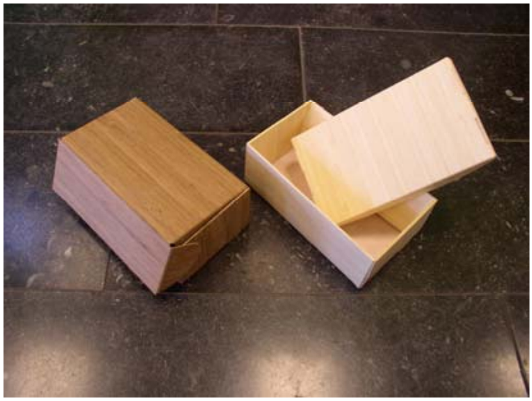


Figure 7.11: Bamboo veneer used for high end shoe boxes

Additional Outputs

Last but not least, an important additional output of the Bamboo Labs is not only the increase in knowledge of the participating designers, but also the development of generic knowledge about bamboo materials. Since each designer set out on a process of experimentation and discovery for their design projects and had received the state of the art information for each material through the MSS (see subsection 2.2.4), through their experiments they were able to find new solutions in processing and finishing to utilize positive material properties and avoid negative ones. As such, the combined designers participating in the Bamboo Labs acted as a powerful think tank through which new knowledge was developed about the various bamboo materials.

This new important bamboo related information has been labeled "new generic knowledge" about the five bamboo materials used, because it has been acquired by various stakeholders during the core intervention and is very useful for the bamboo material producing industry. Apart from the participating designers, the material supplier may take the most advantage of this new generic knowledge, which may be used by the material supplier as a competitive advantage for product- and process innovation compared to competitors.

Although part of the knowledge developed will remain in the heads of the designers who experimented with the material as tacit knowledge, the author has tried to make this generic knowledge explicit and thus available to society by archiving the most important findings in the book *Dutch Design meets Bamboo* and in this dissertation (especially section 4.3 and section 6.2), thus also targeting the problem of lack of availability and diffusion of high quality bamboo information (see also subsection 2.2.1).

Figure 7.12: Material experiments executed by Yvonne Laurysen and Erik Mantel in their design studio in Amsterdam

7.2 Impact Evaluation Extended Intervention

7.2.1 Introduction

In this section it is evaluated what the impact of the extended intervention (diffusion of the results) has been for additional relevant value chain nodes besides the participating designers (evaluation of the core intervention; see previous section) for several rough indicators, sorted into categories of "exposure", "indicators related to additional stakeholders" and "material supplier related indicators". The impact analysis for the extended intervention has been updated through April 2008.

For the evaluation of these indicators data from various sources had to be collected using several methods (see also subsection 3.4.2). The exposure of the results (organized and unorganized) was measured through email inquiries to the organization team, participating designers and the material supplier, aggregated with observations made by the author (internet, magazines, fairs, etc.). Since the financial responsible entity for DDMB, Design Platform Eindhoven, had to monitor all the exposure generated by the project in order to provide a project assessment to the subsidiaries upon termination of the project (report submitted to subsidiary fall 2007), the author could take advantage of this valuable information as well.

To measure the impact for additional stakeholders as a result of the exposure, the attitude and behavioral intention toward the bamboo materials of relevant value chain nodes besides the participating designers (e.g. other designers, processors, application manufacturers) was assessed. Since it is impossible to measure the difference in attitude and behavioral intention for the complete population exposed to the results of the Bamboo Labs (subsection 7.2.2 will show that more than one million people have been exposed to the results), an appropriate sample group was selected to measure the potential increase in attitude and behavioral intention as a result of the exposure. Since for a correct impact assessment the attitude and behavioral intention of the sample group needs to be measured before (T0) and after (T1) the exposure to the results, executing the assessment during the seminar organized around the exposition (see also subsection 2.2.4) provided the most feasible solution. The seminar was attended by 36 people, of which 24 belonged to directly relevant value chain nodes for potential implementation of bamboo in the future (designers, producers, retailers). The names of the respondents including the company they belong to can be found in appendix A. At the start of the

seminar, before the participants had seen the exposition or had received any information about bamboo, they were asked to fill in a questionnaire in which they had to score their attitude and behavioral intention toward the five bamboo materials that were used during the Bamboo Labs. Due to time limits (ten minutes for the complete questionnaire) the scales used were kept simple: a 1-7 semantic differential scale (1 - very negative, 2 - negative, 3 - somewhat negative, 4 - neutral, 5 - somewhat positive, 6 - positive, 7 - very positive) for their attitude toward bamboo as potential natural designers material, and a 1-5 scale (1 - nil, 2 - small, 3 - reasonable, 4 - large, 5 - very large) for their knowledge (with respect to properties and processing & finishing possibilities and constraints) about the bamboo materials and their behavioral intention (chances of implementation of the bamboo materials within two years in their company). A couple of weeks after the seminar the author conducted a telephone interview with the 24 relevant value chain nodes to assess their attitude and behavioral intention at T1. Although the participants of the seminar had received more input about bamboo than a regular visitor of the exposition, or someone who was exposed to the project through the media, it was expected that the seminar participants would provide some indication of the (direction of) change in attitude and behavioral intention for the population of appropriate value chain nodes in general.
For the impact of the extended intervention for additional stakeholders several additional outputs also related to the problems targeted by the extended intervention (see figure 2.1 in subsection 2.2.1), such as the impact on image & trends, were analyzed. Data for these additional outputs was acquired through questionnaires posed per email to the organization team, material supplier, and participating designers, again aggregated with observations made by the author.

The impact of the extended intervention for the material supplier was measured using the same success indicators as for the evaluation of the core evaluation: new value chain contacts, new projects initiated and additional outputs. Data was acquired through questionnaires posed through email and through a face-to-face interview with the material supplier.

The data analysis of most rough indicators was executed by counting and categorizing the various responses. Only the increase in attitude and behavioral intention for the relevant value chain nodes attending the seminar was analyzed statistically before and after the seminar.

It should be noted that in the extended intervention the target was to diffuse the results of the core intervention (Bamboo Labs), through the various people involved in DDMB (designers, organization team, material supplier) but also through the media. Since diffusion through a social system can go very quickly once a new champion adopts the results (Rogers 2003), it is very hard to track the exact impact of the extended intervention. The impact evaluation in this research will therefore never be complete, especially since through the media the results of the Bamboo Labs will have reached many additional social systems in which it could have triggered stakeholders to start innovating with bamboo (e.g. in Asia & Australia several copies of the book *Dutch Design meets Bamboo* have been sold).

7.2.2 Exposure

The impact of DDMB is first measured in terms of exposure. Through the exposure, the commercialization rate of bamboo in products might eventually indirectly be positively influenced, which is also dependent on the quality (credibility, reach) of the exposure channels used. The exposure can be divided into organized exposure (active diffusion by the organization team) and unorganized exposure (diffusion by additional parties such as the media or through the participating designers).

Organized Exposure

The organized exposure is divided in the exposition, the book *Dutch Design meets Bamboo*, activities organized around the Bamboo Labs and some additional miscellaneous outputs.

Exposition

The exposition, designed to travel by the designers of the exhibition Loods 5 designers, was opened by former Dutch Minister Laurens Jan Brinkhorst in the art center "CBK de Krabbedans" in Eindhoven, where it remained for almost two months in May and June 2007. The exposition was visited by 1400 people during that time. According to employees of CBK de Krabbedans many of the visitors were designers, and many of them were inspired by the exposition, taking along material samples provided by the material suppliers after their visit. Also, several students of the neighboring design university, "the Design Academy" visited the exposition.

In the summer of 2007 the materials library "Material Matters" adopted the exhibition. Since then it was leased to the Faculty of Architecture of DUT (Fall 2007) as part of the international conference African Perspectives, and to the National Weaving Museum in Noordwolde in the North of the Netherlands (Spring 2008), visited by a couple hundred persons.

Figure 7.13: The former Dutch Minister Laurens Jan Brinkhorst being shown around in the exposition DDMB in CBK de Krabbedans in Eindhoven

Figure 7.14: The exposition DDMB in the National Dutch Weaving Museum in Noordwolde

Book: *Dutch Design meets Bamboo*

The bilingual full color book *Dutch Design meets Bamboo* was published in June 2007 alongside the DDMB exposition and serves as the exposition catalogue, supplemented with important background information about bamboo. The book was published by [Z]OO producties in a circulation of 2500 copies, of which about half were sold or distributed at the opening of the exposition. The book is for sale through various (online) bookstores in Canada, the USA, Australia and the EU. According to the publisher over three hundred copies had been sold by international customers in April 2008, including customers from Taiwan, China, Japan and Australia.

Figure 7.15: The book Dutch Design meets Bamboo was distributed through various bookstores (left), including online (right)

Activities Organized around Bamboo Labs

Several activities were organized around the Bamboo Labs (for more background information see also subsection 2.2.4). First of all, at the beginning of the project (23 October 2006) lectures were held by Enrique Martinez of the Rhode Island School of Design (RISD) and the author about the past, present and future of bamboo as a potential material for designers (150 attendants); see figure 7.16. A year after the opening of the project a lecture was provided by designer Marco Groenen and the author during the Dutch Design Week 2007 titled "Dutch Design Meets Bamboo, One Year After", attended by 50-100 people. Secondly, at the opening of the exposition (May 25, 2007), a small design fair was organized, targeted toward designers, processors, application manufacturers and retailers in the interior decoration sector and adjacent sectors, attended by about 150 visitors. Thirdly, around the exposition in

CBK de Krabbedans, a half-day seminar (14 June 2007) was organized in collaboration with Material Matters, targeted toward a similar audience as the design fair (36 attendants).

Figure 7.16: DDMB kicked off with a series of lectures in the old Philips building "de Witte Dame" in Eindhoven, attended by about 150 visitors

Miscellaneous

Next to the various exposure generating items mentioned above, the organization team also announced the Bamboo Labs or the results of the Bamboo Labs through press releases (before lectures in October 2006 and October 2007, and before the opening of the exposition in May 2007), through flyers sent to design universities and the Dutch Designers Association (BNO) in October 2006 and May 2007, and through advertisements in October 2006 and May 2007 in several design-related newsletters and magazines (Items, Vormberichten, Uitkrant, Galeriekrant).

Unorganized Exposure

The unorganized exposure is categorized in this thesis into "printed media", "radio & television", "internet", "exposure through participating designers" and some additional "miscellaneous" outputs. Note that there are large differences in reach between the various channels through which the results of the Bamboo Labs were presented, ranging from an exposure to more than one million people (e.g. Printed media: Telegraaf, de Standaard; Radio & television: Eigen Huis & Tuin) to a couple hundred people (e.g. Printed media: European Bamboo Society; Radio & Television: Radio Centraal).

Printed Media

In table 7.3 the printed media that covered the results of the Bamboo Labs are depicted. As can be noted from the table, the combination of bamboo and design seems very susceptible to media coverage with over thirty publications that cover the results of the Bamboo Labs, excluding publications that focused on only one design (see subheading "participating designers" below).

Table 7.3: Newspapers and magazines in which the results of the Bamboo Labs were presented

Title of magazine/paper	Month of publication
Telegraaf Woonkrant	Nov 2006
Product magazine	Jan 2007
Capitalogue (Design Connection Eindhoven), de Standaard Magazine (Belgium)	Apr 2007
Delta (DUT), Echt (Utrecht design sector), Eindhovens Dagblad, Excellent Galeriekrant, Goeie Zaken (magazine for entrepreneurs), O_2 magazine, Soeps, UIT cultuurkrant, Vormberichten BNO, Woonspotkrant	May 2007
BN/DeStem, Brabants Dagblad	June 2007
Bamboe (European Bamboo Society), Tubantia, Dagblad van het Noorden, De Gelderlander, Leidsch dagblad, Haarlems dagblad	Summer 2007
Elsevier thema, VT-wonen, de architect/interieur, Goodies, Magazine American Bamboo Society, Items	Nov 2007
Figaro (Japan)	Jan 2008
VT-wonen	Feb 2008

Figure 7.17: the results of the Bamboo Labs presented in the Japanese magazine "Figaro"

<u>Radio & Television</u>

The results of the Bamboo Labs were also announced or presented on various radio and television shows. Around the opening of the exposition in May 2007 co-initiator designer Marco Groenen was interviewed for Omroep Brabant (radio). The author was interviewed on national radio on May 23, 2007 for Desmet live (about 25,000-50,000 listeners) and on local radio on March 22, 2008 for Radio Centraal (a couple hundred listeners). Furthermore, the author presented the results of the Bamboo Labs on national television in the program "Eigen Huis & Tuin" on April 5, 2008 (1.2 million viewers); see figure 7.18.

Figure 7.18: The author presenting the results of DDMB in the popular Dutch television program "Eigen Huis & Tuin"

Internet

Besides in printed form, the internet is an important medium to spread news and publications digitally. The results of the Bamboo Labs were announced or presented through various websites (a.o. the Dutch Design Week site, the Design Platform Eindhoven site, Design.nl of the Premsela design foundation, the site of the Dutch Association of Designers (BNO), etc). A Google search on April 9, 2008 on the exact match "Dutch Design meets Bamboo" provided 685 exact hits. Note that the internet usually serves as a temporary medium, as items are replaced over time. For example, the International Network for Bamboo and Rattan announced DDMB on their website in June 2007 from which it was removed a couple of months later.

Participating Designers

Especially for the products designed during the Bamboo Labs, but (if satisfied) also for bamboo as material, the participating designers themselves have also served as nuclei of diffusion of the results of the Bamboo Labs, through design fairs, mouth to mouth promotion in their network and through exposure of their results through similar media as mentioned above (printed media, radio & television and the internet).

In subsection 2.2.4 it was already mentioned that in the interior decoration sector, design fairs (especially the ones in Milan and Frankfurt) are the most important venues for designers to present their new designs, and to bring their recent work to the surface. Several designers already presented their prototypes developed during the Bamboo Labs in various fairs (e.g. Leonne Cuppen on the Milan design fair in 2007, Lotte van Laatum and Lara de Graaf in 2007 on the Woonbeurs Amsterdam, Ed van Engelen on Ambiente 2008 in Frankfurt) or are set to do so (e.g. Lara de Greef and Thijs Bakker for the Milan fair in 2008, Yvonne Laurysen and Erik Mantel for the Interieur 2008 fair in Kortrijk, Belgium). Furthermore, if satisfied with bamboo, several of the participating designers mentioned to the author that they had promoted the material to colleagues, clients and producers. Mouth to mouth promotion worked best for young independent designers sharing design studios (e.g. Temporary Art Center in Eindhoven).

Figure 7.19: The stand of Lara de Greef with bamboo furniture at the design fair in Milan in 2008

Finally, designers are usually quite skilled in promoting and marketing their new designs, and know how to acquire exposure of their results through the media. As a result several of the participating designers presented their results in national and international magazines ranging from Transmaterial 2 in Japan & dpi Design magazine in Taiwan (Yvonne Laurysen & Erik Mantel), to ID&c in China (Leonne Cuppen), and to several design magazines in the Netherlands (e.g. Lotte van Laatum in Hide & Chic).

Figure 7.20 (left): Yksi (Leonne Cuppen) presented their work in the biggest design magazine in China, "ID&c"
Figure 7.21 (right): Lotte van Laatum presented her chair in the Dutch life style magazine "Hide & Chic"

The above shows that if designers like a material, they can become very important in the diffusion of the material, and start to act as champion for a new material, especially since they have links with all value chain nodes that are important to convince in the adoption of a new material in high end consumer durables (colleague designers, producers, retailers, consumers). Some of the participating designers that were satisfied with a bamboo material are now acting as material champions for bamboo, which can be perceived as a very important spin-off of the Bamboo Labs (e.g. Ed van Engelen & Thijs Bakker for stem and Plybamboo; Tejo Remy, Rene Veen huizen, Lotte van Laatum & Lara de Greef for Plybamboo, Yvonne Laurysen and Erik Mantel for the stem, strips & Plybamboo). Ed van Engelen noted that the DDMB project has also provided him recognition which has helped him to gain credibility with customers and has enabled him to push the material in the market, especially in France.

Miscellaneous

Another example of unorganized exposure was the adoption of several of the prototypes developed during the Bamboo Labs in another international traveling exposition, D-Compose, organized by Material Sense, with a first stop in Hannover from April 21-25, 2008.

Finally, it should be noted here that various participants and other relevant stakeholders had mentioned to the author that the title of the project "Dutch Design meets Bamboo" was perceived as being very accurate, yet intriguing, making use of the strong (positive) associations with "Dutch Design" and strong (sometimes negative) associations with "Bamboo", to trigger the interest of potential consumers and users. As such, the title of the project has proven to be a strong brand for the project.

7.2.3 Indicators Related to Additional Value Chain Nodes

As a result of the exposure, during the extended intervention various additional relevant value chain nodes besides the participating designers (other designers, producers, retailers) were most likely influenced. For the impact evaluation of the extended intervention the potential increase in attitude and behavioral intention for relevant value chain nodes was therefore measured as well as additional outputs, unforeseen before the intervention started.

Increase in Attitude

In figure 7.22 below, the average attitude (based on a 7-point scale) of the participants of the bamboo seminar about the various bamboo materials used during the Bamboo Labs is represented. Note that in this analysis only the participants belonging to directly relevant value chain nodes have been included (N = 24). Since at T0 many of the participants were not acquainted with some of the bamboo materials, in many cases N < 24. Below, in table 7.4, the average difference in attitude between T1 and T0 of the various bamboo materials is depicted, except for SWB and composite because no (SWB) or too few (composite) data was acquired for T0, since hardly any persons were acquainted with these materials at that time.

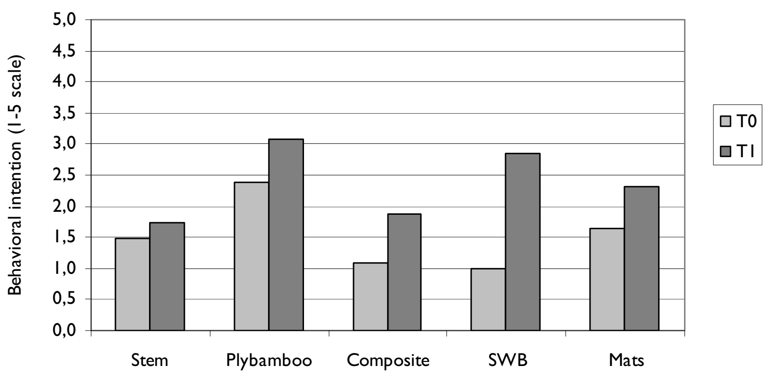


Figure 7.22: Average attitude of participants of the bamboo seminar about the various bamboo materials at T0 and T1

Table 7.4: Difference in average attitude of participants of the bamboo seminar about the various bamboo materials at T0 and T1

	N	Mean	Std. Deviation
Delta Attitude stem T1-T0	24	0.38	0.770
Delta Attitude Plybamboo T1-T0	19	0.79	1.357
Delta Attitude mats T1-T0	21	0.67	0.966

From figure 7.22 it becomes clear that in all cases the attitude of the participants toward the bamboo materials improved after the exposure through the seminar ranging from 0.38 (stem) to 0.79 (board) on a 1-7 scale, excluding composite and SWB due to no (SWB) or limited (composite) data. Through the Dependent t-test (Plybamboo and mats) and the Wilcoxon Signed Rank Test (stem) it was found that this difference was also statistically significant:

Plybamboo T1 ($M=5.95$, $SE=0.18$) versus T0 ($M=5.20$, $SE=0.30$, $t(19)=-2.52$, $p<.05$, $r=.50$)

Mats T1 ($M=4.24$, $SE=0.34$) versus T0 ($M=3.57$, $SE=0.34$, $t(20)=-3.16$, $p<.05$, $r=.58$)

Stem T1 ($Mdn=3.00$) versus T0 ($Mdn=3.00$), $T=10.00$, $p<.05$, $r=-.44$.

Also noteworthy is the fact that the attitude (T1) toward Plybamboo is highest (5.96) followed by the attitude toward SWB (5.6). The other bamboo materials are appreciated less (mats at 4.13, composite at 3.96 and stem at 3.67).

Increase in Behavioral Intention

In figure 7.23 below the average behavioral intention at T0 & T1 (based on a 5-point scale) of the participants of the bamboo seminar about the various bamboo materials used during the Bamboo Labs is represented. Note that also in this analysis only the directly relevant value chain nodes have been included (N = 24). The behavioral intention at T0 toward SWB is "1" (lowest score possible) because none of the designers knew the material at T0 (also note the very low behavioral intention for composite at T0 for the same reason). Below, in table 7.5, the average difference in behavioral intention between T1 and T0 for the various bamboo materials is depicted.

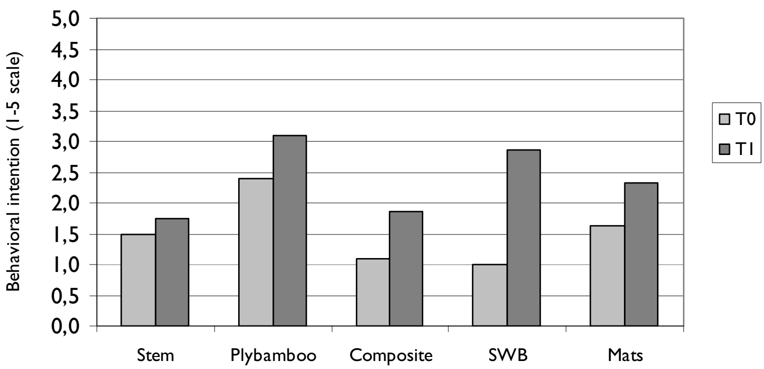


Figure 7.23: Average behavioral intention of participants of the bamboo seminar about the various bamboo materials at T0 and T1

Table 7.5: Difference in average behavioral intention of participants of the bamboo seminar about the various bamboo materials at T0 and T1

	N	Mean	Std. Deviation
Behavioral intention stem T1-T0	23	0.26	0.541
Behavioral intention Plybamboo T1-T0	23	0.70	1.222
Behavioral intention composite T1-T0	23	0.78	0.795
Behavioral intention SWB T1-T0	20	1.85	0.988
Behavioral intention mats T1-T0	22	0.68	0.780

From the table and figure it can be concluded that the behavioral intention of participants of the bamboo seminar at T1 compared to T0 has increased for all bamboo materials, and most for materials with which the participants had not or had hardly been acquainted with at T0: SWB (1.85) and bamboo composite (0.78), followed by the materials with which most were already acquainted at T0: Plybamboo (0.70), mats (0.68) and stem (only 0.26). Through the Dependent T-test (Plybamboo) and Wilcoxon Signed Rank Test (stem, composite, SWB, mats) it was found that this difference was also statistically significant:
Plybamboo T1 (M=1.73, SE=0.16) versus T0 (M=1.48, SE=0.12), $t(22)=-2.31$, $p<.05$, $r=.44$
Stem T1(Mdn=2.00) versus T0 (Mdn=1.00), T=4.50, $p<.05$, $r=-.44$
Composite T1 (Mdn=2.00) versus T0 (Mdn=1.00), T=10.00, $p<.05$, $r=-.66$
SWB T1 (Mdn=3.00) versus T0 (Mdn=1.00), T=10.00, $p<.05$, $r=-.85$
Mats T1 (Mdn=2.00) versus T0 (Mdn=2.00), T=10.00, $p<.05$, $r=-.65$.
Furthermore, it can be noticed, just like for the behavioral intention for the participating designers (see subsection 7.1.2), that compared to the other bamboo materials the behavioral intention for Plybamboo was already higher at T0 (2.39 compared to mats at 1.64 and stem at 1.48), and has held this lead at T1 (3.09 compared to 2.85 for SWB and 2.32 for mats).

With respect to the increase in behavioral intention the impact of the intervention has increased in all cases ranging from 0.26 (stem) to 1.85 (Plybamboo). Above, it was already found that the attitude of all the participants of the seminar had also increased in a positive way for all bamboo materials. It seems that by viewing the results of the exposition and gaining more background information about the various bamboo materials, the attitude and behavioral intention of relevant value chain nodes increases. Although their information input was less intensive than the input during the seminar, from which participants were taken as a sample group for the attitude and behavioral intention evaluation, it may be expected that the attitude and behavioral intention of other relevant value chain nodes who were exposed to the results of the Bamboo Labs in another way (e.g. through the book) will also have increased (probably to a lesser extent).
Of course, it remains unclear to what extent this increase in attitude and behavioral intention of relevant value chain nodes as a result of the exposure will actually lead to the implementation of bamboo in projects of these value chain nodes. Although the seeds of implementing bamboo in projects might already have been planted in the heads of many relevant value chain nodes, it may take years before these seeds germinate, if they germinate at all. Since product development takes time, and a material usually needs to fit in a project, it may take years before the increased attitude and interest in the material might pay off and lead to actual implementation. Although in terms of product development it is still very short after the finish of the Bamboo Labs, in the following subsection it is analyzed to what extent new value chain nodes interested in implementing bamboo have already approached the material supplier by April 2008.

Additional Outputs

Next to the (expected) increase in attitude and behavioral intention of relevant value chain nodes exposed to the results of the intervention, several additional outputs caused by the diffusion of the results were observed. One of the most important additional outputs may be the improved image and trendiness of bamboo as a material for product design. In subsection 1.2.3 and appendix C it was found that the poor image and lack of trendiness of bamboo was perceived as a severe problem in Western Europe. However, as a result of the exposure of the Bamboo Lab prototypes, bamboo was recognized as a trend in several acknowledged design magazines such as VT Wonen (November 2007) and Elsevier (October 2007, see figure 7.24). An excerpt from the text in VT Wonen written by trend watcher Maaike Kooijman (see also introduction picture of chapter 7 on page 196):

"*Away with the corny image of bamboo! Good news: Bamboo as a trend for interior design. This sustainable material is an excellent alternative for hardwood. In the exposition 'Dutch Design meets Bamboo' it was shown what can be done with bamboo. And that is a lot, innovative and mind blowing.*"

Furthermore, in the important trend book published by the Dutch Interior Institute, trend watcher/guru Lidewij Edelcourt mentioned bended bamboo as a trend in interior design for 2008. Since many of these trend watchers and magazines also have a trendsetting character, it can be expected that due to these publications more designers, producers and retail outlets will gain an interest in bamboo.


TRENDDOSSIER

BAMBOE

WE KENNEN HET VAN DE KNEUTERIGE, OUDERWETSE MEUBELS. MAAR NU HEBBEN ONTWERPERS ZICH OP DIT MILIEUVRIENDELIJKE MATERIAAL GESTORT

Figure 7.24: Bamboo recognized as a high end material for product design in the Dutch magazine "Elsevier thema"

Another nice example of a spin-off effect created by the exposure of the results of the core intervention was the invitation in March 2008 of all designers participating in the Bamboo Labs - now perceived as bamboo experts - for an international design workshop by the Chinese toy manufacturer HaPe International. At the time of writing of this thesis it was still unclear which of the designers would accept this invitation.

As an another important spin-off effect for the future it is hoped that the generic bamboo knowledge developed through the Bamboo Labs and archived in the book *Dutch Design meets Bamboo* and this dissertation will be further diffused and exposed, increasing the availability and diffusion of bamboo design related information.

Some negative spin-off effects were also noted, such as the copying of designs made during the Bamboo Labs by Chinese manufacturers. For example, at the Domotex fair in Hannover (January 2008) the technique used by Ed van Engelen for the development of his room divider (using longitudinal slices of bamboo) and also the wall panels designed by Yvonne Laurysen & Erik Mantel were copied by Chinese producers. Although this development is negative from the perspective of the participating designers and material supplier, in a way it is also a compliment; in general only promising products are copied. Furthermore, from the perspective of the Chinese bamboo industry it is a good sign that producers gain a better understanding of the needs in Western markets and the role innovation can play in this process.

7.2.4 Material Supplier Related Indicators

In this subsection the impact of the extended intervention (diffusion of the results) for the material supplier is evaluated, measured by the same rough indicators as used for the core intervention: new value chain contacts, actual projects and additional outputs.
It should be noted that the impact of the extended intervention was only evaluated for Moso International as the main sponsor of DDMB. However, the exposure generated by the project will most likely also have had a positive effect for other bamboo material suppliers and producers (e.g. competitors of Moso International, but also suppliers of other bamboo materials such as the stem, fiber or textile).

New Value Chain Contacts

Besides the dozens of new contacts gained in the manufacturing and processing industry through the Bamboo Labs (see subsection 7.1.3), the material supplier found that after DDMB there was an increased interest in bamboo materials by dozens of (mostly independent and not self producing) designers unleashed by the exposure around the intervention through various media (magazines, websites, exposition, the DDMB book, fairs, seminars, etc.).
Furthermore, the foundation Things Design, introduced to bamboo at the seminar, has developed as a potentially important business partner. Things Design recognized the potential of bamboo and adopted several of the prototypes developed during the intervention, attempting to commercialize them through its network. Things Design has also promoted the use of bamboo in its own network of designers. As such, Things Design has developed into another material champion for bamboo. In section 9.3 it is recommended to actively include these kinds of networking organizations in similar interventions in the future because of their role as incubators of the commercialization process.
Finally, the material supplier noted that during and after the intervention, there was an increased interest in bamboo materials by many large clients (e.g. Artek, Bijenkorf, Ahrend, Levi Strauss, etc.), which they expect has been largely caused by the extended intervention.

Projects

As a result of the many new designers interested in bamboo (see directly above), many of them ordered material for experiments of which several have already initiated concrete new design projects that are already implemented (Maria Blaisse for costumes and flexible shelters, Hanco Ravelli for new furniture, Alexander Pelikan for click furniture, Jochem Galema for furniture).

Figure 7.25: Various new bamboo design projects have been initiated after the invention by additional designers, see for example the click furniture designed by Alexander Pelikan in bamboo (left) and flexible shelter construction designed by Maria Blaisse © 2008 (right)

Additional Outputs

An important additional output of DDMB for the material supplier is that in the exposure of the results of the Bamboo Labs (see subsection 7.2.2), in many cases it was mentioned that the material for the Bamboo Labs was supplied by Moso International. Furthermore, the material supplier has used the intervention to promote its innovative character by mentioning the project on its website: several of the products designed during DDMB are shown (http://en.moso.eu/applications), including a slide show of the complete exposition: http://en.moso.eu/news/dutch-design-meets-bamboo. Moreover, the company provides the book *Dutch Design meets Bamboo* as a gift to its important clients, literally using it as a business card. As a result of all these additional outputs the material supplier received a lot of positive feedback about its innovative character.

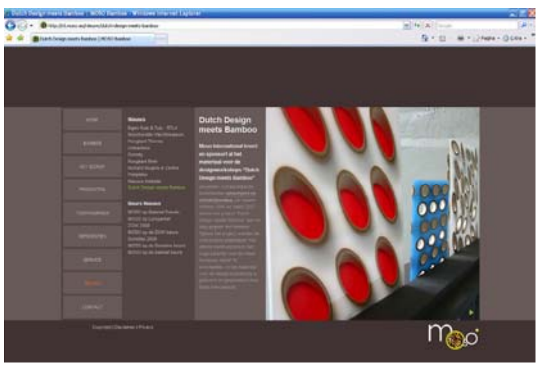


Figure 7.26: The material supplier utilizes DDMB on its website to show its innovative character

Overall Evaluation for Material Supplier

Overall can be concluded that at T2 (April 2008, a little less than one year after the termination of the Bamboo Labs) DDMB has resulted in 10-20 concrete product design projects for which Moso International will supply the material. This means that in terms of direct return of investment, at T2 the whole intervention has been quite successful. When the material supplier was asked if they would sponsor the project again, had they known the results and outputs of the intervention beforehand, the material supplier replied they definitely would. According to the material supplier the intervention has really shaken up the interior design world about the potential of bamboo, has led to a direct increase in interest for bamboo material by various value chain nodes, and has proven to be the ideal business card, highlighting the innovative character of their company.

Another very valuable aspect of the intervention for the material supplier was its function as innovation incubator; during the course of the project the material supplier gained a large amount of knowledge and has initiated many innovation processes. Although all these aspects have not yet resulted in a large increase in sales, the material supplier expects that in due time it will, including the commercialization of the various products developed during the Bamboo Labs.

7.3 Conclusions

This chapter focuses on answering the first research question (RQ1: To what extent is the impact of the intervention successful?). In the previous sections we have seen from the perspective of various stakeholders (participating designers, other value chain nodes, material supplier) that both the core intervention (Bamboo Labs) and the extended intervention have had a different but quite successful impact.

First of all, the Bamboo Labs themselves. Section 7.1 showed us that the participating designers gained a lot of bamboo related value chain contacts and knowledge and that this has also led to an increase in behavioral intention for the participating designers. In section 8.2 it will be further analyzed what the underlying success factors are for the increase in behavioral intention to optimize the intervention for the future. Around one third of the products developed during the Bamboo Labs will certainly be developed toward further commercialization (see table 4.3 in section 4.2). Furthermore, a couple of designers have already started new bamboo based design projects, and have turned into material champions for bamboo. An additional output of the Bamboo Labs was its function as a think tank; through the Bamboo Labs a lot of new generic bamboo knowledge was gained with respect to process- and product innovation. The Bamboo Labs have therefore proven to be very valuable for the material supplier as an innovation incubator. As a result of the Bamboo Labs, the company has entered a process of innovation through which it acquired many insights, competitive advantages and many new value chain contacts, which in the medium to long term should pay itself off. Therefore, the intensive and time consuming process of the Bamboo Labs seems to result in an increase in generic bamboo knowledge (which might be very useful for the commissioner of such an intervention), a couple of new material champions (that generate new projects and exposure) and a couple of products developed in the intervention that will be further commercialized and launched in the short to medium term on the market.

Secondly, the diffusion of the results in the project DDMB. Since the Bamboo Labs resulted in very diverse prototypes based on different bamboo materials and processing techniques, and were tangible for relevant value chain nodes downstream as well as the general public, they proved to be very attractive for media exposure. Also, the name of the project ("Dutch Design meets Bamboo"), helped to directly pinpoint the core focus of the project, draw attention, and raise interest. Therefore, the extended intervention has proven to be a powerful promotion tool. Section 7.2 showed us that as a result, besides the organized exposure, which drew many interested visitors, the project also yielded much unorganized exposure, propelled by the organized exposure but also by the participating designers, several of whom turned out to be diffusion nuclei on their own (material champions). As a result of this additional exposure more than a million people were reached, although it is never certain how many of these receptors are relevant value chain nodes with the power to deploy a material in a product and bring it on the market. The sample survey showed that if appropriate value chain nodes are reached, the results of the Bamboo Labs may help to improve their attitude and behavioral intention toward the material. For the material supplier this increase in behavioral intention of relevant value chain nodes that were reached by the exposure resulted in some new projects. Furthermore, for the material supplier, the exposure including the recognition of bamboo as a trend in various design magazines did result in many new value chain contacts (mainly designers, but also some large professional clients/brands) interested in the material. Only time will tell if in the future this increased interest in the material pays off in the commercialization of many new products and projects in which bamboo is incorporated. However, through the exposure, the image of the material supplier as being innovative did improve.

It can be concluded that the core intervention has focused on thoroughness in information input for a selected group of people (small reach), which has resulted in a high increase in knowledge and behavioral intention in the short to medium term for a small number of relevant value chain nodes. In contrast, the extended intervention has focused on a lower level of thoroughness in information input, diffusing the results of the core intervention in an attractive, compressed manner to a large group of people (large reach), which has resulted in a small increase in attitude and behavioral intention for a larger number of relevant value chain nodes, which in the long term might pay itself off to the bamboo industry as a whole.

Table 7.6: Main outputs found for the core- and extended intervention

Core Intervention (Bamboo Labs) Outputs		Extended Intervention (Scope: DDMB) Outputs	
1.	Development value chain network (downstream)	1.	Exposure with a large reach (with 2 & 3 as a result)
2.	Development of new generic knowledge about bamboo	2.	Improvement of image & trendiness (of bamboo but also of the material supplier)
3.	Strong increase in knowledge and behavioral intention for a limited number of relevant value chain nodes, potentially resulting in new material champions and projects in the short term	3.	Small increase in attitude & behavioral intention for a large number of relevant value chain nodes, potentially resulting in new value chain contacts (possibly also material champions) and projects in the long term

Although this means that both parts of the intervention are complementary, depending on the incentives of the commissioner of similar interventions in the future for other new or lesser known materials, the emphasis may lie on the design workshops or on the diffusion of the results (see subsection 9.3.1).

Another main conclusion of the impact evaluation, and important achievement of the intervention, is that the intervention seems self-propelling. After the intervention, which actively integrated designers and other relevant value chain nodes to bamboo, new material champions have stood up (several of the participating designers, but through the exposure also other designers and incubators such as Things Design), which has resulted in an increasing sustained interest in bamboo. Through these new material champions, and the sustained efforts of the material supplier based on the new insights, many other value chain nodes might be affected in the future as well, further increasing the commercialization rate of bamboo in products in Western Europe, but also outside of this area (see figure 7.27). This shows that - as intended - a one time design intervention at the right time and the right place (in the world, but also in the PCS; see figure 1.18), can indeed have an important and durable impact on the commercialization of a new material.

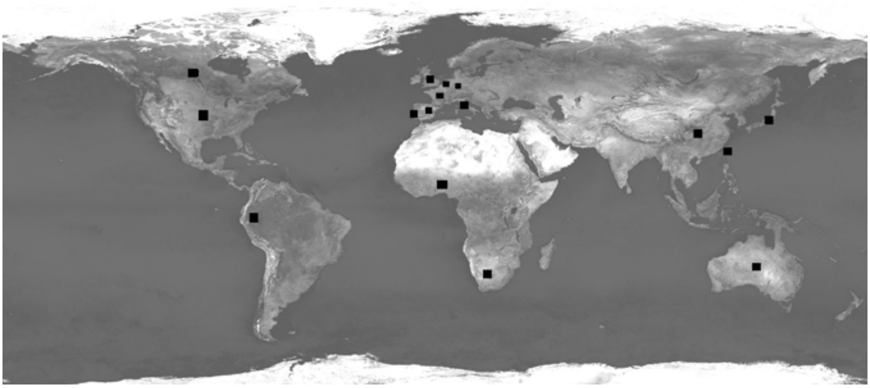
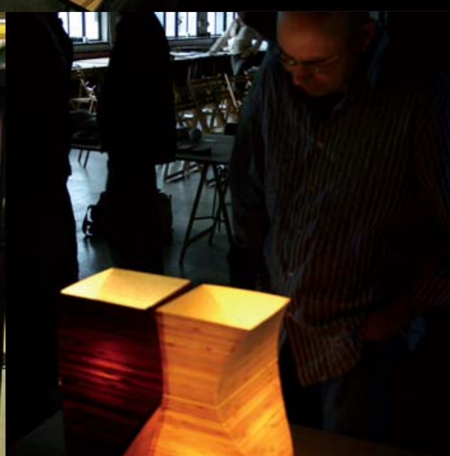


Figure 7.27: Countries in the world where the results of the Bamboo Labs are known to be presented in design fairs and magazines (internet based publications not included), or where books are sold










Design


8 Process Evaluation & Advice for Improvement

In the previous chapter the impact of the intervention was evaluated, which showed that the intervention has proven to be quite successful. Besides measuring the impact, it is also of importance to understand the background and the causes of the success of the intervention. Based on this understanding recommendations can be made on how the elements of this intervention may be improved for similar design interventions in the future. This process evaluation, including advice for improvement, is executed in this chapter.

Section 8.1 first analyzes for the intervention to what extent the Material Support System, consisting of an information material component, an interaction component and the preconditions, has been of value for the material independent success indicators of this research (knowledge and value chain contacts). In section 8.2 the success factors that have contributed to the most important success indicator for the core intervention, the potential future implementation (behavioral intention) of the participating designers, is analyzed, after which the efficiency of the intervention is evaluated. Throughout sections 8.1 and 8.2 several pieces of advice are given on how the intervention can be improved. In the conclusions in section 8.3 the most important success factors found are summarized in an overall model.

8.1 Material Independent Indicators

8.1.1 Introduction

This section analyzes the value of the (sub)components of the Material Support System (MSS) for the material independent success indicators "knowledge" and "value chain contacts", which are expected to have a positive effect on the behavioral intention of the designers. It will be further evaluated in section 8.2 if this is the case. Besides the success indicators linked to the behavioral intention, the value of the various subcomponents of the MSS (introduced in subsection 2.2.4) with respect to inspiration for new product ideas as well as the overall appreciation of the MSS are also analyzed in this section. Furthermore, it is evaluated to what extent the preconditions of the intervention with respect to the material, facilities, organization team and financial resources were satisfactory. If applicable, advice for improvement of the (sub)components of the MSS is provided throughout the text.

To evaluate the value of the subcomponents of the MSS with respect to knowledge-, value chain contacts- and inspiration gained, data was required during questionnaire interviews and focus groups (for more information see subsection 3.4.2). During the questionnaire interviews the designers were asked to fill in a 5-point scale to score each subcomponent on the criteria mentioned above (see table 8.1 for an example). Besides scoring the subcomponents quantitatively, the designers were asked about the background of their scores, and urged to provide recommendations for improvement of the MSS. These recommendations were further completed with observations made by the organization team and the author.

Table 8.1: Scale used to evaluate the value of the subcomponents of the MSS with respect to the knowledge-, value chain contacts- and inspiration gain

Please score the value of the <subcomponent MSS, e.g. reader > with respect to:					
	1. Not valuable	2. Somewhat valuable	3. Reasonably valuable	4. Valuable	5. Very valuable
Gain in bamboo related knowledge					
Gain in bamboo related value chain contacts					
Inspiration for product ideas					

In a similar manner, but based on a 7-point semantic differential scale (with 1 - very negative, and 7 - very positive) the overall score of the MSS was also evaluated.
The preconditions were not scored in a quantitative way, but evaluated in a qualitative manner during face-to-face interviews with the designers, and complemented with observations by the organization team. Data analysis consisted of statistical analysis for quantitative research data and categorization for qualitative research data.

8.1.2 Material Support System

Information Material

In table 8.2 the results of the evaluation of the subcomponents of the information material component of the Material Support System (MSS) by the participating designers are summarized. Note that most of the information material subcomponents were not developed for value chain contact development, explaining the many blanks in table 8.2. Although the internet is not a subcomponent of the MSS, it was included in the evaluation, since the reader contained a list with relevant websites.
In the remainder of this subsection the background of these scores in table 8.2 is explained with a focus on the criterion "value for knowledge" since knowledge development is the most important objective of the information material component. Furthermore, if applicable, recommendations are provided.

Table 8.2: Evaluation of the information material component of the MSS by the participating designers in terms of average value for knowledge, value chain contacts and inspiration on a 5-point scale

	Knowledge			Value chain contacts			Inspiration		
Subcomponent	Average score	Std. Dev.	N	Average score	Std. Dev.	N	Average score	Std. Dev.	N
Printed publications:									
- Reader	3.00	1.58	18	1.28	0.75	18	2.89	1.41	18
- Library	3.26	1.28	19	-	-	-	3.53	1.35	19
Digital publications:									
- Digital database	3.00	1.31	15	-	-	-	2.47	1.25	15
- CD ROMs	2.11	1.05	9	-	-	-	1.44	0.73	8
Internet	2.80	1.69	10	2.90	1.73	10	3.30	0.70	10
Other									
- Material library	4.48	0.68	21	-	-	-	4.38	0.92	21

The bamboo *reader* was scored to be "reasonably valuable" (M=3.00, N=18) for knowledge gain, with a rather high standard deviation (SD=1.58); some designers (N=4) found the reader very valuable with respect to knowledge gain (score of "5"), while the same amount (N=4) of designers found the reader not valuable at all (score of "1"), showing the differences in personal preferences of designers. A similar pattern was found for the value of the reader for inspiration, with a reasonable value (M=2.89, N=18) and a high standard deviation (SD=1.41).
An often-heard complaint during the interviews with the designers was that the reader was too technically oriented and could have been made more attractive from a visual point of view (layout, more pictures, etc.). However, many designers did describe the reader as a useful reference book. Designers working with weaving techniques were very pleased with the weaving patterns described in the reader, derived from the book *Bamboo, Gift of the Gods* by Oscar Hidalgo (Hidalgo Lopez 2003). For example, Ed van Engelen used a pattern shown in the reader in some of his garden furniture designs made from synthetic fibers for the furniture company Haans.

The *library of books* available for the designers was evaluated to be "reasonably valuable - valuable" with respect to knowledge gain (M=3.26, SD=1.28, N=19) and inspiration (M=3.53, SD=1.35, N=19). Although permanently available throughout the intervention at Design Platform Eindhoven, none of the designers visited the library outside of the Bamboo Lab days. However, during the Bamboo Lab days many of the designers really appreciated going through the various books for inspiration, of which the book *Grow Your Own House* (von Vegesack and Kries 2000) and *Bamboo, Gift of the Gods* (Hidalgo Lopez 2003) were appreciated the most because of the many pictures (*Grow Your Own House*) and completeness (*Bamboo, Gift of the Gods*). Since visiting the library proved to be one bridge too far for most designers, it would have been better to provide the books mentioned above, alongside the reader, permanently to the participating designers at the beginning of the intervention.

Figure 8.1 (left): Small library of books made available to the designers throughout the Bamboo Labs
Figure 8.2 (right): The digital database was appreciated for its structured visual overview

The *digital database* was evaluated by the designers to be "reasonably valuable" with respect to knowledge gain (M=3.00, SD=1.31, N=15) and "somewhat valuable" for inspiration (M=2.47, SD=1.25, N=15). Many designers described the digital database as being extremely useful in the phase of first acquaintance with bamboo; it provides a well structured overview of available bamboo materials and processing technologies, in a visually attractive manner. The fact that the digital database did not receive very high scores was caused by the fact that it was not completely finished yet during the intervention: some processing technologies were not complete, some material properties were not included, and the gallery with bamboo applications did not function perfectly. The low number of responses (N=15) was caused by the fact that the digital database did not work on the Macintosh, with which several designers work. Nevertheless, after optimization many designers did see a lot of potential for the use of the digital database as a basic framework for setting up an online bamboo information portal for designers in the future, and recommended the further development and commercialization of the digital database. The author is very pleased to announce that the digital database will most likely indeed be further optimized and commercialized, as it was adopted by INBAR in January 2008. For further recommendations for improvement of the digital database the reader is referred to the MSc thesis of the designer of the digital database, Mika de Bruijn (2007a).

The *CD ROMs* developed by the National Institute of Design (NID) in India were evaluated by the designers to be "somewhat valuable" for knowledge gain (M=2.11, SD=1.05, N=9) and "not valuable" for inspiration (M=1.44, SD=0.73, N=8). The fact that the CD ROMs were evaluated poorly was mainly because they were handed out to the designers during Bamboo Lab day 2, prior to which they had already received the other subcomponents of the MSS at Bamboo Lab day 1 a week earlier. As such, the CD ROMs, containing a vast amount of information, were largely neglected by most designers (explaining the small number of responses) because the designers had already received an information overload.

The *internet* proved to be "reasonably valuable" with respect to knowledge gain (M=2.80, SD=1.69, N=10), value chain contacts gain (M=2.90, SD =1.73, N=10) and inspiration (M=3.30, SD=0.70, N=10). Designers mentioned that the internet remains a useful instrument to quickly gain inspiration due to the visual character. However, they noted that a central information portal for bamboo catered toward the needs of designers is lacking.

The *material library* was evaluated to be "valuable - very valuable" with respect to knowledge gain (M=4.48, SD=0.68, N=21) and inspiration (M=4.38, SD=0.92, N=21), validating the notion found in subsection 2.1.2 that designers need to experiment with and feel the material to be able to understand it. This finding also shows the effectiveness of providing material samples to designers by material suppliers.

Conclusion Information Material

With respect to the information material component of the MSS, two conclusions can be drawn. First, although the designers appreciated the completeness of the information material, the amount of information material was too large for most designers. It even hampered some of the designers in their creativity. This shows the need of most designers to acquire information about materials in a compressed, visually attractive manner. However, it should be mentioned that a couple of designers found the amount of information material excellent and found the information to satisfy their needs, which leads to the second conclusion: information material needs (and interaction needs for that matter; see below) differ per designer and are determined by personal preferences.

For example, designers that categorized themselves with respect to their learning style as "thinker" valued the information intensive subcomponent "reader" a lot more (mean value for knowledge gain by "reader" evaluated at 3.67, SD 1.51, N = 7) than designers that categorized themselves with respect to their learning style as "do-er" (mean value for knowledge gain by "reader" evaluated at 2.57, SD 1.50, N

= 6). This difference in preferences does not only apply to the amount of information material, but also to the medium in which the material is presented (e.g. book vs. digital), the way it is presented (e.g. pictures vs. text) and thoroughness of the information. This diversity in information material needs can be solved in similar future design interventions by facilitating the voluntary use of an information portal to participating designers (see for more recommendations about this information portal subsection 9.3.3).

Interaction with Experts

In table 8.3 below the results of the evaluation of the subcomponents of the interaction component of the MSS are summarized. Please note that the interaction subcomponent "lecture" was not developed for value chain contact development, explaining the blanks in table 8.3.

Table 8.3: Evaluation of the interaction component of the MSS by the participating designers in terms of average value for knowledge, value chain contacts and inspiration on a 5-point scale

	Knowledge			Value chain contacts			Inspiration		
Subcomponent	Average score	Std. Dev.	N	Average score	Std. Dev.	N	Average score	Std. Dev.	N
Lecture	4.57	0.68	21	-	-	-	3.48	1.47	21
Excursion	4.28	0.89	18	3.28	1.45	18	4.00	1.14	18
Interaction during Bamboo Lab days:									
- Participating designers	3.47	1.17	19	3.32	1.57	19	3.53	1.31	19
- In-house experts	4.22	0.94	18	3.39	1.19	18	2.72	1.27	18
- External experts	4.62	0.51	13	3.31	1.80	13	3.31	1.75	13
Blog	1.67	0.90	15	1.60	0.91	15	1.20	0.56	15

The *lectures* were evaluated to be "valuable - very valuable" and "reasonably valuable - valuable" with respect to knowledge gain (M=4.57, SD=0.68, N=21) and inspiration (M=3.48, SD=1.47, N=21), respectively. The designers mentioned that the lectures provided a very good overview of bamboo materials available, their properties, existing processing technologies and applications, and that they had therefore acted as a very useful introduction.

The *excursion* was evaluated as "valuable" for knowledge gain (M=4.28, SD=0.89, N=18), "reasonably valuable" for value chain contacts gain (M=3.28, SD =1.45, N=18) and "valuable" for inspiration (M=4.00, SD=1.14, N=18). The first part of the excursion, with visits to bamboo gardens at the Bamboo Information Center and the warehouse of bamboo material supplier Moso International were appreciated the most by the designers. Seeing how the bamboo plant grows especially inspired many of the designers. An interesting spin-off effect of the excursion was that the day-long journey in a touring car facilitated interaction and social bonding between the group of designers, many of whom did not know each other prior to the intervention.

The *interaction with other participating designers* was evaluated as "reasonably valuable - valuable" for knowledge gain (M=3.47, SD=1.17, N=19), "reasonably valuable" for value chain contacts gain (M=3.32, SD =1.57, N=19) and "reasonably valuable - valuable" for inspiration (M=3.53, SD=1.31, N=19). Many of the participating designers very much appreciated the social setting and circuit of Bamboo Lab days 3-5, and in particular the cooperation and interaction with other designers. However, the diversity of the participating designers with respect to experience, design approach, batch size and organizational structure sometimes also impeded efficient collaboration. Cross fertilization with respect to knowledge development (think tank function) worked best for designers with a similar background. Furthermore, there were also some designers, who categorized their cooperative style as "individualistic", that mentioned that the Bamboo Lab day meetings did not provide an added value for them and that they had preferred to only receive some information and material input, and finish the assignment alone in their design studio. These designers valued the "interaction with other participating designers" a lot lower (mean value for knowledge gain by "interaction with other participants" evaluated at 3.13, SD 1.46, N = 8) than designers that categorized their cooperative style as "collaborative" (mean value for knowledge gain by "interaction with other participants" evaluated at 3.90, SD 0.73, N = 10). The above shows that knowledge-, value chain- and inspiration development through the interaction with other participating designers could have been improved if only designers with a similar background and a collaborative attitude would have been invited.

Figure 8.3: The interaction with other designers throughout the Bamboo Labs was mostly appreciated by designers with a collaborative attitude

The *interaction with in-house experts* was evaluated as "valuable" with respect to knowledge gain (M=4.22, SD=0.94, N=18), and "reasonably valuable" for value chain contacts gain (M=3.39, SD =1.19, N=18) and inspiration (M=2.72, SD=1.27, N=18). The multi disciplinary character of the panel of in-house experts was appreciated by the designers, ranging from technology/engineering oriented (e.g. Dr. Jules Janssen) to more application/practical design oriented (e.g. Marco Groenen).

The *interaction with external experts* was evaluated as "very valuable" for knowledge gain (M=4.62, SD=0.51, N=13), to "reasonably valuable" for value chain contacts gain (M=3.31, SD =1.80, N=13) and inspiration (M=3.31, SD=1.75, N=13). Several designers collaborated during their prototype development with external experts with respect to processing and furniture manufacturing, whose expertise was most valuable for knowledge development. Some designers noted that it would have been nice if a processing expert/furniture manufacturer with knowledge about practical processing do's & don'ts would also have been available as an in-house expert throughout the intervention.

The *blog* was evaluated as "not valuable - somewhat valuable" with respect to knowledge gain (M=1.67, SD=0.90, N=15), value chain contacts gain (M=1.60, SD =0.91, N=15) and inspiration (M=1.20, SD=0.56, N=15). The success of a blog is determined by the number of users that also use the blog, referred to as "network effects" (Farrell and Klemperer 2007). This means that the added value of a blog needs to be directly clear to potential users from the start, which was one of the main problems of the blog used during the intervention. Since the community was not large and only a couple of external experts were enrolled, the blog did not provide the added value required for designers to actually actively participate in the blog. Furthermore, since many designers had trouble logging in, several designers did not try again, as the information material provided to them earlier appeared to be comprehensive enough.

8.1.3 Preconditions

Besides the components of the MSS, several preconditions also needed to be met for the design intervention to be successful: the provision of a large variety of bamboo materials in high quality and sufficient quantity, the availability of adequate facilities, the availability of an adequate organization team, and the availability of sufficient financial resources to fund all activities, including a fee for the participating designers. In this subsection these preconditions will be evaluated, and if required, advice for improvement will be provided.

In general the participating designers were satisfied with the amount and quality of the bamboo *material* available throughout the Bamboo Labs. This can also be seen in the scores for the "material library" in table 8.2, since most designers evaluated the material library as if evaluating the value of the provision of bamboo materials throughout the Bamboo Labs. Some designers noted that they would also have liked to work with the bamboo plant and green bamboo, since it could provide additional design opportunities. Although this is difficult to achieve in design interventions taking place in the North, based on renewable resources grown in the South, in subsection 9.3.2 it is recommended to also execute bamboo design interventions in the future based on processing and application manufacturing in the South, in which green material could also be included.

Many designers mentioned that they had appreciated the *facilities* and the setting in which the Bamboo Lab days took place (at the former Philips factory Strijp S); the space, accessibility and informal atmosphere were often mentioned as being positive. Most designers liked the informal way in which the meetings were facilitated, although some designers found that the facilitators could have played a larger role in creating an atmosphere in which debate and (positive) criticism of each other's work was stimulated.
Several, mostly independent, designers without direct access to production facilities mentioned that they would have liked it if processing facilities were made directly available for experimentation (e.g. machines for compression molding, steam bending, milling, etc.). This could have been solved by integrating application manufacturers & processors at an earlier stage of the core intervention, or by only inviting designers that already had direct access to these facilities (e.g. self producing designers or in-house designers of application manufacturers).

A lot of positive feedback from the participating designers was received with respect to the *organization* of the whole project. Some designers mentioned they "had never participated in such a well organized event", which may be perceived as a very satisfactory outcome.
It should be noted that an adequate organization team is a hard necessity if a design intervention such as DDMB is to succeed, since many different activities need to be performed by the various members of the organization team throughout the various stages of the project: initiative (fundraising, promotion & advertising, acquisition of materials, etc.), execution (logistics, facilitating, project management, communication, etc.), and the aftermath (finances, reporting, dissemination, publication, etc.). Since the

organization team had a multidisciplinary character with members with complementary skills and backgrounds, this precondition was met in a satisfactory way for DDMB. However, for future design interventions it is of crucial importance that this precondition is met, since without a competent organization team this kind of design intervention is prone to fail.

The members of the organization team, as well as the supervisors of the project who were asked to observe the *role of the researcher* throughout the intervention (for more information see subsection 3.4.2) mentioned that the researcher did play an important role in the success of the DDMB project as project champion throughout the various stages of the project. The researcher took the lead in the establishment of an organization team consisting of competent and complementary members, and after that initiated fundraising activities, including the writing of the project proposal. Furthermore, the researcher tried to keep the overview of necessary activities to be executed by chairing project meetings, facilitating the Bamboo Labs meetings (together with Marco Groenen), while keeping track of the overall progress of the project (project management). Some of the organization team members mentioned that this championing role of the researcher was necessary to "keep the fire burning". This was also noted after the finish of the Bamboo Labs, when the author took a more following role to finish this PhD thesis; the idea of a traveling exposition and follow up projects did not continue in the grand manner as planned. It seems that when a project or idea is not intrinsically linked to a certain champion, the innovation might fade out (or a new champion needs to stand up). The role of project champion may be expected of the initiator of such a design intervention. Since in the case of DDMB the researcher was (co)initiator of the design intervention, this role as project champion was to be expected. As will be shown in subsection 9.3.1, in many other cases another entity might be the initiator of the project, and should take on this role.

However, this observation does bring up an important issue for similar future design interventions initiated by researchers from universities and research institutes. Based on the experiences in DDMB it seems that the researcher will need to have certain qualities to be able to act as project champion for such an intervention. The main supervisor of this PhD project, Professor Han Brezet, who observed the researcher during the complete process of the DDMB project (initiation, execution and aftermath), noted that besides a strong intrinsic motivation, entrepreneurial qualities are an important requisite if a researcher is to initiate and execute a design intervention in practice like DDMB. According to Berchicci (2005) entrepreneurs are individuals who perform the function of innovation, discovering, recognizing and exploiting opportunities, through information asymmetry and prior experience.

Important entrepreneurial qualities are: 1) the ability to spot opportunities unlike other existing players in the field (Larson 2000); 2) the ability to develop a network, consisting of formal and informal linkages, through which resources (human, technical and financial), information, capabilities & expertise and legitimacy are acquired (Berchicci 2005, Elfring and Hulsink 2003); and 3) additional personal characteristics such as competence, prior experience, confidence, commitment and imagination (van de Ven et al. 1984). According to the main supervisor, the author largely met these requisites, partly explaining the success of the project. This finding shows that an intrinsically motivated project champion with entrepreneurial skills is another precondition if a design intervention such as DDMB is to succeed. The personal experiences of the author to act as project initiator are shown in the box below.

Does the above mean the design intervention would have failed if the researcher would not have had these qualities? Not necessarily. Group Dynamics theory (Forsyth 2006, Lewin 1948) describes that if circumstances change in a group, individuals act differently. Most likely the entrepreneurial qualities mentioned above are also prevalent in other individuals in the organization team (may even be divided over the various team members complementing each other), which would have taken on the role of product champion to a larger extent if the researcher would not have. However, this is difficult to prove. In subsection 9.3.2 a recommendation is to execute more research about the role and requirements of the researcher and the organization team members during similar design interventions in the future.

Box: Managing a Design Intervention in Action Research

From a personal perspective, the author can endorse the viewpoint mentioned above; researchers interested in initiating a similar intervention should not take acting as project champion in such a design intervention lightly. Acting as project champion is demanding; besides the researcher the person in question has to take on the role of facilitator, chair person, project manager, expert and fundraiser at the same time. Apart from consuming a large amount of precious research time, this switching between roles of the researcher can be demanding if one is to deliver sound and objective research results. However, this process is also highly rewarding, provides lots of insight not acquired if the researcher would not have taken on this participatory role, and provides - unlike in most conventional research - the researcher the opportunity to actually contribute in solving a problem in practice.

Figure 8.4: In order not to miss important observations and remarks made by participants during the Bamboo Labs, the author taped all Bamboo Lab days with a digital audio recorder (around neck of the author)

Most designers found the *financial resources* made available by the organization committee to reimburse the designers for their efforts and time expenditures put in the Bamboo Labs very satisfactory. According to the designers, this showed the professional character of the design intervention from scratch and enhanced the feeling of commitment for the participating designers to deliver a good product.

8.1.4 Overall Evaluation & Conclusions

On an overall level the MSS was evaluated as "positive" on a 1-7 scale (M=5.76, SD=1.02, N=21), with a maximum of 7 and a minimum of 2.5. The most frequently occurring score was 6 ("positive") with a frequency of 11. Many designers noted that participation in the Bamboo Labs was not only perceived as very useful for knowledge-, value chain contact- and inspiration development, but also highly enjoyable, and preferable over other instruments used by material suppliers to get acquainted with new or lesser known materials, such as design competitions (see, for a comparison between the advantages of design competitions and design workshops, table 8.8 in subsection 8.2.3).

If we look at the value of the various components of the MSS in terms of knowledge-, value chain contact- and inspiration development, it appears that on an overall level the interaction component has been more valuable for the participating designers than the information material component. According to the participating designers the necessary preconditions were met and facilitated the success of the intervention.
For some designers the large amount of information provided to them during the Bamboo Labs had the wrong effect and restricted them in their creativity. However, almost all designers did perceive the information material as being useful, especially when used as an information archive that could be used upon request. However, the subcomponents of the interaction component, and especially the lecture, excursion and the interaction with other participants and experts were preferred to the subcomponents of the information material component. It should be noted, however, that preferences differed per designer. This shows that it seems best for similar design interventions in the future to provide a broad range of information material but also interaction possibilities in the form of a comprehensive online information portal, acting as a knowledge map from which the designers can choose, in order to facilitate the best match with the specific preferences of each designer (for more details with respect to such an information portal the reader is referred to subsection 9.3.3).
In subsection 9.3.1 various concrete recommendations will be made for potential future design interventions for other new or lesser known materials based on various scenarios in which the findings and advice for improvement of the participating designers during the Bamboo Labs, found in this section, are integrated (especially in the similar scenario 5, "Generic Material Development").

This section has shown that although the methodical approach of the MSS serves as a good framework facilitating the measurement of the impact of the invention, while safeguarding the success of the intervention, the (less controllable & measurable) properties of the stakeholders involved in the intervention also play an important role in the success. For example, in the precondition analysis it was found that the organization team requires a project champion with entrepreneurial qualities, or at least that entrepreneurial qualities are shared amongst the various team members. Since these kinds of people aspects, relating to the organization team members, but also to the participating designers, are more difficult to measure prior to an intervention, it is more difficult to safeguard preconditions related to participating stakeholders than for the more replicable, methodical part of the intervention (MSS).

In this section and in the previous chapter 7 it was found that the intervention was successful in improving the material independent success indicators amount of knowledge and value chain contacts for bamboo. However, the question remains to what extent the bamboo related value chain contacts- and knowledge gain were the main causes of the increase in behavioral intention (found in the previous chapter as well), which is the most important criterion predicting the actual increase in commercialization of bamboo in products in the future. Therefore, in the following section the key success factors that influenced the behavioral intention will be analyzed, including the assessment to what extent these success factors were linked to the intervention, in order to evaluate the effectiveness of the intervention.

8.2 Behavioral Intention

8.2.1 Introduction

This section analyzes the success factors that have contributed to the most important success indicator for the intervention, the behavioral intention of the participating designers, which is defined as "the expected chance of implementation of the material by the designer in concrete products/projects in the near future (within two years)."

The success factor analysis was based on qualitative data, acquired during face-to-face interviews with the participating designers after the intervention (T1), backed up where possible with quantitative data based on key variables determined in the conceptual model in section 3.2 such as knowledge and attitude (for scales used the reader is referred to subsections 6.1.1 and 7.1.1) acquired during questionnaire interviews with the designers (T1).

The success factors found derived from the transcribed interviews with the designers, which were analyzed in a qualitative manner using labeling techniques. Through clustering and prioritization the most important key factors provided by the participating designers, based on counting the total number of responses for each success factor, were distilled from the interviews. Furthermore, where possible the relationship between the success factors mentioned by the designers and the behavioral intention was statistically analyzed through correlation- and regression analysis.

It should be noted that the success factors found in this section relate to the specific intervention executed in this research, focusing on the role of the designer as a hub between material supplier and value chain nodes downstream such as application manufacturers & retail outlets. However, once a product prototype has been materialized by a designer, and reaches the final commercialization phases of the product innovation process (especially the launch phase; see figure 2.3), many additional factors of success and failure come into play (see appendix G), also applying to additional value chain nodes downstream. Evidently, these factors of success and failure are not taken into account in this success factor analysis.

8.2.2 Results

The most important success factors found during the interviews, based on the number of responses by the complete sample group of participating designers, are presented in figure 8.5. In this subsection the background of these success factors will be explained and in some cases backed up by additional quantitative data.

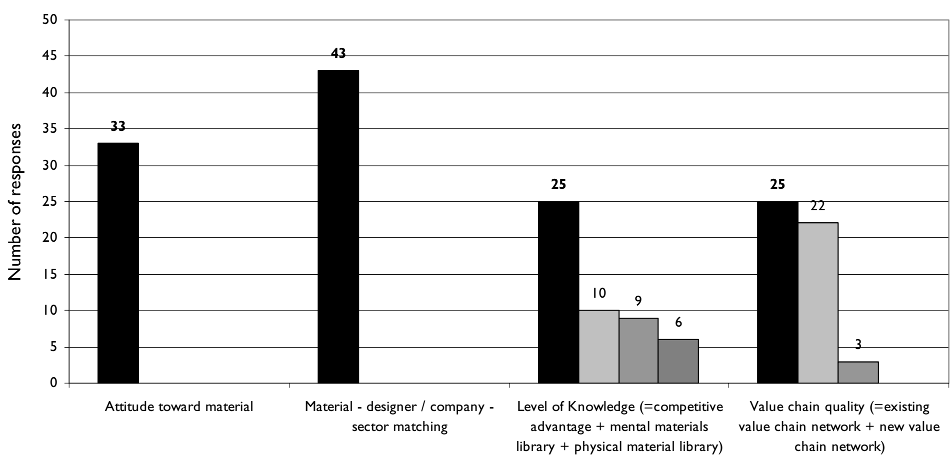


Figure 8.5: Key success factors for the potential future implementation (behavioral intention) of bamboo by the participating designers.

Note: for the success factors "level of knowledge" and "value chain quality" the sub success factors of which these factors comprise are also depicted.

Attitude toward Material

Many designers mentioned that their attitude toward the various bamboo materials had a large impact on their behavioral intention. This qualitative finding was backed up by correlation- and regression analysis of the quantitative data, revealing a significant ($p < .05$; stem and mats) or marginal significant ($p < .10$; Plybamboo) relation between the attitude and the behavioral intention for three of the five bamboo materials: stem ($r = .70$), Plybamboo ($r = .42$) and mats ($r = .82$). As can be seen from the tables, in all cases the relation between the attitude (7-point scale, for more information see subsection 6.1.1) and the behavioral intention (in percentages) was positive:

Stem: Behavioral intention T1 = -7.54 + 9.19 * Attitude T1 with $\beta = .58$

Plybamboo: Behavioral intention T1 = 14.91 + 8.38 * Attitude T1 with $\beta = .42$

Mats: Behavioral intention T1 = -17.76 + 9.8 * Attitude T1 with $\beta = .75$

This means that an increase in attitude will lead to a significant increase in behavioral intention. No significant relationship ($p > .10$) could be found between attitude and behavioral intention through correlation analysis for the other two bamboo materials deployed during the intervention, composite ($r = .16$) and SWB ($r = .20$).

Table 8.4: Regression analysis for the bamboo stem; Attitude T1 (independent variable) & Behavioral intention T1 (dependent variable), with SE = Standard Error

	B	SE B	β
Constant	-7.54	11.50	
T1 Attitude stem	9.19	2.95	0.58*

R = 0.34; * p<.05, **p<.10

Table 8.5: Regression analysis for Plybamboo; Attitude T1 (independent variable) & Behavioral intention T1 (dependent variable), with SE = Standard Error

	B	SE B	β
Constant	14.91	22.74	
T1 Attitude Plybamboo	8.38	4.15	0.42**

R = 0.18; * p<.05, **p<.10

Table 8.6: Regression analysis for bamboo mats; Attitude T1 (independent variable) & Behavioral intention T1 (dependent variable), with SE = Standard Error

	B	SE B	β
Constant	-17.76	8.09	
T1 Attitude mats	9.80	2.05	0.75*

R = 0.56; * p<.05, **p<.10

In section 6.2 the background of the attitude of the participating designers, based on material properties, processing and finishing possibilities & constraints and other attributes, was already explained. In the same chapter it was also found that a higher level of knowledge positively correlates with the attitude toward various bamboo materials.

Material - Designer - Sector Matching

The success factor mentioned most by the participating designers was the level of material - designer - sector matching. Several designers noted that some of the bamboo materials just do not fit in the sector in which they are active, with respect to industrial processing (e.g. stem), aesthetic quality (e.g. composites for high end furniture) and several other properties (e.g. Plybamboo for outside use). If the material does fit in the sector in which the designer is active, the personal preferences and design

philosophy of the designer should also concur with the material (see also attitude toward the material above). This preference is very personal. For example, Maarten Baas chose to work with the stem because the material has a "strong" character and personality, which he liked.
If the designer works for a company, the material should match the mission, strategy and philosophy of the company. For example, with its focus on Asia, sustainability and visible natural materials, most bamboo materials in which bamboo is still visible (thus excluding, for example, bamboo composites) fit extremely well with the furniture company Haans, for which in-house designer Ed van Engelen participated in the Bamboo Labs.

Level of Knowledge

The level of knowledge about the various bamboo materials was also mentioned by many designers as an important success factor. Although correlation- and regression analysis only revealed a significant positive relationship between the amount of knowledge (10-point scale; see also subsection 7.1.1) and the behavioral intention for bamboo mats ($r=.54$, $p<.05$, Behavioral intention mats T1 = -29.27 + 7.81 * Knowledge T1 with $\beta = .52$; see also table 8.7 below), indirectly through the attitude (positive correlation with amount of knowledge for stem, Plybamboo and mats; see subsection 6.1.3), which in its turn has a positive correlation with the behavioral intention (see above, "attitude toward material"), the amount of knowledge seems to positively influence the behavioral intention.

Table 8.7: Regression analysis for bamboo mats; Knowledge T1 (independent variable) & Behavioral intention T1 (dependent variable), with SE = Standard Error

	B	**SE B**	β
Constant	-29.27	18.69	
T1 Knowledge mats	7.81	3.02	0.52*

R = 0.27; * $p<.05$, ** $p<.10$

Analyzing the recorded interviews with the participating designers it was found that respondents, who noted the level of knowledge as a success factor with respect to their behavioral intention, mentioned this for three reasons.
First, there is a group (10 of the 25 responses) which perceives this amount of knowledge gained, and the time invested in the project, as a competitive advantage compared to other Dutch designers, which they want to make profitable. For example, Daan van Rooijen mentioned that he would like to use his knowledge gain in future projects of his design company. Members of this group of designers may turn into material champions for bamboo.
Another group (9 of the 25 responses) mentioned that through the increase in knowledge, bamboo is now included in their "mental materials library" and is therefore in the back of the mind of the designers, and may be automatically included in their material selection process for future design projects. For example, whereas Mette Hoekstra would not have considered using bamboo before the intervention, she now already considered using bamboo as a potential alternative in a couple of her interior projects.
Besides the integration of bamboo in their mental material library, through their increase in knowledge, several designers noted the inclusion of bamboo in their physical materials library as a success factor toward potential implementation of the material in the future (6 of the 25 responses). For example, since the Bamboo Labs Yvonne Laurysen and Erik Mantel now include bamboo in the material samples map they bring to clients. As such, bamboo is more often considered as a potential alternative.

Value Chain Quality

The quality of existing linkages with value chain nodes downstream, capable to bring the product in which the new material is implemented on the market, is perceived as another important success factor by the participating designers. For example, Yvonne Laurysen and Erik Mantel are experienced designers that have gained recognition for their designs. Over the years they have developed a strong value chain network which they have used for the further development toward commercialization of their new material developed during the Bamboo Labs, which is set to be launched in the market in 2008-2009.
The value chain quality of designers is also a result of personal characteristics of each designer, such as entrepreneurial qualities (for more information about entrepreneurial qualities see subsection 8.1.3) and the talent of the designers. Very talented designers will usually gain more recognition, which ensures that application nodes downstream will approach them automatically (instead of the other way around), making value chain network development self propelling.

Value chain integration was also observed to be an important sub success factor with respect to value chain quality. If, besides "design", other value chain nodes downstream such as "application manufacturing" and "retail" are also under the umbrella of the same company, it is easier for an (in-house) designer to ensure that a product made from a new material reaches the final consumer market. As an example from the Bamboo Labs can be referred to the value chain in which Ed van Engelen, in-house designer for the large furniture manufacturer Haans is active; see figure 8.6. At the top of the figure the value adding activity is depicted and in the rectangles (value chain nodes) the main stakeholder that takes care of this activity in the value chain is represented. The figure shows that several activities are executed by Haans, facilitating easier adoption by value chain nodes downstream since only stakeholders within the company itself have to be convinced. This also partly explains why Haans has been faster in launching the bamboo products developed by in-house designer Ed van Engelen in the Bamboo Labs in the consumer market than Yvonne Laurysen and Erik Mantel (Lama Concept), who first had to convince several external value chain nodes to adopt the material.

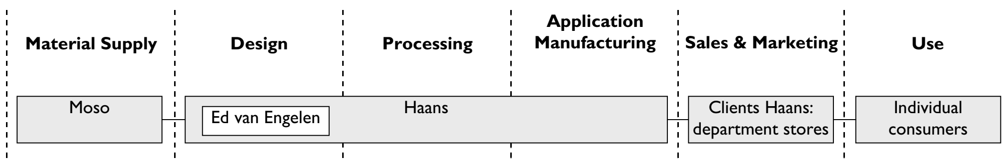


Figure 8.6: Value chain of the bamboo products designed by Ed van Engelen, in-house designer of Haans

Although it was expected before the intervention took place that the increase in new value chain contacts for bamboo would be an important success factor toward an increased behavioral intention, only a couple of (younger) designers noted the new value chain contacts gained as a success factor. Most experienced designers chose to try to commercialize their prototypes through their own existing value chain network.

8.2.3 Conclusions & Efficiency

In this section the most important success factors toward the potential future implementation of bamboo (behavioral intention) were reviewed. In subsection 3.3.1 it was substantiated that it was expected that through an intervention focusing on increasing the material independent variables knowledge and value chain contacts, the material dependent variable behavioral intention would also increase. In this section it was found that the increase in knowledge directly (the perception of this knowledge as a competitive advantage; adoption of bamboo in mental and physical material library) but

also indirectly (through a better attitude toward bamboo materials), indeed improved the behavioral intention of the participating designers. However, it was also found that unlike what was intended, the increase in value chain contacts (found in section 7.1) did not have a large influence on the increase in behavioral intention, and that the existing value chain quality of participating designers proved to be a far more important success factor. Furthermore, a strong material - designer/company - sector match also proved to be a more important success factor facilitating an increase in behavioral intention.
The above shows that unlike the choice to focus on increasing new value chain contacts, focusing on increasing the knowledge of participating designers through design interventions proves to be a viable strategy in order to improve the behavioral intention of participants. It should be noted that for the best chance of success for similar design interventions in the future for other new or lesser known materials, all these success factors should preferably be met. For example, if all success factors are met except the material - designer - sector match, and the material does not fit in the sector of the designer, the behavioral intention will not improve through the intervention.

Analyzing the efficiency of the intervention in terms of the short term behavioral intention of participants shows it could have been improved by inviting: 1) designers with initial preferences for bamboo, in whose sector applicability of bamboo is high, and 2) in-house designers of large application manufacturers with retail outlets, and/or by inviting self producing designers.
Furthermore, one might expect that interventions in another format, e.g. in the form of a design competition, would have been a more cost effective intervention to meet the objectives of the intervention. However, when the participating designers were asked about this possibility during the face-to-face interviews after the Bamboo Labs, most of them noted that they would not have participated if the Bamboo Labs would have had the form of a design competition. The most important advantages of the design workshops strategy (as used during the Bamboo Labs) mentioned by the participating designers are compared to the most important advantages of a design competition in table 8.8.

Table 8.8: Advantages of a design intervention in the form of a design workshop compared to a design competition

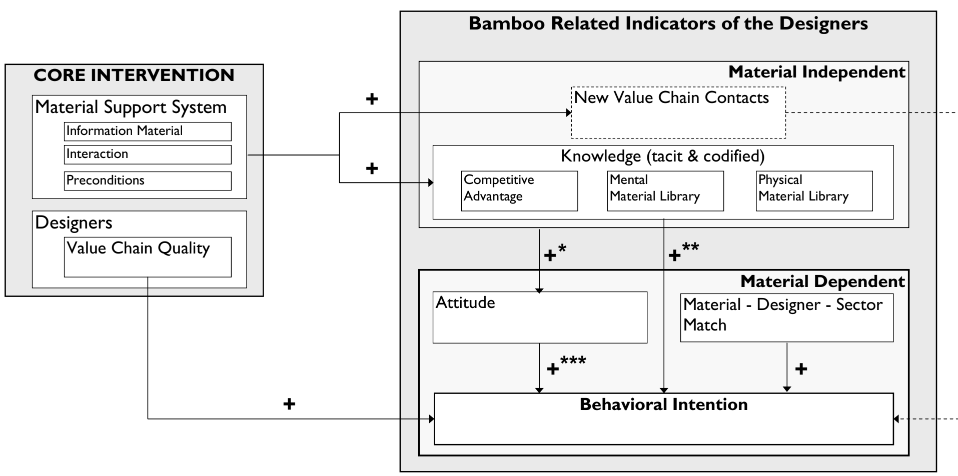
Design workshops	Design competition
- More peer pressure, usually resulting in better results - More cross fertilization and collaboration; also learning from the processes of other participants - Development of value chain network - Bigger knowledge gain (which leads to a higher behavioral intention; see subsection 8.2.2) - More generic knowledge development (think tank function) - More fun, with as a result a higher intrinsic motivation - More control on the results by the commissioner - Higher commitment	- Less money and less time intensive - Broader reach in terms of knowledge development for participating designers (i.e. more designers can participate at the same time)

It should be noted that besides an increase in short term behavioral intention, the intervention in the current form in chapter 7 was found to have yielded many other important outputs beneficial for bamboo, which in the long term could also result in an increase in behavioral intention (e.g. generic knowledge); see table 7.6. In subsection 9.3.1 it will be shown that depending on the objectives of the commissioner of similar design interventions in the future, the configuration of the design intervention should be adjusted into a custom-made solution for maximum efficiency to meet one (or more) of the specific outputs. For example, in some cases (e.g. scenario 3 "Awareness Raising" in section 9.3.1) design competitions may even be preferred to design workshops. Therefore, taking into account the additional outputs of the intervention shown in chapter 7, the intervention may be evaluated as being efficient, and is therefore used as a blueprint for the development of scenario 5 "Generic Material Development" in subsection 9.3.1. Besides the recommendations made in this chapter, additional, more specific recommendations are also included in the development of this scenario in subsection 9.3.1.

8.3 Conclusions

This chapter focuses on answering the fourth research question (RQ4: What are the causes of the success/failure of the intervention and how can the intervention be improved?). In section 8.1 it was found that most of the subcomponents, including the preconditions, of the MSS facilitated the knowledge- and value chain development of the participating designers. However, in general the interaction component appeared to be somewhat more valuable for these success indicators. In section 8.2 it was found that of both of these material independent variables only the gain in knowledge had increased the potential future implementation (behavioral intention) of bamboo by the designers. Furthermore, the attitude toward the material, the material - designer - sector match and the existing value chain quality of the designers were perceived as additional important success factors. Throughout both sections various suggestions to improve the intervention were provided.

In figure 8.7 the main findings of sections 8.1 and 8.2 are summarized. In the figure, the most important components from the conceptual model established in section 3.2 were supplemented with other success factors found in this chapter that contributed directly or indirectly to potential future implementation of bamboo (behavioral intention). The material independent variable "new value chain contacts" is dashed because, as explained above, it - contrary to expectations - did not prove to be an important success factor. Relationships found to be statistically significant are highlighted with a star (*).



Significant relationship for:
* stem, Plybamboo, mats
** mats
*** stem, Plybamboo, mats

Figure 8.7: Model showing the most important success factors toward potential future implementation (behavioral intention) of bamboo by participating designers

PART III: CONCLUSIONS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Aeropuerto
IBERIA
El mayor Puente Aéreo del mundo

9 Conclusions & Recommendations

In the previous chapter the most important factors leading to the success of the intervention were analyzed. This chapter, which concludes this thesis, provides the most important conclusions, recommendations and theoretical contributions of this thesis.

First, section 9.1 presents the main research findings including the answers to the research questions through which the design intervention was evaluated. In section 9.2 the theoretical contributions of this research are discussed, including the replicability of the design intervention executed in this research. Finally, in section 9.3 recommendations are provided toward stakeholders in the material industry (subsection 9.3.1), academic world (subsection 9.3.2) and bamboo industry (subsection 9.3.3).

9.1 Main Research Findings

In chapter 1 bamboo was introduced as a largely unknown renewable material in Western Europe with a low market share but a lot of potential to help meet the increasing demand for raw materials, including hardwood, due to its good properties and high growing speed. In this action research, it was investigated to what extent design interventions can successfully stimulate the commercialization of bamboo in products in the interior decoration sector in Western Europe (main research question).
The intervention consisted of design workshops called "Bamboo Labs" (core intervention, executed in winter 2006-2007) and the diffusion of the results from these workshops (extended intervention starting in April 2007). During the design workshops the following bamboo materials were used: stem, Plybamboo, composite, Strand Woven Bamboo (SWB) and mats. The intervention was evaluated, with a focus on the core intervention, on:
1) Impact - To what extent is the impact of the intervention successful?
2) Developed prototypes - To what extent are the products developed in the intervention successful?
3) Materials - To what extent is bamboo perceived by Dutch designers as a successful material for product design?
4) Process - What are the causes of the success/failure of the intervention and how can the intervention be improved?

In terms of *impact,* the *core intervention* was evaluated through various success indicators for both the participating designers and the material supplier before (T0) and after (T1) the intervention.
At T1, compared to T0, the 21 participating designers altogether gained 92 new value chain contacts, experienced an increase in bamboo related knowledge (1.75 for mats to 4.5 for composite on a 1-10 scale), and an increase in behavioral intention (i.e. the expected chance of implementation of bamboo by the designer in concrete products/projects in the near future) ranging between 8% (mats) to 27% (Plybamboo).
For the material supplier the core intervention yielded almost 50 new value chain contacts of which some have led to important new collaborations that might lead to commercialization of bamboo in new projects in the future. Besides the gained value chain contacts (processors, application manufacturers, knowledge institutes, retail outlets, other designers, etc.) the core intervention acted as a powerful "think tank", yielding a significant amount of important generic knowledge about bamboo, which the

material supplier can use in the future as a competitive advantage over competitors in new product development projects. Next to these gains, eight prototypes developed during the Bamboo Labs will be further developed toward commercialization, for which the material supplier will most likely also provide the material. Furthermore, the material supplier will most likely provide the material for individual follow up projects initiated after the core intervention by four of the participating designers, which have developed into material champions for bamboo.

The *impact* of the *extended intervention,* measured about a year after the conclusion of the core intervention (T2, April 2008), has been very different from the impact of the core intervention, yielding different results, reaching more people, but with a less intense short term effect in terms of an increase in commercialization effects compared to the core intervention. In table 9.1 the most important outputs of both the core intervention and extended intervention are summarized.

Table 9.1: Main outputs found for the core- and extended intervention

Core Intervention (Bamboo Labs) Outputs		Extended Intervention (Scope: DDMB) Outputs	
1.	Development value chain network (downstream)	1.	Exposure with a large reach (with 2 & 3 as a result)
2.	Development of new generic knowledge about bamboo	2.	Improvement of image & trendiness (of bamboo but also of the material supplier)
3.	Strong increase in knowledge and behavioral intention for a limited number of relevant value chain nodes, potentially resulting in new material champions and projects in the short term	3.	Small increase in attitude & behavioral intention for a large number of relevant value chain nodes, potentially resulting in new value chain contacts (possibly also material champions) and projects in the long term

Since the Bamboo Labs resulted in very diverse prototypes based on different bamboo materials and processing techniques, and as they were tangible for relevant value chain nodes downstream as well as the general public, they proved to be very attractive for media exposure. Therefore, the diffusion of the results of the Bamboo Labs has proven to be a powerful promotion tool. Besides the organized exposure (exposition, publication of the book *Dutch Design meets Bamboo* and the organization of several activities around the exposition, such as seminars and lectures), the project results also yielded a lot of unorganized exposure, propelled by the organized exposure, but also by the participating designers, several of whom turned out to be diffusion nuclei of their own (material champions). As a result of this additional exposure, the results of the Bamboo Labs reached more than a million people, and bamboo was recognized as a trend by trend watchers in several acknowledged design magazines. A sample survey showed that in general the attitude and behavioral intention toward the bamboo materials increased (ranging from 0.38 for stem to 0.79 for Plybamboo on a 7-point scale for the attitude, and ranging from 0.26 for stem to 1.85 for SWB on a 5-point scale for the behavioral intention) after relevant value chain nodes were exposed to the results.
Although the extended intervention for the material supplier has led to a large number of interested value chain contacts (mainly designers, but also some large professional clients/brands), of which a couple have already led to concrete design projects, and improved the image of the material supplier as being innovative, the real impact of this exposure for the material supplier (and the bamboo industry as a whole) may only become evident in a later stage, since commercialization processes often take a long time. Finally, it should be noted that it is impossible to accurately measure the exact impact of the diffusion of the results of the Bamboo Labs. An innovation might spread through social networks globally like a virus, which might also apply to the results of the Bamboo Labs (e.g. through coverage on

design related internet sites, global online sales of the book *Dutch Design meets Bamboo*, etc.). Therefore, the impact of the extended intervention noted in this thesis will most likely be larger in reality and will still increase over time.
Although at the start of the project the focus of the intervention was on increasing the behavioral intention of the participating designers, the above shows that the intervention has also been very beneficial for the material supplier (and the bamboo industry as a whole for that matter), and that the intervention has resulted in many additional outputs, to some extent unexpected before the intervention (e.g. the development of new generic knowledge about bamboo). Although it is difficult to draw a line as to when the impact of the intervention can be labeled successful, the total outputs of the combined core- and extended intervention can definitely be labeled as satisfactory.

To some extent, the above also answers the second research question about the *success* of the *products* developed during the core intervention. As can be seen from the high number of prototypes that will be further developed toward commercialization (eight pieces), accounting for around one third of the total amount of prototypes designed, in terms of market potential the success of the developed prototypes is high. This was already forecast by the expert panel who evaluated 11 of the 22 evaluated prototypes as having at least a high level of market potential. In terms of innovative character the prototypes also score well; 12 of the 22 evaluated prototypes were rated by an expert panel as having at least a high level of product innovation, while 10 of the 22 prototypes were evaluated as having at least a high level of process innovation. Through their innovative character these prototypes provide important generic knowledge about bamboo which can be utilized by the bamboo industry, and might in the long term lead to an increasing commercialization of bamboo materials.
To evaluate the performance of the prototypes in terms of environmental sustainability, extensive analysis of the bamboo materials they were made from was executed, in terms of their environmental impact measured in Eco-costs (LCA based method) at the debit side and annual yield at the credit side of the environmental sustainability balance. It was found that in terms of eco-costs bamboo materials used in Western Europe - and thus also the prototypes - score worse than (prototypes made from) locally grown wood; however, in general they score better than wood grown in other continents (e.g. tropical hardwood) and several materials based on finite abiotic resources (e.g. steel and plastics). Furthermore, in terms of annual yield giant bamboo species such as Guadua in general has a higher annual yield (m3/ha semi finished materials) than wood (including fast growing softwood species such as Eucalyptus), a higher applicability of the yield in various applications and a higher potential for reforesting degraded land. Obviously, this annual yield advantage of giant bamboo also applies to the prototypes developed during the Bamboo Labs.
Although in the future bamboo may be utilized best to meet the exponentially increasing demand for raw materials in emerging economies such as India and China where it grows (and where it is on a similar level as locally grown wood with respect to eco-costs), it may help to meet demand in Western countries as well, if local grown softwoods fail to do so. The prototypes developed in the intervention, and the subsequent exposure and increased commercialization rate, may have as an additional spin-off that the image of bamboo as a suitable alternative for housing and product development improves in trend-following emerging economies and developing countries where bamboo mainly grows.

The core intervention also provided valuable information about the perception of the participating designers about the *potential of bamboo as a successful material for product design*. The evaluation, based on the attitude of the participating designers toward the materials, showed that most bamboo materials on a 7-point scale, ranging from 1 - very negative to 7 - very positive (3.52 for stem, 3.65 for mats, 4.02 for SWB and 4.2 for bamboo composite) are still evaluated slightly worse than softwood (Pine;

evaluated at 4.29), and that only Plybamboo (evaluated at 5.24) can compete in terms of attitude with hardwood (Oak, evaluated at 5.48). However, the evaluations did show that for the bamboo materials stem, Plybamboo and mats, an increase in knowledge leads to a statistically significant ($p < .05$ for stem, $p < .10$ for Plybamboo and mats) increase in attitude toward these materials. Furthermore, the evaluation provided a lot of generic knowledge about the various bamboo materials in terms of properties, processing & finishing possibilities and constraints, and additional aspects such as the future potential of the materials after improvement. Most designers mentioned that their attitude toward the various bamboo materials will further increase if these proposed improvements will be met in the future.

Finally, the *causes of the success* of the core intervention were analyzed for the participating designers, based on which several *suggestions for improvement* for the core intervention were made in this thesis.
First, the various components of the Material Support System - MSS (information material component, interaction component and preconditions) - were evaluated with respect to their value for the material independent variables knowledge-, value chain contacts- and inspiration development. The evaluation showed that scores for the various subcomponents of the MSS components were very dependent on the personal preferences of each designer, and thus varied considerably. However, in general the interaction component scored better than the information material component, which was perceived by many designers as being too extensive, and was more appreciated as reference material and a knowledge archive. Furthermore, according to the participating designers, the necessary preconditions were met, and facilitated the success of the intervention.
Secondly, the causes of the success of the intervention were analyzed for the most important success indicator, the behavioral intention of the participating designers. The analysis showed that an increase in behavioral intention was caused - as intended - by an increase in knowledge, which directly (the perception of this knowledge as a competitive advantage and adoption of bamboo in mental and physical material library) and indirectly (through a better attitude toward bamboo materials) impacted the behavioral intention. However, the analysis also showed that the increase in new value chain nodes - unintended - had a small influence on the behavioral intention. The analysis revealed that existing value chain quality and a good designer - sector - material match are more important success factors toward an increase in behavioral intention, showing the crucial importance of appropriate designer selection for these kinds of design interventions. In figure 8.7 in section 8.3 the most important variables directly or indirectly affecting the success of the intervention, including their relationships, are depicted. The above shows that unlike the choice to focus on increasing new value chain contacts, focusing on increasing the knowledge of participating designers through design interventions proves a viable strategy in order to improve the behavioral intention of participants. If the objective is to increase the short term commercialization rate, the design intervention may be improved through designer selection (designer - sector - material match as well as selection of in-house designers or self producing designers). Nevertheless, as was found above, besides an increase in behavioral intention the broad intervention has also had many additional important outputs for the various stakeholders involved, such as an increase in knowledge and relevant value chain nodes, the development of generic knowledge about the various bamboo materials, and an increase in awareness and image for bamboo caused by the exposure generated (see table 9.1). These additional outputs may also, in the long term, help to increase the commercialization rate of bamboo (see below).
Taking into account the additional outputs of the intervention besides the increase in short term behavioral intention, the intervention may be evaluated as being efficient, since alternatives for the configuration of the design intervention (e.g. design competitions), with the same output requirements, were valued by the designers as being less effective (see table 8.8). In subsection 9.3.1 it will be shown

that depending on the objectives of the commissioner of similar design interventions in the future (for other new or lesser known materials), the configuration of the design intervention should be adjusted into a custom-made solution for a maximum efficiency to meet one (or more) of the specific outputs mentioned in table 9.1, in which in some cases alternative configurations (such as design competitions) may also prove to be eligible.

If we return to the main question of this research - *To what extent can design interventions successfully stimulate commercialization of bamboo in products in the interior decoration sector in Western Europe?* - it may be concluded that if the required preconditions are met (e.g. sufficient high quality material, good facilities, adequate organization team and sufficient finances), design interventions can indeed be used as a strong instrument to successfully stimulate the commercialization rate of bamboo in the interior decoration sector in Western Europe.

The design intervention executed in this action research has shown that a one-time injection in the bamboo production-to-consumption system (PCS), at the right place, with the right partners and at the right time, has resulted in a sustained impact on the commercialization process of bamboo. The one-time intervention, which actively integrated designers and other relevant value chain nodes to bamboo, has become self propelling; since the intervention new material champions have stood up (several of the participating designers, but through the exposure also other designers, application manufacturers and incubators such as Things Design). Through these new material champions, and the sustained efforts of the material supplier based on the new insights acquired during the intervention, many other value chain nodes might be affected in the future as well, further increasing the commercialization rate of bamboo in products in Western Europe. Furthermore, through diffusion of the results, areas outside of Western Europe may also be influenced, also fostering an increasing adoption of bamboo as high end material in trend adopting markets in the South, where bamboo often grows and is still perceived as "poor man's timber".

The methodical approach for the intervention, developed in the form of the MSS in this action research, makes it feasible to replicate (and refine) the intervention based on a similar format, for the stimulation of the commercialization of other new or lesser known materials in the future, which will be further analyzed in subsection 9.2.1 below.

9.2 Theoretical Contributions

Besides contributing to solving a current problem in the bamboo PCS, through this action research, executed from an Industrial Design Engineering perspective, generic understanding is also created about the role of the designer during new material commercialization processes, as well as about research methodology for action research based on design interventions. In this section these theoretical contributions deriving from this research are further reviewed. As part of the contribution of the new material commercialization theory, the replicability of the design intervention made in this research for other materials is substantiated as well.

9.2.1 Design Interventions in New Material Commercialization; Replicability

In chapters 1 and 2 it was found that little knowledge is available to what extent, and under which circumstances designers can play a role in stimulating the commercialization process of new materials, and which concrete instruments may be used on firm level to actually involve designers in this process. In this research the potential role designers can play to stimulate new material commercialization was tested by executing a design intervention in practice for bamboo, as a relatively new material in the Western European market (especially in industrial form).

In this thesis it was found that designers - once thoroughly introduced to a new material, and convinced of the added value - can transform a new material (bamboo) into a concrete, marketable product, and, through their central position in the value chain, may be able to convince the necessary value chain nodes downstream to adopt this product (including material). Furthermore, the intervention showed that most designers know how to reach the media, and are therefore very well able to diffuse the results of their work, including the material, through various exposure channels. It was found that through the organization of design workshops, designers can acquire the required knowledge to possibly turn into future champions for the material. Moreover, the design workshops also proved to act as a thinking tank, developing new generic knowledge about the new material, which can be utilized for further innovation in the producing industry of the material.

This potential role of designers as champions for a new material - in this case bamboo in the interior decoration sector - and the use of design interventions - in this case in the form of design workshops - as a suitable instrument to actively integrate designers during the commercialization process of a new material is an important finding of this research, which may also be generalizable for other new or lesser known materials.

Although this replicability of the design intervention cannot be proven yet to be valid for other materials, through careful analysis, similarities in obstacles, mechanisms and actors over the PCS during the commercialization process of these materials might be found, which are tackled in this intervention for bamboo but could therefore potentially also work for other materials.

As a result of this analysis it could be expected that similar design interventions executed for a new material, for which the material producing industry is commissioner, may therefore be successful and/or appropriate if the same circumstances are met as for the bamboo intervention, which depends on:

1) The type of sector in which the material producer operates
2) The size, reputation and resources of the material producer
3) The commercialization phase of the material

These three aspects, which may be perceived as preconditions, will be further explained below.

Type of Sector

It only makes sense to execute design interventions in value chains where designers are included in the value chain nodes. This applies mostly to industries in which material costs sensitivity is low, and in which softer properties of materials (sensorial properties, intangible properties) can have an added value, such as in high end consumer durables. The potentialities of the new material, i.e. the potential functions it could perform based on technology assessment (Poelman 2005), should be suitable to meet requirements in these high end consumer durables markets (e.g. materials that are hazardous to human health or that are too expensive will not be eligible).
In subsection 1.2.3 it was found that in the consumer durables sector, value chain nodes as well as obstacles to be overcome are quite similar[49] for most generic materials (see figure 1.17) and bamboo (see figure 1.18), when consumed in Western Europe. Therefore, it seems likely that the same obstacles that were targeted by the design intervention in this research along the bamboo PCS (lack of availability of information and generic knowledge about the material, lack of material related knowledge of designers and other relevant value chain nodes, lack of product design capacity, lack of value chain networks, and the lack of image & trendiness of the material) may be targeted by similar design interventions in the future for other materials if used in high end consumer durables.
Obviously, the design intervention should be custom-made to target the exact obstacles along the PCS of the new material in the most efficient way. In subsection 9.3.1 several types of design interventions will be presented that can act as building blocks for the development of custom-made design interventions that meet the specific objectives of the commissioner.

Size, Reputation and Resources

Besides the type of sector, the usefulness of design interventions also depends on the reputation, resources, value chain network including client base, and marketing competences of the material producer. As was shown in subsection 1.3.1, large material producers often already have good connections with large application manufacturers (that have the value chain nodes of design, processing, and application manufacturing under one roof; see figure 1.16 in subsection 1.2.3) and can often stick to a market pull approach to retain their market position. In case large material producers do develop new materials, they are usually based on incremental innovations of established materials, pushed into the market by convincing their existing client base of the virtues of the new material.
Usually large material producers directly target platform applications representing relative high volume markets by organizing master classes for the various departments of a large application manufacturer representing the various value chain nodes (e.g. design department, production department, marketing & sales department) in order to convince the application manufacturer to adopt the material. Thus, for them, in most cases executing a separate design intervention may not be necessary. Only in case they want to gain understanding about a new material they have developed (see scenario 1 "Innovation Incubator" in subsection 9.3.1), or target a completely new sector (e.g. scenario 2 "Quick Market Introduction" in subsection 9.3.1; see the cardboard example below), an external design intervention may be fruitful to execute for a large material supplier.

For small material producers the situation is different since they usually lack the existing client base, reputation or the in-house facilities that large material producers have to directly convince large application manufacturers (e.g. through master classes). Therefore, they will need to convince relevant

[49] Note that the intensity of the problems might differ slightly per material (e.g. the image problem, production capacity differences with respect to resource processing between synthetic engineered materials and natural materials, etc.), and that there will always be material specific problems that will play a role (e.g. the lack of dimensional stability of the bamboo stem).

value chain nodes downstream, one by one, to adopt the material. As such, especially for small material suppliers, it can be very fruitful to organize design interventions.

Commercialization Phase of the Material

Finally, the commercialization phase of a material determines the suitability to deploy design interventions. In subsection 1.2.3 it was found that most materials take at least 20 years to be mass commercialized (or are not commercialized at all), and go through the development- and introduction phase, before they are mass adopted in the acceptance phase (van Kesteren and Kandachar 2004). If a material is still in the development phase, the emphasis of problems usually lies on the first part of the PCS, mostly related to the material producer. In the introduction phase most problems during the commercialization of a new material will apply to value chain nodes downstream from the material supplier. In the acceptance phase, problems - if any - will mostly be located at the consumption end of the PCS.

Unless the objective of a material producer is to develop new generic knowledge about a new material for process- or product innovation (see scenario 1 "Innovation Incubator" in subsection 9.3.1), a material needs to have reached the introduction phase, i.e. it should be optimized in terms of properties, and be available in large quantities of constantly high quality, before it makes sense to initiate a design intervention. If these preconditions are not met, and the material is still in the development phase when the design intervention is executed, a designer might find a use for the material in a promising application, but due to constraints linked to the material (supply, quality, guarantees, etc.) the product will not yet make it to the market. For example, of the prototypes developed in the Bamboo labs, the ones that are being commercialized are almost all based on the only bamboo material in the introduction phase: Plybamboo. Most other bamboo materials are still in the development phase and should be optimized first before new design interventions are started. Surprisingly, this also applies to the bamboo stem, which is one of the oldest materials around, but has never made it to the acceptance phase in many sectors in Western Europe, such as in the building industry (see also the box in subsection 9.3.3).
Therefore, in most cases design interventions seem most suitable for materials that have just entered the introduction phase; in this phase materials meet quality and availability criteria, but are still largely unknown to value chain nodes downstream. At that particular moment a design intervention can help to stimulate knowledge development and awareness along value chain nodes, which may lead to an increase in commercialization in the short term or the long term, depending on the scenarios chosen for the design interventions (see subsection 9.3.1).

Once a material has reached the acceptance phase, executing design interventions will most likely not be necessary anymore to retain the market position of the material (supplier). However, if the market position is fading, design interventions focusing on exposure development (e.g. scenario 4 in subsection 9.3.1) and awareness raising (e.g. scenario 3 in subsection 9.3.1), might be used to give the material a new boost. This may be applicable to many traditional materials that have lost popularity over the years such as cork, rattan, and - until a couple of years ago when some material suppliers executed design interventions for the material - ceramics.

It is important to remember that a material might be in the acceptance phase in one industry, but still in the development- or introduction phase of another. For example, whereas cardboard is adopted as one of the most important materials in the packaging industry, it is still in the introduction phase in the building industry. Therefore, it could still be interesting to develop a design intervention (Cardboard

Labs) in the high end building industry (involving architects) or - interior decoration sector (designers) for a cardboard material supplier in order to stimulate the future commercialization rate of his material in other industries as well.

Figure 9.1: Cardboard is slowly being adopted in the building industry, especially in temporary buildings (e.g. pavilions)

Concluding, from the above it seems likely that if a (small) material producer, active in the medium to high end consumer durables sector, is commercializing a material in the development- or introduction phase, design interventions can act as an important instrument to develop (generic) knowledge, raise awareness, generate exposure and as a result stimulate the commercialization rate of a new or a lesser known material.
However, this conclusion is based on the findings of this particular research. Therefore, although this thesis may provide a small contribution to theory about the use of design interventions in new material commercialization, knowledge in this field should further increase by executing and evaluating similar interventions through action research in the future.

It should be noted that once the preconditions mentioned above are met, there are still many additional factors that also may facilitate the success of the intervention, which depend on the actual goals and required outputs of the commissioner of such an intervention. For example, in subsection 8.2.2 it was found that for largest chances of short term commercialization of a new material it is best to invite in-house designers of application manufacturers that match with the material, while if exposure and improvement of trendiness is most important it is best to invite star designers. In subsection 9.3.1 several suggestions are made about how future design interventions can be configured to meet each of these outputs in the most efficient way.
Finally, it should be remembered that although design workshops target several obstacles in the PCS of a new material directly related to designers (and to some extent also to additional value chain nodes downstream; see figure 2.1), there are many additional factors of success and failure relating to additional value chain nodes during the final phases of the commercialization process that also determine the actual launch of a new material in a product on the market (see appendix G).

9.2.2 Research Methodology for Design Interventions in Action Research

The second theoretical contribution of this research is in the field of research design methodology. As was found in the previous subsection, very little knowledge is available about the use of design interventions to stimulate the new material commercialization process, and there is not an existent research methodology on how to execute action research based on design interventions.

The conceptual framework developed in this research in chapter 3, which provided the building stones of the intervention (independent variables) as well as the various success indicators (dependent variables), which were based on actual problems found over the PCS, may be used as a structuring element for similar action research based on design interventions in the future.
Depending on the actual objectives of the commissioner the design of the intervention will have to be custom-made (see various scenarios in subsection 9.3.1), based on which also the conceptual framework (i.e. components of the intervention as well as success indicators) can be adjusted.

In this research especially the information material and interaction component consisting of a range of different tools and subcomponents introduced in subsection 2.2.4 were found to act as a sound, replicable and methodical approach that can be used to structure similar design interventions in the future. However, in this research it was also found that the (less controllable & measurable) properties of the stakeholders involved in the intervention also play an important role in the success of design interventions. For example, in subsection 8.1.3 it was found that the availability of a project champion with entrepreneurial qualities is an important success factor for a design intervention. If the researcher also acts as initiator, he/she will most likely need to take on the role of project champion, for which a strong intrinsic motivation is required. Alternatively, the required entrepreneurial qualities should be distributed (and thus be available) through the complete organization team, acting as a complementary unit. In subsection 9.3.2 it is recommended that further research be conducted about the required properties of the researcher (or the organization team the researcher consists of).

9.3 Recommendations

9.3.1 For Stakeholders in the Materials Industry

Introduction

In section 7.1 it was found that besides the main success indicator (behavioral intention), the core intervention yielded many other outputs as well. Furthermore, preliminary impact analysis of the extended intervention (section 7.2) showed that the extended intervention had a different and complementary impact compared to the core intervention. In table 9.1 the various outputs of the core- and extended intervention were depicted. Depending on the objectives of the commissioner of similar design interventions for other new or lesser known materials in the future, the focus of the intervention may shift to specifically focus on one (or more) of the outputs mentioned. For example, a bamboo research institute may be most interested in the output "development of new generic knowledge about bamboo" of the core intervention.

In this subsection various recommendations for an adjusted configuration of the whole intervention (core and extended intervention) will be provided, based on various scenarios. Each scenario was developed in such a way that the outputs found in table 9.1 were matched with objectives of different kinds of potential commissioners of possible future design interventions in the most cost- and time efficient way. The scenarios were developed based on observations by the organization team and the author, supplemented with feedback received from the participating designers during the face-to-face interviews. In the case of a new material with an innovative or sustainable character, there are several possibilities for subsidies available in the European Union, such as through the Seventh Framework Program (FP7), the Competitiveness and Innovation Program (CIP), the LIFE program or the ALA-program, to fund these kinds of design interventions.
It should be noted that the scenarios developed in this subsection are not a guarantee for success, but may help to tackle some of the obstacles, centered around designers, in the PCS of the new material.

However, as can be seen in appendix G many additional factors, relating to additional value chain nodes, and various phases of the product innovation process play a role in the successful commercialization of a product - in which a new material may be used - on the final market.

Scenarios

In table 9.2 below the various scenarios developed are summarized. Although the scenarios are very different from each other, the recommendations and preconditions applicable for the core intervention (see chapter 8), used as blueprint to develop scenario 5 "Generic Material Development", to a large extent apply to all scenarios. For example, preconditions such as the availability of sufficient material are required for all interventions. Furthermore, the scenarios were developed taking into account the preconditions found for replicability in subsection 9.2.1.

It should be noted that the scenarios only sketch the broad outlines of the framework for future design interventions. Depending on the specific objectives of the commissioner, scenarios may be combined and/or adjusted. Furthermore, it should be noted that the property "focus" in the table shows if the focus of an intervention will lie with the core intervention or with the extended intervention (diffusion of the results). Unless the results of the core intervention are meant to remain inside of the organization of the commissioner (e.g. scenario 1 "Innovation Incubator" for material producers), it is recommended to also execute an extended intervention. In section 7.2 it was found that if the results of the intervention are noteworthy, a couple of elements of organized exposure (book, exposition, activities around exposition) are sufficient to start a self propelling avalanche of diffusion, which may result in many benefits. Further, it should be noted that in the table only the most important (main) outputs of the design intervention are mentioned; in various cases some of the other outputs mentioned in table 9.1 will also become manifest; however, most likely in smaller numbers.
In case a design intervention is executed out of environmental sustainability incentives, the author would like to add the requirement to execute environmental assessments (based on LCA and annual yield calculations) to the new or lesser known material before the design intervention takes place. If the environmental assessment shows the material does not score well from an environmental point of view, the intervention may be cancelled.

Table 9.2: Main properties and requirements of the various scenarios for design interventions

	1. Innovation Incubator	2. Quick Market Introduction	3.Awareness Raising	4. Image Building	5. Generic Material Development
Expected main output	- New generic knowledge (process & product innovation)	- Development value chain network - Increase in short term behavioral intention	- Increase in knowledge participants (designers) - Exposure - Improvement of image & trendiness - Increase in long term behavioral intention	- Exposure - Improvement of image & trendiness - Increase in long term behavioral intention	- Development value chain network - Increase in knowledge (participants & generic) - Increase in short term & long term behavioral intention - Exposure - Image & trendiness improvement
Method	In-house design workshops	Design workshops	Design competition with knowledge input	Material provision and knowledge input	Design workshops
Suitable for (stakeholder)	- Material producers - Material research institutes	- Small material producers - Sectoral organizations (e.g. INBAR, bamboo industry)	- Sectoral organizations (e.g. INBAR, bamboo industry) - Design oriented universities - Platform- and trade organizations for designers	- Sectoral organizations (e.g. INBAR, bamboo industry)	- Sectoral organizations (e.g. INBAR, bamboo industry) - Design oriented universities - Small material producers
Suitable for (sector)	All, but best in enabler applications in (high end) consumer durables	(High end) consumer durables	(High end) consumer durables	(High end) consumer durables	(High end) consumer durables
Required commercialization phase	Development or introduction phase	Introduction phase	Introduction phase	Introduction phase	Introduction phase
Requirements of intervention **- Designers** **- MSS** **- Preconditions**	- 2-5 experimental, collaborative designers - Availability of information portal & production experts - Availability of processing facilities/machines	- 2-5 in-house designers or independent self producing designers - Availability of information portal & production experts	- 10-200 designers/students - Availability of information portal & panel of experts - Availability of processing facilities/machines	- 2-5 star designers (self producing) - Availability of production experts	- 10-20 in-house designers or independent self producing designers with similar background and collaborative attitude - Availability of information portal & panel of experts
Focus	Core intervention	Core intervention	Core & extended intervention	Extended intervention	Core & extended intervention

The various scenarios and their properties will be further explained and elaborated upon below.

1. Innovation Incubator

The innovation incubator scenario is suitable as an intervention for (both small and large) material producers and research institutes working with materials in the development- and/or introduction phase, which require the development of new generic knowledge with respect to process- and product innovation for their materials. A design intervention in the form of in-house design workshops, taking place at the premises of the commissioner, may be the best format to meet this objective. If the commissioner is a material producer, there may not be an extended intervention executed since the company will most likely keep the generic knowledge developed for itself to use it as a strategic advantage over competitors. In case the commissioner of the intervention is a research institute (e.g. a university), it might also be interesting to diffuse the results of the intervention. A commissioner interested in generic knowledge development of their material in the development- or introduction phase may be interested in product innovation, i.e. searching the best application in which the new material may be deployed, or in process innovation, i.e. searching for new processing technologies facilitating the development of new semi finished materials and/or applications (or a combination of the two).

The innovation incubator scenario seems most suitable for commissioners in the consumer durables industry, although in some cases also for other commissioners outside of this industry this scenario might be relevant.

Since it is of importance for the generic knowledge development objective in this scenario that the designers are able to experiment together and collaborate intensively, the number of invited designers should be low (maximum of around five designers), and the designers should have a collaborative attitude. Depending on the generic knowledge need of the commissioner (focus on product- or process innovation), the kind of designers to invite may be different. For a broad application search (product innovation) it might be best to invite designers from various disciplines, sectors and backgrounds, including designers-artists, who more often think out of the box.

In the case of a process innovation focus, a commissioner is recommended to invite a small group of designers with an experimental attitude, who are knowledgeable in industrial processes used in the sector in which the commissioner operates (e.g. the invitation of package designers to explore the possibilities of bamboo veneer in the packaging industry). It might be considered that one designer-artist for this objective be invited as well, to inspire the other participating designers with out of the box solutions.

Below, the other requirements posed to the Material Support System (MSS) for the innovation incubator scenario are explored, first for generic knowledge development based on product innovation, and secondly for process innovation.

In the case of an application search, the intervention may be relatively simple. First of all, the designers would require a one-day input to acquire basic information about the new material with respect to its properties, processing possibilities & -constraints, and application possibilities, which could be provided to them by processing- and production experts of the commissioner. Preferably, the designers should be able to experiment themselves with the material in the production facilities of the commissioner.

If possible, for background information the designers should have access to a newly-to-be developed, comprehensive online information portal (see subsection 9.3.3). After this input day the designers would need to be able to bring the material home to their studios for more experiments and brainstorm sessions. After an incubation period of 1-2 weeks, a half-day professionally-led brainstorm/creativity session should be held, in which the potentialities, i.e. the unique possibilities of the material through

technology assessment, should be linked to applications in which these unique possibilities could be utilized best to meet a functional requirement (functionalities). Poelman (2005) found that exploring the potentialities of a material from a technology oriented perspective may result in many overlooked application possibilities. Besides the designers, production experts should be invited to the brainstorm session. During the session the production experts (focus on potentialities; what can the material do?) and the designers (focus on functionalities; in which product can these potentialities be used to fulfill a function?) can build on each other's ideas and knowledge to develop unique product ideas. An example of an unexpected result of such an exploration for bamboo could be the linking of the potentiality "hollowness" of bamboo, with the functionality "resonance", of importance for example in loudspeakers (see figure 9.2).
From the extensive product idea output this brainstorm session may yield, it would be best to shortlist the applications that have the characteristics of an enabler, i.e. high visibility, use of specific material properties, high fault tolerance and simple value chains and if possible a low material-cost sensitivity (for more information see subsection 1.3.2).

Figure 9.2: Bamboo Speaker by Bird-Electron taking advantage of the potentiality "hollowness" of the bamboo stem

In the case of process innovation the participating designers would also require a similar information input day guided by production experts, including the possibility to bring along material for first experiments. After an incubation time of about a month the designers would need to be able to experiment with the material full time in available production facilities on the premises of the commissioner, with the guidance of production experts, for at least a couple of days. Enrique Martinez, initiator of a similar process innovation exploration workshop for bamboo (Martinez and Steinberg 1999), noted that in such a setting, experimenting together, group members may inspire each other and together may come to new solutions. Based on the findings during experimentation, the commissioner may use this knowledge for the development of new applications, or request each designer to come up with a product prototype that utilizes the process innovation knowledge gained during the experiments.

An advantage of the innovation incubator scenario is that many designers are interested in gaining hands-on experience with a new material, especially if production facilities are provided and opportunities for commercialization of their ideas in collaboration with the commissioner are available. As a result, they will often not need to be financially compensated by the commissioner for their time expenditures during the intervention. This means that the commissioner will only need to make in-kind contributions (availability of in-house production experts and processing facilities) in order to facilitate this particular intervention scenario. For example, the famous Knotted Chair by Dutch designer Marcel Wanders, made from carbon and aramid fibers, was designed in design workshops during the Dry-tech project of Droog Design, organized in the laboratory of the Faculty of Aerospace Engineering at DUT in 1996 (Beukers and van Hinte 2001).

Figure 9.3: "Knotted Chair" designed by Marcel Wanders

After the design intervention has been executed, the commissioner may consider organizing a new, similar design intervention, in which other participants may build on the generic knowledge developed in previous interventions (relay format). Especially for research institutes this may be an interesting format for generic knowledge development, which, once it acquires recognition in the design world, may also serve as an interesting promotion tool for diffusion of the results (see example of European Ceramics Works Center in the box in subsection 2.1.2).

2. Quick Market Introduction

The quick market introduction scenario is especially suitable for small material producers with materials in the introduction phase, that are active in supplying high end consumer durables industries, which want to improve their value chain network and short term commercialization rates. A design intervention in the form of compressed design workshops, in which a small number (2-5) of in-house designers and/or independent self-producing designers active in the target market of the material supplier are invited, may be the best format to meet this objective. In this scenario the designers should be able to experiment with the material in their own production- and processing facilities.

As found in subsection 8.2.2, the advantage of inviting in-house designers of large application manufacturers (e.g. self producing furniture labels), is that in these companies the value chain nodes "design", "processing" and "application manufacturing" may be available under one roof, facilitating the adoption of ideas developed by the in-house designer (who takes the production constraints and mission statement of the company into account when designing his/her products), by value chain nodes downstream, including the subsequent market launch. If in-house designers whose company mission statements match the properties of the material are selected (e.g. in Western Europe the furniture manufacturers Haans and Habitat for bamboo, because of their focus on natural materials, Asia and CSR practices), chances of a successful adoption of the new material may be further increased. However, small material producers should be aware that for them it usually is not interesting to invite in-house designers of very large application manufacturers such as IKEA that have all value chain nodes under one roof (including material production and supply) or only have the retail and design value chain nodes under their roof, and have outsourced processing and application manufacturing to the South (e.g. in the Netherlands, the company HEMA). In the case of the former, a design intervention may help to increase the interest of IKEA designers in bamboo; however, they will source the material from their own value chain instead of from the material supplier. For the latter, something similar happens; the

HEMA designers might become convinced of the virtues of the material and design bamboo products, for which they will source the material from the South (and not from the material supplier initiating the design intervention). For resource promoting organizations and sectoral platform organizations (e.g. INBAR for bamboo) this does not apply, and if they are commissioner of such a design intervention, approaching these parties may be a viable option.
Although the emphasis will most likely lie on the design workshops themselves (core intervention), the output of the intervention may also be diffused actively in an extended intervention, showing what the material can do in concrete, marketable products.

A danger of inviting several in-house designers from different companies is that they compete in the same market and therefore may not want to participate together in such an intervention. Furthermore, the in-house designers will most likely design products with high commercial value; surprises in product- or process innovation (see innovation incubator scenario) are not to be expected in this scenario.
If a material supplier wants to avoid these problems he/she could also consider inviting experienced, self producing, independent designers with strong value chain networks, which usually work in smaller batches (and thus often have more room for products with an experimental character). Another alternative could be to invite a larger group of independent designers with weaker value chain networks (e.g. young designers), in combination with a broker organization that links designers with application manufacturers and retail outlets, in a similar way as the foundation Things Design has acted for the Bamboo Labs (see subsection 7.2.4).

The quick market introduction scenario could be organized as a compressed version of the Bamboo Labs. It should start with an information input day in which the material properties, processing possibilities & constraints, and application possibilities are introduced by processing and production experts, the design brief and the use of the permanently available online information portal (see subsection 9.3.3) are explained, and the material is handed out. Halfway through the process (1-2 months later) the designers should present their first ideas and prototypes to other participants, during which they can discuss with several production experts their questions and doubts. The intervention finishes with a final presentation about a month later, in which the results are presented to the other participants and to the commissioner.
The advantage of this intervention from the point of view of the material supplier is that it is an inexpensive solution that may boost the commercialization rate of their material in the short term. First of all, when in-house designers of application manufacturers are convinced about the use of learning about the possibilities of the new material for their company, they can often execute the intervention during working hours and will most likely not require financial compensation for their time (as the in-house designers from Leolux and Haans also did not require compensation for their participation during the Bamboo Labs). Secondly, by choosing in-house designers working for companies that have processing- and application manufacturing value chain nodes under the same roof, the material supplier also does not need to supply production facilities, further cutting costs of this design intervention scenario compared to other scenarios (e.g. innovation incubator).

3. Awareness Raising

The awareness-raising scenario is especially suitable for commissioners without a direct commercial interest (e.g. sectoral organizations, design oriented research institutes and platform organizations for designers) that want to get designers, and through exposure of the work of the designers also the general public, acquainted with the possibilities and virtues of a new material in the introduction phase.

In the long run the intervention may lead to an improvement of image & trendiness, and subsequent adoption of the material by relevant value chain nodes.
Although we have seen in subsection 8.2.3 that design workshops hold many advantages over design competitions (see table 8.8), for this particular scenario design competitions may be a more cost- and time efficient solution, since more designers may be reached at once. However, a design competition for a new material can only work if a lot of knowledge and technical support can be provided to participants in order to prevent them from reinventing the wheel.
Furthermore, a design competition is only effective if many designers are inclined to participate, which depends on the gains for the designer which may lie in an increase in knowledge, and the exposure and awards related to the competition (e.g. review in a premier design magazine). If the incentives of the commissioner mostly have an educational nature, organizing a design competition in collaboration with design universities may be a viable option.

The MSS of the awareness-raising scenario could be organized as follows. First, a general information input day should be organized in which through plenary lectures the main properties and processing characteristics of the material are introduced, the design brief is explained, and the material and information material is handed out. If applicable, it should be explained by production experts how the processing facilities, made available throughout the intervention, are to be used. After this input day, the designers have one month to experiment with the material and to develop a concept for a product design. During this time they may be supported by the online information portal (see subsection 9.3.3 for more details), in which for this scenario it would be recommended to integrate a blog function to communicate with other participants and an invited panel of experts. Although the blog was not successful for the Bamboo Labs due to the soft launch and the small community of designers (see subsection 8.1.2), if appropriately launched it is expected to be a more suitable tool for the design competition setting. After the design concept is submitted, a jury can select the best ideas and invite these designers to develop a prototype, for which additional material will be provided. Approximately two months later the invited designers should present their prototypes to the jury, who will select the best design. It is recommended that the results will be diffused in various ways (similar to the diffusion of the results of the Bamboo Labs); for example, through an exposition, activities organized around the exposition, and exposure through various media.
If a design competition is organized through design universities this may be a cost effective option for the commissioner, especially if the university has processing facilities available. Although this scenario will not result in a quick increase in commercialization figures, if organized well it has a broader reach than design workshops, it will provide many new product ideas and exposure, and may raise an interest in the participating designer students to use the knowledge acquired during the intervention in future design projects after their graduation.

4. Image Building: Toward a New Trend

The image building scenario is suitable for commissioners with interests on the sectoral level (e.g. trade organizations) that want to improve the image & trendiness of the new material through exposure of the material in exclusive products. For this scenario the commissioner should approach star designers with high recognition to experiment with the material and try to challenge them to develop a product which could function as an icon for the material. In the image building scenario the commissioner will supply the material and should make a production expert available who can assist the designer upon request. It would be preferable to invite star designers that have their own production facilities, since as such the commissioner does not have to provide these.

The focus of this design intervention is on diffusion of the results (extended intervention). The advantage of approaching star designers such as Philippe Stark is that they are trend setting. Because they have such recognition it is very easy for them to generate exposure for their latest designs through various media (usually media come to them). Although the prototypes developed during the design intervention may never be launched on the market, through the exposure they generate and the association with the star designer, in the long term the intervention may result in an increased commercialization when the material is recognized as a trend.
Although convincing star designers to adopt the new material is challenging, once the commissioner has succeeded in doing so, the intervention is a cost effective, self-propelling way to improve the image of the material.

Figure 9.4: Chairs designed by the famous designer Philippe Starck

5. Generic Material Development
The generic material development scenario is based on the intervention (Dutch Design meets Bamboo) executed in this action research in the form of design workshops, including diffusion of the results, which has proven to be successful in terms of various outputs such as the development of a value chain network, increase in knowledge (both generic as for participants), generation of exposure yielding, an improvement in image & trendiness, and an increase in both short term and long term behavioral intention of participants. As such, this scenario is suitable for commissioners that want to give a boost to a material in the introduction phase on various scales, combining elements of the previous scenarios. Therefore, the generic material development scenario may be interesting for small material producers, sectoral organizations and design oriented research institutes (e.g. universities) active in the consumer durables sector. In chapter 8 the success of the intervention was already analyzed and various recommendations were provided for the improvement of the intervention, which are also applicable here. Besides these recommendations, some additional recommendations are made below for the improvement of the MSS for this scenario.

For the generic material development scenario it is recommended to invite between 10 and 20 highly motivated designers with a similar background (e.g. in sector, batch size, material-designer match) and a collaborative attitude in order to further facilitate cross fertilization between the participants and strengthen the think tank function of the intervention. In order to make sure that participating designers fit in this profile, it is recommended to post the upcoming intervention in design magazines and associations (e.g. in the Netherlands the Dutch Designers Society, BNO), inviting designers to fill in an application form detailing their interest in participating in the design intervention.

In order to improve chances of the short term commercialization of products developed during the intervention (depends on the focus of the commissioner), it would be recommended to also invite a number of in-house designers of large application manufacturers and/or independent self producing designers (see also recommendations in scenario 2 "Quick Market Introduction"). Inviting these kinds of designers also prevents the commissioner from having to arrange production facilities. If it is not a problem for the commissioner to provide production facilities from the start, another alternative could be to invite a larger group of independent designers with weaker value chain networks, in combination with a broker organization linking designers with application manufacturers and retail outlets (see example of the foundation Things Design in subsection 7.2.4).

The intervention could be organized as a compressed version of the Bamboo Labs, and would need to comprise of: 1) an information input day in which the lectures, excursion, information material & material handout and design brief explanation are combined, and in which also a brainstorm session would be recommended, 2) a meeting halfway through the process (after 1-2 months) in which the designers can present their first ideas and prototypes to other participants, and during which they can discuss with a panel of experts their questions and doubts, and 3) a final presentation in which the results are presented to the commissioner, other participants and potentially interested value chain nodes downstream. If the focus of the intervention (depending on the commissioner) is on generic knowledge- and value chain development and exposure of the results, it could be considered to organize the intervention in relay format (see also scenario innovation incubator). In this way participants may not only build on each others' knowledge, but also value chain contacts involved in earlier interventions may be involved in later interventions which may help to further strengthen the value chain network around the new material.
An advantage of the Generic Material Development scenario is the broad range of outputs the complete intervention (core- and extended intervention) might yield, facilitating a higher chance of success by not betting on one horse (e.g. scenario "quick market introduction"). A disadvantage of this scenario is that the intervention is more cost- and time intensive than the other scenarios. Nevertheless, as the experiences during DDMB have shown, if the material that is to receive a boost in its commercialization rate has an innovative and sustainable character (e.g. renewable, recyclable, socially responsible, energy efficient, etc.), there are ample possibilities to request subsidies to help fund this kind of design intervention.

9.3.2 For Further Research

Further Development of the Design Intervention Framework

With respect to the structure and components of the design intervention, several recommendations can be made.

First, it is recommended to further develop and improve the structure and components of each design intervention scenario proposed in this research (in subsection 9.3.1), by testing them in practice for various new or lesser known materials.
Secondly, it is recommended to conduct more research about the role and requirements with respect to either the personal characteristics of the initiator, or the characteristics of the organization team of which the initiator is a part, for a successful design intervention, especially if in the case of action research the researcher is the initiator of the project (see subsection 8.1.3). It is recommended to also investigate if requirements with respect to the personal characteristics of the researcher/organization team would differ for design interventions executed in different countries, caused by cultural differences (e.g. North vs. South).

Thirdly, it is recommended to integrate sustainability criteria into the design intervention framework, facilitating a benign outcome from the point of view of sustainability, which could refer to all the pillars (People, Planet, Profit) of sustainability. Especially if the design interventions will be based on production scenarios in the South (see below), the "People" aspect may become more important, since especially in the South the social component of sustainability (see also table 9.3 below), is under pressure.

Table 9.3: Topics for which the Global Reporting Initiative (GRI) has developed various performance indicators to measure the social performance (People) of a business (GRI 2006)

Labor practices & decent work	Human rights	Society	Product responsibility
Employment Labor/management relations Occupational health and safety Training and education Diversity and equal opportunity	Investment and procurement practices Non-discrimination Freedom of association and collective bargaining Abolition of child labor Prevention of forced and compulsory labor Complaints and grievance practices Security practices Indigenous rights	Community Corruption Public policy Anti-competitive behavior Compliance	Customer health and safety Product and service labeling Marketing communications Customer privacy Compliance

Finally, it is recommended to test the suitability of the design intervention methodology based on production scenarios in the South. Although this thesis focused on executing a design intervention in the North, it may be important to test the suitability of the approach also in the bamboo producing regions themselves. This may not only apply to bamboo, but also to other renewable materials grown in the South such as rattan and various other NWFPs.

It should be noted that compared to the production scenario of this action research focusing on the North, many additional obstacles play a role if the bamboo products are produced in the South, with respect to knowledge, design capacity and production capacity of both material producers and application manufacturers, since designers are hardly integrated in the value chain (for more information see van der Lugt (2005a) and van der Lugt and Otten (2007)). This was also found by Eliza Noordhoek and Lara de Greef, two of the participants of the Bamboo Labs, who, prior to the intervention had executed an assignment for INBAR in India, through the platform organization Dutch Design in Development (DDiD), assisting the local craftsmen working in INBAR projects to design products which would meet requirements of Western markets. The project showed that only sending Western designers to the South, targeting the problem of lack of product design capacity, is not enough; similar to design interventions in the North, a design intervention in the South can only be successful once problems in the first part of the value chain (e.g. good material and tools) have been solved. Furthermore, in the case of a design intervention in the South, various additional obstacles need to be overcome that can be perceived as preconditions for success, such as language and cultural barriers (e.g. many small producers in the South do not understand that trends are an important factor in the North that may influence wishes of the Western consumer. These aspects would also need to be taken into account in the development of a design intervention framework suitable for use in the South.

Figure 9.5: Lara de Greef and Eliza Noordhoek encountered many cultural barriers during their design assignment for DDiD in India

It should also be tested which configuration of a design intervention in the South is most efficient in terms of commercialization outputs compared to money and time inputs. For example, if Western designers are to be integrated in a design intervention based on production in the South, it may be considered to either send a team of Western designers to the South to work and experiment in production facilities over there, or mimic the Southern production situation, including the typical constraints, in the North, and later transfer the findings to producers in the South. The latter option is not uncommon, since sending Western experts to the South is usually very costly. For example, Philips has developed various tools with which Dutch product designers developing products for the Indian market can map the local context to better understand the local situation and needs of customers without having to travel to India themselves (Rodríguez et al. 2006). On the other hand, if the designers can work in the production facilities in the South, they are closer to the source, which also provides additional possibilities for processing of the vegetable materials in green state (e.g. bamboo is considerably easier to bend in green state providing new design possibilities). For example, Jared Huke, an American designer who has developed several bamboo products in Vietnam for Western markets, mentioned in an interview with the author (van der Lugt 2005b): "Western designers need to go to the source of the material; 99% of all design opportunities I have had with bamboo are a direct result of being around where people are growing the material. Not one of my pieces could have been designed sitting 10,000 km away from where bamboo grows. At this moment most Western designers are cut out of the production process and limited to working with the semi finished materials available to them in the Western market."

Figure 9.6: Bamboo chair designed by the American designer Jared Huke produced with coiling techniques in Vietnam

Furthermore, if organized in a proper way through transfer of design knowledge from participating designers to local producers, in the case of sending Western designers South, a more sustainable and durable solution might develop, which endures after the design intervention. Masera (1999) and Diehl & Crul (2006) have developed various manuals on how to successfully integrate sustainable product development practices in small and micro enterprises in developing countries. In the case of future interventions in the South focusing on sustainability, their guidelines could be integrated or used as complementary input.

Since obstacles in the PCS in the South are similar for bamboo as for other NWFPs (van der Lugt and Otten 2007), if design interventions in the South for bamboo appear successful, they may potentially be used for other lesser known NWFPs as well. There are plenty of cases available, since there are many neglected renewable materials present in developing countries with development potential. International NGOs and (local) governments can be useful in identifying potential beneficiaries (i.e. local producers). The Dutch Design platform organization "Dutch Design in Development" (DDiD) could play an important role in matching beneficiaries in the South (small producers) and designers, since DDiD subsidizes designers that want to contribute their design skills in developing countries (beneficiaries only have to supply accommodation and food).

Besides organizing solutions in which Western designers are actively integrated in design interventions in the South, the possibility for native designers, usually working in urban areas in the South, to also start experimenting with bamboo should be facilitated. In the next subsection it will be recommended to develop an information portal through which information about bamboo, catered toward the specific information needs of designers, should become permanently available online, which could also be used by designers in urban areas in the South not participating in a design intervention.

LCA Based Research

In section 5.4 several recommendations were made with respect to additional LCA-based research to be executed for bamboo in the future. As was noted in the outcomes in chapter 5, as a result of the increasing pressure on raw materials, through annual yield calculations (section 5.2), the factor time should also be taken into account in environmental assessments of materials based on LCA. It is therefore recommended that annual yield calculations are integrated and standardized in LCA-based calculations in the future.

9.3.3 For Stakeholders in the Bamboo Industry

In chapter 5 it was found that giant bamboos, through their high annual yields, a higher applicability of this yield in various applications (ranging from high end to low end) and a higher potential for reforestation on degraded land, score better in terms of annual yield than wood, including fast growing softwood species such as Eucalyptus. As such, bamboo may prove to be one of the most important raw materials of the future, able to meet the growing demand for raw materials in a range of applications, especially in emerging economies, once more bamboo plantations have been established in (sub)tropical regions.

However, the worldwide (industrial) bamboo industry is still young and many large steps are required if bamboo material is to reach the acceptance phase in various mass raw material consuming sectors. Below, some of the most important stepping stones toward reaching this phase are put down in the form of recommendations on personal title and are based on the findings of the author during seven years of research (this PhD research and the MSc study of the author), interviews with hundreds of stakeholders in the bamboo industry, and visits to dozens of projects, production sites, conferences and workshops in Asia, Australia, Africa, North America, Europe and Latin America.

Research & Promotional Activities by a United Bamboo Industry

The high potential of bamboo as a raw material should be further investigated and diffused, using combined powers, by a united bamboo industry. Although sectoral and trade organizations are being established for bamboo on a growing basis in China, both in other bamboo producing countries and in the West, bamboo companies should unite instead of perceiving each other as competitors, whereas, in fact, the wood industry is the most notorious competitor for them. The wood industry has already learned the importance of uniting and has formed several unions and trade organizations promoting the use of wood, while protecting the interests of the wood industry as a whole (e.g. Centrum Hout in the Netherlands). The International Network for Bamboo and Rattan (INBAR) could take a leading role in facilitating the establishment of a strong union in the bamboo industry, or increasingly take on this role itself. Once this union has been established, it can further act as a base for research and promotion of the potential of bamboo as a raw material. This promotion- and research campaign should be based on sound scientific proven facts, instead of on opportunism, since many stakeholders in the bamboo industry still tend to wrongly over-emphasize the green image of bamboo, whereas on various occasions in terms of eco-costs locally grown wood performs better (see section 5.1).

Three major recommendations are made, which should facilitate further knowledge development and promotion of bamboo as a raw material of the future on a durable basis once the bamboo industry has united (precondition). First, it is recommended to develop an online information portal for bamboo; second, it is recommended to set up a certification scheme for bamboo; third, it is recommended to launch a promotion campaign informing the general public of the potential of bamboo.

Figure 9.7: INBAR representatives Coosje Hoogendoorn (director general) and Rebecca Reubens (consultant) and Moso International director René Zaal discussing obstacles in the bamboo industry with Professor Han Brezet and the author at DUT

Recommendation 1: Development of an Information Portal

In chapter 2 it was found that there is a lack of available adequate information about various bamboo related topics, especially on aspects at the end of the PCS relating to product design and marketing issues. Furthermore, it was found that if this information is available, it is often very hard to find (lack of diffusion of information). In several places worldwide bamboo based research is being executed, but there is not a central place were newcomers to the topic may go to in order to get a complete overview of bamboo based information and research. During the Bamboo Labs the participating designers were provided with a selection of the best information available worldwide, compiled from various sources. Although this has helped the participating designers, it did not solve the global problem of the lack of availability & dissemination of bamboo based information.

Therefore, it is recommended to develop an online information portal, which could be used for any stakeholder interested in bamboo, including designers. This information portal should provide information on a more fundamental, scientific level as well as on a more informal level for the general public. It is recommended to develop the more fundamental part of this information portal as an online expert community (see for example the online expert community for chromatographers at http://www.chromedia.org/). Since the only global bamboo journal (the *Journal of Bamboo and Rattan*) available has a limited scope and reach, a new, well accessible, flexible and scientific knowledge base is required for bamboo, reviewing and publishing high quality related research in the form of downloadable articles. This community should not only map all relevant and sound bamboo research executed so far on various topics (knowledge domains), it should also serve as a research incubator, with appointed experts for each knowledge domain keeping track of developments in the field and stimulating appropriate research to be executed to fill gaps in the knowledge. In this community one expert could be the coordinator and editor for each knowledge domain, backed up by a scientific committee for peer reviewing of articles submitted. Accepted articles should be published online in the domain they belong to. Furthermore, the domain coordinator, in collaboration with the review committee, should identify knowledge gaps, post these online, and invite research to be executed to fill these gaps. As such it can point (PhD) students and researchers in the right direction, instead of having them reinvent the wheel (as happens all too often in the bamboo sector). Subsequently these researchers would be requested to submit an article on the topic to the expert community. The domain coordinators could also encourage the execution of similar design interventions as the Bamboo Labs in the future for their use as think tank, and post generic knowledge found during the intervention on the information portal, which would continuously evolve in this way.

Once it will have gained recognition, and a strong panel of coordinators and peer reviewers has been developed for each domain, this community may develop into the most acknowledged knowledge base available for bamboo. Furthermore, for each domain the following aspects should be listed: references of high quality bamboo related articles published earlier through other sources (including links to the journal that has published the article), the best books on the topic (including bibliographical information), other relevant websites, and contact data of experts in the field. A question & answer section could be included in the online expert community as well. The structure of this expert community (as well as the complete information portal) could be based on the transformation process of bamboo divided into resource related topics, material related topics and application related topics, besides some cross cutting topics (see table 9.4).

Table 9.4: Suggestion for the information structure of a new to-be-established online information portal for bamboo

Resource ⇒	Materials ⇒	Applications (sectors)
Plantation management	Stem	Building industry/interior
Reforestation	Production & processing	- Technology
Genetics & anatomical research	Material properties & testing	- Sustainability (LCA & annual yield)
Preservation	Economics & marketing	- Economics & marketing
Economics	Strips & mats	Building industry/bearing structures
	Bamboo Mat Board	Furniture
	Plybamboo	Accessories & utensils
	Strand Woven Bamboo	Sports equipment
	Bamboo composites	Garden
	Fibers	Biomedical
	Other bamboo materials	Appliances
		Transport
		Energy
		Paper & cardboard
		Food
		Other
Cross cutting topics: - Policy - Trade - Legislation - PCS		

In the more informal part of the information portal, categorized along the same domains, information catered toward the general public could be presented in various downloadable formats in the form of brochures, reports, presentations, movies and pictures. This part of the information portal could have a more commercial character and could be sponsored by companies in the bamboo industry, for example by including "yellow pages", and the possibility of visitors to request samples of the various bamboo materials. Furthermore, a blog and online forum could be included in this part of the information portal as well.

If the visually appealing digital database developed within the framework of DDMB, adopted by INBAR in January 2008, could be developed into an online tool, and the above mentioned aspects could be integrated, the database could be used as a good, basic framework for the development of this bamboo information portal.

Recommendation 2: Development of a Certification Scheme for Bamboo

The second major recommendation, which can also be perceived as a precondition if bamboo is to further develop into the introduction- and acceptance phase, is the development of a certification scheme for bamboo. Long have industrial bamboo producers been able to take advantage of the green image of bamboo, evading questions with respect to the sustainability of their materials, which were already being asked to (tropical) hardwood suppliers in the 1990s and formalized into certification schemes (e.g. FSC) for the wood industry. However, with sustainability becoming more and more important worldwide, and the market share of industrial bamboo materials growing, this question backfires again at the bamboo industry. Only this time it is not enough to inform potential clients about the high growing speed of bamboo for them to be convinced to adopt bamboo; many criteria over the complete chain of custody with respect to sustainability (People, Planet, Profit) need to be met. Once met, this approval needs to be certified by an acknowledged label, guaranteeing the sustainability of the chain in which the bamboo materials and products are produced. Especially large application manufacturers are increasingly obliged to work with material producers that have a certified production chain, in order to retain their "license to operate" (SustainAbility 2003).

For the bamboo industry this is the second challenge to be met in the near future, and it is a formidable one since the credibility of bamboo is at stake. For example, on various green consumer fora (e.g. treehugger.com) the environmental sustainability of industrial bamboo materials is increasingly being questioned. For producers in the South it is often very difficult to understand why, all of a sudden, their traditional way of working is not satisfactory anymore, and many difficult demands with respect to production and the rights of employees have to be met. Awareness raising amongst stakeholders in the bamboo sector is therefore important, and an adequate response to the call for certification is crucial.

Roughly speaking, there are two directions the bamboo industry can go with respect to certification: adopt an existing certification scheme for wood, or develop a new certification system.
The most commonly adopted certification scheme for hardwood in Western Europe is the FSC-label (Centrum Hout 2007). Although the label is widely acknowledged and has a high level of credibility, the current FSC guidelines are hardly usable for bamboo since the production chain of bamboo is far more small-scaled and scattered than for wood, for which the FSC guidelines were initially developed. According to the director of Moso International, René Zaal, bamboo materials will become too expensive and not competitive anymore if current FSC guidelines are to be met. Although some FSC guidelines are available for bamboo forests (e.g. in Colombia), they are not transferable to the situation in bamboo plantations. Therefore, if existing guidelines for wood are to be adopted for bamboo, a dialogue should be started with FSC (or other acknowledged certification schemes such as PEFC) to develop a new custom-made certification scheme for bamboo.
Alternatively, the united bamboo industry could try to develop its own certification scheme, custom-made for the situation in the bamboo sector. A problem with this option is that this new scheme and label still lack the recognition of existing labels such as FSC, which could form a problem. However, if the label could be backed up by globally acknowledged organizations such as the World Wildlife Fund (WWF), in time, this obstacle could also be tackled.

Recommendation 3: Set up a Global Promotion Campaign
While the previous recommendation can be perceived as a crucial precondition for the further development of the bamboo industry, and the first recommendation is required to build a strong, durable information base, the final recommendation has a more temporal nature, recommending the launch of a promotion campaign with lasting effects. Through this campaign, the potential of bamboo as a sustainable raw material should be promoted to the general public. This campaign can be built following the same structure as the information portal (resource, materials and applications) using complementary instruments (similar to *An Inconvenient Truth* by Al Gore) to convey the intended message: a traveling exposition, a contemporary international book and an international movie. This dissemination project would fill an important need, since there is not yet a contemporary exposition, book nor movie available apt for informing the general public worldwide about the real potential of bamboo in an informal, attractive, understandable and comprehensive way. The exposition, book and movie should wake a flame of interest in bamboo by visitors, readers and watchers, which they should

be able to further fuel in the information portal (see recommendation 1). The promotion campaign could be launched during a large event (e.g. world fair).

Once the bamboo industry has united, and the three recommendations mentioned above are followed, the requisites necessary may have been acquired for bamboo materials to start moving into the introduction and acceptance phase of its commercialization, leading to adoption in the medium to long term in platform- and mass-market applications. Below, it is explored in which markets bamboo has most chance for mass adoption in the future.

Future Markets for Bamboo

In subsection 1.3.2 it was explained that the commercialization process of new materials toward acceptance can be accelerated through strategic market selection, by first targeting enabler applications (i.e. application markets with high visibility, use of specific material properties, high fault tolerance, simple value chains, a low material-cost sensitivity and if possible large adjacent markets) in order to gain credibility, while developing knowledge and capability along the value chain nodes, after which the material may be launched in platform applications and subsequently in mass markets (Musso 2005). In this thesis the interior decoration was chosen as the enabler market for bamboo. In the impact evaluation (chapter 7) of the design intervention in this action research it was found that the interior decoration sector has indeed proven to be a suitable market for bamboo to present and further develop itself toward the introduction- and acceptance phase. Below, other potential enabler applications will be introduced for bamboo that can be interesting to target in the short term, after which potential larger volume platform- and mass markets in which bamboo may be used on the medium to long term, will be investigated.

<u>Enabler Applications for Bamboo</u>

Enabler applications are often found in small volume, high end markets. Besides the interior decoration market, some examples of other promising applications meeting enabler criteria can be mentioned, which in some cases are already being commercialized. For Plybamboo, and especially veneer, luxury packaging, consumer electronics and the sports industry are examples of very visible markets that in the high end regions have a low material-cost sensitivity. Although in high end packaging (see figure 7.11 in subsection 7.1.3) and consumer electronics Plybamboo is only used for its environmental and aesthetic properties (see figure 9.8 right), in various kinds of sports equipment such as snow-, surf- and skateboards Plybamboo, but also several bamboo mats and composites, may also be chosen for their technical properties (see figure 9.8 left).

Figure 9.8: Plybamboo (veneer) used in high end consumer durables; snowboard by Indigo-Bogner ski (left) and laptop by Asus (right)

For the bamboo stem, with its explicit form, other enabler applications should be targeted. A nice example of a simple product, which takes advantage of the intrinsic qualities of the stem, is the recent use of the hollowness of the stem for the development of high end loudspeakers (see figure 9.2). The friendly, exotic character of the stem may also be suitable for use in children's toys.

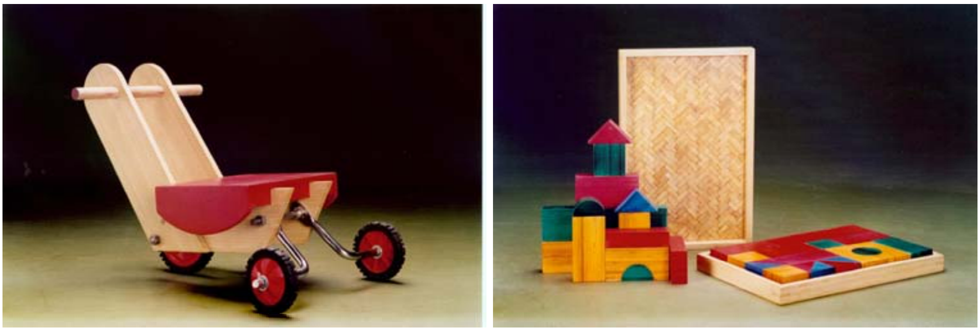

Figure 9.9: Bamboo used in toys (NID 2003)

Although these markets are highly visible and material-cost insensitive, they are very small in volume and so far away from potential high volume markets for bamboo (building industry, see below) that on a large scale they will not make a big difference. However, on firm level these enabler applications can make a difference in the SME sector and help to improve the image and applicability of the material with the general public. Furthermore, the possibly overlooked "killer application" in a large industry might be found by accident this way.

Platform and Mass Markets for Bamboo

Because of the similarities in appearance and chemical composition, and therefore also in processing technologies, bamboo and other natural fibers should first focus on the substitution of markets in which wood is used, before in the medium to long term markets in which plastics and synthetic fibers (e.g. glass fiber) are the incumbent materials (bamboo fiber based composites) may be targeted.

Substituting Wood

Wood is the first natural fiber that has seen mass adoption in Western markets. Taking a look at the consumption of wood in the Netherlands, it can be found that wood is mostly consumed in the building industry followed by the garden sector, DIY sector, pallet industry, furniture industry and in civil engineering projects (see figure 1.20 in subsection 1.3.2). Note that for industrial bamboo materials, adoption will probably be easier in countries such as Austria, Germany and the Scandinavian countries where wood is more popular and total wood consumption is considerably higher.

In chapter 6 it was found that of all bamboo materials available in Western Europe, Plybamboo is the only material in the introduction phase. Plybamboo was already introduced in the platform markets in which it most likely fits best: the high end segments of the flooring, interior finishing and furniture industry. The Plybamboo industry should try to further increase the market share of bamboo in these markets, which is still very low (see subsection 1.2.2). Furthermore, with some smart adjustments in processing technology, the high volume low to medium end segments of these markets could also be targeted by bamboo strip-based products in the future. For example, by attaching bamboo strips on textile carriers an inexpensive new kind of carpet can be developed (taped mats; see figure 9.10).

Installation- and production costs of this product are a lot lower than for regular bamboo flooring. Although in this case the innovation was made by the bamboo producer itself (Moso International) the active integration of industrial designers in the development process of new bamboo materials can incubate these kinds of process innovations (see scenario 1 "Innovation Incubator" in subsection 9.3.1).

Figure 9.10: Samples of taped mats developed by Moso International, which combine the advantages of bamboo and carpet

Since the costs attached to Strand Woven Bamboo (SWB) are still quite high, the material should, once it has been optimized in material properties (e.g. durability outside) and has reached the introduction phase, try to target niche markets in the large volume building- and civil engineering industry, such as window frames, decking and cladding. In these markets SWB may substitute expensive and increasingly scarce tropical hardwood.

Due to their lower costs and good mechanical properties, in the future Bamboo Mat Board (BMB) could potentially also find its way as a bulk material in large volume industries such as the building-, pallet- and garden industry, competing also with softwood and wood based board materials (e.g. use of BMB for pallets). However, due to the low margins, high performance standards and competition in this sector, BMB would also need to prove itself in specific enabler- and platform applications first.
Systematic exploration of the potential of the bamboo stem (e.g. the hollowness and efficient structural design) shows that some specific applications might exist in which the low costs and efficient structural form can be utilized in enabler- or platform applications in the building industry. In Western Europe demountable building systems for pavilions based on bamboo with prefabricated endings could possibly serve as an enabler- or platform application for the bamboo stem in the Western building industry (see figure 9.11), although these prefabricated endings do make the bamboo stem significantly more expensive.

Figure 9.11: CONBAM® building system developed by Christoph Tönges

However, for the use of the bamboo stem in construction in Western Europe many additional obstacles experienced earlier in the PCS need to be overcome, as was found in previous studies executed by the author. A summary of the results of these studies, which were published in various journals (van der Lugt et al. 2003, van der Lugt et al. 2006), including an introduction about the virtues and vices of the stem, is presented in the box below.

Box: Bamboo Stem as a Building Material in the West

The tubular form of bamboo offers some major advantages. Janssen (2000) has proven that bamboo in terms of the relation between the moment of inertia and the diameter is 1.9 times more effective than the rectangular solid cross-section of a wooden beam, which leads to material savings. Furthermore, the cellulose distribution in the stem increases from the inside toward the outside, which is very effective in terms of bending strength. This means that the structural design of the bamboo stem is very efficient, which is also evident in the relation of the weight per volume and the strength and stiffness of bamboo compared to more traditional building materials (see figure 9.12). Therefore, the assumption of most structural engineers in the West that the bamboo stem is not suitable for use as a structural beam is unfounded, which fact is also supported by the efficiency of the design of the bamboo stem. The reason why steel beams, for instance, are manufactured in a tubular or "I" form is to save material and to be able to absorb a greater mechanical moment. Bamboo already comes in this efficient tubular form directly from nature.

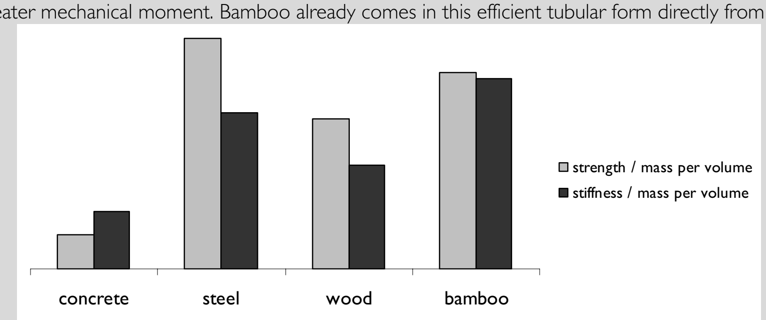

Figure 9.12: Comparison in strength and stiffness of bamboo with other commonly used building materials (Janssen 2000)

However, making statements about the mechanical properties of bamboo is complicated. To start with, there are many different bamboo species and even for one specific species, the differences in mechanical properties due to climatic circumstances and soil conditions can be considerable.

Still, from a general point of view it can be stated that mechanically speaking, bamboo has a relatively high tensile strength and stiffness, high flexibility, a low weight, and a high hardness. Disadvantages from a mechanical point of view are the relatively low compressive strength and the risk of shear stress in joints in the constructional application of bamboo. The Columbian architect Simon Vélez has solved this problem by filling the last bamboo compartments with concrete, thus realizing a larger contact area and better bonding with the metal connection parts (von Vegesack and Kries 2000); see figure 9.13.

Figure 9.13: The Colombian architect Simon Vélez fills the final chambers of bamboo with concrete to create a stronger connection with protruding bolts

In developing countries, bamboo has been used as a building material for centuries, mainly by people of the lower income groups. In the past couple of years, however, architects such as the Columbian Simon Vélez have started applying bamboo as a high-grade material in exclusive buildings. In his structures, Vélez makes maximum use of the lightness and efficient mechanical design of bamboo, for example, by applying the bamboo stem in roof structures with large eaves.

Figure 9.14: The strength of bamboo shown through various constructions in Colombia designed by Simon Vélez with spectacular eaves and spans

Despite the mechanical efficiency of the bamboo stem, the material is hardly applied as a building material in Western Europe. The three main causes for this are:
- Inadequate knowledge
- Absence of building standards
- Lack of dimensional stability

Inadequate Knowledge

Due to inadequate knowledge of bamboo, most Western architects handle the material ineffectively. They use the wrong bamboo stems (not preserved and dried), or expose the stem directly to climatic circumstances such as sun and rain, which cause the stem to split and decay faster. As a result of this inappropriate application, bamboo has gained the image of being a non-durable material with a short life span. If the bamboo stem were protected against direct climatic conditions (rain, sun) by a "hat" and "shoes" (weatherproof foundation), like in the constructions by Simon Vélez, it could last for decades, even in Western Europe.

Absence of Building Standards

As bamboo is still a relatively unknown building material in Western Europe, adequate building standards have not yet been developed. As a result very little (reliable) data is available about the mechanical properties of the bamboo stem, which is in fact available for wood (grades and classifications). During construction processes, the absence of (mechanical) data of bamboo often leads to problems and extra costs incurred by fire safety- and mechanical testing to be executed in laboratories. However, since 2003, international ISO standards (ISO 22156 and 22157) have been made available for bamboo, providing guidelines for structural design as well as a common framework for mechanical testing of bamboo stems worldwide, facilitating comparisons in mechanical properties of bamboo in various regions in the future (ISO 2004a, ISO 2004b, ISO 2004c).

Lack of Dimensional Stability

The form of the bamboo stem (round, hollow, tapering, with extruded rings) also causes many problems in the rectangular-oriented building culture in Western Europe, in which dimensional stability plays a crucial role. In the past few years, there have been a few innovations that standardize the bamboo stem ends with prefabricated connections in order to solve the dimensional stability problem (see figures below). Solutions in this field are still in a development stage and are not yet fully commercialized nor applied industrially. The solutions with the wooden props are less expensive and are therefore more appealing for use in construction in the South, whereas the solutions with steel connectors are more expensive but more visually appealing, therefore more suitable for niche markets in the North.

Figure 9.15: Connections with the bamboo stem based using wooden props facilitating easier connections; left connection by Bambu Tec, right connection by Oscar Arce

Figure 9.16: Connections with the bamboo stem with prefabricated standardized endings and steel connections; right connection developed by Sam van Veluw, left connection developed by the University of Aachen

Still, it is always good to search for new areas in which a new material can be used. For example, the consumption of wood has historically grown mostly in the furniture and building industry, but there may be various other applications that have not been taken into consideration where it may be used. In subsection 9.3.1 a design intervention is introduced (scenario 1 "Innovation Incubator") which may be used to conduct an application search which matches best with the specific advantages of the material. Note that in the South the bamboo stem has already found suitable mass markets in the building industry, such as in low cost housing and in scaffolding[50], and is increasingly being adopted in high end

[50] The Polytechnical University of Hong Kong has developed several scaffolding systems combining bamboo with steel that meet local safety requirements

building projects as well, especially in Latin America (see figure 9.14). In section 5.3 it was concluded that if used locally the bamboo stem is by far the most environmentally friendly material around.

Figure 9.17: In Asia the bamboo stem is commonly used in scaffolding, even for the construction of skyscrapers

Once the various bamboo materials have proven themselves in enabler- and platform applications in the building industry and have reached the introduction phase, larger mass markets in the building industry may be targeted by bamboo materials. Below, some suggestions are provided to material producers to facilitate adoption of bamboo in the building industry. It should be noted that this should not be undertaken unless proper testing has been done on aspects such as fire safety, strength and durability, and the quality and availability of materials can be guaranteed.

Since the configuration of project based value chains such as in the building- and civil engineering industry is very different from product based industries such as the consumer durables industry, other stakeholders play a role, and other strategies are required to convince these industries to adopt bamboo. For product based value chains there are usually many nodes in the chain (see figure 1.17), whereas in a building project usually the commissioner (who wants a building to be made), an architect (who develops the design of the building) and a contractor (who executes the project) are the most important players. Besides these stakeholders many additional advisors play a role in this process (e.g. building management, cost management, etc.).

For material suppliers that have developed a new material with certain properties that are beneficial for society, the government (local or national) is a good potential client to target because of its character as an early adopter due to its function to set examples in society.
However, in the value chain of building- and civil engineering projects, material suppliers do not often have direct contact with the commissioner of the project, and usually interact with contractors and architects who they will try to convince of the benefits of the material. Architects are the designers of the building industry and are therefore very important stakeholders for material producers to influence as prescribers of materials in projects, but also because in general they are more open minded toward the adoption of new materials. In contrast, in the building and civil engineering industry most contractors are perceived as anti champions because of their conservative character. Contractors earn their money by executing a project - as described in the specifications - as economically as possible through savings in labor and material. Usually they already have experience with a couple of materials and have good relationships with suppliers of these materials that can deliver them for a low price. Therefore, in general contractors are not very eager to adopt new materials because of the higher costs and risks involved.

However, of course architects also have to keep to the proposed budget. Therefore, especially if some of the bamboo materials considered by an architect for a new project are still expensive (which is the situation in the short term), they might be surpassed by cheaper alternatives. This also depends on the kind of project to be built. In projects with a high status, which need to function as icon of the organization of the commissioner (e.g. head office of multi nationals, buildings of the Ministry of Environment, airports, city halls, etc.), architects usually have a larger budget and thus a larger freedom in material selection, including the choice for some of the more expensive bamboo materials. Usually, architects with a high recognition are invited for these kinds of large, high status projects. Once the material has been adopted in such a prestigious, highly visible project, the building itself will act as an important promotion instrument for bamboo directly, by influencing visitors, and indirectly, by serving as reference project in various media. For example, the adoption of curved Plybamboo by Richard Rogers for use in the eye catching ceiling of the new airport in Madrid (see figure 9.18 and introduction picture of this chapter on page 242), has proven to be an ideal business card for stakeholders in the bamboo industry showing that bamboo can be a serious alternative for wood, also in the building industry.

Therefore, for bamboo material producers and suppliers it is recommended to convince architects with a high recognition and/or specialized in high status projects, to adopt or experiment with their material. It is also smart to try to convince architects specialized in public buildings (for which the government is commissioner) to adopt bamboo materials, since the local or national government is usually more prone to the adoption of (potentially more expensive) sustainable materials in their projects because of their exemplary role. Convincing these architects to get acquainted with bamboo may be facilitated by executing similar design interventions as the one executed in this action research.

Figure 9.18: Curved plybamboo laths used in the ceiling of the new airport in Madrid designed by Richard Rogers

Substituting other Commonly Used Materials

In terms of volumes of raw materials deployed, bamboo in the form of the fiber may also have a lot of potential in the medium to long term to substitute for other materials besides wood, such as plastics in various platform and mass applications in several other industries. In subsection 5.2.3 the suitability of bamboo fibers for input in composites, textile, biofuel and pulp was already mentioned. In these industries the annual yield advantage of bamboo was shown to be even larger than in the furniture- and building industry, due to shorter harvesting cycles.

In line with the increasing scarcity of various, especially abiotic, raw materials, the use of the bamboo fiber will become increasingly interesting in industries which utilize composites (e.g. automotive industry, boat industry, caravan industry, casing of appliances, furniture industry, building industry, etc.), textiles

(clothing industry), and pulp (paper and cardboard industry). This increasing interest will most likely be driven by both the consuming side and the supply side, based on different incentives.
From the consumption side sustainability requirements will most likely prevail for individual consumers and the government, whereas from the supply side material producers and application manufacturers, besides having to meet these sustainability requirements, will start considering bamboo fibers once they represent cost benefits and while meeting quality requirements (e.g. strength for use in composites).
However, before bamboo fibers and the subsequent semi finished materials that can be made from it (composites, textile and pulp) will be mass adopted in these industries in the West, they will need to become available in large quantities in constant, high quality with a competitive price, which requires additional research, especially with respect to cost-, time-, eco- and material efficient methods to isolate the bamboo fibers from the stem.[51] Once these requirements have been met and the material has reached the introduction phase, several large material suppliers and application manufacturers active in the aforementioned industries might become interested in testing bamboo as a potential material alternative in pilot projects in enabler applications.
In order for bamboo fibers, including composites, textile and pulp, to reach the introduction phase in the West, research consortia are to be formed, in which knowledge institutes (e.g. universities), a united bamboo sector (see recommendation above) but also representatives of the aforementioned large volume industries are to be integrated. There is a lot of financial funding available from national governments (e.g. through SenterNovem in the Netherlands), as well as from the European Union (e.g. the FP7, CIP, LIFE and ALA-programs) for these kinds of public private research programs combining sustainability and innovation.

It may take years to decades, but if enough stakeholders in the various industries get acquainted with the enormous potential of bamboo - in terms of its reforestation potential (short establishment time, possibility to restore degraded land), high annual yield and large versatility for use in many high end to low end applications - and adopt the material, bamboo may finally take on its role as the raw material of the future (see also subsection 5.3.3). It is the author's hope this thesis may serve as a stepping stone toward this goal.

[51] Note that at the University of Leuven, Belgium, Colombian researchers are analyzing methods to distill the micro fiber from the stem for the Guadua species (Dr Aart van Vuure, personal communication 2007). According to these researchers for fiber production, the stem from which the fibers are derived do not need to be mature, meaning that the possible annual material yields might be a couple of times higher than the already high material output in terms of biomass of other bamboo materials (see subsection 5.2.3).

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Samenvatting

In hoofdstuk 1 wordt de probleem analyse en centrale vraagstelling van dit promotie onderzoek geïntroduceerd. Het belang van materialen is in de geschiedenis van de mens terug te vinden in de classificatie van verschillende tijdperken zoals het Stenen Tijdperk, het Bronzen Tijdperk en het IJzeren Tijdperk. De benaming van elk tijdperk refereert aan het meest gebruikte materiaal tijdens deze periode en toont zo de impact van materialen op technologische ontwikkelingen in de historie van de menselijke maatschappij. Daarnaast heeft het gebruik van materialen een grote invloed op de ecologische duurzaamheid van de producten waarin ze worden gebruikt, en dragen zo bij aan de drie wereldwijde milieuproblemen: 1) uitputting van grondstoffen, 2) aantasting van ecosystemen en 3) aantasting van de humane gezondheid. Door de groeiende bevolking en veranderende consumptiepatronen worden er mondiaal meer grondstoffen verbruikt dan dat er worden geproduceerd. Van de drie milieuproblemen lijkt de uitputting van grondstoffen de urgentste: de verwachting is dat verschillende abiotische grondstoffen in de 21^{e} eeuw uitgeput zullen raken.
Hoewel hernieuwbare grondstoffen zoals hout een goed alternatief lijken, verdwijnen door de toegenomen vraag naar vooral langzaam groeiend tropisch hardhout, tropische wouden in een hoog tempo. Dankzij de hoge groeisnelheid en goede eigenschappen kan bamboe een interessant alternatief hernieuwbaar materiaal zijn als substituut voor verschillende grondstoffen, met name hardhout, om zo bij te dragen aan de toenemende vraag naar grondstoffen wereldwijd. In West-Europa is bamboe echter nog een vrij onbekend materiaal met een klein markt aandeel, veroorzaakt door verschillende problemen tijdens het Productie-tot-Consumptie Systeem (PCS).
Gezien hun strategische positie in de waardeketen en hun vermogen om een nieuw materiaal te vertalen in een concreet waardevol product, kunnen ontwerpers fungeren als "kampioenen" voor nieuwe materialen in de hoge marktsegmenten van consumentengoederen, zoals in de sector interieurinrichting (meubilair, woonaccessoires en interieurafwerking). In dit actie-onderzoek is onderzocht in hoeverre de commercialisatie van bamboe kan worden gestimuleerd in de sector interieurinrichting door het actief betrekken van ontwerpers als materiaalkampioenen. Deze opgave is vertaald in de centrale vraagstelling van dit onderzoek: *In hoeverre kunnen ontwerpinterventies de commercialisatie van bamboe in producten voor interieurinrichting in West-Europa succesvol stimuleren?*

In hoofdstuk 2 wordt de voorgestelde ontwerpinterventie verder uitgewerkt. Door middel van interviews met belanghebbenden in de materiaalindustrie werd gevonden dat, vooral voor kleine materiaalproducenten, de organisatie van multidisciplinaire ontwerpworkshops - waarbij ook andere schakels verderop in de waardeketen zoals verwerkingsbedrijven, applicatieproducenten en verkoopkanalen betrokken worden - de meest geschikte strategie zou kunnen zijn om ontwerpers actief te betrekken.
De ontwerpinterventie, gebundeld onder de naam "Dutch Design meets Bamboo", bestaat uit de kerninterventie (de ontwerpworkshops genaamd "Bamboo Labs" zelf, uitgevoerd in de winter van 2006-2007) met ontwerpers als doelgroep, en de uitgebreide interventie (diffusie van de resultaten van de workshops vanaf april 2007) met relevante schakels aan de consumptiekant van de waardeketen als doelgroep. Dit onderzoek concentreert zich op de kerninterventie, die zich richt op het aanpakken van drie belangrijke obstakels gevonden in het PCS van bamboe: een gebrek aan bamboekennis van

ontwerpers, een gebrek aan bamboe-gerelateerde netwerken rondom ontwerpers in de waardeketen, en een gebrek aan ontwerpers die met bamboe werken.
De uitgebreide interventie heeft een breder bereik en probeert ook andere obstakels, gevonden tijdens het bamboe PCS, aan te pakken: gebrek aan kennis van overige schakels in de waardeketen (verwerkers, applicatieproducenten, verkoopkanalen en het grote publiek), het gebrekkige imago en het gebrek aan bamboe-gerelateerde netwerken in de waardeketen. De overall doelstelling van zowel de kern- als de uitgebreide interventie is het stimuleren van de commercialisatie van bamboe in consumentenproducten.
Tijdens de kerninterventie werden 21 ontwerpers uitgedaagd om tijdens vijf workshopdagen (Bamboo Lab dagen) een bamboeproduct met hoge potentie voor de West Europese markt te ontwerpen. Daarbij hadden ze de keuze uit vijf bamboematerialen: stam, Plybamboo, composiet, Strand Woven Bamboo en matten. Gedurende de Bamboo Labs werden de ontwerpers bijgestaan door het Materiaal Ondersteuning Systeem, bestaande uit verschillende soorten informatiemateriaal en interactie met experts.
In de uitgebreide interventie werden de resultaten van de workshops, in de vorm van productprototypes, verspreid. Dit gebeurde door middel van een expositie, de publicatie van een tweetalig boek en door de organisatie van verschillende activiteiten rondom de expositie, zoals een ontwerpbeurs, een symposium en verschillende lezingen.

In hoofdstuk 3 wordt de onderzoeksopzet verder geïntroduceerd. Op basis van de belangrijkste elementen van de interventie en het gebruik van typische actie-onderzoekcriteria, wordt het onderzoeksmodel ontwikkeld en geoperationaliseerd in vier onderzoeksvragen. Deze onderzoeksvragen evalueren en analyseren de interventie op basis van:

1. De impact van de interventie;
2. De productprototypes ontwikkeld tijdens de interventie;
3. De bamboematerialen gebruikt tijdens de interventie;
4. De oorzaken van het succes van de interventie, inclusief verschillende adviezen tot verbetering.

Tenslotte wordt de onderzoeksmethodologie geïntroduceerd, bestaande uit een combinatie van kwantitatieve en kwalitatieve onderzoeksmethoden voor dataverzameling en -analyse.

In hoofdstukken 4 en 5 worden de verschillende productprototypes geëvalueerd.
In hoofdstuk 4 geschiedt dit op basis van de criteria marktpotentie en innovativiteit, door middel van expertwaardering. De helft van de 22 ontwikkelde prototypes werd geëvalueerd door het panel van experts als een ontwerp met een hoge tot zeer hoge marktpotentie. Dit komt ook tot uiting in het relatief grote aantal prototypes (acht stuks) dat uiteindelijk verder wordt ontwikkeld met marktintroductie als doel. Daarnaast werden de prototypes in ongeveer de helft van de gevallen geëvalueerd als innovatief tot zeer innovatief met betrekking tot productinnovatie en procesinnovatie.

In hoofdstuk 5 wordt de ecologische duurzaamheid van de prototypes geëvalueerd door middel van een diepgaande analyse van de bamboematerialen waaruit ze zijn opgebouwd. De materialen zijn beoordeeld op basis van 1) Eco-kosten (een methode gebaseerd op LCA methodologie) aan de "debet" kant van de ecologische duurzaamheidbalans, en 2) hernieuwbaarheid met betrekking tot de jaarlijkse oogst aan de "credit" kant van dezelfde balans.
Op basis van de eco-kosten analyse blijkt dat bij gebruik in West-Europa bamboematerialen slechter scoren in eco-kosten dan lokaal verbouwd hout, maar in het algemeen beter dan hout afkomstig van andere continenten, zoals tropisch hardhout, en materialen gemaakt van abiotische grondstoffen, zoals staal en plastics.

Op basis van de jaarlijkse oogst (m3 industrieel halffabricaat per hectare) scoren reuzenbamboesoorten zoals Guadua over het algemeen beter dan hout, en zelfs beter dan snel groeiende zachthoutsoorten zoals Eucalyptus. Een extra voordeel van reuzenbamboes ten opzichte van hout is hun bredere toepasbaarheid in diverse applicaties en hun betere geschiktheid als herbebossinggewas op braakliggende gronden.
In verband met de hogere eco-kosten bij gebruik in West Europa wordt aanbevolen om bamboematerialen met name lokaal toe te passen in opkomende, grondstof verslindende economieën als India en China, waar reuzenbamboes in grote getalen groeien en het meest milieuvriendelijke alternatief zijn. Als in de toekomst in regios zoals West-Europa de vraag naar grondstoffen niet door lokaal verbouwd zachthout gedekt kan worden, zijn bamboematerialen vanuit milieu-oogpunt ook hier een vrij goed alternatief.

In hoofdstuk 6 worden de verschillende bamboematerialen, gebruikt tijdens de Bamboo Labs, geëvalueerd door de deelnemende ontwerpers op basis van hun attitude ten opzichte van het materiaal. De evaluatie liet zien dat de ontwerpers de meeste bamboematerialen (stam, composiet, Strand Woven Bamboo en matten) negatiever beoordelen ten opzichte van zachthout en alleen Plybamboo beter beoordelen dan zachthout en gelijkwaardig beoordelen ten opzichte van hardhout. De resultaten lieten echter ook zien dat een toename in kennis van de bamboematerialen leidde tot een significante toename in de attitude ten aanzien van deze materialen. Verschillende ontwerpers plaatsten concrete aanbevelingen ter verbetering van de bamboematerialen, en merkten op dat deze verbeteringen kunnen leiden tot betere beoordelingen in de toekomst.

In hoofdstuk 7 wordt de impact van zowel de kerninterventie als de uitgebreide interventie beoordeeld op basis van verschillende succesindicatoren, gekoppeld aan de verscheidene geïdentificeerde obstakels in het bamboe PCS.
De kerninterventie had een aanzienlijke toename in bamboe-gerelateerde waardeketencontacten, kennis en gedragsintentie (kans op implementatie van bamboe binnen twee jaar) van de ontwerpers tot gevolg. De bamboeleverancier constateerde een sterke toename in nieuwe waardeketencontacten en de ontwikkeling van generieke kennis met betrekking tot product- en procesinnovaties voor de verschillende bamboematerialen (denktankfunctie van de Bamboo Labs). Deze nieuwe kennis kan fungeren als concurrentievoordeel voor de materiaalleverancier in de toekomst. Daarnaast bleek ongeveer een derde van de ontwikkelde prototypes verder ontwikkeld te worden met een marktlancering in 2008-2010 als doelstelling, terwijl vier andere ontwerpers zelfs nieuwe bamboe-ontwerpprojecten hadden opgestart.
Als gevolg van de diffusie van de resultaten tijdens de uitgebreide interventie is er veel exposure geweest. Dit werd in grote mate veroorzaakt door de deelnemende ontwerpers zelf die in verschillende gevallen inderdaad bleken te fungeren als materiaalkampioenen. De verschillende soorten van exposure bereikten meer dan één miljoen mensen en als een gevolg werd bamboe als trend herkend door verschillende erkende ontwerptijdschriften. Een steekproef toonde aan dat blootstelling aan de resultaten van de kerninterventie, leidde tot een toename in de attitude en gedragsintentie van relevante waardeketenschakels ten aanzien van de bamboematerialen. Hoewel voor de bamboeleverancier de uitgebreide interventie heeft geleid tot een toename in geïnteresseerde waardeketencontacten (met name ontwerpers maar ook professionele klanten en labels) en enkele nieuwe ontwerpprojecten, zal de totale impact van de interventie voor de materiaalleverancier pas over een paar jaar duidelijk worden.

In hoofdstuk 8 worden de oorzaken van het succes van de kerninterventie geanalyseerd.
Ten eerste is de waarde van het Materiaal Ondersteuning Systeem (MOS) met betrekking tot de ontwikkeling van kennis, inspiratie, en waardeketencontacten van de deelnemende ontwerpers geëvalueerd. Het waarde-oordeel met betrekking tot de MOS onderdelen bleek aanzienlijk te verschillen en zeer persoongebonden te zijn. In het algemeen beoordeelden de ontwerpers de interactiecomponent beter dan de informatie-materiaalcomponent.
Ten tweede toonde de analyse aan dat het succes van de interventie, in termen van een toename in gedragsintentie (tot implementatie), was veroorzaakt - zoals bedoeld - door een toename in kennis waardoor: 1) de attitude ten opzichte van bamboe verbeterde, 2) bamboe eerder werd meegenomen in denkprocessen van de ontwerper met betrekking tot materiaalkeuze in toekomstige ontwerpprojecten (inclusie in "mentale materialenbibliotheek"), 3) bamboe werd geadopteerd in de fysieke materialenbibliotheek van ontwerpers, en 4) deze kennis werd gezien als concurrentievoordeel als gevolg van een grote investering in tijd, die ontwerpers rendabel wilden maken.
De analyse toonde echter ook aan dat de toename in waardeketencontacten geen grote invloed heeft gehad op de toename van de gedragsintentie. De bestaande waardeketenkwaliteit van de ontwerper, alsook een goede ontwerper - sector - materiaal match, bleken belangrijkere succesfactoren te zijn voor een toename in gedragsintentie. Dit laat zien dat de selectie van ontwerpers cruciaal is voor het succes van ontwerpinterventies.

In hoofdstuk 9 worden de belangrijkste conclusies, aanbevelingen en bijdragen van dit proefschrift verschaft.
De interventie is succesvol geweest in het stimuleren van de commercialisatie van bamboe in producten in West-Europa. Daarnaast heeft de interventie nog andere interessante output opgeleverd.
De kerninterventie heeft een beperkte reikwijdte gehad, doch een grote impact in termen van een toename in bamboe-gerelateerde kennis, waardeketencontacten en gedragsintentie voor de deelnemende ontwerpers en een toename in nieuwe waardeketencontacten, nieuwe projecten en generieke kennis over de verschillende bamboematerialen voor de materiaalleverancier.
De uitgebreide interventie daarentegen heeft een veel bredere reikwijdte gehad maar een kleinere impact. De diffusie van de resultaten van de Bamboo Labs bleek een uitstekend promotie-instrument, dat voor een grote exposure heeft gezorgd met betrekking tot de potentie van bamboe, geëtaleerd in concrete producten. Als gevolg van deze exposure zijn veel relevante schakels in de waardeketen bereikt, wat tot een kleine toename in de attitude en gedragsintentie tot implementatie van deze partijen heeft geleid. Voor de materiaalleverancier heeft deze exposure geleid tot relevante waardeketencontacten waarvan verscheidene bamboe al hebben toegepast in concrete projecten. In verband met de lange incubatietijd van commercialisatieprocessen kan de gegenereerde exposure ook later nog leiden tot nieuwe projecten.
Indien ook de additionele output van de interventie in ogenschouw wordt genomen, kan de interventie als geheel worden beschouwd als een efficiënt instrument. Alternatieve configuraties van de ontwerpinterventie, zoals ontwerpprijsvragen, zijn volgens de ontwerpers minder effectief om in dezelfde output te voorzien. Daarnaast blijkt de ontwerpinterventie, te zien als éénmalige injectie op het juiste moment en op de juiste plaats in het PCS, zelfvoorzienend. Als gevolg van de interventie zijn er verschillende nieuwe bamboekampioenen opgestaan. Zij zullen ervoor zorgen dat het commercialisatietempo van bamboe verder gestimuleerd zal blijven worden.

In hoofdstuk 9 worden naast de algemene conclusies ook de theoretische bijdragen van dit promotie-onderzoek behandeld.

De eerste theoretische bijdrage van dit proefschrift ligt in het grotere begrip dat is verworven over de vraag in hoeverre en onder welke omstandigheden, ontwerpers een rol kunnen spelen in het stimuleren van de commercialisatie van nieuwe of vrij onbekende materialen. Als onderdeel van deze theoretische bijdrage is de repliceerbaarheid van de ontwerpinterventie in dit onderzoek voor andere materialen onderzocht. Er wordt verwacht dat voor met name kleine materiaalproducenten, actief in de midden tot hoge segmenten van markten voor consumentengoederen, wier materialen in de ontwikkelings- of introductiefase zitten van het commercialisatieproces, soortgelijke ontwerpinterventies als belangrijk instrument kunnen fungeren om kennis te vergaren, bewustzijn en exposure te genereren, met als uiteindelijk resultaat de versnelling van het commercialisatietempo van een nieuw of minder bekend materiaal. Tevens worden verschillende aanbevelingen gedaan in de vorm van scenario's hoe toekomstige ontwerpinterventies op een zodanige manier kunnen worden geconfigureerd dat deze een maatoplossing vormen op de specifieke eisen van verschillende mogelijke opdrachtgevers.

De tweede theoretische bijdrage van dit onderzoek ligt in het domein van onderzoeksontwerpmethodologie voor actie-onderzoek gebaseerd op ontwerpinterventies, ten behoeve waarvan het conceptuele raamwerk ontwikkeld in het kader van dit onderzoek, gebruikt kan worden als structurerende leidraad voor gelijksoortige actie-onderzoeksprojecten.

Tenslotte worden, naast de aanbevelingen aan belanghebbenden in de materiaalindustrie in de vorm van verschillende scenario's op maat, diverse aanbevelingen gedaan voor gewenst nader onderzoek om het ontwerpinterventieraamwerk verder te optimaliseren en te modificeren, inclusief de mogelijkheid tot aanpassing voor gebruik in de bamboeproducerende landen zelf. Daarnaast worden uitgebreide, concrete aanbevelingen gedaan aan de bamboe sector, met betrekking tot benodigde innovaties op sector niveau, alsook gewenste marktontwikkelingen op strategisch niveau. Indien deze aanbevelingen worden opgevolgd kan bamboe zijn latente potentie als grondstof van de toekomst daadwerkelijk gaan claimen.

Pablo van der Lugt

Appendix A: Respondents

New Material Commercialization

Name & position	Organization name & type	Material	Target market/expertise
Yvette Bogaert Head Custom Innovation Center (CIC)	GE Plastics Large multinational company	Polymers (Plastics)	For high end markets: - Domestic appliances - Consumer electronics (especially mobile phones) - Automotive - Other high end consumer durables
Anne Ruth van Rijn Industrial design engineer; PIF department	CORUS Steel Large multinational company	Focus during interview on the material "Protact" (steel sheets with polymer layer), which is produced with Polymer Injection Forming (PIF).	Protact: - Small domestic appliances - Consumer electronics
Gert Berendsen Senior director R&D	Dow Large multinational company	Polymers (Plastics)	Any large volume market (automotive, building industry, packaging, etc.)
Remy Jongboom Founder/director	Biopearls SME company	Bioplastics	- Garden sector - Packaging - Small niche markets in which biodegradability is required (e.g. urns)
Arnold van Bezooyen Founder/director	Material Stories (Materials consultancy) SME company	All; in interview focus on industrial bamboo materials	High end consumer durables & interior architecture
Ignaas Verpoest Professor, Head Composite Materials Group	University of Leuven (Belgium), department of Material Science	Composites	High end consumer durables
Gerbrand Bas Director	Material Matters (Materials library and consultancy) Foundation	All; In interview focus on new specialized materials such as carbon fiber	High end consumer durables

PCS Obstacle Analysis Bamboo - South (Latin America)

Respondent	Organization (position)
John Jairo Ocampo	Asocateg (Program Assessor) & Technical University Pereira (Teacher)
Marcello Vorneo	Bamboa, (Managing Director)
Jorge Manzur	Acero Vegetal (Managing Director)
Anton Kruft	CBI, Netherlands (Senior Consultant)
Michael Tistl	GTZ (Project Assessor)
Martin Ibanez	Acero Vegetal, Pereira (Director)
Mario Naranjo	Ecuabamboo (Project Manager)
Arienne Henkemans, Gerben Stegeman	INBAR Latin America (Project Manager, Regional Coordinator)
Rubelio Giraldo Munoz	Xiurru Handicraft (Managing Director)
Norbert Gerstl	FEPP (Technician)
Patricio Cathme	INBAR Latin America (Industrial Designer)
Rafael Wong, Otto Suarez	Grupo Wong (Managing Director, Project Manager)
Adriana Mejia	Cafe de Colombia (European Representative)
Nohelia Mejia	Cadena Productiva de la Guadua (Coordinator)
Jorg Stamm	Ecoguadua (Managing Director)
Giovanni Montenegro	Ecuadorian Ministry of Agriculture (Coordinator)
Jorge Moran	INBAR Latin America (Senior Consultant)
Dr. Guerrero	Ambassador Ecuador in Holland
Tanya Gonzalez, Maria Louisa Buya	Hogar de Cristo (General Manager, Communication Manager)
Ligia Tamayo	Ecuadorian Ministry of Industry MICIP
William Hernandez, Gustavo Paredes	FECD (Director, Project Manager)
Ramon del Salto	Ecuadorian ministry of Agriculture (Sub Secretary)
Marjon Durang, Christian Marlin	SNV (Project Managers)
Ana Jaramillo Zurita, Lissy Velez	Conexus (President, General Manager)
Paulina Castro	CORPEI (Sectoral Coordinator)
Javier Restrepo	Premuebles (Sales Manager)

PCS Obstacle Analysis Bamboo - South (China)

Respondent	Organization (position)
Hu Bo, Jimmy Zeng	Hefeng Bamboo & Wood Industry (President, Product Manager)
William Zhang	Ya Feng Bamboo Products (Vice General Manager)
Koen Au, Titan	DMVP (Vice General Manager, Sales Manager)
Lu Fengbin	Zhuhong Bamboo Veneer Factory (Factory Director)
Hu Jian Jun	Zhejiang Xiangshan Faye Bamboo Timber (General Manager)
Xuhe Chen	ICBR (Professor)
Rachel Speth, Jeff Delkin	Bambu (Managing Director, Business Partner)
Ding Zingcui	China National Bamboo Research Centre (Director)
René Zaal, Aliang, Melinda	Moso International (Managing Director, Sales Managers)
Prof. Lingfei, Du Churgui	Zhejiang Forest University (Professor, Associate Professor)
Coosje Hoogendoorn, Fu Jinhe, Ren Hong	INBAR (Director General, Program Officer, Assistant Program Manager)
Wenji Yu	Research Institute of Wood Industry (Professor)

PCS Obstacle Analysis Bamboo - North (Western Europe)

Respondent	Organization (position)
René Zaal	Moso International (Managing Director)
Mark van der Wildt	Wild Navy (Managing Director)
Antoon Oostherhuis	Bylsma (Managing Director)
Andries van Ekkeveld	A van den Berg (Marketing Manager)
Enrique de Mul, Jelle Maijer	Cocowood.nl (Managing Director, Designer)
Thomas van Zijst	Winkel Wilhelmina (Managing Director)
Charley Younge, Pim de Blaey	Bamboo Information Centre (Managing Director, Senior Consultant)
Geertje Otten	ProFound (Consultant)
Marion Vrijburg	Fair Trade (Designer)
Thierry Sanders	NCDO/Business in Development Program (Program Director)
Victor de Lange	CREM (Managing Director)
Andre Janssens	Nieuwe Maan Communicatie Adviesgroep (Managing Director)
Gemma Boetekees	ICCO (Program Director NWFP)
Ed van der Kleij	Intratuin (Purchasing Agent Furniture)
Theo Kruyer	Xenos (Purchasing Agent Accessories)
Glenn Berndtsson	IKEA (Production Technician NWFP)
Helen Reniers, Brigit van Daelen	HEMA (Designer, Buyer Furniture & Accessories)
Mariluz Fernandez, Ed van Engelen	Haans (Product Manager, Designer)
Sander Vroone	Kwantum (Purchasing Agent Furniture)
Jesse Kuiper	Kinnarps (Managing Director)
Hessel van Straten	NIBO NV (Managing Director)
Arienne Henkemans	INBAR (Project Manager)
Charles de Roo	Galerie Ecce (Managing Director)
Dick Oskamp	Van Binnen (Sales Manager)
Marco Groenen	De onderneming in architectuur (Designer/Owner)
Anthony Marschak	Adapt Design (Designer/Owner)
Jared Huke	Xeno Objects (Designer/Owner)
Robert Admiraal	Studio Admiraal (Designer/Owner)
Alexander Schmidmeier	High Touch (Sales Manager)

Sample Survey Impact Extended Intervention

Respondent	Organization
Harry Dona	Dona Consult
Caspar Bosma	7 C's
Patrick Vermeire	Bruns
Bart Peels	KonB
Cees Laureijs	Laureijs vormgeving
Bas Lamers	Buro Bas
Cees Hoogendoorn	Syntens
Rudy Daams	Brabantia
Jeroen op ten Berg	GBO
Jurre Groeneboom	HEMA

Marije van der Park	Marije van der Park Design
Alexander Pelikan	Peli Design
Ingrid Meijer	Timber Trail
Mr Heijnen	Heijnen Ontwerp
Willem Kars	Things Design
Sander Paulen	Haagse Hogeschool, IPO
Hugo de Ruiter	Hugo de Ruiter Design
Hein Schutte	Things Design
Willem Gorisse	Horizon Design & Development
Bas van Rooij	Buro Bas
Martin Jooss	Kembo
Guy van Loo	Things Design
Ad van den Heuvel	Libra Design
Rixt Reitsma	Rixt Reitsma Design

Appendix B: Obstacles during New Material Commercialization

In this appendix key obstacles found along the PCS during the commercialization of new materials in consumer durables are analyzed based on a review of relevant literature (mostly about the commercialization of various plastics and metals). Below, the main obstacles found are presented in a sequential manner, in the order in which they usually occur along the PCS (thus, starting at the production side). Each obstacle will add costs directly or indirectly (e.g. time loss) to the commercialization process of the material and in the worst case can stop the commercialization of the material. The found obstacles including their relationships are summarized in figure 1.17 in subsection 1.2.3.

Production Capacity

The first obstacle found over the PCS relates to production capacity and in particular to the sub obstacles research & development, material production and appropriability.

Research & Development

An initial obstacle that has to be mastered during the commercialization of new materials is to get the properties of the new material optimized and stabilized, including all the underlying processes required. A first important precondition is the availability of sufficient raw materials and resources required to produce the material. This seems obvious, but the commercialization process of various plastics was delayed because of long delivery times of raw materials, and scarcity of raw materials leading to high costs (Frieling 1986).

Once these preconditions have been met, the material has to be tested and optimized. This process demands elaborate laboratory testing (and subsequent modification) of the material in various mechanical and climatic circumstances by the R&D department of material producers, which requires significant investments in manpower, facilities, resources and time.

Care should be taken that this testing and optimization process does not take too long. A problem for engineered materials is that much research takes places in government and university labs on a very fundamental level with a focus on high performance, not taking into account the commercial feasibility, which makes it understandable why most materials never leave these laboratories (Baba et al. 2004, Eagar 1998, Maine and Garnsey 2006). Only in sectors where performance is far more important than price, such as in the aerospace industry, materials developed through this fundamental research have a chance of actually being implemented by the market (Eagar 1995).

Material Production

In the previous obstacle the focus was on quality; optimizing the properties of the material under various conditions. The next obstacle a material producer faces has to do with quantity - building the necessary production capacity in order to be able to produce high quality materials in high quantities, so that large potential orders can be delivered in time. Since most new materials are made with new processes, they usually require new tools and machines which must be built or purchased (Bement et al. 1995). Furthermore, very few materials are cost effective unless they are produced on a large scale. Since economies of scale are required when setting up a production plant, high amounts of capital investment are needed (Maine et al. 2005), without any knowledge of how successful the material will actually be (market risk).

Appropriability

Appropriability refers to the ability of a firm to protect the intellectual property of its invention. This is also an important issue in the field of (engineered) materials. Unless a company registers its invention carefully through detailed patents, a competitor might copy the material and sell it as its own invention. However, acquiring patents is a time consuming process which might delay the commercialization process for months and sometimes even years (Musso 2005).

Market Identification

For many material producers market identification is perceived as an obstacle since most materials have potential applications in many different markets, making it difficult to make an adequate selection (Hagedoorn and Schakenraad 1991, OECD 1998, Williams 1993). For each potential target market a material producer must perform specific research and development activities with respect to aspects such as applicable regulations, application requirements and process innovations required (for economies of scale). Once a target market has been selected, other nodes in the value chain must be convinced, production processes need to be modified, prototypes should be developed and market testing should be executed (Hounshell and Smith 1988, Maine and Garnsey 2006). The fact that market identification turns into an obstacle for many material producers is caused by their upstream position in the value chain; they are out of touch with the final markets in which the material should be implemented. Rather than an obstacle, market identification should be perceived as an opportunity. In this thesis the market selection strategy developed by Musso (2005) was used to select the right initial target market for bamboo, with the purpose of stimulating the commercialization process (see subsection 1.3.2).

Product Design

Once a material meets external qualifications and standards (see before) and the properties are optimized, the next step is to convince designers to experiment with the new material, because they are usually the stakeholders that transform a material into a concrete product. Through their properties, materials have an important impact on the product design process (for more information about the role of materials in product design the reader is referred to appendix D).

From the perspective of a designer a new material offers opportunities but also great risks. Designers are usually hesitant to work with a new material, because they have a lack of knowledge about the material with respect to its manufacturing- and processing possibilities, and the behavior and performance of the new material in an application (Ashby and Johnson 2002, Eagar 1995, Maine and Garnsey 2006). Furthermore, there is not a historical body of design experience with the new material, information provided by material suppliers is usually insufficient, costs of the new material are usually still high and availability is limited (Ashby and Johnson 2002).

Knowledge Transfer

Most of the obstacles found apply to only one or some value chain nodes. However, the obstacle of knowledge transfer applies to all nodes.

The main cause of the obstacle of lack of knowledge transfer between nodes is the inability, mostly of the material producer, to communicate in understandable terms for the receiver (value chain nodes downstream, and especially the application manufacturer and the designer) the added value of the new material. This knowledge transfer is necessary to convince the value chain nodes to adopt the material, but also, in the case of adoption, to integrate the material in their processes in the appropriate way in order to avoid failure in the final market. However, this is difficult for most material producers. Since they produce an intermediate good (Williams 1993), they do not deal directly with consumers in the broad range of applications in which their material may be used (Maine and Garnsey 2006). Although large material producers have developed tools such as technical support centers and engineering manuals for their materials, they usually do not cover all necessary data for the potential application base (Musso 2005). Furthermore, the information is usually in "another language" than the other value chain nodes speak. Sometimes this can even be taken literally, as many times different terms are used for the same aspect (Berendsen 2007).

The problem of knowledge transfer might be the largest between material producers and designers. Due to a lack of interaction between the worlds of material science and design, designers usually lack the knowledge to implement new materials, and therefore require information about the new material.
Material producers should better understand the information needs of the designers if they are to implement their material in concrete applications. The normal tools for information provision of material producers are data sheets and product catalogues. The problem with them is that they rarely mention objectively the negative aspects of the material and overemphasize technical attributes of a material, whereas designers, especially in the beginning of the design process, need more information about visual and tactile attributes (Ashby and Johnson 2002, Karana et al. 2008). Because of the lack of appropriate tools for designers, it takes a long time before designers know what a new material actually can and cannot do. For example, for wood, designers know exactly what to expect, since it has already been used by humans for millennia and has been processed and used in every possible way (Manzini 1986). For a new material this trajectory still needs to be executed.

Development Value Chain Network

<u>Processor</u>

Once a design has been developed, the semi finished material, which derives from the material supplier, will most likely be processed into a more workable form before the application is manufactured (e.g. transformation of logs into planks or resin and fibers converted into composite molds). As found before for the material supplier, new materials require completely different forming processes than existing materials, forcing an investment in new equipment and supplies. Also, developing capability on the part of the converters on how best to process the new material takes time and requires capital investments (e.g. adjustment of the machinery), in order to be able to meet the required quality standard. If this is not done, and existing machinery and old design rules are deployed, this will most likely result in products that do not meet quality standards, which happened during the development of various plastics (Eagar 1995). This means that processors of new materials must be willing to internalize these required expenditures necessary for new processes (Musso 2005). Therefore, convincing processors to modify their processes in order to be able to adopt the new material can prove to be a serious obstacle.

<u>Application Manufacturer</u>

For application manufacturing the same applies as was mentioned for the previous obstacle (processor). If an application manufacturer is to adopt a new material this requires a lot of investments in time and money to modify the existing machinery and equipment in order to develop the required capability for handling and processing the material to be able to deliver a high quality product in the end. Because of the risks related to field failures, application manufacturers usually integrate long testing and qualification times (which a material producer wants to avoid) before a new material might be adopted. Note that the activities of processing and application manufacturing can be separate, but are also often executed by the same value chain node.

External Environment

Several obstacles found do not directly apply to value chain nodes but to external parties that influence the value chain.

Governmental Influence

Codes and standards are developed by governments and watchdog organizations to make sure products or materials will meet certain specifications, usually related to safety. They are usually inflexible and are mostly related to incumbent materials, which makes it hard for new materials to enter if they do not fit within existing codes, since it is very difficult to change codes. However, through skillful lobbying it is possible to do so and if codes are modified accordingly, this can actually create captive markets for material producers that are protected from competitors (Eagar 1995).

Image

Image obstacles should not be a problem if a material producer has completely mastered all obstacles with respect to the production capacity (see before), can deliver a high quality material, and knows exactly how it performs. If value chain nodes downstream have also mastered the material and know how to process it into a good end product, a negative track record resulting in a poor image of a material should not be an issue. However, all too often material producers want to get their return on investment back as soon as possible, launching a material too early which might result in failures in the field, severely damaging the reputation of the material (including the long term return on investment). For example, the failure of Polystyrene (PS) in children's toys had a very negative impact on the image of plastics in general, which in the 20th century were (and sometimes still are) referred to by the general public as "cheap plastics" (McAllister 1996). As a result, because of the negative connotation with plastics, composites, which were first named reinforced plastics, were renamed into "composites" (Pil and Verpoest 2006).

Competition

Another threat that should be taken into account during the commercialization process of a new material is competition and counter attacks from the industry of the incumbent materials, in the market that is being targeted by the new material. For new materials attacking incumbent industries this threat of competitive response can be solved by doing homework beforehand. This can be done by, firstly, developing standards for the new material in the targeted applications based on thorough testing in approved testing facilities, and secondly, by keeping a track record in established projects showing the performance of the material in the new application (Musso 2005).

Trends

Trends can sometimes have a positive impact on the commercialization process of new materials (e.g. new fashion trends that fit the material very well), but can also have a negative impact on the commercialization process (e.g. scarcity of materials because of wars, disasters, etc.).

Another important trend that can either negatively or positively impact new materials is the increasing attention for the environment, mostly directed by governmental and EU regulations which are becoming more stringent on aspects such as health, toxicity and eco-efficiency. The increasing focus on the environment can serve as an opportunity for environmental friendly materials such as biodegradable plastics, but can mean a threat to various other materials (Bogaert 2007, van Rijn 2007).

Use & Maintenance

In the case of applications in which safety plays a critical role (e.g. helmets, the car industry), failure of the material during use could result in high liability claims posed on the material producer (Musso 2005). Additionally, once the material is in use, depending on the application, it might be necessary to perform maintenance on the material (e.g. pipes, automobiles). Usually, procedures and techniques will be different for new materials and it will take time until knowledge and techniques will be disseminated and adopted by maintenance providers.

Appendix C: Obstacles during Bamboo Commercialization

Since giant bamboos suitable for industrial processing and large scale production only grow in countries with a (sub)tropical climate, it takes a long time and trajectory before bamboo can be marketed as a product in export markets in the North (consumption side of PCS), since cultivation, harvesting, preservation, first processing, packaging and transport all take place in the South (production side of PCS). Relevant previous PCS studies executed for bamboo at the production side in the South (Belcher 1999, Cleuren and Henkemans 2003, Held and Manzano 2003, Klop et al. 2003, Mathew 1998) show there are many obstacles in the South that need to be solved before bamboo can be successfully mass commercialized. However, hardly any research was executed in the past analyzing problems at the consumption side of the PCS in the case of export of bamboo products to the North. Similarly, most previous PCS studies in the South have focused on local markets and have not taken extra constraints into account for local producers in the case of exports to Western markets.
Therefore, in order to get a better understanding about relevant obstacles (weaknesses and threats) but also about strengths and opportunities over the PCS in the case of exports of bamboo products to Western markets, the author executed several separate field studies in 2005-2006 in South East Asia[52] and Latin America.[53] Besides, in these producing regions, various interviews were also conducted with key stakeholders along the PCS in Western Europe[54] as the consuming region. For a full overview of respondent data and characteristics, the reader is referred to appendix A.

The interviews conducted can be considered half open focused interviews, using an elaborate topic list structured along the PCS as a guideline which was based on literature about the commercialization of products in general (Cooper 1996, Pugh 1990, Smulders et al. 1996) and a questionnaire used for forest product development (Belcher and Ruiz-Pérez 2001). Each interview followed the SWOT[55] methodology (Marijs and Hulleman 2000), focusing on positive (strengths and opportunities) and negative (weaknesses and threats) aspects influencing the commercialization of bamboo in consumer durables over the PCS. All recorded interviews were written out and analyzed using qualitative labeling techniques (Baarda et al. 2005). Through labeling, the data was categorized on the elements of the SWOT framework, before being categorized to a specific part of the PCS and appropriate processing technology. The findings from the interviews were aggregated with observations on site by the author.

Below, the main obstacles found along the PCS, based on design and production of products in the North are presented, in the order in which they are found along the PCS. Note that depending on the bamboo materials deployed (industrial bamboo materials versus non-industrial bamboo materials, such as the bamboo stem and hand woven mats), obstacles might differ. If the obstacles found are not of a generic nature (i.e. do not apply to all bamboo materials), in the text will be mentioned to what

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[52] Represented by China as the leading bamboo producer and exporter worldwide
[53] Represented by Ecuador and Colombia as leading bamboo producers and exporters in the American region, with latent potential for growth due to the large bamboo reservoirs
[54] Represented by the Netherlands and Germany
[55] SWOT analysis is often used as a strategic marketing tool in business and is normally considered from the perspective of a company or organization. In this method, "strengths" and "weaknesses" are factors internal to the organization over which it has direct control. "Opportunities" and "threats" are factors in the environment external to the organization and on which the organization does not have direct control but needs to respond to (Marijs and Hulleman 2000).

bamboo materials the obstacles apply. Please note that the results are a generalization of the results of the interviews and represent opinions of the respondents; they draw the big picture on the sectoral level, but do not say all.
The found obstacles are visually presented in figure 1.18 in subsection 1.2.3. For a more elaborate overview of obstacles, opportunities and strengths for many different industrial and non-industrial bamboo materials over the PCS for both the scenario of design and production in North and the scenario of design and production in South, including specific recommendations to overcome obstacles and grasp opportunities, the reader is referred to van der Lugt and Otten (van der Lugt and Otten 2007) and van der Lugt (van der Lugt 2005a).

Production Capacity

Weaknesses during the production of industrial bamboo materials in China are numerous because of the long and complex manufacturing process. In many factories the conditions and facilities are not sufficient to meet the delivery time, volume and quality requirements for Western Europe. For example, many factories are fully or semi-open, resulting in high temperature and humidity variations, while dust from the sawing and milling machines that disperse in the open space might also end up in the final product, negatively influencing the quality.

Figure C1: The production chain of bamboo materials can still be improved in terms of efficiency (left) and safety (right)

Furthermore, of the hundreds of bamboo processing factories in China, only a few have machines and facilities that meet Western standards. Most companies have simple, outdated machines, negatively affecting the quality of the industrial bamboo materials in terms of exact dimensions, straightness and pollution in the final products. Additionally, the quality of the glue or resin used in many cases does not meet EU norms with respect to toxicity. Other main problems are the often inadequate labor conditions of employees in China, and the relatively high pricing of products. However, despite these problems, at the moment, the price-performance ratio of industrial bamboo materials from China is superior to other bamboo producing regions like Latin America, where quality and capacity problems are even worse.
Finally, not many industrial bamboo material suppliers see the importance yet in complying with Corporate Social Responsibility (CSR); various bamboo materials are promoted as being sustainable, no matter what the labor circumstances and toxic additives might be. With the increasing importance of sustainability and the increasing export of industrial bamboo products to the West, CSR audits checking the chain of custody requirements might pinpoint that in some cases bamboo materials are not sustainable at all, severely damaging the reputation of bamboo as potential sustainable material.

Transport

Since all giant bamboo species grow in (sub)tropical climates, far away from Western Europe, high transport costs for bamboo materials (by sea and over land) are an obstacle, especially for space consuming bamboo stems. Furthermore, for bamboo stems, the inside of the bamboo stem is very susceptible to mold, which is especially a problem during sea transport because of the high temperature and humidity differences. This can be prevented by the use of air-conditioned containers, or the use of silica bags or fumigants in containers. However, it is wiser to focus on more permanent solutions earlier in the production chain: good preservation and drying of the bamboo material before shipping.

Figure C2: Transport of bamboo stems in Anji county in China on a truck

Availability and Diffusion of Information

Another major obstacle affecting many other problems further on in the PCS is the lack of availability of scientific, objective, well presented information about bamboo as a resource and material. Most bamboo related research derives from small incidental projects at companies, or in knowledge institutes and universities as part of larger research programs not specifically focusing on bamboo. Research reports and books sometimes pop up at various locations worldwide, but their scientific level varies greatly; a lot of gray literature is available. Furthermore, due to different frames of reference results are usually hard to compare because different methods are deployed for data collection for bamboo based research. For example, in many research institutes around the world, the mechanical properties of bamboo species have been tested using different methods, usually based on national standards for wood testing, making it impossible to compare results on a global basis.[56]

Furthermore, there is a large amount of incorrect or oversimplified information about bamboo available (for instance, "bamboo is stronger than steel"[57]), raising the expectations of bamboo as a material to an extent it cannot live up to. Most research that is being executed largely focuses on aspects in the first parts of the PCS in the South, such as taxonomy, plantation management and the anatomy of bamboo. Research and information related to problems later in the PCS is either very technically oriented, focusing on hard mechanical data for engineers, or oriented toward simple hands-on capacitation of rural producers in bamboo producing regions based on handicraft techniques.

Little information is available about aspects more relevant in the case of exporting to foreign markets, such as product development, image and marketing issues. De Bruijn (2007a) has executed an elaborate scan of available bamboo information sources, divided in internet resources, printed publications, digital publications and databases (see table C1) for product designers as a target group. His analysis shows that existing information sources mostly fail to cover relevant topics for value chain nodes in the North,

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[56] Fortunately, with the development of ISO standards for the mechanical testing of bamboo stems (ISO 22156 and ISO 22157), theoretically this should not prove to be an obstacle for the future.

[57] Bamboo is only stronger than steel in terms of the tensile strength of the bamboo fiber per weight unit.

and if these topics are covered, fall short in presenting them in a visually attractive way, not utilizing opportunities offered by the latest information technology developments (de Bruijn 2007a).

Table C1: Summary and evaluation of available information sources for bamboo for Western product designers as target group (de Bruijn 2007a)

Evaluation criteria	**Internet resources**	**Printed publications**	**Digital publications**	**Databases**
Target audience	Never specifically focused on (Western) designers and architects	Structural engineers, architects and, in the last place, designers	Not specifically focused on (Western) designers and architects	Material and process experts, structural engineers, designers, architects
Information contents	Poor and very few examples of modern product applications Limited overview of modern and traditional processing technologies Little information available on material and product properties	Poor and very few examples of modern product applications Generally focused on bamboo as a structural material rather than a material for designers Very little consideration for the aesthetic and intangible properties of the material Data is not always accurate and is therefore unreliable	Poor and very few examples of modern product applications Limited overview of modern and traditional processing technologies No information available on material and product properties	No examples of product applications Very limited overview of modern processing technologies No documentation of traditional processing techniques
Information representation	Poor and very little visual material of manufacturing technologies Poor visual material of product applications, i.e. low resolution and low quality	Poor and very little visual material of manufacturing technologies Often poor use of English and inconsistent use of technical vocabulary	Inconsistent and divergent quality of visual material Use of unpractical file formats	Hardly any visual material of both processing technologies and product applications
Information lay-out	Often basic and unattractive	Often basic and unattractive, but consistent	Inconsistent and cluttered	Basic, but systematic
Accessibility	Membership and registration required in some cases Not always evident domain names	Limited editions make these publications hard to obtain	Unavailable to the general public	License, registration or membership is often required

Nevertheless, some of the information available could be useful for Western designers, processors and application manufacturers. However, the following problem is that in general, bamboo based information is hard to find; diffusion of bamboo based information is another major obstacle. As a result, relevant information does not reach relevant stakeholders in the North, most of whom already have a slightly negative image of bamboo as a resource (see below). The lack of accessibility can be due to the fact that the information sources are unknown or are not accessible for various reasons (e.g. membership requirements, language barriers, file incompatibility in case of digital publications, etc.); see table C1.

Level of Knowledge

Unsurprisingly, because of the lack of information availability and diffusion, one of the main weaknesses in the bamboo PCS is the lack of knowledge among stakeholders in the North (designers, producers, retailers and consumers) about the specific characteristics of bamboo (hardness, strength, processing do's and don'ts, etc.), including the behavior in various circumstances (durability outdoors, fire resistance, etc.). Due to this lack of knowledge, the image problem (see below) also remains intact. In its turn this image problem does not help to stimulate relevant value chain nodes to acquire information about bamboo.

Product Design Capacity

The lack of product design capacity is another obstacle that contributes to the low market share of bamboo in consumer durables. Not many Western designers have yet experimented with bamboo because of problems such as the lack of knowledge and availability, as well as the bad image of bamboo as material. This is a missed opportunity since designers are the persons who can play an important role in making innovative designs that capture the possibilities of bamboo, linking to contemporary trends to create products with market potential, which could help to improve the image of bamboo. The potential of the fusion of Western design capacity with bamboo can be shown based on the output of the few pioneering Western designers that did find their way to the material, like Anthony Marschak, Jared Huke and Marco Groenen (see figure C3).

Figure C3: Bamboo chairs by Western designers; Anthony Marschak (left), Jared Huke (center) and Marco Groenen (right)

Value Chain Network

As with any new industry, especially one that is based on a resource from another country, at the beginning designers, producers and retailers would need to be convinced to adopt the new material into their stock. The problems of lack of knowledge about bamboo and the mediocre image of the material hamper the adoption of bamboo materials by value chain nodes downstream. As a result, value chain networks, consisting of designers, processors, application manufacturers and retailers, through which bamboo can be commercialized in consumer products, are still too scarce in Western Europe.

External Environment

Sectoral Organization

Since the industrial bamboo industry in Western Europe is relatively young, there are still too few companies (importers, designers, processors, application manufacturers and retailers) in the bamboo business to unite in trade organizations in order to protect interests, foster research and promote bamboo products, as is available for many already established materials (e.g. Wood Centre Netherlands, in Dutch "Centrum Hout"). This makes the bamboo industry in Western Europe very vulnerable for competitive response (see heading "competition").

Although bamboo as a sustainable resource is mentioned in the strategies of some Western NGOs (e.g. WWF, ICCO), besides the existence of some organizations for bamboo as a garden plant, there are no strong organizations in the EU focusing purely on bamboo and safeguarding the interests of bamboo on the sectoral level.

Image

One of the main bottlenecks hampering the commercialization of bamboo in consumer durables in Western Europe is the poor image bamboo has as a material. This is mainly caused by the poor quality of the available bamboo products on the market, caused by a lack of product development capacity (lack of market knowledge and product design proficiency) in the bamboo producing countries in the South. Nevertheless, the Western European market is flooded with these kinds of low quality bamboo products (see figure C4), which usually end up for sale as cheap gadgets in discount stores, which further weakens the image of bamboo as material. Since almost every respondent in the North mentioned the image of bamboo as a serious obstacle (see table C2 below), the author had various studies executed by design students to better understand the image problem in the North. The main results from these studies (de Bruijn 2007a, de Goede and van Loon 2006) can be found in appendix E.

Figure C4: Typical examples of traditional bamboo products with little potential for Western European markets

Trends

Consumer trends can apply to any material, technique or product, and can relate to different aspects such as fashion trends (e.g. aesthetics), consumption trends (e.g. sustainability) and cultural trends (e.g. use). Due to their unpredictability, trends can be considered both an obstacle and an opportunity, because the whims of the markets can make or break a material. For example, the bamboo bowls and vases produced using coiling techniques were considered trendy recently (2000-2005) in the Netherlands. However, because of the wide availability of copied products in a broad range of low-end retail chains, these kinds of bowls have gone out of fashion in the Netherlands at present (2008), whereas they are more popular than ever in countries such as the United States, Japan, The United Kingdom, Australia and France.

A threatening trend for bamboo is the increasing popularity of synthetic materials (lower maintenance and greater durability) as replacements for natural materials in interior and exterior applications (flooring, furniture, decoration). The popularity of fake bamboo furniture such as chairs (figure C5) is an immediate threat for the use of bamboo in consumer durables in the Western European market.

Figure C5: Steel-plastic chair mimicking bamboo

Competition

When a new material finds its way onto the market through an application, counter attacks can be expected from the producers of incumbent materials in these markets that will try to undermine the reputation of the new material. For bamboo, the wood industry is the incumbent industry from which the counter attack can be expected. The wood industry will refer to bamboo as an inferior material compared to wood, and thus influence the opinion of material prescribers such as designers and architects.

Marketing

For industrial bamboo materials, the launch of new bamboo materials in products can be perceived as a potential obstacle. The first launch can make or break the reputation of a product. If the launch happens too early, and product quality is not on par with expectations, this can severely damage the reputation of the material. For example, the image of bamboo flooring saw some damage a couple of years ago when the first bamboo floors lacked the quality of the products available now (2008). The first launch is especially important for bamboo products because of the already slightly negative consumer perception of these products. Finally, many respondents felt that industrial bamboo products should not be marketed as a grass (accommodation) because of the negative associations with grass (weak, cheap, non-durable), but under a new name (in which it is not clear that it refers to bamboo) as a new kind of sustainable hardwood (assimilation).

Figure C6: Adequate branding of bamboo products by the Shanghai based company "Bambu"

Use and Maintenance

One of the weaknesses of most bamboo materials - which also applies to many wood species - is degradation from mold and other biological agents and ultraviolet graying when used outdoors.[58] Besides this biological degradation, bamboo culms used outdoors also tend to crack because of tensions from shrinkage and expansion caused by changes in temperature and moisture content, particularly when directly exposed to sunlight and rain. The cracks, highly undesirable from the point of view of aesthetics and structural integrity expose the softer inner part of the stem wall, which is more susceptible to mold. Rotting, mildew and cracking of bamboo stem can be prevented by proper preservation and drying, and taking care not to directly expose bamboo in its natural state to climatic conditions. When used inside in Western climates the bamboo stem may crack in the case of very dry climatic circumstances (e.g. caused by central heating systems used in cold winters).

Relative Importance of Obstacles

Table C2 summarizes the interview responses from the respondents in the North for the most important obstacles presented above, during the commercialization of bamboo in consumer durables in Western Europe. The factors are clustered and prioritized according to the number of responses received. For a more complete categorization of all the factors mentioned during the interviews, arranged according to the stages in the PCS, the reader is referred to appendix 5 in van der Lugt and Otten (2007).

Table C2: Responses for the various clusters, arranged based on the number of responses. Note: only obstacles with more than 5 responses are depicted

Issue & Rank	Number of responses (out of a possible 31 responses)
1. Image	28
2. Marketing	27
3. Product design	22
4. Level of knowledge	21
Availability and diffusion of information	21
Value chain network	21
5. Production capacity	20
6. Trends	17
7. Use and Maintenance	9
Transport	9

[58] Note that after optimization modified SWB seems suitable for outdoor use in the future; see also footnote 12 in subsection 1.2.1.

Appendix D: Role of Materials in Product Design

Selection of Materials during the Design Process

Usually a function or need is the point of departure when starting a regular product innovation project. During the design phase of this process, designers materializing a product idea toward the final product need information about materials in various levels of breadth and precision. Basing themselves on technical constraints and constraints related to (industrial) design, they narrow down the choices for materials to use during the various phases of the design process (Ashby 1999); see figure D1.

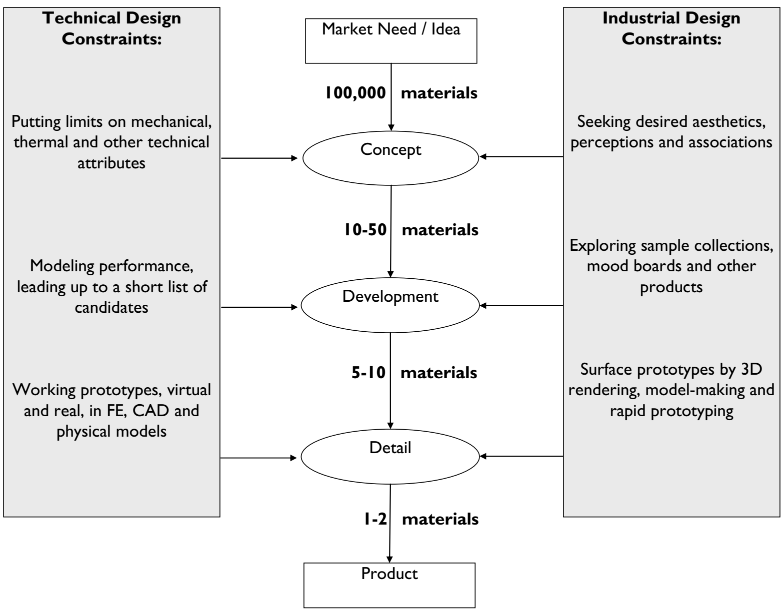


Figure D1: Material selection during the product design process. Technical and industrial design constraints narrow the choices in each step during the design process (Ashby 1999)

In general, designers tend to make a first decision about which kind of material to use (stone, plastic, natural, etc.) in the beginning of the design process, after which they come back to specific material selection only after some time (van Kesteren 2008). There are plenty of tools and instruments available that can support designers during the material selection process. For a useful overview of available material selection techniques and tools the reader is referred to van Kesteren (2008).

However, most material selection tools are developed by material producers and scientists and are therefore not synchronized toward designers as a specific group. Usually these instruments have an analytical approach deriving from the field of mechanical engineering, focusing on hard technical data (Ashby 1999, Cornish 1987, Farag 1989), while neglecting more subjective softer information support, i.e. sensorial and intangible properties of materials (Ashby and Johnson 2002, Diehl 2005, Karana et al. 2008, van Bezooyen 2007); see below.

Furthermore, most material databases focus on industrially manufactured materials such as metals and plastics pushed by industry, whereas information about traditionally - usually natural - materials is far less abundant (Diehl 2005). The development of new tools to support designers in material selection that includes these softer aspects is a whole new area of research which is still in its earlier stages; an example is the "Materials in Products Selection" (MiPS) technique developed by Ilse van Kesteren (2008) for her PhD research at DUT. Also newer online material databases (e.g. Material Explorer, Material ConneXion) start to integrate softer material aspects in their systems.
However, due to the lack of a central point for all their information needs with respect to material selection, designers need to derive their information from various information sources (Beiter et al. 1993, Ferrante et al. 2000, Fidel and Green 2004, Karana et al. 2008); for an overview of sources used by designers, the reader is referred to van Kesteren (2008).

Main Considerations during Product Design

To better understand the impact of materials on all the design considerations during product design the reader is referred to the Material Selection Considerations model (van Kesteren et al. 2005); see figure D2, which builds on the model developed by Ashby (1999) by integrating the use- and product personality aspects. These aspects are added because they play an important role in the product experience during the use phase of a product. Product experiences can be defined as "the entire set of effects that are elicited through the interaction between product and user" (Hekkert 2006). Product experience has currently become a crucial success factor in product design (Bloch et al. 2003, Desmet 2002, Govers 2004, van Kesteren 2008).

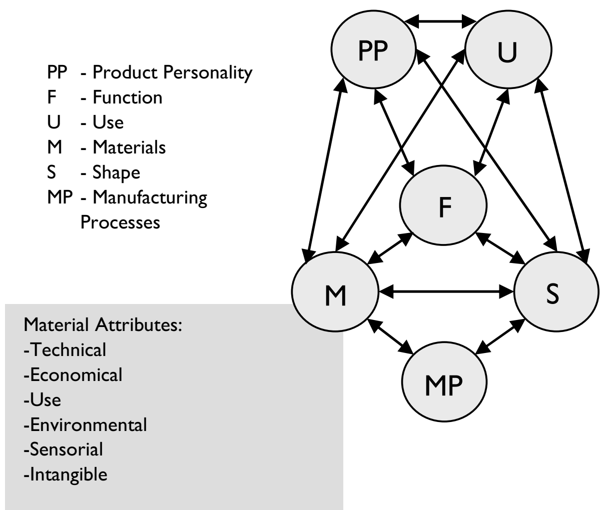


Figure D2: The Materials Selection Considerations model, showing the main considerations to take into account during material selection in product design (van Kesteren et al. 2005)

Van Kesteren et al. (2005) define the various design considerations in the Material Selection Considerations model as follows:
Product personality (PP) is defined as "the appearance of the product and how the user's senses react to the appearance, including the associations and emotions it elicits in the user."
Function (F) is defined as "the aim of the product and the way it operates. The function of a product is what you can do and achieve with it."

Use (U) is defined "as the designed interaction the user has with the product."
Materials (M) are defined as "the physical and chemical substances the product is made from." Materials have characteristics in different aspects (e.g. technological, sensorial, etc.) which will be explained below.
Shape (S) is defined as "the geometry of the product including details such as texture or finishing."
Manufacturing processes (MP) are defined as "the processes that are needed to make the product, including tooling, assembling, shaping, joining and finishing."

The arrows in the Material Selection Considerations model represent interaction, which shows that many considerations influence each other during the design process. As can be seen in the model, the arrows go two ways, meaning there is a two-way interaction between each aspect. Depending on the assignment and the designer, some considerations may be more important than others during the design process. Since this thesis concerns materials, the information below will focus on the influence of materials on the other design considerations during product design.

Material as Consideration during Product Design

Materials play an important role during product design as materials affect all other considerations (see arrows in figure D2). Materials are versatile; they have multi dimensional properties that influence the other design considerations in different ways (Ashby and Johnson 2002, van Kesteren et al. 2005). According to van Kesteren (2008) materials are becoming more and more a distinguishing factor in product experiences. The various properties of a material (see also figure D2) can be clustered into six categories, which are introduced below.

Technical properties relate to physical, mechanical, thermal and electrical properties of a material, which strongly influence the functioning of a product in which the material is used (Ashby and Johnson 2002).
Economical properties relate to the price and availability of the material.
Use properties of a material influence a product during use, for example, through their impact on ergonomics or product interface (e.g. using elastomers for grip).
Environmental properties entail the impact the material has on the environment.
Sensorial properties relate to the influence of the material on the five senses, such as visual attributes (e.g. color), tactile attributes (e.g. softness) and acoustic attributes (e.g. sound absorption). The sensorial properties, and especially the visual and tactile properties of a material, play an important role in the first overall quality judgment of a product (Sonneveld 2007).
Finally, a material is perceived and can evoke certain associations and emotions with people as a result of the sensorial properties. For example, metals might seem clean, cold and precise (Ashby and Johnson 2002) and plastics are sometimes perceived as cheap imitations. These properties are hard to make explicit, and understanding as well as defining them is quite a new area of research. Different scholars use different definitions for these properties, such as qualitative properties (Edwards 2002, Jee and Kang 2001) material personality, personal dimensions of materials (Ashby and Johnson 2002), and intrinsic cultural meanings of materials (Manzini 1986). In this research the definition developed by Karana et al. (2008) is used. She has combined the various prior definitions under the term "intangible characteristics of materials", which covers perceptions (e.g. modern), associations (e.g. plastic products - cheap) and emotions (e.g. nostalgia) attached to a material. These *intangible properties,* as they are referred to in this thesis, are influenced by various contextual factors such as previous memories & experiences, and cultural and social values, and will therefore differ per person (van Kesteren 2008). Although the sensorial properties have a strong influence on intangible properties (e.g. wood is usually perceived as a warm material due to its look and feel), intangible properties refer to characteristics that cannot be perceived by the senses and are not easily identified. Karana et al. (2008) also show that after sensorial

properties, intangible properties are deemed the most important characteristic for designers in the beginning of a design process.

Based on all these properties, materials have a strong influence on the various other design considerations or vice versa. The interaction of materials with these other considerations from figure D2 is explained below, with the dominant consideration mentioned first. Extra emphasis will be put on the relationship between product personality and materials because of the newness of the field and its consequence for bamboo.

Materials and Shape

The choice for a specific material might provide limitations in the shape of the product. Depending on the material not all shapes are feasible and a material may impose several limitations in the form of the product (Pil and Verpoest 2006). For example, some materials can be bent in far sharper angles than others. Furthermore, depending on the material choice the character of the surface of the product will be very different. Caused by the frustrations about the limitations of a material, the implementation and invention of a new material can take place. For example, the first composite chair developed by Charles Eames ("Dining arm chair") arose out of his frustration when trying to make three dimensional double curved forms out of plywood (Pil and Verpoest 2006).

Materials and Manufacturing Processes

The properties of the material might impose restrictions on the way the material can be processed. For example, in contrast to plastics, metals cannot be injection-molded.

Function and Materials

Depending on the function of a product the most appropriate materials should be chosen during use. For example, besides affecting the product personality (PP) through its appearance, the use of a polymer strip (with lower thermal conductivity) around a ceramic cup enables the user to hold the cup, even if it is filled with hot coffee.

Figure D3: Ceramic coffee cup with polymer strip

Use and Materials

This interaction is similar to the interaction Function and Materials covered above. Through the senses, users interact with materials from which the product is made. Materials can give the user feedback during use, such as the difference between the use of keys of hard and softer plastics on keyboards for computers (van Kesteren 2008).

Product Personality and Materials

The PP is formed by the sensorial perception of the product, including the emotions and associations this evokes. PP and materials have a very strong and interesting connection. During use, the consumer's senses are in contact with the materials that form the product. Through colors, smells and sounds of the material, designers develop a sensory experience that appeals to consumers. Furthermore, through intangible properties of materials, such as associations, designers will try to positively influence the PP through appropriate material selection. For example, the use of metals is usually associated with high quality and status, and for these reasons the high end version of the Senseo® coffee making machine developed by Philips is executed in aluminum, compared to the cheaper plastic version (van Rijn 2007).

Figure D4: The aluminum version of the Senseo® coffee machine by Philips is about twice the price of the plastic version which cannot be justified based on higher material costs alone

In many cases, the material helps in forming the PP, but sometimes the opposite is also true and the material is first connected to a product in which it is first mass commercialized. If a material is completely new, its identity is still "moldable". When a material is first implemented in a trendy, high end product, the material and the product might grow up together and the material might be associated with the product, and will be perceived as being trendy and high end. Examples of materials that have followed this strategy are the high end aluminum suitcase of the German company Rimowa GmbH, high performance sports wear of Gore Tex®, and the Good Grips® kitchen equipment set by OXO International (van Bezooyen 2007).

Figure D5: Elastomers used in the grips of Good Grips® kitchen equipment developed by OXO International

Figure D6: Aluminum travel set developed by Rimova

Replication of the material in other applications might bring along the positive association of the material derived from the use in the first application. An example is the association of consumers with neoprene as being high tech and sporty because of their well known use in wet suits for surfers. Replication in cup-, bottle- and food holders brings along this sporty association in the new product, of which the company Built NY, Inc. has successfully taken advantage in its product line (van Bezooyen 2007); see figure D7.

Figure D7: The company Built uses the sporty associations of neoprene in its products

In the case of established materials the relationship of PP - materials can be very strong. For example, although cork is perceived as the best material for wine stoppers in high quality wines, which might provide positive associations, the application itself is so simple, with so little added value, that cork is usually not taken into account by designers as a suitable potential material for other applications. In appendix E the relationship of PP - materials is further elaborated upon for bamboo as a material.

Appendix E: The Image of Bamboo

In the the design considerations model of van Kesteren et al. (2005) in appendix D it was found that the manufacturing process (MP) and the product personality (PP) have a direct link to the material (M) used. In the case of the image (intangible properties) of bamboo, both the MP and the PP of the products developed in bamboo so far have a strong influence on its image, which will be further explained below.

The Influence of Product Associations (PP) on the Image of Bamboo (M)

In appendix D various examples were provided for materials that derive their image from associations with products in which they have traditionally been used. This can have positive effects on materials in the case of high end applications (e.g. the traditional use of silk in ties), but can have negative effects in the case of low end applications. The latter is the case for bamboo. Because in the past bamboo was used in many low end traditional products of poor quality, bamboo as a resource is commonly associated with these products. To investigate the image of bamboo, de Bruijn (2007a) and de Goede & van Loon (2006) interviewed more than 100 consumers in the Netherlands. The most common product associations for bamboo found in these studies were "rustic furniture", followed by "fences", "basketry", "fishing rods" and "plant supports". Associations most often mentioned in these studies for bamboo as a resource were "Asian", "panda", "cheap", "low quality", "non durable", "natural" and "rustic".

Furthermore, bamboo is commonly associated with China, a country that currently has a poor image in terms of sustainability (deforestation, rapid industrial development, toxic waste and pollution, bad labor conditions) and quality (low durability, poor finish). In general, people also believe that giant pandas only feed on bamboo and could go extinct because of the mass harvesting of bamboo for material production in China.[59]

Figure E1: Common associations of consumers in the Netherlands with bamboo (picture made by Mika de Bruijn, see de Bruijn 2007a)

[59] This problem is not caused by a shortage of bamboo, but by the destruction of the ecosystem in which the panda bear lives. In China, where the panda bear mainly has its habitat, more than 5 million hectares of bamboo are available, an area that in terms of proportion is larger than the Netherlands. Furthermore, pandas only eat the (low-hanging) leaves of bamboo species that are not suitable for industrial processing.

Please note that the term bamboo, just like wood, is a collective concept to refer to various species. As found in subsection 1.2.1 various bamboo species can considerably differ in size, thickness, color and texture, which might impact the image. For example, the dark bamboo species *Gigantochloa atroviolacea* also known as "Widjaja" in general has a more "classy" appearance than "yellow" bamboo species (e.g. Moso); see figure E2.

Figure E2: The dark bamboo species "Widjaja" used in a sculpture in the Netherlands

However, most people are not acquainted with these species and are only acquainted with either Moso bamboo or thin bamboo poles (usually *Phyllostachys Aurea*), which both have a yellowish color.
It should be noted that positive associations with industrial bamboo materials need to be fostered and nurtured. As explained in appendix D, when a new material is first being introduced on the market its image is still moldable, and the associations with the products in which it is first introduced can play an important role in the eventual image of the material. It is therefore important that new industrial bamboo materials are used in high end applications which yield positive associations, instead of low end applications in the discount stores where most non industrial bamboo products end up. This is a realistic threat since many industrial bamboo producers in China do sell inferior bamboo products to sales agents of these low cost discount stores in Western Europe (see figure E3).

Figure E3: Sometimes industrial bamboo materials also end up in low end discount stores in Western Europe

Finally, it should be remembered that associations are also formed by the product name. Product naming and branding can be very important tools to make a product appeal to a specific target group. Therefore, the name of the material can play an important role in its image since it is the first acquaintance of a customer with a new material and may imprint lasting first associations. A good example of a mediocre name for a bamboo material is "Strand Woven Bamboo". First, the name does not reflect the look of the material, and makes most Western consumers associate the material with low cost woven bamboo mats. Secondly, the name is long and does not provide any suggestion toward the unique selling points of the material.

The Influence of Manufacturing Processes (MP) on the Image of Bamboo (M)

Bamboo is one of the few materials that can be directly used, without further processing, in its raw form in products. This is quite unique; for example, trees are hardly ever used in products in their raw form and are almost always further processed into sawn timber (beams, planks, laths, etc.). By (industrial) processing of the bamboo resource all kinds of new materials, such as Plybamboo, Bamboo Mat Board, Strand Woven Bamboo, Bamboo Particle Board and various other bamboo composites can be formed that have a completely different image. Interestingly, the image of bamboo in products in Western Europe seems to strongly correlate with the level of processing the bamboo products have gone through; in the case of industrial processing of bamboo the negative image of bamboo seems to turn around and the positive aspects of bamboo are highlighted instead of the negative ones.[60] For example, de Bruijn (2007a) has shown that respondents in the Netherlands, if acquainted with industrial bamboo products such as flooring, differ considerably with unacquainted respondents in their perception of bamboo as a material, describing it to a larger extent as an innovative, exclusive and high-end material. Some consumers like the fact that they can still recognize features of bamboo (such as the nodes) in Plybamboo. However, it may be noted that in the sample test conducted by de Bruijn (2007a) of all industrial bamboo flooring and wooden flooring samples, the aesthetics of SWB, in which bamboo's typical appearance is largely lost, scored the best (sample E in figure E4).

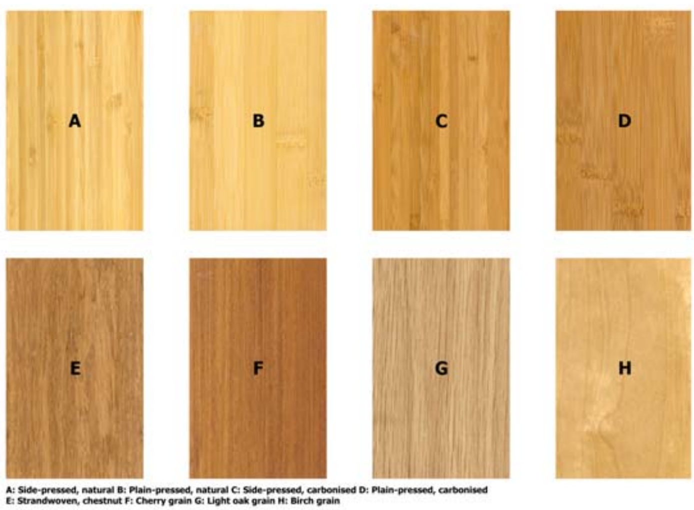


Figure E4: Samples used in consumer research by de Bruijn (2007a)

The negative prejudices mentioned above, therefore, seem to apply to products based on the bamboo stem, and less to products based on industrial bamboo materials. However, the problem is that most people are not acquainted yet with the existence of industrial bamboo materials and initially associate bamboo with the bamboo stem. For example, the study by de Goede and van Loon (2006) revealed

[60] Please note that the image (attitude) toward the bamboo materials stem, Plybamboo, composite, Strand Woven Bamboo and mats is further evaluated for the designers participating in the intervention in section 6.2.

that Dutch respondents associate bamboo furniture in 94 percent of the cases with stem-based furniture. In the study by de Bruijn (2007a) only 28 percent of the respondents were acquainted with bamboo flooring.

Appendix F: Main Elements of Action Research

In general, action research entails the following five main elements (den Hartog and van Sluijs 1995):

1. Cooperation. There needs to be a joint objective for all participants in the organization or intervention context, based on shared values and drives. A thorough preparatory phase is required. The participants need to adequately represent the organization or setting in which the intervention occurs.
2. Involvement of the researcher itself. This is an element very different from other research strategies, since in most strategies the role of the researcher is usually more observant instead of participatory. The active involvement of the designers means that the researcher brings his owns beliefs, drives and values into the system.
3. Involvement of the members of the organization team in the research. Besides the researcher the other organization team members are directly involved with the design and structure of the intervention process. Such an action research, in which the researcher executes the intervention in collaboration with the members of the organization team (who can be perceived as co-researchers), can also be labeled as "participatory action research" (Whyte et al. 1991).
4. Joint frame of reference. During the intervention process it is of importance that all theoretical and practical points of departure are made explicit, i.e. put to discussion. In this way all stakeholders in the intervention (participants and organization team members) construct a common shared image of the situation, and even more important, of the future desirable situation (Elden and Chrisholm 1993).
5. The phasing of the process. The diagnosis - action - evaluation process steps of Lewin (1948) were further developed by Susman (1983) into an evaluation cycle (see figure F1), with a strong emphasis on continuous learning and adjustment of the intervention throughout the process. Note that an organization team that implements the intervention will usually go through this diagnosis - action - evaluation cycle several times during the intervention, thus continuously adjusting the intervention for maximum results. This continuous feedback of results is essential in action research (Susman 1983).

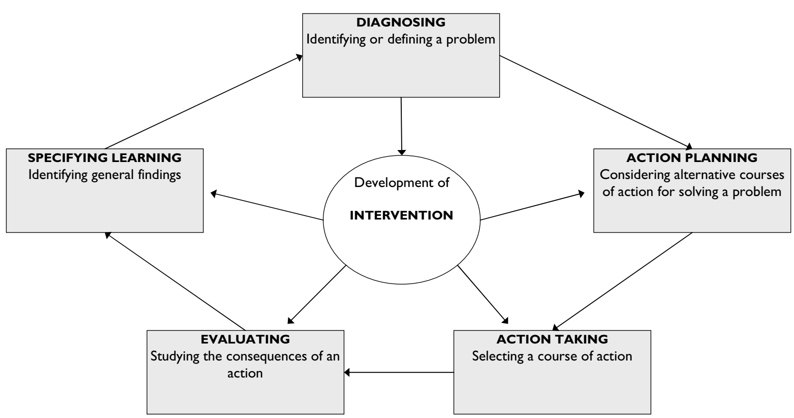


Figure F1: The cyclic process of action research (Susman 1983)

Appendix G: Factors of Success and Failure during Product Innovation

Of the thousands of product ideas a company might come up with in the first phases of the innovation process, only a dozen will actually be developed and launched on the market, of which usually only a few will be successful. It is not surprising that factors that determine the success (or failure) of new products is a popular and important area of research. It is a broad area too, which has been investigated from many different theoretical perspectives and on various scales (e.g. product level, company level, sector level). As a result, various scholars present a wide array of key factors for success during product innovation, which differ depending on the focus of the study. The most important factors toward success or failure of a new product mentioned in key literature are summarized in table G1 below. The factors of success and failure mentioned in the table are usually complementary and can often be reversed. It depends from which perspective the studies were executed if a factor of success or failure was found (e.g. the strategic factor of failure "deficient resources" implies that "sufficient resources" would be a factor of success for successful product innovation). Note that many factors of success can be seen as a standard requisite for innovation (e.g. sufficient company resources). The importance of the various factors may differ per industry, organization type and the development stage of the new product. For example, according to Langerak, Hultink and Robben (Langerak et al. 2004), the launch stage represents the costliest and riskiest part of the product innovation process. However, many of the factors mentioned in the table might impede the new product from even reaching the launch stage.

Table G1: Factors of success and failure during production innovation (Berchicci 2005, Crul 2003)

	Factors of Success	Factors of Failure
Strategic and marketing factors	- Clear and well communicated new product strategy (Cooper and Kleinschmidt 1995, Montoya-Weiss and Calantone 1994) - Product advantage (Montoya-Weiss and Calantone 1994) - Sufficient company resources (Cooper and Kleinschmidt 1995, Montoya-Weiss and Calantone 1994) - Healthy economic situation of the company (Buijs 1987) - Marketing synergy/explicit marketing strategy (Buijs 1987, Montoya-Weiss and Calantone 1994) - Proficiency of marketing activities - Proficiency of up-front activities - Protocol (product definition) - Speed to market - Financial/business analysis All based on Montoya-Weiss and Calantone (1994)	- Lack of product superiority - (Biemans 1989, Cooper 1996, Cooper 1975, Cooper and Kleinschmidt 1987, Karakaya and Kobu 1994, Link 1987) - Inadequate market analysis and effort - (Biemans 1989, Cooper 1996, Cooper 1975, Cooper and Kleinschmidt 1987, Crawford 1977, Karakaya and Kobu 1994, Link 1987) - Deficient resources (Cooper 1975) - Poor distribution (Karakaya and Kobu 1994) - Wrong pricing (Karakaya and Kobu 1994)

	Success factors	Failure factors
	- Launch proficiency (Hultink 1997) - Clear goal and strategic focus in New Product Development (NPD) program (Cooper and Kleinschmidt 1995, Griffin 1997, Thamhain 1990) - Market information and NPD program (Balbontin et al. 1999, Cooper and Kleinschmidt 1995) - User involvement (Hippel 1977)	
Technological Development factors		
	- Proficiency of technical activities/high technological level (Buijs 1987, Montoya-Weiss and Calantone 1994) - R&D expenditure and program development (Kleinknecht et al. 1992) - Applying for subsidies and patents (Kleinknecht et al. 1992)	- Technical difficulties (Cooper 1975) - Poor timing and planning (Cooper 1975, Crawford 1977) - Higher costs than expected (Cooper 1975)
Market environment factors		
	- Market potential/size - Market competitiveness - External environment All based on Montoya-Weiss and Calantone (1994)	- Stronger competitors (Cooper 1975, Karakaya and Kobu 1994, Link 1987) - Overestimated number of users (Biemans 1989, Cooper 1975, Karakaya and Kobu 1994, Link 1987) - Unexpected events and regulations (Crawford 1977, Montoya-Weiss and Calantone 1994)
Organizational factors		
General	- Internal/external relations - Organizational factors based on Montoya-Weiss and Calantone (1994) - Cross functional team (Cooper and Kleinschmidt 1995, Dougherty 1992, Griffin 1997) - A strong and responsible project leader (Cooper and Kleinschmidt 1995) - NPD team and team leader commitment (Dougherty 1992, Thamhain 1990) - Management involvement and commitment (Cooper and Kleinschmidt 1995) - Allow the emergence of "intrapreneurs" and risk taking attitude (Cooper and Kleinschmidt 1995) - Existence of product champions (Barczak 1995) - Intensive communication (Cooper and Kleinschmidt 1995, Dougherty 1992)	- Poor internal communication (Cooper and Kleinschmidt 1987, Crawford 1977, Montoya-Weiss and Calantone 1994) - Lack of managerial skills (Cooper 1975, Cooper and Kleinschmidt 1987, Crawford 1977, Montoya-Weiss and Calantone 1994)

	- High independency (Buijs 1987) - Process oriented consultancy approach (more efficient than the technical or management oriented approach) (Buijs 1987)	
Characteristics of organizational structure	*For established organizations:* - Complexity (level of knowledge & expertise of the members of the organization) - Interconnectedness - Organizational slack (uncommitted resources) - Size All based on Rogers (2003) *For new organizations* (besides the general organizational factors mentioned above) the following entrepreneurial characteristics are found to be influential for success (van de Ven et al. 1984): - Competence - Confidence - Prior experience - Imagination - Commitment	- Centralization (of power and control to a relative small number of individuals) - Formalization All based on Rogers (2003)

Appendix H: Product Prototype Evaluation Sheets

In this appendix the evaluation of the product prototypes in chapter 4 in terms of market potential and innovative character is motivated. Unlike stated otherwise, all scores, motivations, remarks and suggestions for improvement for each product evaluation are supported by the complete expert panel. If the Scientific Committee (SC) did not agree with the initial evaluation, their judgment is mentioned separately in the text.

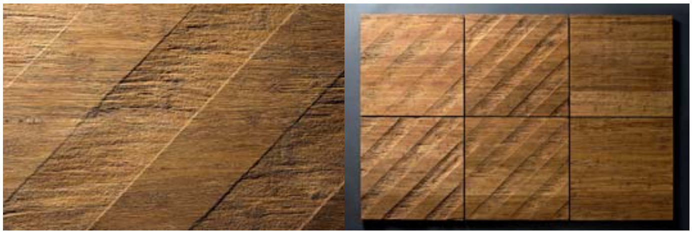
1. Ro Koster & Ad Kil (Ro & Ad Architects): Coffin

MARKET POTENTIAL			
Product Quality		**Score**	**Motivation/Suggestions for improvement**
Functionality & use	Weight	+	
	Sturdiness (life span)	+	The product has a short life span, but for this application that is perceived as a desirable attribute
	Reparability	n/a	
	Specific functionality	-	Rough look for a coffin. The coffin is not completely closed (air holes). In its current form, the product will not be accepted by legislation in the West.
Aesthetics & intangible properties	Aesthetic quality & trendiness	+/- SC: +	Although the looks do not, the concept does fit very well with current consumer trends (responsible consumption).
	Originality; strength of concept	+ SC: ++	The complete biodegradability fits very well with a coffin, "from cradle till grave". SC: The whole concept, including ash seeds embedded in the biodegradable composite, is brilliant.
Production Costs			
Transportability		+	Can be transported as thin sheet material and can be "rolled" into a coffin at place of destination.
Manufacturing costs in North/South		-	The production of bio composites requires large specialized presses and bio resins, which are expensive and not widely available. Therefore, the product needs to be manufactured in the North.
Market Potential (value/price)			
Current market potential		--	In this form it will never reach the market (not air sealed, too rough, resin looks too much like plastic and still holds air bubbles).
Future market potential after optimization		-	This product will not reach the market in its current form. If the design can be improved, look dignified and be air sealed, there could be a small niche market in the future.
INNOVATIVE CHARACTER			
Utilization of specific properties of bamboo		+/-	Use of tensile strength and length of bamboo fibers in lowering bands.
Contribution to new image of bamboo		-	Although the bands show the interesting possibilities of the combination of fibers and resins, the product as a whole still has a cheap image.
Level of process innovation (processing and manufacturing technology) - Bamboo		++	One of the first times bamboo fibers and veneer are combined with bio resins to form a completely biodegradable composite. By using small sticks and veneer as matrix material, new possibilities for natural fiber based composites in general are shown in this product.
Overall future market potential of new processing technology (if applicable)		+	Bamboo fibers are long, strong and abundantly available in various forms (pure fiber, sticks, veneer). The combination with (bio)resins holds a lot of potential as a new (sustainable) material for various other industries besides the furniture industry.

2. Lara de Greef: Chair

MARKET POTENTIAL			
Product Quality		**Score**	**Motivation/Suggestions for improvement**
Functionality & use	Weight	-	Quite heavy and massive product. SC Recommendation: Develop a sandwich construction in which only the outer 5 mm uses Plybamboo boards. As a result, the product will be cheaper and lighter.
	Sturdiness (life span)	++ SC: +	SC: Although the construction is strong, the cushion of bamboo textile is vulnerable for wearing out.
	Reparability	+	
	Specific functionality	+/-	SC: Tops of armrests are too narrow.
Aesthetics & intangible properties	Aesthetic quality & trendiness	+	Very "pure" design.
	Originality; strength of concept	+/-	
Production Costs			
Transportability		+	Consists of various boards facilitating the flat pack possibility.
Manufacturing costs in North/South		+	Can be produced efficiently (economically) both in North and South. In North the product can be easily produced in batches with high quality milling machines. In the South this is not a standard asset in furniture factories. However, the product can also be produced with ordinary sawing machines, which are available in abundance in the South.
Market Potential (value/price)			
Current market potential		+/-	In its current form the product is still a little expensive (FOB costs in South East Asia estimated at $60-70/piece) and heavy. However, the product facilitates mass production, has a trendy look and these kinds of chairs do well in the current furniture market in Western Europe.
Future market potential after optimization		+	If made lighter (see suggestion for sandwich construction before) and more efficient (no bamboo dowels), this is a trendy chair which can be produced efficiently.
INNOVATIVE CHARACTER			
Utilization of specific properties of bamboo		+/-	Through the innovative use of bamboo dowels and bamboo textile in combination with the bamboo boards, the chair consists of 100% bamboo. Furthermore, the bamboo grain is clearly visible as is the multi layer structure of the Plybamboo board. However, the chair does not take specific advantage of the mechanical properties of bamboo.
Contribution to new image of bamboo		+	Nice look. Based on the chair a whole new furniture set can be developed.
Level of process innovation (processing and manufacturing technology) - Bamboo		+/-	The use of bamboo dowels and bamboo fibers in textile forming a 100% bamboo chair is quite innovative.
Overall future market potential of new processing technology (if applicable)		+/-	High quality milling (CNC, water cutting, etc.) can yield interesting results for Plybamboo (complex patterns and taut edges very possible), which provides many opportunities in the furniture sector. SC: Furthermore, the use of bamboo in textile seems promising; the bamboo textile has very good tactile properties.

3. Jacqueline Moors: Floor tiles



MARKET POTENTIAL			
Product Quality		**Score**	**Motivation/Suggestions for improvement**
Functionality & use	Weight	+	Tiles are heavy. In this application this is a desirable attribute.
	Sturdiness (life span)	+	
	Reparability	+	Each tile can simply be replaced once damaged.
	Specific functionality	+/-	The diagonal rays make the surface less slippery. However, a carrying system on which the tiles can be located still needs to be developed.
Aesthetics & intangible properties	Aesthetic quality & trendiness	+	Some consumers will appreciate the hardwood look of Strand Woven Bamboo (SWB); some will find it too dull. The structure of the diagonal rays in the tiles provides added value to the material.
	Originality; strength of concept	+/-	
Production Costs			
Transportability		+/-	Flat pack is possible; however, the base material is very heavy (1050 kg/m3) which means that containers for transport cannot be fully packed with the tiles.
Manufacturing costs in North/South		-	Based on production in the North; since the half fabricate is very hard, the rays have to be sand blasted for a long time with special machines, which are hardly available in the South. It should be investigated if there are no other (less time consuming) ways to develop the rays in the tiles (e.g. using molds). Furthermore, the base material (SWB) is still quite expensive.
Market Potential (value/price)			
Current market potential		-	At the moment the base material of the tiles (SWB) is quite expensive and still needs to be further developed before it can be used outside. Also, the tile system as a whole should be further developed including the carrying system on which the tiles can be placed (e.g. rails, possibly also in SWB).
Future market potential after optimization		+	In a couple of years the price of SWB should lower and the material should be able to be used outside. As such, despite its weight, SWB can become a very interesting alternative to scarce and expensive tropical hardwood species that are suitable for use outside.
INNOVATIVE CHARACTER			
Utilization of specific properties of bamboo		+	Uses hardness of bamboo and the structure of SWB to create a rough surface. Solid tiles this size cannot be produced in one piece in hardwood.
Contribution to new image of bamboo		+/-	Looks like hardwood and is easily mistaken for Bangkirai, which can be perceived as an opportunity (new exclusive hardwood species) or threat (no own identity).
Level of process innovation (processing and manufacturing technology) - Bamboo		+	The novelty of this design mostly lies in the material on which it is based (SWB). This semi finished material combines hardness, strength, good looks and high durability (in the future, also outside) in one piece in a size which is not easily available in wood.
Overall future market potential of new processing technology (if applicable)		+	See "future market potential after optimization" above

4. Leonne Cuppen (Yksi): Chair

MARKET POTENTIAL			
Product Quality		**Score**	**Motivation/Suggestions for improvement**
Functionality & use	Weight	-	Although the stems are light, many of them are used, resulting in a heavy chair.
	Sturdiness (life span)	+ SC: -	Simple yet sturdy construction. SC: However, the stems easily fall out of the steel strips (e.g. upon transport of the chair).
	Reparability	+	Each stem can be easily replaced.
	Specific functionality	- SC: --	Does not sit very well.
Aesthetics & intangible properties	Aesthetic quality & trendiness	+	
	Originality; strength of concept	+/-	
Production Costs			
Transportability		+/-	Possible to demount and assemble after transport; however, the stems take up a lot of space.
Manufacturing costs in North/South		+/-	Based on production in the South; although the design and corresponding production is relatively simple, the combination with a steel frame can be problematic in South East Asia.
Market Potential (value/price)			
Current market potential		-	Does not sit very well. More a gimmick or museum object than a serious product.
Future market potential after optimization		- SC: -/+	SC Recommendation: Develop the steel strip, which holds the stems together, in another material so that the strip can be bent by the consumer, and adjusted to a form the consumer prefers. This concept could have reasonable potential in a small high end market in the future.
INNOVATIVE CHARACTER			
Utilization of specific properties of bamboo		+	It is almost impossible to copy this product with the same look in another material.
Contribution to new image of bamboo		-	
Level of process innovation (processing and manufacturing technology) - Bamboo		--	
Overall future market potential of new processing technology (if applicable)		n/a	

Leonne Cuppen (Yksi): Clothing hangers

MARKET POTENTIAL			
Product Quality		**Score**	**Motivation/Suggestions for improvement**
Functionality & use	Weight	-- SC: -	Too heavy and massive for a clothing hanger. SC Recommendation: Make this product hollow or in a sandwich construction with a lighter carrier.
	Sturdiness (life span)	+	
	Reparability	n/a	
	Specific functionality	+	
Aesthetics & intangible properties	Aesthetic quality & trendiness	+/-	
	Originality; strength of concept	+/-	
Production Costs			
Transportability		- SC: +/-	
Manufacturing costs in North/South		+/-	Very suitable for mass production in the North if good milling machines are used. However, for a clothing hanger, material and manufacturing costs will be relatively high. SC: if the right factory in the South is found (with good milling machines) this product could also be manufactured in the South.
Market Potential (value/price)			
Current market potential		- SC: +/-	Probably too expensive for this application. SC: For very high end markets this could serve as a niche product. Furthermore, in a sandwich construction the product can be produced in a lighter and cheaper way.
Future market potential after optimization		- SC: +/-	See directly above
INNOVATIVE CHARACTER			
Utilization of specific properties of bamboo		-	Only aesthetic properties of bamboo are used.
Contribution to new image of bamboo		+	Modern design.
Level of process innovation (processing and manufacturing technology) - Bamboo		+/- SC: -	The product shows Plybamboo can easily be processed with high quality milling machines (CNC, water cutting, etc.). SC: However, the cutting pattern is not that complex and groundbreaking.
Overall future market potential of new processing technology (if applicable)		+/-	High quality milling (CNC, water cutting, etc.) can yield interesting results for Plybamboo (complex patterns and taut edges very well possible).

Leonne Cuppen (Yksi): Lamps

MARKET POTENTIAL			
Product Quality		**Score**	**Motivation/Suggestions for improvement**
Functionality & use	Weight	+/-	The bamboo stem is light, and ceramics are heavy. Not a very good combination.
	Sturdiness (life span)	--	Instable construction.
	Reparability	+/-	
	Specific functionality	-	Gives nice light, but construction is not very efficient.
Aesthetics & intangible properties	Aesthetic quality & trendiness	+/- SC: --	
	Originality; strength of concept	+/- SC: -	Idea of creating a bamboo forest of lamps is nice, but does not come to the surface in the final product.
Production Costs			
Transportability		-	Difficult; each lamp consists of three components of three different materials.
Manufacturing costs in North/South		-	Probably best to develop in the North, since in the South it is very difficult to develop a good furniture piece based on three different materials and good electronic wiring. However, sandblasting is quite labor intensive, making the production in the North also expensive.
Market Potential (value/price)			
Current market potential		- SC: --	Hard to produce for a realistic price and also not a really trendy product. SC: Many missed chances in this design. It would have been better to use existing processing technologies like bending the bamboo stem or imitating constructions used for the development of bamboo torches in order to develop a nice bamboo lamp.
Future market potential after optimization		-	See directly above
INNOVATIVE CHARACTER			
Utilization of specific properties of bamboo		+/- SC: -	Utilization of the hollow bamboo stem for wiring. SC: This can also easily be done with a PVC or iron tube.
Contribution to new image of bamboo		- SC: --	This design does not help bamboo to lose its colonial image.
Level of process innovation (processing and manufacturing technology) - Bamboo		+/-	Sandblasting and sanding the bamboo stem gives it a slightly different look (more sophisticated).
Overall future market potential of new processing technology (if applicable)		+/-	Sandblasting the bamboo stem can help the material get a more modern look.

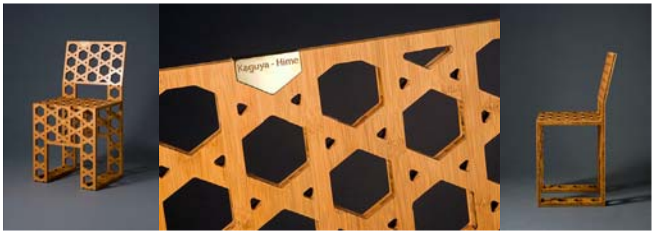
5. Ed van Engelen (Haans): Room divider

MARKET POTENTIAL			
Product Quality		**Score**	**Motivation/Suggestions for improvement**
Functionality & use	Weight	+	Light structure.
	Sturdiness (life span)	-	Vulnerable construction (especially the inside of the bamboo stem is vulnerable). SC Recommendation: Maybe the construction can be cast in transparent resin to fix the slices. Also the framework and bottom fixture could be developed in a sturdier manner to avoid tumbling of the product.
	Reparability	- SC: --	
	Specific functionality	+ SC: ++	SC: If the product should also function as a visual room divider, then rice paper could be added. Sublime design.
Aesthetics & intangible properties	Aesthetic quality & trendiness	+ SC: ++	Using a coating with flat, black color works very well on the bamboo stem.
	Originality; strength of concept	+ SC: ++	Simple twist in processing and use of color gives bamboo a completely new look.
Production Costs			
Transportability		+	Flat pack possible.
Manufacturing costs in North/South		+	Production in South is definitely feasible since this design can also be made with a good saw.
Market Potential (value/price)			
Current market potential		+ SC: ++	Easy to produce, not expensive (FOB costs in South East Asia estimated at $40 apiece), and new trendy look. However, the market for room dividers is not very large.
Future market potential after optimization		+ SC: ++	
INNOVATIVE CHARACTER			
Utilization of specific properties of bamboo		++	In this form the product is nearly impossible to make in any other material.
Contribution to new image of bamboo		+ SC: ++	
Level of process innovation (processing and manufacturing technology) - Bamboo		+/-	Simple adjustment of method (longitudinal milling of bamboo) provides surprising new looks
Overall future market potential of new processing technology (if applicable)			

Ed van Engelen (Haans): Dinner table

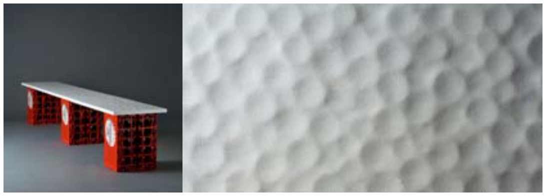
MARKET POTENTIAL			
Product Quality		**Score**	**Motivation/Suggestions for improvement**
Functionality & use	Weight	+/- SC: +	Bamboo stems are light, but the tabletop of massive bamboo board is quite heavy. SC: Very smart to use light bamboo stems. Normally this kind of table would use massive legs, making it even heavier.
	Sturdiness (life span)	+	Strong construction.
	Reparability	+/-	
	Specific functionality	+	
Aesthetics & intangible properties	Aesthetic quality & trendiness	+	
	Originality; strength of concept	+ SC: +/-	Combination of bamboo stem and board. By painting the stem black, a new image around the stem is created.
Production Costs			
Transportability		++	Flat pack possible, only six bolts are required to set up the complete table.
Manufacturing costs in North/South		+	Based on production in the South; the construction is relatively simple, however, the bottom construction with the bamboo poles is quite labor-intensive and requires specific bamboo related skills, which are abundantly available in the South.
Market Potential (value/price)			
Current market potential		+/- SC: +	The table is easy to produce, has a trendy look, but is still quite expensive (FOB costs estimated at $200 in South East Asia). SC: This product can be sold very well in the high end market and as such these costs are still reasonable. Recommendation: Use bamboo veneer on a cheaper and lighter carrier instead of a solid board in order to bring the costs down and make the table lighter.
Future market potential after optimization		+	
INNOVATIVE CHARACTER			
Utilization of specific properties of bamboo		+	Uses form and strength of the bamboo stem in the lower construction, and utilizes hardness of bamboo board in the tabletop.
Contribution to new image of bamboo		+	Use of the traditional bamboo stem while keeping the feeling of "new bamboo". SC: The use of flat, black coating works very well for the bamboo stems. The monumental character of the bamboo stems now appears as an added value instead of a weak point (colonial image).
Level of process innovation (processing and manufacturing technology) - Bamboo		+/-	Although the techniques used are not very new, coating the bamboo stem and combining board and stem provides surprising effects.
Overall future market potential of new processing technology (if applicable)		+/- SC: +	The mere application of flat (in this case black) coating gives a completely new feeling to the bamboo stem. The combination of board and stem can work very well in furniture.

6. Lotte van Laatum: Chair



MARKET POTENTIAL			
Product Quality		**Score**	**Motivation/Suggestions for improvement**
Functionality & use	Weight	+ SC: +/-	
	Sturdiness (life span)	-	Vulnerable construction.
	Reparability	-	
	Specific functionality	-	Does not sit very well.
Aesthetics & intangible properties	Aesthetic quality & trendiness	+ SC: ++	Beautiful chair with strong cultural connotation.
	Originality; strength of concept	+/- SC: +	Old fashioned bamboo pattern (plaiting) presented in a completely new and trendy way.
Production Costs			
Transportability		-	In the current form flat pack does not seem possible.
Manufacturing costs in North/South		+/-	Since the design requires many processing activities with a programmable high quality automatic milling machine, the design would need to be produced in the North.
Market Potential (value/price)			
Current market potential		- SC: +	Does not sit well and is quite expensive to produce (in Western Europe manufacturing costs estimated at $200 apiece). SC: When perceived as an artistic object this chair does have potential for very high end markets due to its exclusive look.
Future market potential after optimization		- SC: +	See directly above.
INNOVATIVE CHARACTER			
Utilization of specific properties of bamboo		- SC: +/-	Only the concept behind this chair justifies the use of bamboo (based on plaiting techniques) SC: Such clear, taut edges through milling are very hard to acquire in wood.
Contribution to new image of bamboo		+	
Level of process innovation (processing and manufacturing technology) - Bamboo		+/-	The product shows that bamboo board can be milled in very difficult patterns with high quality milling machines.
Overall future market potential of new processing technology (if applicable)		+/-	High quality milling can yield interesting results for Plybamboo (complex patterns and taut edges very well possible).

7. Bertjan Pot: New board material



MARKET POTENTIAL			
Product Quality		**Score**	**Motivation/Suggestions for improvement**
Functionality & use	Weight	++	This sandwich construction results in a light material.
	Sturdiness (life span)	+	Strong (glue) connection between bamboo tubes and veneer layers which form the surface of the material. The connection between layers and tubes is even increased through vacuum suction of the tubes forming the "dimples" in the board.
	Reparability	-	
	Specific functionality	+ SC: ++	Decorative yet strong new material.
Aesthetics & intangible properties	Aesthetic quality & trendiness	++	
	Originality	++	New look for bamboo which uses the specific qualities of bamboo.
Production Costs			
Transportability		+	Flat light material, which is easily stacked.
Manufacturing costs in North/South		+/- SC: +	In principle, the design does not require specialized facilities and can be produced in the South; vacuum suction can be done in a simple manner using a vacuum cleaner. Allocation of the tubes can be very labor intensive, which makes this material expensive to manufacture in the North.
Market Potential (value/price)			
Current market potential		+/- SC: +	The material is strong, light and has good looks. However, the best application and target market for this new material still needs to be found (Interior design? Furniture?) and production needs to become more efficient, which would require setting up new production facilities.
Future market potential after optimization		+	See directly above; if a new production plant can be set up to efficiently produce the material, the material could potentially be manufactured at an estimated cost of $10-20/m2.
INNOVATIVE CHARACTER			
Utilization of specific properties of bamboo		++	This board material can hardly be produced in any other material; the crosscut side of the bamboo stem absorbs the glue very well and forms a very strong connection with the veneer. With plastic tubes this strength (and the random visual effect) cannot be created. With carton tubes this could be done; however, this material is more vulnerable to moisture. Furthermore, a sandwich panel is a very efficient structure.
Contribution to new image of bamboo		++	Completely new, sophisticated look for bamboo. SC: It would be interesting to investigate how the material would look if the bamboo tubes were visible by using transparent layers instead of the veneer layers. Furthermore, it should be experimented what the looks of the material are with other colors besides white.
Level of process innovation (processing and manufacturing technology) - Bamboo		++	Sandwich panels of bamboo have been produced before, but not with the use of vacuum compression and with such a sophisticated look.
Overall future market potential of new processing technology (if applicable)		+	See "future market potential" above.

8. Eliza Noordhoek: Lamp

MARKET POTENTIAL			
Product Quality		**Score**	**Motivation/Suggestions for improvement**
Functionality & use	Weight	+	Very light.
	Sturdiness (life span)	-	Fragile product.
	Reparability	-	
	Specific functionality	++ SC: +	Provides nice light. SC: However, the details and edges of the product are still executed in a very rough way and should really be improved in the future.
Aesthetics & intangible properties	Aesthetic quality & trendiness	+ SC: +/-	SC: Outdated form. However, it might fit well in current retro styles.
	Originality; strength of concept	++ SC: +	A new bamboo specific look including a link with bamboo culture & tradition, through the "Ying Yang" concept.
Production Costs			
Transportability		++	Complete flat pack possible
Manufacturing costs in North/South		++ SC: +/-	This product can be very well and quickly mass produced in a good production facility in the North, deploying die-cutting machines. SC: However, the connection of both ends of the sheet in the corners is still difficult and may inhibit efficient mass production in its current form, and therefore still needs to be optimized.
Market Potential (value/price)			
Current market potential		+	This is a simple product that can be economically produced, efficiently transported, has a good look and a strong concept. However, the edges will need to be refined.
Future market potential after optimization		++	Once edges are improved this product has high market potential for the medium end mass market.
INNOVATIVE CHARACTER			
Utilization of specific properties of bamboo		++ SC: +	No other wood-like veneer is so strong that it can be bent in curves without a textile backing. The specific bamboo grain is very well visible.
Contribution to new image of bamboo		++ SC: +/-	SC: These kinds of lamps were already developed in the 1950s based on wood veneer.
Level of process innovation (processing and manufacturing technology) - Bamboo		+	Bamboo veneer seems very suitable for die-cutting. Furthermore, veneer bent in this way is hard to execute with other kinds of wood veneer without textile backing. SC: Furthermore, the production process of bamboo veneer as a material is innovative compared to regular veneer from wood; bamboo veneer is not manufactured by rotary slicing (like wood), but from slicing layers of a laminated block of bamboo strips which provides a strong and thin kind of veneer.
Overall future market potential of new processing technology (if applicable)		+	Through die-cutting, bamboo veneer may be used in many new applications (e.g. high end packaging).

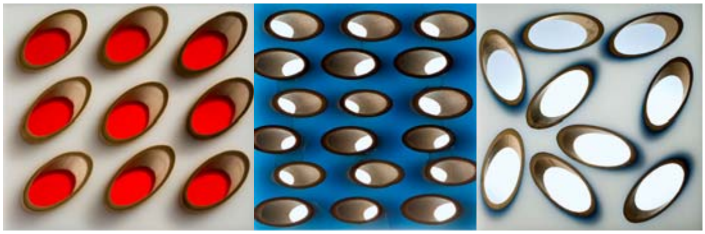
Eliza Noordhoek: Vase

MARKET POTENTIAL			
Product Quality		**Score**	**Motivation/Suggestions for improvement**
Functionality & use	Weight	+/-	
	Sturdiness (life span)	+	This product has a short life span, which is perceived as a desirable attribute for this particular application.
	Reparability	n/a	
	Specific functionality	+	Does what is has to do: degrade.
Aesthetics & intangible properties	Aesthetic quality & trendiness	+/-	Although the looks do not, the concept does fit with current consumer trends (responsible consumption).
	Originality; strength of concept	+	
Production Costs			
Transportability		+/-	
Manufacturing costs in North/South		-	Since bio resins are still quite expensive, scarcely available and usually require specific processing facilities, production in the North seems most suitable. In the future, once bio resins will be available in the South, simple products such as this one could be made manually in the South, using simple molds.
Market Potential (value/price)			
Current market potential		-	In this form the looks of the product are still too rough. Furthermore, bio resins (PLA) are still quite expensive and scarcely available.
Future market potential after optimization		+/-	If the material looks can be improved and costs can be lowered, there could be a small niche market.
INNOVATIVE CHARACTER			
Utilization of specific properties of bamboo		- SC: +	This design could also be executed in any other natural fiber. SC: If the amount of resin is not too high, the strength comes from the bamboo fiber, which is very sturdy and strong.
Contribution to new image of bamboo		-	Bamboo looks like a cheap material in this design.
Level of process innovation (processing and manufacturing technology) - Bamboo		+	The combination of bamboo fibers/sawdust, and bio resin is relatively new.
Overall future market potential of new processing technology (if applicable)		+	Although many experiments and developments are still needed for bamboo fiber reinforced composites for use in applications such as trays and packaging, it holds a lot of potential. Since the bamboo fiber is very strong, its strength should be utilized to the fullest in these kinds of materials. Research should be executed to find the right binder/resin that combines strength and biodegradability.

9. Daan van Rooijen (Kiem): Chair

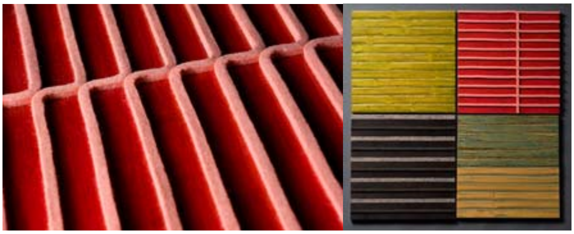
MARKET POTENTIAL			
Product Quality		**Score**	**Motivation/Suggestions for improvement**
Functionality & use	Weight	+	Light construction based on stems.
	Sturdiness (life span)	+/-	
	Reparability	--	The materials are fixed with resins, so it is hard to substitute parts.
	Specific functionality	+/-	Although the product sits well, the aesthetics are poor. The resin looks too much like plastic and contains air bubbles.
Aesthetics & intangible properties	Aesthetic quality & trendiness	-	The aesthetics are very poor, although the concept does fit in current trends (responsible consumption). However, this concept would fit better in applications in which the biodegradability is required (see coffin above).
	Originality	+/-	
Production Costs			
Transportability		-	After production the product cannot be disassembled.
Manufacturing costs in North/South		-	North; the production of bio composites requires large specialized presses and bio resins which are expensive and not widely available. The construction, which combines split stems and jute, is very labor intensive.
Market Potential (value/price)			
Current market potential		--	In this form this product will not reach the market, since it is still too expensive to produce and holds no aesthetic quality (resin looks too much like plastic and still holds air bubbles).
Future market potential after optimization		-	If the looks of the material / design can be improved, and manufacturing costs can be lowered, there could be a small niche market in the future.
INNOVATIVE CHARACTER			
Utilization of specific properties of bamboo		+	Use of strength and length of bamboo fibers in back support. Use of bamboo stems as construction material in the legs and supports (use of mechanical properties of bamboo). 100% biodegradable.
Contribution to new image of bamboo		-	Although the seat back shows the interesting possibilities of the combination of fibers and resins, the product still has a cheap image.
Level of process innovation (processing and manufacturing technology) - Bamboo		++	Innovative connections that use the bamboo stem in combination with natural textile (jute) and bio resins result in a strong and completely biodegradable solution. Furthermore, by using bamboo sticks in combination with transparent resin new (visual) possibilities are shown for natural fiber-based composites in general.
Overall future market potential of new processing technology (if applicable)		+	The same remarks as for the coffin (see before). Furthermore is recommended that various experiments should be executed with the placement of the long bamboo fibers, which holds potential for interesting visual effects However, production facilities need to improve in capacity and quality in order to provide a trustworthy semi finished material with good adhesion, properties and finishing (no air bubbles), which will take years. Finally, the new way of utilizing the bamboo stems in this design by splitting them at the ends and combining them with resin and jute provides several stepping stones to further develop this technique in various other applications in the future (furniture, building industry, etc.), especially in developing countries (e.g. low cost housing).

10. Yvonne Laurysen & Eric Mantel (Lama Concept): New material



MARKET POTENTIAL			
Product Quality		**Score**	**Motivation/Suggestions for improvement**
Functionality & use	Weight	+/-	
	Sturdiness (life span)	+/-	Some cracks have already developed in the material, which shows the need to further investigate and optimize the bonding between the bamboo material and resins deployed.
	Reparability	-	
	Specific functionality	++	Very decorative. As a partitioning wall this material has very good acoustical qualities and provides very interesting light effects.
Aesthetics & intangible properties	Aesthetic quality & trendiness	++	Very beautiful, 3D effect. Many variations still possible.
	Originality	++	New bamboo specific look.
Production Costs			
Transportability		+	Like most semi finished materials, it is flat, facilitating efficient packing and transport.
Manufacturing costs in North/South		- SC: +/-	Because of the high manufacturing quality requirements and availability of high quality resins, the material can probably be best produced in the North. However, production of the oval bamboo slices is labor intensive and it could be imported directly from the South. SC: If the production system is industrialized in a smart way (prefabricating the ovals, division of slices in molds using vibrating machines, etc.), manufacturing this product in the North should be economically feasible.
Market Potential (value/price)			
Current market potential		+/-	The material is still quite expensive to manufacture and has cracks in the resins of the first prototypes, and thus still requires optimization. By setting up a specific production facility in which the material can be produced in an efficient way, the material has much potential, especially for specialized project markets (e.g. luxury hotels).
Future market potential after optimization		+ SC: ++	See directly above; a specialized production facility should be set up for the efficient manufacturing of this new material. SC: Furthermore, it could be very interesting to experiment with the resin. By using a softer polyurethane resin, maybe a flexible board/mat could be created. Another additional worthwhile experiment would be to place the slices closer together, by which the resin would only act as a binder.
INNOVATIVE CHARACTER			
Utilization of specific properties of bamboo		+	This material can hardly be produced in another material; the cross cut side of the bamboo gives a visual effect that is hard to match.
Contribution to new image of bamboo		++	Completely new sophisticated look for bamboo.
Level of process innovation (processing and manufacturing technology) - Bamboo		+	A simple twitch through not making circles but ovals of the bamboo stem while adding color through resin application gives a completely different feel to the material.
Overall future market potential of new processing technology (if applicable)		+	The combination of oval slices with resin holds potential for various applications in the interior decoration sector.

Yvonne Laurysen & Eric Mantel (Lama Concept): Flooring/new board material



MARKET POTENTIAL			
Product Quality		**Score**	**Motivation/Suggestions for improvement**
Functionality & use	Weight	+/-	
	Sturdiness (life span)	+	Hard outside part of bamboo used, facilitates a longer life span.
	Reparability	+/-	
	Specific functionality	+	Very decorative product. SC: A point of concern is that dust might easily assemble between the strips.
Aesthetics & intangible properties	Aesthetic quality & trendiness	+ SC: ++	With its rough, weathered look the material fits very well in the vintage trend in the Netherlands.
	Originality; strength of concept	+ SC: ++	New bamboo specific look.
Production Costs			
Transportability		+	Like most semi finished materials, it is flat, facilitating efficient packing and transport.
Manufacturing costs in North/South		+	Same process can be used in the South as for the development of regular bamboo flooring (excluding some steps); It should be technically feasible to solve the coloring in the South as well.
Market Potential (value/price)			
Current market potential		+	If the coloring process can be controlled in Plybamboo factories in South East Asia, this product has much potential for high end markets.
Future market potential after optimization		+	See directly above
INNOVATIVE CHARACTER			
Utilization of specific properties of bamboo		+/-	Coloring rough bamboo strips provides very specific aesthetic results and creates a differentiated look.
Contribution to new image of bamboo		+	
Level of process innovation (processing and manufacturing technology) - Bamboo		+/-	Simple adjustments in the production process (processing rough bamboo strips to remove the outermost layer and adding color) gives a completely different feeling to bamboo.
Overall future market potential of new processing technology (if applicable)		+/- SC: +	This design shows that simply using rough bamboo strips has a lot of potential for use in the interior decoration sector. Furthermore, the results show that experimentation with coloring bamboo can yield interesting results and may give a whole new image to bamboo.

11. Gilian Schrofer (Concern): Exposition system

MARKET POTENTIAL			
Product Quality		**Score**	**Motivation/Suggestions for improvement**
Functionality & use	Weight	+/-	The boards are quite heavy; however, the stems are relatively light.
	Sturdiness (life span)	+	
	Reparability	+	The system consists of various components that can be replaced upon damage.
	Specific functionality	+	SC: The use of bamboo poles and the construction system to hold the boards in the bamboo columns is very well done. The use of the heavy and expensive bamboo boards might not be necessary and could be replaced by cheaper wooden alternatives in the future.
Aesthetics & intangible properties	Aesthetic quality & trendiness	+/- SC: +	
	Originality; strength of concept	+/- SC: +	
Production Costs			
Transportability		+	Can be dismounted.
Manufacturing costs in North/South		+/-	Since the design is not very complicated, it can be well produced in the South. However, finding a shrink sleeve (plastic sheet around electric wiring) in this size to encapsulate the bamboo stem might be difficult in the South. Stem selection and processing is quite labor intensive, which might raise the costs if the product is manufactured in the North. The use of the massive bamboo boards might also raise the manufacturing costs.
Market Potential (value/price)			
Current market potential		-	For this application the product is rather expensive; cheaper and lighter solutions would be possible using wood board materials or a sandwich construction.
Future market potential after optimization		+/-	If a lighter wooden board is used in combination with the bamboo poles, this system could have potential.
INNOVATIVE CHARACTER			
Utilization of specific properties of bamboo		+/-	Use of bamboo pole as a structural and aesthetic element.
Contribution to new image of bamboo		+/-	
Level of process innovation (processing and manufacturing technology) - Bamboo		+/- SC: +	Using the shrink sleeve over the bamboo stem gives a nice, smooth visual effect. SC: Besides the nice visual effect, vulnerability to moisture is also solved and the strength of bamboo remains intact, even after splitting of the stem.
Overall future market potential of new processing technology (if applicable)		+/-	The use of the shrink sleeve to visually enhance and protect the bamboo stem could have potential for replication in the furniture and building industry.

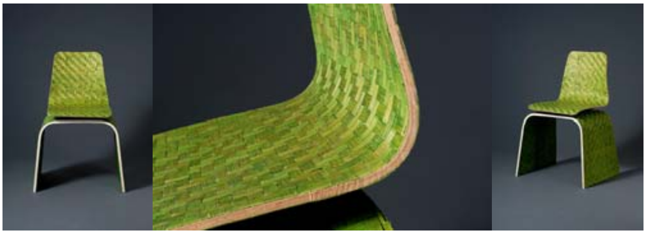
12. Mette Hoekstra (Concern): Mirror

MARKET POTENTIAL			
Product Quality		**Score**	**Motivation/Suggestions for improvement**
Functionality & use	Weight	+/-	
	Sturdiness (life span)	-	Fragile product.
	Reparability	-	
	Specific functionality	+	
Aesthetics & intangible properties	Aesthetic quality & trendiness	-	Baroque style is not trendy anymore.
	Originality; strength of concept	-	The added value of using bamboo in this design is unclear.
Production Costs			
Transportability		+	Flat pack possible.
Manufacturing costs in North/South		+/-	Based on production in the North; Required high quality milling machines are available, but because of the difficult pattern the milling process will be time consuming and thus quite expensive.
Market Potential (value/price)			
Current market potential		-	Rather expensive solution (manufacturing costs in the North estimated at $60-80 per piece in larger batches, otherwise $100/piece); cheaper and lighter solutions are possible in wood.
Future market potential after optimization		-	See directly above.
INNOVATIVE CHARACTER			
Utilization of specific properties of bamboo		+/-	Multi layered character of bamboo board utilized in this design. The taut and sharp detailing is difficult to mimic in wood.
Contribution to new image of bamboo		+/-	
Level of process innovation (processing and manufacturing technology) - Bamboo		+/-	The product shows that bamboo board can be milled in very difficult patterns with taut details when using high quality milling machines.
Overall future market potential of new processing technology (if applicable)		+/-	Milling Plybamboo in complex forms with clear, clean finishing has potential for replication in various other furniture applications.

13. Maarten Baas: Chair

This product cannot be evaluated because no working prototype was developed (the figures are renderings of a product concept developed digitally).

14. Maarten Baptist (Wat Design): Chair



MARKET POTENTIAL			
Product Quality		**Score**	**Motivation/Suggestions for improvement**
Functionality & use	Weight	+/-	
	Sturdiness (life span)	+/-	
	Reparability	+/-	
	Specific functionality	+	The chair sits well; however, the material used is splintery and needs to be better detailed.
Aesthetics & intangible properties	Aesthetic quality & trendiness	+	
	Originality; strength of concept	+/-	
Production Costs			
Transportability		+	Can be dismounted and stacked in two pieces
Manufacturing costs in North/South		+	This product could potentially be mass produced both in the North and in the South. If the quality of the base material (bamboo mats) can be assured, mass production in the North would be preferred since it is questionable if the required molding facilities are available in the South.
Market Potential (value/price)			
Current market potential		+/-	Once a good mold is developed, this product can be mass produced for reasonable costs (estimated at $50/piece). The finishing is still too rough and should be improved.
Future market potential after optimization		+	Once the detailing and finishing of this product is improved, this is a chair with potential for the medium end market.
INNOVATIVE CHARACTER			
Utilization of specific properties of bamboo		+	The product shows that bamboo mats can be bent and molded into 3D forms, while retaining many new visual possibilities based on the pattern of the material (based on weaving techniques).
Contribution to new image of bamboo		- SC: +	
Level of process innovation (processing and manufacturing technology) - Bamboo		+ SC: ++	This design shows that 3D molding with bamboo, which has not often been done before, is very well possible. It would be interesting to investigate to what extent more extreme 3D forms would be possible using this technique.
Overall future market potential of new processing technology (if applicable)		+	By 3D bending bamboo mats a very cheap semi finished material can be used in various high end applications, in which it could potentially be a strong competitor for wooden veneer (e.g. birch), commonly used in bended seats. Furthermore, the various weaving patterns offer many aesthetic possibilities.

15. Patrick Kruithof (The Moment Company): Flooring/new board material

MARKET POTENTIAL			
Product Quality		**Score**	**Motivation/Suggestions for improvement**
Functionality & use	Weight	+/-	
	Sturdiness (life span)	+/-	
	Reparability	+/-	
	Specific functionality	+/-	The same as regular bamboo flooring.
Aesthetics & intangible properties	Aesthetic quality & trendiness	+ SC: ++	SC: Very beautiful; also, the sides have a very high aesthetic quality and invite touching.
	Originality; strength of concept	+/- SC: +	SC: Strong concept.
Production Costs			
Transportability		+	Like most semi finished materials, it is flat, facilitating efficient packing and transport.
Manufacturing costs in North/South		-- SC: -	In this product the strips are placed in the material based on the location they derive from in the stem, meaning that the part of the strip where most nodes are apparent (bottom of the stem) should be located at the same part of the board. Extra strip placement, strip selection, quality control, sawing and gluing process steps make this process difficult to control, and too complex to produce in the South. Due to the complexity of the process and the high labor intensity, the production of the material in the North is very expensive.
Market Potential (value/price)			
Current market potential		--	As it is, the product is far too expensive
Future market potential after optimization		- SC: +/-	If the strip placement according to the original position in the mother stem can be avoided, the design becomes economically more feasible to produce, but will nevertheless remain rather expensive. SC: However, the aesthetic quality is of such a level that high end markets might consider paying premium prices for this design. It is recommended to use this material in applications in which its beautiful details come out, such as in kitchen utensils (e.g. cutting boards).
INNOVATIVE CHARACTER			
Utilization of specific properties of bamboo		+	Such taut edges and inlays are difficult to manufacture in wood.
Contribution to new image of bamboo		+/- SC: +	
Level of process innovation (processing and manufacturing technology) - Bamboo		-	The new patterns in this bamboo material are nice, but not ground breaking.
Overall future market potential of new processing technology (if applicable)		-	The new patterns developed in this new bamboo material are interesting, but make the material quite expensive.

16. Tejo Remy & René Veenhuizen: Chair

MARKET POTENTIAL			
Product Quality		**Score**	**Motivation/Suggestions for improvement**
Functionality & use	Weight Sturdiness (life span) Reparability Specific functionality	+ +/- - + SC: -	Not a lot of material is used. SC: The chair does not sit very well; it is difficult to get in or out of the chair (too much gradient) and there are no usable armrests. The gradient should be decreased and the corners of the boards should be rounded in order to develop more sitting comfort for the user.
Aesthetics & intangible properties	Aesthetic quality & trendiness Originality; strength of concept	++ SC: + +	
Production Costs			
Transportability		+/-	The design takes up too much space as it is. However, if the various curved planks fit into each other and can be assembled later, transportability can be improved.
Manufacturing costs in North/South		+	The product can potentially be manufactured both in the North and in the South. The boards can be bent with steam techniques, for which facilities in the North are better. If the boards are bent without steam techniques, the labor intensive process could be better executed in the South.
Market Potential (value/price)			
Current market potential		+ SC: +/-	Nice trendy lounge chair, which should not be too expensive in manufacturing costs (estimation of $70/piece FOB in South East Asia). SC: However, the chair needs to be optimized, because it does not sit well.
Future market potential after optimization		++ SC: +	If the ergonomics can be optimized and production can be made more efficient (transport, industrial production) the market potential of this product is high in medium to high end markets.
INNOVATIVE CHARACTER			
Utilization of specific properties of bamboo		++	Few materials can bend as easily as bamboo, which is utilized to its fullest in this design.
Contribution to new image of bamboo		++ SC: +	Trendy sophisticated look
Level of process innovation (processing and manufacturing technology) - Bamboo		+	The techniques implemented show bamboo can bend very well, which can serve as a competitive advantage as compared to wood.
Overall future market potential of new processing technology (if applicable)		+	Bending bamboo yields many interesting new possibilities for furniture design, which cannot be easily copied in other natural materials.

17. Nathalie Meijer (Leolux): Dinner table

MARKET POTENTIAL			
Product Quality		**Score**	**Motivation/Suggestions for improvement**
Functionality & use	Weight	+/-	
	Sturdiness (life span)	+/-	
	Reparability	+/-	
	Specific functionality	+	Good look. Furthermore, the table is easily expandable.
Aesthetics & intangible properties	Aesthetic quality & trendiness	+ SC: ++	SC: Magnificent design
	Originality; strength of concept	+/- SC: +	
Production Costs			
Transportability		+	Flat pack should be possible.
Manufacturing costs in North/South		+/-	Due to the extra sawing and gluing process steps to produce the tabletop, the table is too complex for production in the South. Because of the labor intensive process the production in the North is quite expensive.
Market Potential (value/price)			
Current market potential		+/- SC: +	Quite expensive (manufacturing costs in Europe estimated at $500), but nice aesthetics and expandability make the table still a contender in high end markets.
Future market potential after optimization		+/- SC: +	
INNOVATIVE CHARACTER			
Utilization of specific properties of bamboo		+	Such taut edges and inlays are difficult to reproduce in wood.
Contribution to new image of bamboo		+/- SC: +	
Level of process innovation (processing and manufacturing technology) - Bamboo		-	
Overall future market potential of new processing technology (if applicable)		-	The new patterns developed in this new bamboo material are interesting, but make the material quite expensive.

18. Thijs Bakker: Chair

MARKET POTENTIAL			
Product Quality		**Score**	**Motivation/Suggestions for improvement**
Functionality & use	Weight	-	The chair is quite heavy.
	Sturdiness (life span)	++	
	Reparability	--	
	Specific functionality	+ SC: -	Sits quite well because of the good gradient. Furthermore, the chair has a handy, small table at the back of the chair (e.g. for in schools). SC: However, the chair is over dimensioned and the seat is too long.
Aesthetics & intangible properties	Aesthetic quality & trendiness	+	
	Originality; strength of concept	+/-	
Production Costs			
Transportability		--	Cannot be dismounted and is quite big
Manufacturing costs in North/South		-	Because the product consists of many pieces that need to fit exactly together, it is difficult to control quality when the product is manufactured in the South. Since it is very labor intensive to connect boards (rectangular) and stems (natural irregular forms), manufacturing costs in the North will also be high.
Market Potential (value/price)			
Current market potential		+/-	Chair with potential for project markets or for children. Labor intensive connections make chair still too expensive.
Future market potential after optimization		+/-	
INNOVATIVE CHARACTER			
Utilization of specific properties of bamboo		+/-	The product uses the aesthetic qualities of bamboo by combining the stem and Plybamboo.
Contribution to new image of bamboo		+/-	
Level of process innovation (processing and manufacturing technology) - Bamboo		+/-	The development of custom-made connections in which the bamboo stem and board come together is quite innovative. SC: It is too bad the connections of the round stems do not really function like a hinge; now the stems only have an aesthetic function.
Overall future market potential of new processing technology (if applicable)		+/-	The combination of the bamboo stem and board could have potential for other furniture applications as well.

Appendix I: Environmental Assessment of Bamboo Materials

In this appendix the complete data processing for the environmental impact assessment of one bamboo material (3-layer bleached Plybamboo board) is presented (for conclusions see chapter 5). For various other bamboo materials (1-layer Plybamboo board and -veneer, bamboo stem, and Strand Woven Bamboo) the environmental effect of all activities in the production chain was (partly) based on the calculation for 3-layer bleached Plybamboo board, and therefore presented in a more compressed manner.

General Points of Departure for Calculation

Production site: Plantation and first processing in the Anji region, final processing in Huangzhou, both in the province of Zhejiang, China.
Consumption site: Warehouse of Moso International b.v. in Zwaag, the Netherlands
Time period of data collection: July 2007
Resource: *Phyllostachys Pubescens* (Moso)

- Density: 700 kg/m3 (dry state)
- Length: up to 15 m
- Diameter: 10-12 cm on the ground, tapering to the top
- Thickness: 9 mm at bottom of stem, tapering to the top

Data suppliers:
[1] DMVP and Dasso (Plybamboo board and veneer producers in Huangzhou, China), Mr Xia
[2] Moso International (bamboo board importer), Mr René Zaal (director)
[3] Pablo van der Lugt, based on visits to various bamboo factories in the Anji region, China, March 2006
[4] Huangzhou Dazhuang Floor Co., Ms Isabel Chen

Further data was derived from a previous study executed by the author based on the TWIN 2002 model:
[5] van der Lugt, P., van den Dobbelsteen, A. and Abrahams, R. 2003. Bamboo as a building material alternative for Western Europe? A study of the environmental performance, costs and bottlenecks of the use of bamboo (products) in Western Europe. *Journal of Bamboo and Rattan* 2(3): 205-223.

Since all bamboo materials evaluated during this environmental impact assessment are derived from China, it is important to understand that the Chinese bamboo industry is very efficiently organized; almost every part of the resource (bamboo stem) is used for a certain product. The central dimension for most industrial bamboo materials is 2.66 meters, based on which the complete Chinese industrial bamboo industry is synchronized. Usually about 8 meters (3 x 2.66 m) of a harvested Moso stem will be used for the development of bamboo products. The bottom two parts of 2.66 meters are mostly used as input for the manufacturing of industrial bamboo materials such as Plybamboo boards, while the upper part may be used for smaller bamboo products such as blinds and chopsticks [2, 3]. For the Plybamboo industry the bottom segments of the stem will first be processed into rough strips

(approximately 2630 × 23 × 8 mm) and then in fine planed strips (2500 × 20 × 5 mm) that end up in the final product [1]. According to [1, 2], per stem part (2.66m), 12 rough strips can be made from the bottom part of the stem. Due to the smaller diameter only 8 rough strips can be derived from the second segment of the stem, making an average of 10 strips per stem part for the lower two parts of the stem (bottom and middle segment).
The dimension of 2.66 meters was chosen because it provides tolerance for failure for the production of Plybamboo boards, which is usually based on the international standard of 1.22 × 2.44 m. For this reason the Functional Units (FUs) chosen for the environmental impact assessment of the various bamboo materials in this research were based on these dimensions as well. Please note that the FU mentioned in this appendix is only used to establish the eco-costs/kg of the various bamboo materials based on a standard element. In section 5.1 other FUs are established to assess the eco-costs of bamboo compared to wood in various relevant applications.

3-layer Plybamboo board (bleached)

General Data
Product: bleached 3-layer Plybamboo (consisting of two layers of 5 mm plain pressed Plybamboo at the outsides, and one layer of 10 mm side pressed Plybamboo in the core).
The FU used as the base element for this assessment is one board of 2440 × 1220 × 20 mm (2.98 m2), with a weight of 41.7 kilograms (based on a density of 700 kg/m3), in which 244 fine planed strips (2500 × 20 × 5 mm) are used [1].

Full Production Process (Cradle till Site)
1. Harvesting of bamboo on sustainably managed plantations
2. Transport from plantation to strip manufacturing facility
3. Strip making
4. Transport from strip manufacturing facility to factory
5. Rough planing
6. Strip selection
7. Preservation & coloring: bleaching
8. Drying
9. Fine planing
10. Strip selection
11. Glue application
12. Pressing strips to 1-layer board
13. Sanding 1-layer board

14. Glue application
15. Pressing three layers to one board
16. Sawing
17. Sanding 3-layer board
18. Dust absorption (during all steps)
19. Transport from factory to harbor
20. Transport from harbor to harbor
21. Transport from harbor to warehouse

To calculate energy consumption back to the FU it is important to understand how many strips are necessary to produce one board. In the final board 244 strips are used. Due to energy consumption allocation the strips that do not end up in the final product also need to be taken into account for the calculation. According to [1], during the production process there are two selection rounds (after rough planing and fine planing) where strips that do not meet quality standards are discarded (and used as bio fuel). In each round 6% of the strips are discarded. This means that at the beginning of the production process 12% more strips than the 244 strips in the final product were processed, which results in 277 strips. As was explained above, per stem part of 2.66 m, 10 rough strips can be derived, meaning that 277/10 = 27.7 stem pieces of 2.66 m are required per FU.

Determination of Input Data per Process Step

1. Harvesting of bamboo on sustainably managed plantations

In the calculation it is assumed that no fertilizers and pesticides were used on the plantations from which the stems were extracted. Harvesting figures are based on [5], in which is estimated that 234 stems can be harvested with chain saws on one gallon (3.785 liters) of gasoline, which comes down to 0.016 liters of gasoline per stem. Since for one FU 27.7 stem segments of 2.66 m are required, 27.7/2 = 13.85 stems are required per FU (taking into account that per 8 m stem only the bottom two parts of the stem can be used for Plybamboo board production). This means that per FU: 13.85 × 0.016 = 0.224 liters of gasoline is consumed.

Input in LCA: Cultivation of bamboo on a sustainably managed plantation

Gasoline consumption	**0.224 liters/FU**

2. Transport from plantation to strip manufacturing facility


It is important to understand that in the Eco-costs method the environmental burden of transport is based on the kind of transport vehicle (boat, 5-ton truck, 24-ton truck, etc.), the efficiency of packing (how many FUs can be transported per transport load), and the number of kilometers of the journey (usually based on a 50% payload, i.e. empty return of the containers). The weight of the load itself is integrated in the earlier mentioned parameters, based on average transport loads.[61]

According to [1] an average of around 320 stems with a length of 8 meters are transported per truck load with a 5-ton truck over a distance of 15 kilometers [2], which results in 320 stems/13.85 stems per FU (see step 1) = 23.1 FUs being transported per truckload. For small trucks the eco-costs are usually calculated based on the eco-costs per km of a certain vehicle, based on an empty truckload for the return (thus calculating with 2 x 15 = 30 km).

Input in LCA: Transport plantation to strip manufacturing facility

Distance	30 km
Kind of transport	5-ton truck
Amount of FU per load	23.1 boards (FU)

3. Strip making



According to [1], 9000 strips can be produced in 8 hours with the strip making machine (5.5 kW), which corresponds to 1125 strips per hour, which corresponds to 1125 strips/277 strips per FU = 4.06 FU (boards)/hour. It takes 1/ 4.06 = 0.25 hour to produce one FU. Energy consumption per FU is then 0.25 hour x 5.5 kW = 1.38 kWh/FU

[61] Only for very low weight loads (under 400 kg/m3) the volume should be integrated in the eco-costs (Vogtländer 2008), which was done for sea transport of bamboo stems (see later in this appendix).

Input in LCA: Strip making

Energy consumption/FU	1.38 kWh/FU

4. Transport from strip manufacturing facility to factory

According to [1, 2] 8 tons of strips are transported per truckload (10-ton truck) from the strip processing facility to the factory in Huangzhou, over 300 kilometers.[62] One rough strip weighs approximately: 2.6 × 0.023 × 0.009 m = 0.00054m3 × 700 kg/m3 = 0.38 kg per strip. Per truckload 8000/0.38 = 21052 strips of 2.6 m long are transported, resulting in 21052 strips/277 strips per FU = 77.6 FUs per truckload. For small trucks the eco-costs are usually calculated based on the eco-costs per km of a certain vehicle, based on an empty truckload for the return (thus calculating with 2 × 300 = 600 km).

Input in LCA: Transport from strip manufacturing facility to factory

Distance	600 km
Kind of transport	10-ton truck
Amount of FU per load	77.6 boards (FU)

5. Rough planing


According to [1], 4500 strips can be produced in 8 hours with the rough planer (15-20kW), which corresponds to 562 strips per hour, which corresponds to 562 strips/277 strips per FU = 2.03 FUs (boards)/hour. It takes 1/2.03 = 0.49 hour to produce one FU. Energy consumption per FU is then 0.49 hour × 17.5 kW = 8.62 kWh/FU.

Input in LCA: Rough Planing

Energy consumption/FU	8.62 kWh/FU

6. Strip selection

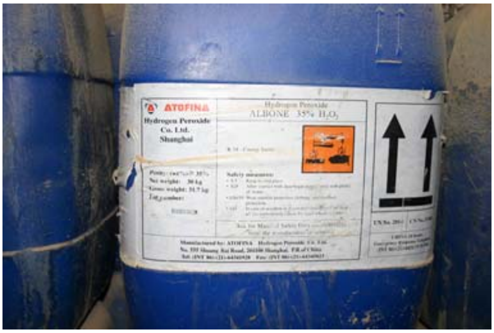
According to [1], after quality control, 6% of the strips will be discarded and burnt in the oven.
This means that after this process step 277 - 6% = 260 strips are needed for the final product, which consists of 244 strips (another 6% will be lost in the second strip selection after fine planing in step 9

[62] Note that this is a very factory dependent calculation; some bamboo factories located near the harbor of Ningbo, China have bamboo plantations next to the factory.

below). Because of energy consumption allocation also the strips that do not end up in the final product need to be taken into account.

7. Preservation & coloring: bleaching

Preservation and coloring take place at the same time and can be performed by either bleaching or carbonizing the strips. In this case the bleaching process is analyzed (the carbonizing process is analyzed later in this appendix).



Addition of chemical substances

According to [1], the bamboo strips are bleached by "cooking" them for 4 hours in a boiling pool in a H_2O_2 solution at 70-80 degrees Celsius. After the first round additional H_2O_2 will be added for the second round of strips to be bleached. After this round, the solution cannot be used again and is settled through chemical treatment.

For $H_2O_2$2 consumption per FU the following calculation can be made, based on the figures provided by [1]. Per 8 hours 3000 strips are bleached (two rounds of 4 hours). This corresponds to 3000/260 = 11.53 FUs. Per day (8 hours), 120 kg H_2O_2 solution (27% concentration) is used (80 kg for the first round, 40 kg added for the second round), which corresponds to 0.27 × 120 kg = 32.4 kg H_2O_2. Per FU H_2O_2 consumption is then 32.4/11.53 = 2.81 kg H_2O_2.

Input in LCA: H_2O_2 addition for bleaching

Added H_2O_2 per FU	**2.81 kg H_2O_2/FU**

Energy consumption

The boiling pool is heated through the use of a 2-ton boiler. Strips required for the production of 11.53 FUs are bleached each day (8 hours). This corresponds to 11.53/8 = 1.44 FU per hour, which corresponds to 1/ 1.44 = 0.69 hour per FU, and therefore an energy consumption of 2.3 kW (boiler, see box below) x 0.69 = 1.59 kWh/FU.

Box: Energy Consumption by the 2-ton Boiler (22kW)

The steam produced by the boiler is used for various machines in the factory (drying chamber, hot presses, boiling pool, carbonization, etc.). Sometimes all heat from the boiler goes to various machines, sometimes only to one. However, in this calculation it is assumed that all machines connected to the boiler are running at the same time. It is difficult to estimate how much energy from the boiler each machine uses; however, the temperature required for each process step is expected to be an important indicator. According to [1] the drying chamber requires steam (evaporated water) at a temperature of 50-60 degrees Celsius, the boiling pool at 70-80 degrees Celsius, while the carbonization kettle will require 120-130 degrees Celsius. The temperature of the water required by the press is unknown but will probably be in the same line as the carbonization kettle, since it is based on steam. If the energy consumption of each machine sourced by the boiler (drying chamber, hot press, boiling pool, carbonization kettle) is based on the temperatures used, then the energy distribution is as follows: drying chamber : boiling pool : hot presses : carbonization = 1 : 1.4 : 2.4 : 2.4. According to [1] there are two boiling pools, two carbonization kettles and two one-layer hot presses in the factory. All these machines are attached to the boiler so the number of machines also has to be taken into account for the energy distribution:
Drying chamber : boiling pool : hot presses : carbonization = 1 : 2.8 (1.4 x 2) : 4.8 (2.4 x 2) : 4.8 (2.4 x 2).

Based on these ratios the division of the capacity of the boiler (22 kW) can be divided over the various machines:
Drying chamber: 22 x 1/13.4 (= 1 + 2.4 + 4.8 + 4.8) = 1.64 kW.
Boiling pools: 22 x 2.8/13.4 = 4.59 kW for two pools, and 2.3 kW for one pool.
Hot presses: 22 x 4.8/13.4 = 7.88 kW for two presses, and 3.94 kW for one press.
Carbonization kettles: 22 x 4.8/13.4 = 7.88 kW for two kettles, and 3.94 kW for one kettle.

Besides electricity, the boiler consumes 400 kg sawdust per hour [1], which is sourced from waste produced in the other process steps.

Input in LCA: Energy consumption for bleaching

Energy consumption/FU	**1.59 kWh/FU**

8. Drying

After bleaching, the strips are dried in a drying chamber. Besides the energy consumption of the drying chamber itself (15kW), steam is used in the drying chamber produced by the boiler (1.64 kW, see box before). According to [1], the drying room is able to dry 30000 strips at once. The drying times for bleached strips are different from those for carbonized strips. Bleached strips require a 72-hour drying cycle. This means that 30.000/260 = 115.4 FUs can be dried in one cycle, corresponding to 115.4/72 = 1.60 FU/hour, which corresponds to 1/1.6 = 0.625 hour/FU. Energy consumption per FU is then 15 (drying chamber) + 1.64 (boiler) = 16.64 Kwh x 0.625 = 10.4 kWh/FU

Input in LCA: Drying bleached strips

Energy consumption/FU	**10.4 kWh/FU**

9. Fine planing

According to [1], 38-40 meters of strips can be processed per minute by the fine planer (20 kW). The strips are 2.63 meters long, which corresponds to 15 strips per minute, which corresponds to 900 strips per hour, which corresponds to 900 strips/260 strips per FU = 3.46 FUs (boards)/hour. It takes 1/3.46 = 0.29 hour to produce one FU. Energy consumption per FU is then 0.29 hour x 20 kW = 5.8 kWh/FU.

Input in LCA: Fine planing

Energy consumption/FU	**5.8 kWh/FU**

10. Strip selection

According to [1], after selection, 6% of the strips will be discarded and burnt in the oven.
This means that after this process step 260 - 6% = 244 strips will end up in the final product.

11. Glue application (1-layer boards)

According to [1], glue consumption for making 1-layer plain pressed bamboo boards of 5 mm thick is 50 grams urea formaldehyde[63] per m2 in wet conditions. The kind of Urea formaldehyde glue used

[63] Note that depending on the final application in which the Plybamboo board is used, different kinds of glue may be used, e.g. because of required moisture resistance. For the furniture board industry usually urea formaldehyde is used, but for example for 2-layer bamboo parquet, formaldehyde free glues are used while for veneer formaldehyde-, melamine-, and poly urethane glues are used [2], each with different eco-costs/kg.

complies with the European E1 norm [2]. Since for each 3-layer bamboo board, two 1-layer plain pressed boards are used, this figure needs to be doubled to 100 grams per m2.
For the development of a 1-layer side pressed 10 mm thick board, eventually used in the middle of the 3-layer board, 4 x 50 = 200 grams glue/m2 is consumed, since the thickness of the strips (and therefore the glue surface) measures 10 mm per strip instead of 5 mm, while there are twice as many strips used. The total glue consumption (in wet conditions) for making the three separate boards is then 300 g/m2, which corresponds to 300 x 2.98 m2= 894 grams per FU (board) in wet conditions.

Input in LCA: Glue application (1-layer boards)

Type of glue	Urea formaldehyde complying with E1 norm
Weight/amount of glue	894 grams per FU (wet state)

12. Pressing strips to 1-layer board

After glue application the strips are processed into 1-layer boards using hot presses. Besides the energy consumption of the press (5.5kW), steam from the boiler is required. Energy consumption of the boiler that can be allocated to the hot presses is 3.94 kW per machine (see box above).
According to [1], 350 m2 board can be processed per day (8 hours), corresponding to 43.75 m2 per hour. Each FU consists of three layers (two 1-layer plain pressed boards of 5 mm thickness and one 1-layer side pressed board of 10 mm thickness; for this calculation it is assumed that their processing time at the press is the same), which means that in the final product three 1-layer boards are required. This means 43.75/3 = 14.58 m2 of 3-layer board can be produced per hour based on the various 1-layer boards. This corresponds to 14.58/2.98 (m2 per board) = 4.89 FU/hour, which corresponds to 0.20 hour/FU. Energy consumption per FU is then 0.20 hour x (5.5 + 3.94)kW = 1.89 kWh/FU.

Input in LCA: Pressing strips to 1-layer board

Energy consumption/FU	1.89 kWh/FU

13. Sanding 1-layer board
According to [1], 400 m2 1-layer board can be processed per hour with the sanding machine (55-90 kW). Each FU consists of three layers, meaning that in the final board three 1-layer boards are required. This means 400/3 = 133.33 m2 of 3-layer board can be processed per hour. This corresponds to 133.33/2.98 (m2 per board) = 44.7 FU/hour, which corresponds to 1/44.7 = 0.022 hour/FU. Energy

consumption per FU for the sanding machine is then 0.022 x 72.5 (average of 55-90 kW) = 1.62 kWh/FU.

Input in LCA: Sanding 1-layer board

Energy consumption/FU	**1.62 kWh/FU**

14. Glue application (3-layer board)

According to [1], gluing the boards together requires an additional 150-180 grams of glue per m2 (average: 165 g/m2). Since two planes need to be glued, 2 x 165 = 330 g/m2 is required, which corresponds to 330g x 2.98 m2 = 983 grams per FU (board) in wet conditions.

Input in LCA: Glue application (3-layer board)

Type of glue	**Urea formaldehyde complying with E1 norm**
Weight/amount of glue	**983 grams per FU (wet state)**

15. Pressing three layers to one board

After glue application to the 1-layer boards, the boards will be processed into 3-layer boards using multi layer cold presses (5.5kW). According to [1], around 80 m2 3-layer board can be processed per day (8 hours), corresponding to 10 m2/hour. This corresponds to 10/2.98 (m2 per board) = 3.35 FU/hour, which corresponds to 0.30 hour/FU. Energy consumption per FU for the press is then 5.5 x 0.3 = 1.65 kWh/FU.

Input in LCA: Pressing three layers to one board

Energy consumption/FU	**1.65 kWh/FU**

16. Sawing

In order to acquire boards of exact dimensions, the borders of the boards need to be sawn. According to [1] the sawing machine (5.5 kW) used can process 450m2 of boards per day (8 hours), which corresponds to 450/8 = 56.25 m2/hour, which corresponds to 56.25/2.98 = 18.8 FUs/hour, which corresponds to 0.053 hour per FU. The energy consumption for sawing per FU is then 0.053 x 5.5 = 0.29 kWh/FU.

Input in LCA: Sawing

Energy consumption/FU	**0.29 kWh/FU**

17. Sanding 3-layer board

According to [1], 250 m2 3-layer board can be processed per hour with the sanding machine (55-90 kW), which corresponds to 250/2.98 (m2 per board) = 83.9 FU/hour, which corresponds to 1/83.9 = 0.012 hour/FU. Energy consumption per FU for the sanding machine is then 0.012 x 72.5 = 0.86 kWh

Input in LCA: Sanding 3-layer board

Energy consumption/FU	**0.86 kWh/FU**

18. Dust absorption (during all steps)

According to [1], there is a dust absorption system active in the board-producing factory (see box).
As explained in the box, the allocation of energy consumption per FU to the dust absorption system depends on the maximum number of FUs/hour that can be produced in the complete factory. The maximum output of the whole factory is determined by the critical process step (rough planing; see box). The maximum output of the rough planing activity (based on the use of three planers in the factory) is 2 x 3 = 6 FUs/hour, which means it takes 1/6 = 0.17 hour to produce one FU. The energy consumption per FU that can be allocated to dust absorption is then 0.17 x 51 kW (average of 22 - 80 kW) = 8.67 kWh/FU.

Box: Energy Production and Consumption by the Dust Absorption System (22-80 kW)

Since the dust absorption system applies to the complete factory, and is running all the time, it is very difficult to allocate its energy consumption to a specific machine or number of FUs produced. Since most machines are running at the same time, parallel processing strips and producing boards, at the end of the production chain there is a consistent output of boards. This output is dependent on the number of FUs (in the form of processed strips) that can be processed in every process step. The step that has the lowest FU/hour output determines the critical path (and thus energy consumption with respect to dust absorption) of the complete production system. To make things even more complex, many factories in China specialize in one specific production step (e.g. production rough strips, carbonization, etc.), so board producers usually outsource their critical production steps. With a production of 77 FUs every three days for bleached 3-layer board or even 77 FUs per ten days for carbonized 3-layer board (see later in this appendix), drying would be the critical production step. However, time consuming steps such as boiling, carbonizing and drying do not produce dust and are usually located in a different part of the factory [3]. The dust absorption system is used in the places where most dust is produced: near the planing-, sawing- and sanding machines. Of these machines, the rough planers usually have the lowest output (2 FUs/hour). To solve this problem usually more planers are used at the same time in many factories (3-4 planers; see photos of production step "rough planing" above). Still, since the presses and sanders have a higher capacity and are usually also available in multiple machines, the planers usually remain the critical factor.

Therefore, for this calculation it was assumed that the planers are the critical factor with an output of three planers of 3 x 2 = 6 FUs/hour. This means that if all machines run parallel to each other (which they do), then the planers determine the maximum output of FUs per hour for the factory as a whole. The consumption of the dust absorption system is therefore based on this figure.

Input in LCA: dust absorption system

Energy consumption/FU	**8.67 kWh/FU**

19. Transport from factory to harbor

After sanding, the boards are packed in containers ready for transport. This assessment was calculated with a 20-foot container which has standard internal dimensions of 5.90 x 2.35 x 2.39 meters (33.2m3) and a maximum load of around 30 tons (including weight of the container of 2.3 tons), which was transported by a 28-ton truck, over a distance of 300 km (factory in Huangzhou to Shanghai harbor). For larger trucks and for sea transport the eco-costs are usually calculated based on the eco-costs per ton.km of a certain vehicle (empty return figures taken into account in the one-way distance). The amount of ton.km per FU is 41.7 kg x 300 km = 12.51 ton.km/FU. Based on the eco-costs/ton.km of a 28-ton truck the eco-costs per FU can then be calculated.

Input in LCA: Transport from factory to harbor

Distance	**300 km**
Kind of transport	**28-ton truck**
Ton km per FU	**12.51 ton.km/FU**

20. Transport from harbor to harbor

Calculations for the environmental burden for sea transport are based on transport with a trans-oceanic freight ship in a 20-foot container, with a travel distance from Shanghai to Rotterdam of 19208 kilometers. As found above, for sea transport the eco-costs are usually calculated based on the eco-costs per ton.km of the boat used (empty return figures taken into account in the one-way distance). The amount of ton.km per FU is 0.0417 tons x 19208 km = 801 ton.km/FU. Based on the eco-costs/ton.km of a 20-foot container transported by a trans-oceanic freight ship, the eco-costs per FU can then be calculated.

Input in LCA: Transport from harbor to harbor

Distance	**19208 km**
Kind of transport	**Trans-oceanic freight ship (20-foot container)**
Ton km per FU	**801 ton.km/FU**

21. Transport from harbor to warehouse (the Netherlands)

The distance from the harbor in Rotterdam to the warehouse in Zwaag is 115 km. For the calculation it was assumed that one 20ft container is transported by a 28-ton truck. The amount of ton.km per FU is 0.0417 tons x 115 km = 12.51 ton.km/FU. Based on the eco-costs/ton.km of a 28-ton truck the eco-costs per FU can then be calculated.

Input in LCA: Transport from harbor to warehouse (the Netherlands)

Distance	**115 km**
Kind of transport	**28-ton truck**
Ton km per FU	**4.80 ton.km/FU**

<u>Results</u>

All the input data of the various production- and transport activities found above, including the corresponding eco-costs, and the resulting overall eco-costs is summarized in table I1 below. The eco-costs were added by Dr. Joost Vogtländer based on the Eco-costs 2007 database available through the website www.ecocostsvalue.com (Vogtländer 2008).

Table I1: Input data and results for the environmental impact assessment of bleached 3-layer Plybamboo board

Process step	Amount	Unit	Eco-costs (€)/unit	Eco-costs (€)/FU	Eco-costs (€)/kg	%
1. Cultivation and harvesting from plantation Gasoline consumption	0.224	liter/FU	0.83/liter	0.186	0.0045	1.1%
2. Transport from plantation to strip manufacturing facility; Eco-costs of a 5-ton truck (transport of 23.1 FUs)	30	Km	0.243/km per 5t truck	0.316	0.0076	1.9%
3. Strip making: Energy consumption	1.38	kWh/ FU	0.083/kWh	0.115	0.0027	0.7%
4. Transport from strip manufacturing facility to factory; Eco-costs of a 10-ton truck (transport of 77.6 FUs).	600	Km	0.32/km per 10t truck	2.474	0.0593	15.1%
5. Rough planing: Energy consumption	8.62	kWh/ FU	0.083/kWh	0.715	0.0172	4.4%
6. Strip selection						
7. Bleaching: Energy consumption	1.59	kWh/ FU	0.083/kWh	0.132	0.0032	0.8%
7. Bleaching: Added amount of H_2O_2	2.81	Kg H_2O_2/FU	1.33/kg H_2O_2	3.737	0.0896	22.8%
8. Drying: Energy consumption	10.4	kWh/FU	0.083/kWh	0.863	0.0207	5.3%
9. Fine planing: Energy consumption	5.8	kWh/FU	0.083/kWh	0.481	0.0115	2.9%
10. Strip selection						
11. Glue application (1-layer boards) Added amount of Urea formaldehyde (wet)	0.894	Kg /FU	0.746/kg	0.667	0.0160	4.1%
12. Pressing strips to 1-layer board: Energy	1.89	kWh/FU	0.083/kWh	0.157	0.0038	1.0%
13. Sanding 1-layer board: Energy	1.62	kWh/FU	0.083/kWh	0.134	0.0032	0.8%
14. Glue application (3-layer board) Added amount of Urea formaldehyde (wet)	0.983	kg/FU	0.746/kg	0.733	0.0176	4.5%
15. Pressing three layers to one board: Energy	1.65	kWh/FU	0.083/kWh	0.137	0.0033	0.8%
16. Sawing: Energy consumption	0.29	kWh/FU	0.083/kWh	0.024	0.0006	0.1%
17. Sanding 3-layer board: Energy	0.86	kWh/FU	0.083/kWh	0.071	0.0017	0.4%
18. Dust absorption (during all steps) Energy consumption	8.67	kWh/FU	0.083/kWh	0.720	0.0173	4.4%
19. Transport from factory to harbor Eco-costs (28-ton truck)	12.51	ton.km/FU	0.033/ton.km	0.413	0.0099	2.5%
20. Transport from harbor to harbor Eco-costs (20ft container in a trans-oceanic freight ship)	801	ton.km/FU	0.0052/ton.km	4.165	0.0999	25.4%
21. Transport from harbor to warehouse Eco-costs (28-ton truck)	4.80	ton.km/FU	0.033/ton.km	0.158	0.0038	1.0%
Total eco-costs (€)				**17.91**	**0.393**	**100.0%**

Carbonized Plybamboo Board (3-layer)

The input data as described above for the bleached 3-layer board applies in total to the carbonized version except for activity 7 (preservation & coloring) and activity 8 (drying), which are adjusted below.

7. Preservation & coloring: carbonization

Instead of bleaching, the bamboo strips alternatively can be carbonized for preservation and coloring. This is done by melting the sugars in the bamboo strips under high pressure (0.21-0.25 mPa) and temperature (120-130 degrees Celsius) with the use of steam [1]. As a result of the carbonization process the bamboo strip will be preserved and acquires a darker, caramelized color.

According to [1], the bamboo strips will go through two rounds of carbonization, which take 150-170 minutes for each round (depending on the level of darkness required for the board). In the first round 4000 strips can be processed per day (8 hours), and in the second round 6000 strips per day.
For the first round 4000/8 strips = 500 strips can be processed per hour, corresponding to 500/260 = 1.92 FU/hour, which corresponds to 1/1.92 = 0.52 hour per FU.
For the energy consumption of the carbonization kettle for the first carbonization round this implies the following. According to [1], the carbonization kettle is powered by a carbonizing boiler (1.5kW) as well as the 2-ton boiler (3.94 kW allocated to one carbonization kettle; see box "energy consumption by the 2-ton boiler" above). The energy consumption per FU is then: (1.5 + 3.94) x 0.52 = 2.83 kWh/FU.
For the second carbonization round, the same calculation can be made, but for 6000 strips instead of 4000 strips. The energy consumption per FU is then: (1.5 + 3.94) x 0.35 = 1.9 kWh/FU.
Total energy consumption during carbonization is then 2.83 + 1.9 = 4.73 kWh/FU.

Input in LCA: Carbonization

Energy consumption/FU	**4.73 kWh/FU**

8. Drying
After carbonizing, the strips are dried in a drying chamber. Besides the energy consumption of the drying chamber itself (15kW), steam is used in the drying chamber derived from the boiler (1.64 kW, see box before). According to [1], the drying room is able to dry 30000 strips at once. The drying times for carbonized strips are different from those for bleached strips. Carbonized strips require a 168-hour drying cycle after the first carbonization round and a 72-hour drying cycle after the second carbonization round (in total 240 hours). This means that 30.000/260 = 115.4 FUs can be dried in 240 hours, corresponding to 115.4/240 = 0.48 FU/hour, which corresponds to 1/0.48 = 2.08 hour per FU. Energy consumption per FU is then 15 + 1.64 = 16.64 Kwh x 2.08 = 34.6 kWh/FU.

Input in LCA: Drying carbonized strips

Energy consumption/FU	**34.6 kWh/FU**

Results
All the input data of the various production- and transport activities found above, including the corresponding eco-costs and the resulting overall eco-costs for the production of one carbonized 3-layer Plybamboo board is summarized in table 12 below. The eco-costs were added by Dr. Joost Vogtländer based on the Eco-costs 2007 database available through the website www.ecocostsvalue.com (Vogtländer 2008).

Table 12: Input data and results for the environmental impact assessment of carbonized 3-layer Plybamboo board

Process step	Amount	Unit	Eco-costs (€)/unit	Eco-costs (€)/FU	Eco-costs (€)/kg	%
1. Cultivation and harvesting from plantation Gasoline consumption	0.224	liter/FU	0.83/liter	0.186	0.0045	1.2%
2. Transport from plantation to strip manufacturing facility; Eco-costs of a 5-ton truck (transport of 23.1 FUs)	30	Km	0.243/km per 5t truck	0.316	0.0076	2.1%
3. Strip making: Energy consumption	1.38	kWh/ FU	0.083/kWh	0.115	0.0027	0.8%
4. Transport from strip manufacturing facility to factory; Eco-costs of a 10-ton truck (transport of 77.6 FUs).	600	Km	0.32/km per 10t truck	2.474	0.0593	16.6%
5. Rough planing: Energy consumption	8.62	kWh/ FU	0.083/kWh	0.715	0.0172	4.8%
6. Strip selection						
7. Carbonization: Energy consumption	4.73	kWh/FU	0.083/kWh	0.393	0.0094	2.6%
8. Drying: Energy consumption	34.6	kWh/FU	0.083/kWh	2.872	0.0689	19.2%
9. Fine planing: Energy consumption	5.8	kWh/FU	0.083/kWh	0.481	0.0115	2.9%
10. Strip selection						
11. Glue application (1-layer boards) Added amount of Urea formaldehyde (wet)	0.894	Kg /FU	0.746/kg	0.667	0.0160	4.5%
12. Pressing strips to 1-layer board: Energy	1.89	kWh/FU	0.083/kWh	0.157	0.0038	1.1%
13. Sanding 1-layer board: Energy	1.62	kWh/FU	0.083/kWh	0.134	0.0032	0.9%
14. Glue application (3-layer board) Added amount of Urea formaldehyde (wet)	0.983	kg/FU	0.746/kg	0.733	0.0176	4.9%
15. Pressing three layers to one board: Energy	1.65	kWh/FU	0.083/kWh	0.137	0.0033	0.9%
16. Sawing: Energy consumption	0.29	kWh/FU	0.083/kWh	0.024	0.0006	0.2%
17. Sanding 3-layer board: Energy	0.86	kWh/FU	0.083/kWh	0.071	0.0017	0.5%
18. Dust absorption (during all steps) Energy consumption	8.67	kWh/FU	0.083/kWh	0.720	0.0173	4.8%
19. Transport from factory to harbor Eco-costs (28-ton truck)	12.51	ton.km/FU	0.033/ton.km	0.413	0.0099	2.8%
20. Transport from harbor to harbor Eco-costs (20ft container in a trans-oceanic freight ship)	801	ton.km/FU	0.0052/ton.km	4.165	0.0999	27.9%
21. Transport from harbor to warehouse Eco-costs (28-ton truck)	4.80	ton.km/FU	0.033/ton.km	0.158	0.0038	1.1%
Total eco-costs (€)				**16.45**	**0.358**	**100.0%**

Plybamboo Board (1-layer)

A similar calculation was made for 1-layer Plybamboo board in various variations (carbonized or bleached, plain pressed or side pressed). The FU used as a base element for this assessment is one board of 2440 × 1220 × 5 mm (2.98 m2), with a weight of 10.4 kilograms (based on a density of 700 kg/m3), in which 61 fine planed strips (2500 × 20 × 5 mm) are used. For the side pressed version it is assumed that each of these strips is cut up into four smaller pieces of 2440 × 5 × 5 mm after fine planing.

The input data and results for the various production- and transport activities, including the corresponding eco-costs and the resulting overall eco-costs, for the production of the various 1-layer Plybamboo boards are summarized in the tables below. The eco-costs were added by Dr. Joost Vogtländer based on the Eco-costs 2007 database available through the website www.ecocostsvalue.com (Vogtländer 2008).

Table 13: Input data and results for the environmental impact assessment of 1-layer plain pressed Plybamboo board (bleached)

Process step	Amount	Unit	Eco-costs (€)/unit	Eco-costs (€)/FU	Eco-costs (€)/kg	%
1. Cultivation and harvesting from plantation Gasoline consumption	0.06	liter/FU	0.83/liter	0.046	0.0044	1.2%
2. Transport from plantation to strip manufacturing facility; Eco-costs of a 5-ton truck (transport of 92.4 FUs)	30	Km	0.243/km per 5t truck	0.079	0.0075	2.0%
3. Strip making: Energy consumption	0.35	kWh/ FU	0.083/kWh	0.0286	0.0027	0.7%
4. Transport from strip manufacturing facility to factory; Eco-costs of a 10-ton truck (transport of 310.4 FUs).	600	Km	0.32/km per 10t truck	0.619	0.0590	16.1%
5. Rough planing: Energy consumption	2.16	kWh/ FU	0.083/kWh	0.1789	0.0171	4.6%
6. Strip selection						
7. Bleaching: Energy consumption	0.40	kWh/ FU	0.083/kWh	0.0330	0.0031	0.9%
7. Bleaching: Added amount of H_2O_2	0.70	kg H_2O_2/FU	1.33/kg H_2O_2	0.9343	0.0891	24.3%
8. Drying: Energy consumption	2.60	kWh/FU	0.083/kWh	0.2158	0.0206	5.6%
9. Fine planing: Energy consumption	1.45	kWh/FU	0.083/kWh	0.1204	0.0115	3.1%
10. Strip selection						
11. Glue application (1-layer boards) Added amount of Urea formaldehyde (wet)	0.149	kg/FU	0.746/kg	0.1112	0.0106	2.9%
12. Pressing strips to 1-layer board: Energy	0.64	kWh/FU	0.083/kWh	0.0531	0.0051	1.4%
13. Sawing: Energy consumption	0.29	kWh/FU	0.083/kWh	0.0241	0.0023	0.6%
14. Sanding 1-layer board: Energy	0.54	kWh/FU	0.083/kWh	0.0448	0.0043	1.2%
15. Dust absorption (during all steps) Energy consumption	2.17	kWh/FU	0.083/kWh	0.1799	0.0171	4.7%
16. Transport from factory to harbor Eco-costs (28-ton truck)	3.13	ton.km/FU	0.033/ton.km	0.1032	0.0098	2.7%
17. Transport from harbor to harbor Eco-costs (20ft container in a trans-oceanic freight ship)	200.24	ton.km/FU	0.0052/ton.km	1.0413	0.0993	27.0%
18. Transport from harbor to warehouse Eco-costs (28-ton truck)	1.20	ton.km/FU	0.033/ton.km	0.0396	0.0038	1.0%
Total eco-costs (€)				**3.85**	**0.367**	**100.0%**

Table I4: Input data and results for the environmental impact assessment of 1-layer side pressed Plybamboo board (bleached)

Process step	Amount	Unit	Eco-costs (€)/unit	Eco-costs (€)/FU	Eco-costs (€)/kg	%
1. Cultivation and harvesting from plantation Gasoline consumption	0.06	liter/FU	0.83/liter	0.046	0.0044	1.1%
2. Transport from plantation to strip manufacturing facility; Eco-costs of a 5-ton truck (transport of 92.4 FUs)	30	Km	0.243/km per 5t truck	0.079	0.0075	1.9%
3. Strip making: Energy consumption	0.35	kWh/ FU	0.083/kWh	0.0286	0.0027	0.7%
4. Transport from strip manufacturing facility to factory; Eco-costs of a 10-ton truck (transport of 310.4 FUs).	600	Km	0.32/km per 10t truck	0.619	0.0590	14.8%
5. Rough planing: Energy consumption	2.16	kWh/ FU	0.083/kWh	0.1789	0.0171	4.3%
6. Strip selection						
7. Bleaching: Energy consumption	0.40	kWh/ FU	0.083/kWh	0.0330	0.0031	0.8%
7. Bleaching: Added amount of H_2O_2	0.70	kg H_2O_2/FU	1.33/kg H_2O_2	0.9343	0.0891	22.3%
8. Drying: Energy consumption	2.60	kWh/FU	0.083/kWh	0.2158	0.0206	5.2%
9. Fine planing: Energy consumption	1.45	kWh/FU	0.083/kWh	0.1204	0.0115	2.9%
10. Strip selection						
11. Glue application (1-layer boards) Added amount of Urea formaldehyde (wet)	0.596	kg/FU	0.746/kg	0.4446	0.0424	10.6%
12. Pressing strips to 1-layer board: Energy	0.64	kWh/FU	0.083/kWh	0.0531	0.0051	1.3%
13. Sawing: Energy consumption	0.29	kWh/FU	0.083/kWh	0.0241	0.0023	0.6%
14. Sanding 1-layer board: Energy	0.54	kWh/FU	0.083/kWh	0.0448	0.0043	1.1%
15. Dust absorption (during all steps) Energy consumption	2.17	kWh/FU	0.083/kWh	0.1799	0.0171	4.3%
16. Transport from factory to harbor Eco-costs (28-ton truck)	3.13	ton.km/FU	0.033/ton.km	0.1032	0.0098	2.5%
17. Transport from harbor to harbor Eco-costs (20ft container in a trans-oceanic freight ship)	200.24	ton.km/FU	0.0052/ton.km	1.0413	0.0993	24.9%
18. Transport from harbor to warehouse Eco-costs (28-ton truck)	1.20	ton.km/FU	0.033/ton.km	0.0396	0.0038	0.9%
Total eco-costs (€)				**4.19**	**0.399**	**100.0%**

Table I5: Input data and results for the environmental impact assessment of 1-layer plain pressed Plybamboo board (carbonized)

Process step	Amount	Unit	Eco-costs (€)/unit	Eco-costs (€)/FU	Eco-costs (€)/kg	%
1. Cultivation and harvesting from plantation Gasoline consumption	0.06	liter/FU	0.83/liter	0.046	0.0044	1.3%
2. Transport from plantation to strip manufacturing facility; Eco-costs of a 5-ton truck (transport of 92.4 FUs)	30	Km	0.243/km per 5t truck	0.079	0.0075	2.3%
3. Strip making: Energy consumption	0.35	kWh/ FU	0.083/kWh	0.0286	0.0027	0.8%
4. Transport from strip manufacturing facility to factory; Eco-costs of a 10-ton truck (transport of 310.4 FUs).	600	Km	0.32/km per 10t truck	0.619	0.0590	17.7%
5. Rough planing: Energy consumption	2.16	kWh/ FU	0.083/kWh	0.1789	0.0171	5.1%
6. Strip selection						
7. Carbonization: Energy consumption	1.18	kWh/FU	0.083/kWh	0.098	0.0094	2.8%
8. Drying: Energy consumption	8.65	kWh/FU	0.083/kWh	0.718	0.0684	20.6%
9. Fine planing: Energy consumption	1.45	kWh/FU	0.083/kWh	0.1204	0.0115	3.5%
10. Strip selection						
11. Glue application (1-layer boards) Added amount of Urea formaldehyde (wet)	0.149	kg/FU	0.746/kg	0.1112	0.0106	3.2%
12. Pressing strips to 1-layer board: Energy	0.64	kWh/FU	0.083/kWh	0.0531	0.0051	1.5%
13. Sawing: Energy consumption	0.29	kWh/FU	0.083/kWh	0.0241	0.0023	0.7%
14. Sanding 1-layer board: Energy	0.54	kWh/FU	0.083/kWh	0.0448	0.0043	1.3%
15. Dust absorption (during all steps) Energy consumption	2.17	kWh/FU	0.083/kWh	0.1799	0.0171	5.2%
16. Transport from factory to harbor Eco-costs (28-ton truck)	3.13	ton.km/FU	0.033/ton.km	0.1032	0.0098	3.0%
17. Transport from harbor to harbor Eco-costs (20ft container in a trans-oceanic freight ship)	200.24	ton.km/FU	0.0052/ton.km	1.0413	0.0993	29.9%
18. Transport from harbor to warehouse Eco-costs (28-ton truck)	1.20	ton.km/FU	0.033/ton.km	0.0396	0.0038	1.1%
Total eco-costs (€)				**3.485**	**0.332**	**100.0%**

Table I6: Input data and results for the environmental impact assessment of 1-layer side pressed Plybamboo board (carbonized)

Process step	Amount	Unit	Eco-costs (€)/unit	Eco-costs (€)/FU	Eco-costs (€)/kg	%
1. Cultivation and harvesting from plantation Gasoline consumption	0.06	liter/FU	0.83/liter	0.046	0.0044	1.2%
2. Transport from plantation to strip manufacturing facility; Eco-costs of a 5-ton truck (transport of 92.4 FUs)	30	Km	0.243/km per 5t truck	0.079	0.0075	2.1%
3. Strip making: Energy consumption	0.35	kWh/ FU	0.083/kWh	0.0286	0.0027	0.7%
4. Transport from strip manufacturing facility to factory; Eco-costs of a 10-ton truck (transport of 310.4 FUs).	600	Km	0.32/km per 10t truck	0.619	0.0590	16.2%
5. Rough planing: Energy consumption	2.16	kWh/ FU	0.083/kWh	0.1789	0.0171	4.7%
6. Strip selection						
7. Carbonization: Energy consumption	1.18	kWh/FU	0.083/kWh	0.098	0.0094	2.6%
8. Drying: Energy consumption	8.65	kWh/FU	0.083/kWh	0.718	0.0684	18.8%
9. Fine planing: Energy consumption	1.45	kWh/FU	0.083/kWh	0.1204	0.0115	3.2%
10. Strip selection						
11. Glue application (1-layer boards) Added amount of Urea formaldehyde (wet)	0.596	kg/FU	0.746/kg	0.445	0.0424	11.6%
12. Pressing strips to 1-layer board: Energy	0.64	kWh/FU	0.083/kWh	0.0531	0.0051	1.4%
13. Sawing: Energy consumption	0.29	kWh/FU	0.083/kWh	0.0241	0.0023	0.6%
14. Sanding 1-layer board: Energy	0.54	kWh/FU	0.083/kWh	0.0448	0.0043	1.2%
15. Dust absorption (during all steps) Energy consumption	2.17	kWh/FU	0.083/kWh	0.1799	0.0171	4.7%
16. Transport from factory to harbor Eco-costs (28-ton truck)	3.13	ton.km/FU	0.033/ton.km	0.1032	0.0098	2.7%
17. Transport from harbor to harbor Eco-costs (20ft container in a trans-oceanic freight ship)	200.24	ton.km/FU	0.0052/ton.km	1.0413	0.0993	27.3%
18. Transport from harbor to warehouse Eco-costs (28-ton truck)	1.20	ton.km/FU	0.033/ton.km	0.0396	0.0038	1.0%
Total eco-costs (€)				**3.818**	**0.364**	**100.0%**

Plybamboo Veneer

A relatively new bamboo product from China is bamboo veneer with a thickness of 0.6 mm. This product is available in the same pattern (side pressed and plain pressed) and colors (carbonized and bleached) as other Plybamboo materials. The production process of the veneer is very similar to that of the 1-layer Plybamboo board, based on which an estimation can be made for the eco-costs/kg for the production of veneer. For the production of veneer an extra process step is added in which the veneer is sliced, like a slice of cheese, from a large laminated bamboo block (in essence consisting of many 1-layer boards) with a machine, specially developed for this purpose. Since the veneer is very thin, it is more susceptible to deficiencies, which results in a higher material loss after quality control than for the 1-layer boards. After slicing the veneer from the block, only 40-45% of plain pressed bamboo veneer meets the highest quality requirements and 55-60% is discarded, while for side pressed bamboo veneer 70-75% meets the highest quality requirements and 25-30% is discarded [2]. This means that compared to the production of 1-layered boards for plain pressed bamboo veneer 100%/42.5% = 2.35 times more material is needed. For side pressed bamboo 100%/72.5% = 1.38 times more material is needed compared to the 1-layered boards. Based on these ratios the eco-costs/kg, found for 1-layer Plybamboo board (see above), can be modified to provide the eco-costs for the various types of bamboo veneer (see table below).

Product	Eco-costs (€)/kg
Plain pressed veneer (bleached)	0.86
Side pressed veneer (bleached)	0.55
Plain pressed veneer (carbonized)	0.78
Side pressed veneer (carbonized)	0.50

Stem

General Data

The FU used as a base element for this assessment is one 5.33 meter-long Moso stem (diameter: 10 cm at bottom, 7 cm at top), which weighs 7.65 kg in its dry state (see table 5.20 in subsection 5.2.2 for the establishment of the weight). If the stem is not used as input for board production (see step 1 in the production process of the various bamboo boards above), it will have to be preserved and dried separately; see production process below.

Full Production Process (Cradle till Site)

1. Cultivation and harvesting bamboo from sustainably managed plantations
2. Transport to stem preservation facility
3. Preservation and drying
4. Transport from stem preservation facility to harbor
5. Transport from harbor to harbor
6. Transport from harbor to warehouse

Determination of Input Data per Process Step

1. Cultivation and harvesting bamboo from sustainably managed plantations

In the calculation it is assumed that no fertilizers and pesticides were used on the plantations from which the stems were extracted. Harvesting figures are based on [5], in which is estimated that 234 stems can be harvested with chainsaws on one gallon (3.785 liters) of gasoline, which comes down to 0.016 liters of gasoline per stem.

Input in LCA: Cultivation and harvesting of bamboo from sustainably managed plantations

Gasoline consumption	**0.016 liters/FU**

2. Transport to stem preservation facility

According to [1] an average of around 320 stems (FUs) with a length of 8 meters are transported per truck load with a 5-ton truck over a distance of 15 kilometers [2]. For small trucks the eco-costs are calculated based on the eco-costs per km of a certain vehicle, based on an empty truck load for the return (thus calculating with 2 x 15 = 30 km).

Input in LCA: Transport to stem preservation facility

Distance	15 km
Kind of transport	5-ton truck
Amount of FU per load	320 stems (FUs)

3. Preservation and drying

According to [5], preservation of stems is best executed through the Boucherie method powered by an air pump, through which the sap of the stem is completely replaced by a boron solution. Boron is perceived as an environmentally friendly preservative, which is also commonly used as a fertilizer. The air pump consumes 1 kWh per stem [5]. After preservation the stems are usually dried in the open air.

Input in LCA: Transport to stem preservation facility

Energy consumption per FU	1 kWh/stem (FU)

4. Transport from stem preservation facility to harbor

After drying the stems are packed in containers ready for transport. Since bamboo stems are relatively light, for this assessment it was calculated with a 40-foot container which has standard internal dimensions of 12.0 x 2.35 x 2.39 meters (67.7m3) and a maximum load of around 32 tons (including weight of the container of 3.7 tons). In a 40-foot container around 1000 stems of 5.33 meters (FU) long and a diameter of maximum 10 cm can be transported per truckload. The stems are then transported with a 28-ton truck over a distance of 600 km to the harbor of Shang Hai [1, 2]. For larger trucks the eco-costs are usually calculated based on the eco-costs per ton km of a certain vehicle (empty return figures taken into account in the one-way distance). The amount of ton.km per FU is 0.00765 tons x 600 km = 4.59 ton.km/FU. Based on the eco-costs/ton.km of a 28-ton truck the eco-costs per FU can then be calculated.

Input in LCA: Transport from stem preservation facility to harbor

Distance	600 km
Kind of transport	28-ton truck
Ton km per FU	4.59 ton.km/FU

5. Transport from harbor to harbor

The calculation to determine the environmental burden for sea transport was based on transport with a trans-oceanic freight ship in a 40-foot container, with a travel distance Shanghai-Rotterdam of 19208 kilometers.

While the environmental burden of sea transport is usually based on the weight of the load (ton.km; see the summary tables for the various Plybamboo boards above), for loads under 400 kg/m3 it should be calculated with a volume bound eco-cost indicator (m3.km; see Vogltänder 2008). Therefore, the eco-costs were calculated based on the eco-costs per m3.km of the boat used (empty return figures taken into account in the one-way distance). One FU takes up 67.7 m3/1000 FU = 0.068 m3 of the container. The amount of m3.km per FU is then 0.068 m3 x 19208 km = 1300m3.km/FU. Based on the eco-costs/m3.km of a 40-foot container transported by a trans-oceanic freight ship, the eco-costs per FU can then be calculated.

Input in LCA: Transport from harbor to harbor

Distance	**19208 km**
Kind of transport	**trans-oceanic freight ship (40-foot container)**
m3.km per FU	**1300 m3.km/FU**

6. Transport from harbor to warehouse (the Netherlands)

The distance from the Rotterdam harbor to the Zwaag warehouse is 115 km. For the rest of the calculation the same parameters as for step 4 are used.

Input in LCA: Transport from harbor to warehouse (the Netherlands)

Distance	**115 km**
Kind of transport	**28-ton truck**
Ton km per FU	**0.88 ton.km/FU**

Results

All the input data of the various production- and transport activities found above, including the corresponding eco-costs and the resulting overall eco-costs is summarized in table I7 below.

Table I7: Input data and results for the environmental impact assessment of a 5.3-meter long bamboo stem

Process step	Amount	Unit	Eco-costs (€)/unit	Eco-costs (€)/FU	Eco-costs (€)/kg	%
1. Cultivation and harvesting from plantation Gasoline consumption	0.016	liter/FU	0.83/liter	0.013	0.0018	0.2%
2. Transport from to stem processing facility; Eco-costs of a 5-ton truck (transport of 320 FUs)	30	Km	0.243/km per 5t truck	0.0228	0.0031	0.3%
3. Preservation & drying: Energy consumption	1	kWh/ FU	0.083/kWh	0.083	0.0108	1.2%
4. Transport from stem preservation facility to harbor (28-ton truck)	4.59	ton.km/FU	0.033/ton.km	0.151	0.0226	2.6%
5. Transport from harbor to harbor Eco-costs (volume based; 400ft container in a trans-oceanic freight ship)	1300	m3.km/FU	0.0043/m3.km	5.590	0.8343	95.2%
6. Transport from harbor to warehouse Eco-costs (28-ton truck)	0.88	ton.km/FU	0.033/ton.km	0.029	0.0043	0.5%
Total eco-costs (€)				**5.89**	**0.877**	**100.0%**

Strand Woven Bamboo

Because of the rather different production process, the production of Strand Woven Bamboo (SWB) is explained below in a more elaborate manner.

General Data

SWB is a relatively new industrial bamboo material that can be used indoors and outdoors. This calculation is based on the carbonized version of the outdoor product (with a higher glue content and higher compression level). SWB floor pieces and planks are sawn from a beam (1900 x 110 x 140 mm) made from compressed rough bamboo strips and resin [3]. Due to the compression and the high resin content the density of SWB is high (1080 kg/m3). Taking sawing and sanding losses into account, per beam 8 planks of 1900 x 100 x 15 mm can be made, which is chosen as the FU for the calculation. The beam weighs 0.029 m3 x 1080 = 31.6 kg, while the plank weighs 0.00285 m3 x 1080 = 3.08 kg.

Since the input strips for SWB will be compressed they do not have to be uniform in size and shape, which means no stringent quality control is needed for the input strips for SWB (in contrast with Plybamboo boards). According to [3], based on visits to various SWB producers, the size of the input strips may vary in width (1-3 cm) and in thickness (1.5-3.5 mm). To keep this calculation workable was calculated with an average input strip size of 2000 x 20 x 3mm (0.000114m3), with a weight of 0.080 kg (= 80 grams).

In order to calculate the number of strips used per beam, first the amount of resin used needs to be taken into account. According to [4], Phenol Formaldehyde is used as glue, of which the solid content in the final product is 23%. The weight of Phenol Formaldehyde lies around 1200 kg/m3 both in wet and in dry states. For the calculation, it is assumed that the weight of the resin is more or less the same as the weight of the compressed bamboo. This means that in the beam the amount of resin is 23% x 31.6 kg = 7.27 kg. The rest of the weight is made up by compressed bamboo material: 31.6 -7.27 = 24.3 kg. The volume of the bamboo material in the beam is 77% x 0.029 m3 = 0.022 m3. Since the material is compressed, an amount of 1080/700 =1.54 times more raw bamboo material is needed to produce the beam, which corresponds to an amount of 1.54 x 0.022 = 0.034 m3 of bamboo material (strips). This corresponds to a number of 0.034/0.000114 = 302 strips per beam, and 298/8 = 38 strips per plank (FU).

Full Production Process

1. Cultivation and harvesting of bamboo on sustainably managed plantations
2. Transport from plantation to strip manufacturing facility
3. Strip making
4. Transport from strip manufacturing facility to factory

5. Rough planing
6. Splitting strips in half
7. Preservation & coloring: carbonizing
8. Drying
9. Crushing strips
10. Glue application
11. Pressing strips to beam
12. Activating glue in oven
13. Sawing beams
14. Sawing planks
15. Sanding planks
16. Transport from factory to harbor
17. Transport from harbor to harbor
18. Transport from harbor to warehouse

Determination of Input Data per Process Step

1. Cultivation and harvesting of bamboo on sustainably managed plantations

In the calculation it is assumed that no fertilizers and pesticides were used on the plantations from which the stems were extracted. Harvesting figures are based on [5], in which is estimated that 234 stems can be harvested with chainsaws on one gallon (3.785 liters) of gasoline, which comes down to 0.016 liters of gasoline per stem.

Since the input strips for SWB have a different size (2000 × 20 × 3mm) than the input strips for Plybamboo, the stem will be cut in four pieces, 2 m long, in the strip manufacturing facility. If we refer to the measures in table 5.20 in subsection 5.2.2 the number of strips that can be sourced from the four 2 m segments deriving from an 8 meter long stem can be estimated, taking into account the tapering character of the stem:

- 0-2 meter: 2 × 12 = 24 strips (2000 × 20 × 3)
- 2-4 meter: 2 × 10 = 20 strips
- 4-6 meter: 1 × 8 = 8 strips
- 6-8 meter: 1 × 6 = 6 strips

In total 58 strips can be sourced per stem. One FU consists of 38 strips. This means that per FU 38/58 = 0.65 stems are necessary. This means that per FU: 0.61 × 0.016 = 0.0104 liters of gasoline is consumed.

Input in LCA: Cultivation and harvesting of bamboo on sustainably managed plantation

Gasoline consumption	**0.0104 liters/FU**

2. Transport from plantation to strip manufacturing facility

According to [1], an average of around 320 stems with a length of 8 meters are transported per truck load with a 5-ton truck over a distance of 15 kilometers [2], which results in 320 stems/0.61 stems per FU (see step 1) = 492.3 FUs (planks) being transported per truck load. For small trucks the eco-costs are usually calculated based on the eco-costs per km of a certain vehicle, based on an empty truckload for the return (thus calculating with 2 × 15 = 30 km).

Input in LCA: Transport plantation to strip manufacturing facility

Distance	**30 km**
Kind of transport	**5-ton truck**
Amount of FU per load	**492.3 FUs**

3. Strip making

According to [1], 9000 strips (full wall thickness) can be produced in 8 hours with the strip making machine (5.5 kW), which corresponds to 1125 strips per hour. From 76% (44/58) of the strips produced in this step, two 3 mm thick strips can be made (in step 6), which corresponds to (1125 × 1.76 strips)/38 = 52 FUs (planks)/hour. It takes 1/ 52 = 0.019 hour to produce one FU. Energy consumption per FU is then 0.019 hour × 5.5 kW = 0.10 kWh/FU.

Input in LCA: Strip making

Energy consumption/FU	**0.10 kWh/FU**

4. Transport from strip manufacturing facility to factory

According to [1, 2], 8 tons of strips are transported per truck load (10-ton truck) from the strip processing facility to the factory, over 300 kilometers. One rough strip measures approximately: 2.0 × 0.023 × 0.009 m = 0.00041m3 × 700 kg/m3 = 0.29 kg per strip.

8000 kg per load means: 8000/0.29 = 27586 strips of 2.0 m long are transported per truckload. As found above, from 76% of the full wall thickness strips, two 3 mm thick strips can be made (in step 6), which corresponds to (27586 × 1.76 strips)/38 strips per FU = 1277.7 FUs, which are transported per truckload. For small trucks the eco-costs are usually calculated based on the eco-costs per km of a certain vehicle, based on an empty truckload for the return (thus calculating with 2 × 300 = 600 km).

Input in LCA: Transport from strip manufacturing facility to factory

Distance	**600 km**
Kind of transport	**10-ton truck**
Amount of FU per load	**1277.7 planks (FU)**

5. Rough planing

According to [1], 4500 strips can be produced in 8 hours with the rough planer (15-20 kW), which corresponds to 562 strips per hour, which corresponds to 562 × 1.76 strips (see explanation in previous steps)/38 strips per FU = 26.0 FUs (planks) per hour. It takes 1/26.0 = 0.038 hour to produce one FU. Energy consumption per FU is then 0.038 hour × 17.5 kW = 0.66 kWh/FU.

Input in LCA: Rough Planing

Energy consumption/FU	**0.66 kWh/FU**

6. Splitting strips in half

After rough planning, the thicker rough strips (thickness 6 mm) will be divided by a splitter into two smaller strips, with a thickness of 3 mm. According to [3], the cutting machine has more or less a similar processing speed as the fine planers (see Plybamboo calculation) in which 38-40 meters of strips can be processed per minute, which corresponds to 20 2-m long strips/minute, which corresponds to 60 × 20 × 1.76 = 2112 strips per hour, which corresponds to 2112 strips/38 strips per FU = 55.6 FUs (planks) per hour.

It is assumed that the power of the strip splitter is the same as for the strip making machine in step 3 (5.5 kW). It takes 1/55.6 = 0.018 hour to produce one FU. Energy consumption per FU is then 0.018 hour x 5.5 kW = 0.10 kWh/FU.

Input in LCA: Splitting strips in half

Energy consumption/FU	**0.10 kWh/FU**

7. Preservation & coloring: Carbonizing

Figures for carbonization can largely be based on the figures for carbonizing strips for Plybamboo production with the difference that the strips used here are half the size of the strips used for Plybamboo production, which means twice the number of strips can be processed in the same time.
According to [1], the bamboo strips will go through two rounds of carbonization, which takes 150-170 minutes for each round (depending on the level of darkness required). In the first round 8000 strips can be processed per day (8 hours), and in the second round 12000 strips can be processed per day.
For the first round 8000 strips can be processed in 8 hours, which means 1000 strips per hour, corresponding to 1000/38 = 26.3 FUs/hour, which corresponds to 1/26.3 = 0.038 hour per FU.
For the energy consumption of the carbonization kettle for the first carbonization round this implies the following. According to [1], the carbonization kettle is powered by a carbonizing boiler (1.5kW) as well as the 2-ton boiler (3.94 kW allocated to one carbonization kettle, see box above). The energy consumption per FU is then: (1.5 + 3.94) x 0.038 = 0.21 kWh/FU. For the second carbonization round the same calculation can be made, but for 12000 strips instead of 8000 strips. The energy consumption per FU is then: (1.5 + 3.94) x 0.025 = 0.14 kWh/FU. Total energy consumption during carbonization is then 0.21 + 0.14 = 0.35 kWh/FU

Input in LCA: Carbonization

Energy consumption/FU	**0.35 kWh/FU**

8. Drying

The figures below can largely be based on the figures for drying carbonized strips for board production with the difference that the strips used here are half the size of the strips used for Plybamboo production, which means twice the number of strips can be processed in the same time.
After carbonization the strips will be dried in a drying chamber. Besides the energy consumption of the drying chamber itself (15 kW), there is steam used in the drying chamber deriving from the 2-ton boiler (1.64 kW; see box before). According to [1], the drying room has a capacity to dry 60000 strips at once. Carbonized strips require a 168 h (7 days) drying cycle after the first carbonization round and a 72 h drying cycle after the second round (in total 240 hours).
This means that 60.000/38 = 1578.9 FUs can be dried in 240 hours, corresponding to 1578.9/240 = 6.58 FU/hour, which corresponds to 1/6.58 = 0.15 hour per FU. Energy consumption per FU is then 15 + 1.64 = 16.64 Kwh x 0.15 = 2.58 kWh/FU.

Input in LCA: Drying

Energy consumption/FU	**2.58 kWh/FU**

9. Crushing strips

To achieve a better glue adhesion and facilitate the pressing procedure later, the strips are crushed by a simple machine (see photos below). The crushing machine has more or less a similar processing speed as the planers [3], in which 38-40 meters of strips can be processed per minute, which corresponds to 20 strips/minute, which corresponds to 1200 strips per hour, which corresponds to 1200 strips/38 strips per FU = 31.5 FUs (planks)/hour.
It is assumed that the power of the crusher is the same as the splitter in step 3 (5.5 kW). It takes 1/31.5 = 0.032 hour to produce one FU. Energy consumption per FU is then 0.032 hour x 5.5 kW = 0.17 kWh/FU

Input in LCA: Crushing strips

Energy consumption/FU	**0.17 kWh/FU**

10. Glue application
As a next step the crushed strips will be soaked in Phenol formaldehyde resin. As was already mentioned in the introduction of the SWB calculation, the amount of resin used differs if SWB will be used for outdoor or indoor products. In the case of outdoor use the solid content of the resin in the final product is 23%; in the case of indoor products this drops to 15.1% [4]. For the calculation it was assumed that the weight of the resin is more or less the same as the weight of the compressed bamboo, and has a similar weight in dry and wet states. This means that in the plank (FU) the amount of resin is 23% x 3.08 kg = 0.71 kg.

Input in LCA: Glue application

Type of glue	**Phenol Formaldehyde**
Weight/amount of glue	**0.71 kg/FU**

11. Pressing strips to beam

As a next step the glue-saturated strips are placed into a mold in which under very high pressure (2200 tons) the strips are compressed into beams of 190 x 11 x 14 cm by a cold press [3]. The power of the very large press deployed is estimated to be five times the power of the cold presses used for board production: 5 x 5.5 = 27.5 kW. It takes around 5 minutes for all the strips to be allocated, pressed and taken out of the press [3]. This means that 12 beams are produced per hour. Per beam, 8 planks can be made, corresponding to a production of 12 x 8 = 96 FUs per hour. This means energy consumption per FU for the press is 1/96 x 27.5 = 0.29 kWh/FU

Input in LCA: Pressing strips to beam

Energy consumption/FU	**0.29 kWh/FU**

12. Activating glue in oven

After pressing, the beams (which are still in the steel mold) will be located for 8 hours in a large oven where the glue will be activated at a temperature of 140-150 degrees Celsius [3]. The oven is assumed to have a capacity of 2 x 2 x 2 = 8 m3. To estimate the power of the oven used, the power of an industrial oven of approximately the same size as the one used in the SWB process was used for the calculation: 50 kW. It is expected that in the oven the beams (190 x 14 x 11 cm), which are still in the slightly bigger mold, would need a space of 0.2 x 0.15 x 2 meters each. This means 143 beams fit into the oven, corresponding to 1144 planks (FUs). Since a round takes 8 hours, 8 x 50 = 400 kWh is consumed per oven load. This means that per FU, 400/1144 = 0.35 kWh is consumed.

Input in LCA: Oven

Energy consumption/FU	**0.35 kWh/FU**

13. Sawing beams

In order to acquire beams of exact dimensions, the borders of the beams need to be sawn. Because of the hardness of the material it is likely that a stronger saw needs to be used than for Plybamboo production. Therefore, it is calculated with a saw with twice the power of the sawing machine used for Plybamboo production (2 x 5.5 kW = 11kW). Assuming from observations [3] that it takes 2 minutes to place the beam and saw the borders, 30 beams can be processed per hour, corresponding to 30 x 8 = 240 FUs/hour, which corresponds to 1/240 = 0.004 hour per FU. The energy consumption for sawing the beams per FU is then 0.004 x 11 = 0.044 kWh.

Input in LCA: Sawing beams

Energy consumption/FU	**0.044 kWh/FU**

14. Sawing planks

As one of the final steps, planks will be sawn from the beam. For the calculation it was assumed that here also a saw with twice the power of the sawing machine used for board production is required (2 × 5.5 kW = 11kW). Assuming from observations [3] that two pieces can be produced from the beam per minute (including allocation and handling of the beam), 60 × 2 = 120 planks can be produced per hour, which corresponds to 1/120 = 0.0083 hours per FU. The energy consumption for sawing the planks per FU is then 0.0083 × 11 = 0.091 kWh.

Input in LCA: Sawing planks

Energy consumption/FU	**0.091 kWh/FU**

15. Sanding planks

According to [1], 250 m2 3-layer board can be processed per hour with the sanding machine (55-90 kW). It can be assumed that sanding the planks will take a little longer since they do not consist of a single board but several pieces: 150 m2/hour. This corresponds to 150/0.19 (1.9 × 0.1) m2 per piece = 789 FUs/hour, which corresponds to 1/789 = 0.0013 hour/FU. Energy consumption per FU for the sanding machine is then 0.0013 × 72.5 = 0.094 kWh

Input in LCA: Sanding planks

Energy consumption/FU	**0.094 kWh/FU**

16. Transport from factory to harbor

After sanding, the boards are packed in containers ready for transport. For the assessment it was calculated with a 20-foot container which has standard internal dimensions of 5.90 × 2.35 × 2.39 meters (33.2m3) and a maximum load of around 30 tons (including weight of the container of 2.3 tons), which was transported by a 28-ton truck, over a distance of 300 km (factory in Huangzhou to Shanghai harbor). For larger trucks and for sea transport the eco-costs are usually calculated based on the eco-costs per ton km of a certain vehicle (empty return figures taken into account in the one-way distance). The amount of ton.km per FU is 0.0031 tons × 300 km = 0.93 ton.km/FU. Based on the eco-costs/ton.km of a 28-ton truck the eco-costs per FU can then be calculated.

Input in LCA: Transport from factory to harbor

Distance	**300 km**
Kind of transport	**28-ton truck**
Ton km per FU	**0.93 ton.km/FU**

17. Transport from harbor to harbor

Calculations for the environmental burden for sea transport are based on transport with a trans-oceanic freight ship in a 20-foot container, with a travel distance from Shanghai to Rotterdam of 19208 kilometers. For sea transport the eco-costs are usually calculated based on the eco-costs per ton.km of the boat used. The amount of ton.km per FU is 0.0031 tons x 19208 km = 59.6 ton.km/FU. Based on the eco-costs/ton.km of a 20-foot container transported by a trans-oceanic freight ship, the eco-costs per FU can then be calculated.

Input in LCA:

Distance	**19208 km**
Kind of transport	**trans-oceanic freight ship (20-foot container)**
Ton km per FU	**59.6 ton.km/FU**

18. Transport from harbor to warehouse

The distance from the Rotterdam harbor to warehouse in Zwaag, the Netherlands, is 115 km. For the calculation it is assumed that one 20ft container is transported by a 28-ton truck. The amount of ton.km per FU is 0.0031 tons x 115 km = 0.36 ton.km/FU. Based on the eco-costs/ton.km of a 28-ton truck the eco-costs per FU can then be calculated.

Input in LCA: Transport from harbor to warehouse

Distance	**115 km**
Kind of transport	**28-ton truck**
Ton km per FU	**0.36 ton.km/FU**

Results

All the input data of the various production- and transport activities found above, including the corresponding eco-costs and the resulting overall eco-costs is summarized in table I8 below. The eco-costs were added by Dr. Joost Vogtländer based on the Eco-costs 2007 database available through the website www.ecocostsvalue.com (Vogtländer 2008).

Table I8: Input data and results for the environmental impact assessment of one carbonized SWB plank

Process step	Amount	Unit	Eco-costs (€)/unit	Eco-costs (€)/FU	Eco-costs (€)/kg	%
1. Cultivation and harvesting from plantation Gasoline consumption	0.010	liter/FU	0.83	0.009	0.0028	0.4%
2. Transport from plantation to strip manufacturing facility; Eco-costs of a 5-ton truck (transport of 92.4 FUs)	30	km/truck	0.243	0.014	0.0045	0.7%
3. Strip making: Energy consumption	0.1	kWh/ FU	0.083	0.008	0.0027	0.4%
4. Transport from strip manufacturing facility to factory; Eco-costs of a 10-ton truck (transport of 1277.7 FUs).	600	km/truck	0.32	0.132	0.0429	6.6%
5. Rough planing: Energy consumption	0.66	kWh/ FU	0.083	0.055	0.0178	2.7%
6. Splitting strips in half	0.10	kWh/FU	0.083	0.008	0.0027	0.4%
7. Carbonization: Energy consumption	0.35	kWh/FU	0.083	0.029	0.0094	1.4%
8. Drying: Energy consumption	2.58	kWh/FU	0.083	0.214	0.0695	10.6%
9. Crushing strips	0.17	kWh/FU	0.083	0.014	0.0046	0.7%
10. Glue application: Added amount of Phenol formaldehyde (wet)	0.710	kg/FU	1.56	1.108	0.3596	54.9%
11. Pressing strips to beam	0.29	kWh/FU	0.083	0.024	0.0078	1.2%
12. Activating glue in oven	0.35	kWh/FU	0.083	0.029	0.0094	1.4%
13. Sawing beams: Energy consumption	0.044	kWh/FU	0.083	0.004	0.0012	0.2%
14. Sawing planks: Energy consumption	0.091	kWh/FU	0.083	0.008	0.0025	0.4%
15. Sanding planks: Energy consumption	0.094	kWh/FU	0.083	0.008	0.0025	0.4%
16. Transport from factory to harbor Eco-costs (28-ton truck)	0.93	ton.km/FU	0.033	0.031	0.0100	1.5%
17. Transport from harbor to harbor Eco-costs (20ft container in a trans-oceanic freight ship)	59.60	ton.km/FU	0.0052	0.310	0.1006	15.4%
18. Transport from harbor to warehouse Eco-costs (28-ton truck)	0.360	ton.km/FU	0.033	0.012	0.0039	0.6%
Total eco-costs (€)				**2.016**	**0.654**	**100.0%**

Appendix J: Carbon Sequestration by Bamboo

In this appendix carbon sequestration by a permanent bamboo plantation is compared to a wood plantation. This calculation and its parameters are largely based on the annual yield calculation in subsection 5.2.2. Therefore, the calculation and the resulting tables are presented in a compressed manner in this appendix. Before the carbon sequestration for bamboo is analyzed in this appendix an introduction about global warming is provided, including the role of CO_2 with respect to this problem.

Introduction

Global Warming and the Role of Carbon Dioxide

Global warming is one the recent developments that will most likely have a high impact on our world in the coming ages. Although the exact consequences of global warming are unclear, it is expected that global warming may have a negative impact on the roots of sustainable development, and for the Planet component may impact the three main environmental problems: depletion of resources, deterioration of ecosystems and deterioration of human health (see table 1.1 in subsection 1.1.1). For example, through global warming sea levels will most likely rise, which is expected to increase extreme weather (hurricanes) and precipitation patterns (droughts and floods), which, as a result may impact agricultural yields, ecosystems, resource supplies, etc.

The most important organization that investigates causes and consequences of global warming is the Intergovernmental Panel on Climate Change (IPCC). In its most recent assessment (2007) the panel concludes that "most of the increase observed in globally averaged temperatures since the mid-twentieth century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations." In other words, through human activity (industry, energy consumption, extraction of resources, agriculture, etc.) the concentration of various gases creating the greenhouse effect causing global warming has increased steadily during the last decennia. One of the most important greenhouse gases contributing to global warming is carbon dioxide (CO_2), followed by methane (CH_4) and ozone (O_3) (Kiehl and Trenberth 1997). Of these greenhouse gases, CO_2 is probably best known by the general public, since it is expected that combustion (burning of fossil fuels) through human activity has contributed to 75% of the increase of CO_2 concentration the past 20 years; the remainder is largely caused by changes in land use, in particular due to deforestation (IPCC 2001).

It is for these reasons that CO_2 has received much attention as a greenhouse gas, and carbon sequestration by plants and trees is increasingly promoted as an important policy instrument against global warming, although there is increasing debate about the effectiveness of these measures due to the often temporal effect of carbon sequestration in this manner.

During their growth, trees (and other plants including bamboo) convert CO_2 (and water) through photosynthesis into carbohydrates, and emit oxygen in the process. The tree uses these carbohydrates to form cellulose and lignin cells, which contain carbon atoms, and thus store the carbon for the lifespan of the tree. The carbon makes up approximately half of the dry weight stored in the wood of the tree (Birdsey 1996). Thus, the higher the dry weight of the tree, the more carbon is stored in the wood of the tree. The carbon will be stored in the living tree, but will also remain stored once the tree is felled and the wood of the tree is used for durable products. When the tree dies or the product in which the wood is used is dumped, the carbon will be released again into the atmosphere in the form of CO_2 for example, through decay or incineration. This means that in essence the use of renewable materials such as wood can be perceived as a CO_2 neutral material (if CO_2 emitted during production and transport is not taken into account). Note that as an end-of-life scenario incineration of the material is preferred over landfill, since in the latter scenario the greenhouse gas methane may be released, which is expected to be over twenty times more harmful as greenhouse gas than CO_2 (Hammond and Jones 2006). Since the chemical composition of bamboo and wood is nearly identical (Liese 1998) it is assumed that per kilogram of resource or material, bamboo and wood contain a similar amount of carbon in their tissue.

Base of Comparison and Main Assumptions

The carbon sequestration comparison was made for bamboo- and wood plantations, which have a lower standing volume than natural forests, but usually a higher yield. A hectare of sustainably managed bamboo- or wood plantation will sequester CO_2 in two ways: first, through the standing volume of plants (which will remain living and have a steady biomass in the case of good plantation management), and second, through the fixation of carbon in products. For this calculation it was assumed that the resource will be used for the manufacturing of durable products, i.e. products with a life span of at least 20 years (e.g. flooring, furniture). Note that there will also be carbon fixated in products that are less durable[64]; however, in this calculation this amount of stored carbon is not taken into account. In case there is a constant yield of bamboo- or wood material, which is continuously fixated in durable products, the additional amount of carbon sequestered by durable products can be added to the carbon fixated in the permanent plantation. Note that the carbon sequestration is only relevant if the plantation will remain standing and keep producing. If this is not the case the carbon captured by the plantation and/or in the products will in time be released again to the atmosphere in the form of CO_2. The calculation is based on carbon sequestered in semi finished materials, similar to the annual yield calculation (see subsection 5.2.2).

Results

Carbon Stored by the Standing Volume of a Plantation

In table J1 the average standing volume (in m3) of an established wood plantation is presented, based on which the amount of tons of carbon stored in the plantation can be determined. Note that the carbon stored in a natural forest is usually significantly higher than in a plantation. For example, the biomass stored by a hectare of tropical rainforest may account for up to 330 tons carbon (Sundquist 2007).

Table J1: Estimates of the carbon stored in a hectare of wood plantation for various species (Kuiper 2006, van Straten 2006)

Wood species	Total standing volume (m3/ha)	Density (kg/m3)	Total dry weight including roots (tons/ha) [65]	Carbon stored per hectare including roots (tons/ha)
Baby Teak	300	700	262.5	131
Regular Teak	350	700	306	153
European oak	312.5	700	274	137
Eucalyptus	350	500	218	109

[64] For bamboo, for example, chop- or match sticks (expected life span of less than a year) or curtains (expected life span of less than five years).

[65] In the total dry weight an additional 25% is assumed to account for biomass stored below ground in the roots of the tree.

Since there are no figures of the carbon storage for Moso plantations, these figures had to be based on the carbon storage of a natural Moso stand. Isagi (Isagi et al. 1997) found the biomass of a natural stand of Moso in the neighborhood of Kyoto, Japan to measure 182 tons/ha (dry weight), of which 44.6 tons (24%) was stored in the part of the plant below the ground (roots and rhizomes) and 137.9 tons (75.6%) was stored in the parts above the ground (mainly in the stem; 116.5 tons). Isagi et al. (1997) noted that "the total above-ground biomass measured is one of the largest among the world's bamboo communities." In a plantation, the number of stems per hectare will be reduced for a maximum yield of straight culms. For this calculation it was assumed that the number of stems will be reduced by 50% for a plantation compared to a natural forest, which results in a dry biomass weight of 182/2 = 91 tons per ha, which refers to 45.5 tons carbon stored per ha of Moso plantation.

Besides Moso, Guadua was also taken into account in this assessment. For Guadua some carbon sequestration studies were executed by Riaño et al. (2002) in sites reforested with Guadua in the river Cauca valley in Colombia. Six years after establishment, Riaño et al. found the total dry weight of the accumulated biomass to be 108.7 tons/ha, of which 21.6 tons (19.9%) was stored in the part of the plant below the ground (rhizomes) and 87.1 tons (80.1%) was stored in the parts above the ground (mainly in the stem; 79.1 tons). Since the plantation had not reached its mature phase yet, it is assumed for this calculation that the dry weight of the biomass would still increase with 33% to measure 144.5 tons, which equals 72.25 tons carbon stored in a hectare of Guadua plantation.

Table J2: Estimates of the carbon stored in a bamboo plantation (Isagi et al. 1997, Riaño et al. 2002)

	Total dry weight including roots (tons/ha)	Carbon stored per hectare (tons/ha)
Moso	91	45.5
Guadua	144.5	72.3

From the tables it can be concluded that depending on the species, a wood plantation in general stores (up to two times) more carbon in its standing volume than a plantation of giant bamboo species.
However, in these figures the establishment phase has not been taken into account. In case degraded land or grassland will be reforested, the establishment time of a plantation may also play a role in carbon fixation. While the establishment time of a (sub)tropical giant bamboo plantation to come to maturity will not take longer than 10 years, the establishment time of a wood plantation to maturity may range from 15 years (Eucalyptus) to 30 years (baby Teak) to 70 years (regular Teak) to 80 years (European oak) (Kuiper 2006, van Straten 2006). This means that in the early years a bamboo plantation will sequester more carbon than the standing volume of a wood plantation; however, in time the total carbon sequestration of a wood plantation will surpass the sequestration by the bamboo plantation.

Carbon Stored in Durable Products

As was mentioned above, besides the fixation of carbon in the plants (trees/stems), in the case of a sustainably managed plantation, the increase in biomass of the plantation can be harvested, processed and used in durable products, through which an additional amount of carbon is stored. The annual yield in cubic meters of a semi finished material, based on which the sequestered carbon can be determined, was already established in subsection 5.2.2 annual yield for production scenarios A and B. If it is assumed that the products in which the wood or bamboo is used have an average lifespan of 20 years (after which the carbon stored in the product will be released again in the atmosphere), and the plantation will have a continuous output of material which will be used in durable products (which compensates for the carbon released by products that reach the end of their lifespan after 20 years), an additional amount of 20 times the annual carbon storage is sequestered in durable products per hectare of plantation (see tables J3 and J4).

Table J3: Estimates of the carbon stored in durable timber products sourced from a wood plantation (Kuiper 2006, van Straten 2006, Wiselius 2001)

Wood species	Scenario A: Annual yield in sawn timber (m3/ha)	Scenario B: Annual yield in MDF (m3/ha)	Density (kg/m3)	Annual yield in dry weight (tons/ha)	Carbon stored per hectare (tons/ha)	Cumulated amount of carbon stored in 20 years (tons/ha)
Baby Teak	4.4	N/A	700	3.1	1.55	31
Regular Teak	2.1	N/A	700	1.47	0.74	14.8
European oak	1.8	N/A	700	1.26	0.63	12.6
Eucalyptus	8.8	10.7	500	4.4	2.2	44
			750 (MDF)	8	4	80

Table J4: Estimates of the carbon stored in semi finished materials sourced from a bamboo plantation

Bamboo species	Annual yield semi finished material (m3/ha)	Density (kg/m3)	Annual yield in dry weight (tons/ha)	Carbon stored per hectare (tons/ha)	Cumulated amount of carbon stored in 20 years (tons/ha)
Moso: A-quality materials	Plybamboo: 2.0 Taped mats: 1.5 SWB:1.2 **Total: 4.7**	700 700 1080	1.4 1.1 1.3 **Total: 3.8**	1.9	38
Guadua: A-quality materials	Plybamboo: 3.9 Taped mats: 2.9 SWB: 2.3 **Total: 9.1**	700 700 1080	2.7 2.0 2.5 **Total: 7.2**	3.6	72
Moso: SWB	4.6	1080	5.0	2.5	50
Guadua: SWB	8.8	1080	9.5	4.8	96
Moso: B-quality materials (MDF)	5.4	1050	5.7	2.8	56
Guadua: B-quality materials (MDF)	10.3	1050	10.8	5.4	108

Total Carbon Fixation Stored by a Bamboo- and Wood Plantation

Based on carbon fixated by the permanent standing volume in the plantation, and carbon accumulated in durable products with an average lifespan of 20 years, the total carbon sequestered by a permanent plantation can be determined, which can be used to compare wood and bamboo (see table J5 and figure J1).

Table J5: Total carbon fixation by a hectare of an established plantation for various bamboo- and wood species

Species	Stored carbon per hectare in plants (tons/ha)	Cumulated amount of carbon stored in durable products in 20 years (tons/ha)	Total carbon fixation (tons/ha)
Baby Teak	131	31	162
Regular Teak	153	14.8	168
European oak	137	12.6	150
Eucalyptus	109	44	153
Eucalyptus (MDF)	109	80	189
Moso: A-quality materials	45.5	38	84
Guadua: A-quality materials	72.3	72	144
Moso: SWB	45.5	50	96
Guadua: SWB	72.3	96	168
Moso: B-quality materials (MDF)	45.5	56	102
Guadua: B-quality materials (MDF)	72.3	108	180

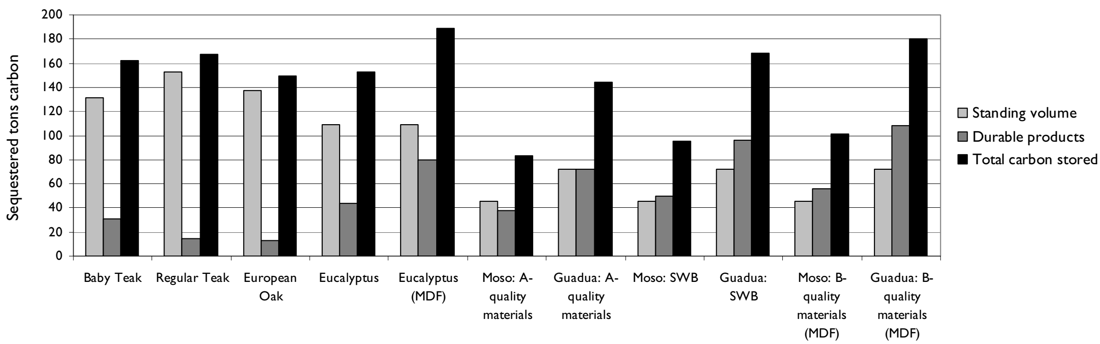


Figure J1: Total carbon fixation by a hectare of an established plantation for various bamboo- and wood species

From figure J1 and table J5 it becomes clear that whereas bamboo in general fixates more amounts of carbon in semi finished materials due to its high annual yields, wood fixates more carbon in the living plants on the plantation, which to some extent level each other out. From figure J1 it can be seen that in the case of an established Moso plantation no matter how the yield will be used (A-quality materials, SWB or MDF), the total carbon fixation per hectare is lower than for a permanent plantation of wood species. For a permanent plantation of the larger bamboo species, Guadua, the situation is different. If a Guadua plantation is used to produce A-quality materials, total carbon sequestration is slightly lower than most wood species. However, in the case of SWB or MDF production, carbon sequestration by Guadua may, due to the higher yields, be slightly higher than most wood species.

It should be noted that in figure J1 the long establishment times of slow growing hardwoods such as regular Teak and European Oak are not taken into account. As a result, in the case of reforestation, in the establishment time of the plantation a bamboo plantation will sequester more carbon than all wood species. Only in time, the wood plantation will catch up in total carbon sequestration.

From the above it can be concluded that the argument - often used by bamboo material producers - that bamboo will sequester more carbon than wood is not valid. From figure J1 it became evident that giant bamboo species such as Guadua can definitely compete in terms of carbon sequestration with the fastest growing hardwood species, but that materials made from the bamboo species most commonly used for bamboo materials used in the West, Moso, in total sequester less carbon than competing hardwood species. However, as was already mentioned in subsection 5.2.3, instead of carbon sequestration, the efficiency in annual yield should be the crucial criterion for crop choice of a hectare of vacant land in the future in order to meet the increasing demand for raw materials, which turns out more positively for bamboo compared to wood.

Epilogue

"It is good to have an end to journey toward; but it is the journey that matters in the end."

Ursula K. LeGuin

This thesis is part of a seven-year long personal journey to better understand the paradox between the potential of bamboo as a fast growing renewable resource in the West and the inability to grasp this potential, visible through the small market share of bamboo in products in Western Europe. As a response to this paradox this thesis has suggested and tested design interventions as a suitable strategy to stimulate the commercialization rate of bamboo in certain markets.
However, the route to this knowledge has not been straightforward at all, as it was characterized by many climbs, descents and steep turns, somewhat similar to the path of the Chinese Wall (see photo above). Let me retrospectively take you on this journey as it sets the stage from which this PhD research derives.

I embarked on my journey of discovery in 2001, when I did an internship at the National Bamboo Project in Costa Rica for my MSc study in architecture. Seeing the high growing speed of the giant bamboo stems at the plantation, the strength of the material combined with the low costs, and the applicability in housing and furniture I became aware of the enormous potential of bamboo as a sustainable raw material. At the same time I wondered why bamboo was still perceived as the poor man's timber in Latin America, and why its use was not common in the West. It was this question that intrigued me and made me set out on an ongoing journey in search of answers, which would eventually lead to this PhD research.

Back in the Netherlands after my trip to Costa Rica, I decided to focus my MSc thesis in 2002 on determining the environmental, economic and practical competitiveness of the bamboo stem for use in building projects in Western Europe (main findings can be found in the box in subsection 9.3.3 of this thesis). After graduation I visited several bamboo projects around the world in Northern America, Latin America, Australia and Asia during a world trip in 2003. Throughout that year I performed various feasibility studies for setting up a bamboo stem venture, as the environmental assessment based on LCA executed for my MSc studies had revealed the stem to be the most environmentally friendly material around, compared to industrial bamboo materials such as Plybamboo. Nevertheless, I did not dare to take this leap in the dark yet, since I felt I still lacked sufficient bamboo related knowledge to make such a venture a success. This was my incentive to scan possibilities for pursuing a PhD research in order to acquire more knowledge about this topic. I was stimulated in this process by my former MSc thesis mentor Andy van den Dobbelsteen and professor Hans de Jonge. However, since the topic did not fit into mainstream research programs of Dutch universities, financing proved to be a problem, which made external fundraising necessary. The Fred Foundation provided me with a start-up fund to cover the first half year of my PhD and with the financial help of Hans de Jonge I was able to start my PhD research in October 2004 at the faculty of Architecture, department of Building Technology, under the supervision of Professor Mick Eekhout.

At the beginning of my PhD I tried to set up consortia with parties in the building industry to execute projects in which the bamboo stem could be incorporated in order to try to overcome the obstacles found in my MSc thesis. However, I did not notice any interest for the adoption of the bamboo stem either outside or inside the faculty. This made me realize two things: 1) that I must broaden my vision and next to the bamboo stem also include industrial materials made from the bamboo stem, and 2) that I should focus on another sector less hesitant than the building industry to adopt a new material. In consultation with Professor Eekhout I decided to pursue my PhD research in 2005 at the faculty of Industrial Design Engineering under the supervision of Professor Han Brezet who led the Design for Sustainability program. By that time I knew the destination of my journey (understanding the small market share of bamboo in Western Europe and if possible increasing this market share) but I did not really know yet how to reach this goal.

I decided I should first gain a holistic overview of the landscape and understand exactly which obstacles along the complete chain - from growing bamboo on the plantations in the (sub) tropics to marketing & sales of bamboo products in Western Europe - actually cause the small market share. This analysis proved to be highly rewarding. By interviewing almost a hundred relevant stakeholders along the chain worldwide in 2005 and 2006 (see respondents in appendix A), each providing a small piece of the puzzle, I developed a thorough understanding of the broad scope of problems causing the small market share of bamboo.

And here I was. I had finally gained the knowledge that made me indulge in this PhD research in the first place. But I was not there yet. Simply understanding the problem was not enough. I had not come this far just to analyze what was wrong, which is the easy part: I wanted to actually contribute to the solution to the problem. Through literature, interviews, but especially through working with design (students) I began to suspect that the active involvement of designers could actually solve some of the most important obstacles along the bamboo chain, and help the commercialization of bamboo materials as a suitable material for product design in Western Europe. By that time I had also acquired a full PhD position at the Faculty of Industrial Design Engineering (first in combination with the Cartesius Institute), which facilitated the continuation and implementation of my ideas. Together with designers Marco Groenen, José Vermeij (Design Platform Eindhoven), Hanneke van den Nieuwenhof (CBK de Krabbedans) and later Arjan van der Vegte (Moso International) we developed the Bamboo Labs concept, and successfully applied for external funding in 2006, after which the Dutch Design meets Bamboo project was launched in Fall 2006. The project proved to be a large source of inspiration, not only to the 21 participating designers whom I thoroughly interviewed before and after the design workshops, but also to the organization team. After the design workshops ended with the official opening of the exposition in May 2007, we had the feeling the project had been a success. Nevertheless, it was not until the impact analysis, executed as part of this research, that I became fully aware of the large impact and broad success of the intervention, which through the diffusion of the results is still increasing as we speak.

After the conclusion of the project one of the most difficult parts of the journey proved to be the analysis of the success of the intervention in the summer of 2007, and writing down the main findings of the research in this thesis (fall 2007-spring 2008). Although the writing process is very solitary, it also provides the opportunity to really analyze the PhD process retrospectively from a helicopter view. As a result I also began to consider anew my incentives to start on my bamboo journey seven years ago, which were sparked by the potential I saw in bamboo as a possible sustainable resource. By working at the Design for Sustainability program, the cradle of several eco-design approaches and LCA based models, I gained more insight over the years about the components impacting the environmental burden of products or materials the most. As a result, I started doubting the input data used in earlier LCA assessments for my MSc thesis, since most bamboo materials derive from China (environmental burden of transport) and industrial bamboo materials go through a lengthy and energy intensive production process. Since the incentive of my PhD research, including the design intervention, sprang from the presumed environmental sustainability of bamboo materials, I decided that to round up the circle and finish my journey in a satisfactory way I would need to perform additional environmental impact assessments for bamboo. Although these additional environmental assessments, executed from summer 2007 until spring 2008, slowed down the writing process considerably, they convinced me that my initial incentives to start on this journey were right and on several occasions (especially when used locally) bamboo materials can certainly be perceived as environmentally sustainable. More importantly, these assessments provided me with the drive to continue the journey for knowledge about the potential of renewable materials, since as I have found out over the last several years, the real gift lies in the process of the journey itself.

Pablo van der Lugt
July 2008

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Colophon

Design Interventions for Stimulating Bamboo Commercialization -
Dutch Design meets Bamboo as a Replicable Model
Pablo van der Lugt
PhD thesis Delft University of Technology, Delft, the Netherlands
Design for Sustainability (DfS) Program publication nr. 18
ISBN: 978-90-5155-047-4

English editing by Dr. Guido van Rijn and Cheri Wirthlin
Layout and coverdesign by Pablo van der Lugt
Printing by Scan Laser

Photo credentials (in alphabetic order):

Alexander Pelikan	Figure 7.25 (left)
Arienne Henkemans	Figure C4 (left & center)
Arjan van der Vegte	Main introduction figures of chapter 1, 2, 3, 5, 9 and references
	Figures: 1.7, 1.10, 1.11, 1.13 (right), 1.15, 2.9-2.12, 2.16, 5.20, 5.25, 6.11, 7.11, 7.16, 8.1-8.4, 9.10, C1, C2, and all figures in appendix I (except material samples)
	Picture in epilogue
Asus	Figure 9.8 (right)
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Fasting Fotografie	All pictures on cover
	Main introduction figure chapter 4
	Figures: 4.2-4.25, 4.27, 4.28, 4.30-4.34, 5.7, 5.11, 5.21, 6.6, 6.7, 6.10, 6.13, 6.14, 6.19, 6.21, 7.9 (right), and all pictures in appendix H
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Pablo van der Lugt	Figures: 1.12, 1.13 (left), 1.19, 2.5, 2.8, 2.13, 2.14 (except picture in center), 4.1 (right), 4.26, 4.35 (left), 5.1, 5.3, 5.9, 5.13, 5.15 (left), 5.16, 5.18, 5.25, 5.26, 5.32, 5.33, 5.36 (left), 6.4, 6.8, 6.18, 6.23, 7.4, 7.14, 7.15, 7.18, 9.13, 9.14 (right), 9.15 (left), 9.16, 9.18, C4 (right), C5, C6, D3, E2, E3 and pictures of material samples in appendix I
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Unknown	Figures: 1.22, 5.4, 5.15 (right), 5.23, 5.36 (right),9.1-9.4, 9.9, 9.14 (left & center), 9.17 and D4
Walter Liese	Figure 1.8
Wolfgang Eberts	Figure 1.6

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The book *Dutch Design meets Bamboo* (ISBN 978-90-74009-49-2) which can be perceived as additional appendix to this thesis, serving as product catalogue, can be ordered through www.zooproducties.nl

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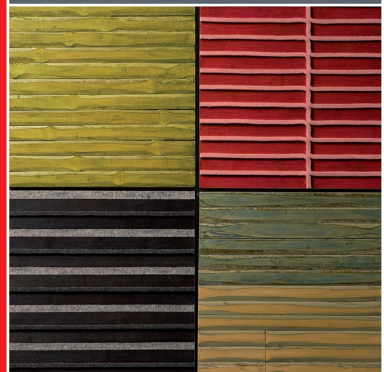
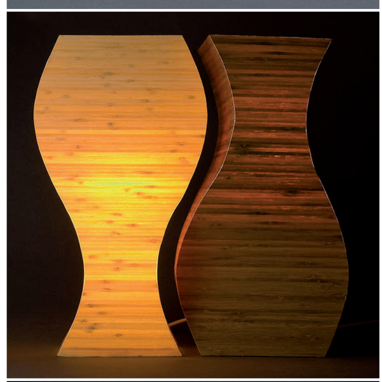
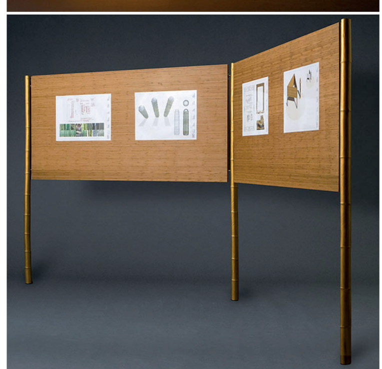
Curriculum Vitae

Pablo van der Lugt (Rotterdam, 1976) received his MSc degree at the Faculty of Architecture of Delft University of Technology where he graduated with honors for his MSc thesis about the economical and ecological (LCA) feasibility of the bamboo stem as a building material alternative in Western Europe. Intrigued by the subject and the potential of bamboo as a fast growing hard wood substitute he decided to further investigate the causes of the small market share of bamboo products in the West through his PhD research at the Design for Sustainability program at the Faculty of Industrial Design Engineering of Delft University of Technology. Besides analyzing the problem through various field studies at the production side in bamboo producing countries in Latin America and Asia as well as at the consumption side in Western Europe, part of his PhD focused on solving part of the problem through design workshops actively involving professional Dutch designers in the project named "Dutch Design meets Bamboo". The project, initiated and organized in collaboration with various organizations and companies, finished with a travelling exhibition, and received a lot of media attention and positive feedback because of the replicable hands-on approach. The prototypes developed during the project can be found in van der Lugt's book *Dutch Design meets Bamboo* (ISBN 978-90-74009-49-2, available through www.zooproducties.nl). Besides the book, van der Lugt has published his research in various scientific journals, technical reports as well as in popular magazines, and has given several lectures worldwide at international conferences about his research findings.







Delft University of Technology

Design for Sustainability program

Materials have a considerable impact on the environmental sustainability of the products in which they are used. Due to the increasing population and consumption worldwide, more raw materials are consumed than can be produced globally, making especially resource depletion of both abiotic and biotic resources an urgent problem.

Due to its good properties and high biomass production, bamboo - a giant grass - could have the potential to help meet the increasing demand for raw materials, especially as a substitute for scarce and slow growing tropical hardwood. Nevertheless, in Western Europe, bamboo, especially in industrial form, is still a largely unknown material with a small market share. In this action research it is investigated how the commercialization of bamboo may be stimulated in consumer durable markets through the active integration of designers as potential material champions by means of design workshops.

Besides providing insight into the effectiveness of this method and the potential replicability to deploy similar design interventions to stimulate the commercialization rate for other new or lesser known materials as well, this PhD thesis also presents the prototypes developed during the project "Dutch Design meets Bamboo" as well as the findings of the 21 participating Dutch designers about the potential of bamboo as a Western designer's material. Finally, the environmental sustainability of the various bamboo materials deployed during the design intervention is assessed based on LCA-methodology and annual yield predictions in order to reveal if bamboo is actually a more environmentally sustainable choice than timber.

DfS *publication no. 18*

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