BAMBOO, THE BUILDING MATERIAL OF THE FUTURE!

An experimental research on glueless lamination of bamboo.

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Figure 1 Bamboo pavilion concept (own illustration)

ABSTRACT

Bamboo, one of the most sustainable building materials we know today. Though, the market seems to be sceptical about its use for constructive elements. This might be explained by the fact that some structural standards still have to be proven. On the other hand cabinetmakers have already adopted (laminated) bamboo as a valuable material to make their products. These issues mainly apply to Western countries, whereas Eastern countries take a fundamental different approach. Bamboo is what they know as a material to make temporary structures or as a material for the poor, known as the 'poor men's timber'. Regarded as poor in the sense of poor quality on the one hand and affordable for the poor on the other. So, for bamboo to be accepted in Western countries we need to clarify technical data and comply with structural standards. In Eastern countries the challenge is to make people invent bamboo as a structural building material.

As the history of laminated bamboo lumber traces back only 10-15 years, developments are still going on. Laminated lumber is known to make use of different layers of wood, glued and pressed together. The same principals have been applied to bamboo, which turned out to be a more labour intensive process regarding the assemblage of a multiplicity of strips. Therefore bamboo, the grass, has difficulties to compete against comparable 'wooden' products. A future task will be to simplify the current production process in order to intensify sales. Moreover we need to come up with a solution to replace adhesives and make 'all-bamboo' materials.

Focussing on the Indonesian kampung this paper will discuss on feasibility as well. Why should we use bamboo as a building material for kampung housing specifically? What kind of operational or business model would you need to introduce laminated bamboo? And how do you involve communities in the production process? Questions to be asked in order to investigate if bamboo has a future within the kampung.

Next to the technical or material research on bamboo there will be elaboration on its use to produce housing, especially 'micro' housing. Kampung environments require maximized usable space on a minimized footprint, a microenvironment. Merging functions, transformability and flexibility will be relevant topics in this field.

In relation to the concept of a 'public workshop', which will be discussed as a business model, the idea of prefab housing will be connected as a line of inquiry. How to facilitate rigid houses for kampung residents having them involved in the construction process? Prefab housing will be assessed as a method to improve housing quality, continuing into production efficiency improvement.

Coen Kampinga, Delft 2015

KEYWORDS:
Bamboo – Laminated bamboo – Lamination methods – Splitting methods – Bamboo preservation – Bamboo design – Poor men's timber – Sustainable materials – Renewable resources – Fast growth – CO_2 footprint – Kampung environments – Kampung housing – Kampung development – Micro housing – Minimal footprint – Transformability – Flexibility – Prefab housing – Prefabrication - Manufactured – Modular – Factory-built – Factory-made – Public workshop – Craftsmanship – Self building

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INTRODUCTION

PROBLEM STATEMENT

As the kampung becomes a place for self-building, houses will be poorly constructed resulting in low lifetime. In order to increase craftsmanship workshops should be facilitated to carry out knowledge and skills to the local community. Regarding the approach towards bamboo in Indonesia nowadays people seem to refuse bamboo on principle. This approach is a result of the primitive use of bamboo throughout its history as a building material. In order to act different on the use of bamboo there are a few problems to address:

- The conception of bamboo as a 'poor men's timber' slows the development of bamboo used for kampung dwellings, so bamboo should be encountered as a valuable building material.
- Self built or community built housing leads to uncontrolled growth and low quality construction. Solutions have to be found to maintain community building while improving construction quality. Besides, the use of better suitable building methods should enhance efficiency.
- Indonesian climates are perfect for growing bamboo; unfortunately this is not acknowledged jet. Starting to grow bamboo locally could both improve air and soil quality striving for a sustainable future of the kampung. So, growing, harvesting, processing and constructing (with) bamboo has to be intensified locally.

From these observations the following problem statement can be erected:
The use of bamboo as a constructive (building) material has to be acknowledged by both housing development organizations and kampung residents. Relating this to the community strength of a kampung there has to be involvement of local people in order to convince them about the opportunities of bamboo to improve their environments.

OBJECTIVE

The formulation of the objective is twofold:
- Shifting the Indonesia kampung's approach of bamboo from poor man's timber to sustainable self-building material.
- Using the value of the kampung community and the strength of bamboo as a solid/rigid building material to strengthen each other.

Thus, both community engagement and upgrading bamboo as a building material are involved.

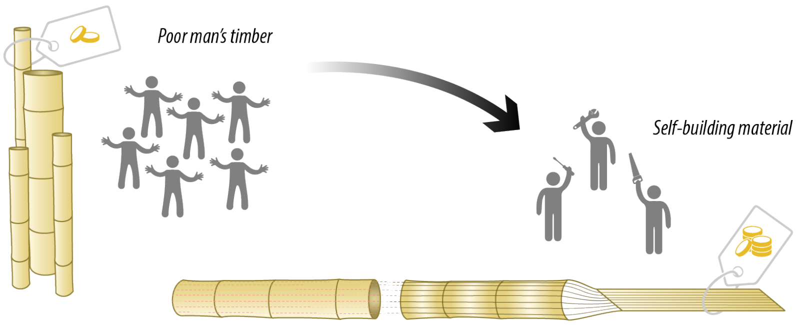

Figure 2 Upgrading bamboo (own illustration)

RELEVANCE

Increasing the use of bamboo will intensify local bamboo plantation and thereby the purification of the air and filtration of the soil. New ways of using bamboo in Indonesian kampungs will uplift the image of bamboo as a 'poor mans building material' towards a 'sustainable self-building material'. Integrating the use of bamboo with the tendency of self-building might improve craftsmanship and thereby the economic and environmental situation of kampung residents.

RESEARCH QUESTIONS

Having introduced the field of this research an overall design question and a technical research question will be extracted. The overall design question will be relevant in finding the right form, technique or system. The technical research questions tries to focus on a specific interest within the broader field of bamboo research. Most preferably a technical research generates input for the design process and visa versa. The concept of research by design will be followed in that sense (Hauberg, 2011, p. 51).

Ideas on community engagement to enhance local craftsmanship fascinated me to put forth the concept of a 'public workshop', producing prefab element to build safer housing. The following **OVERALL DESIGN QUESTION** was than distilled:
In what way can we reinvent bamboo and use it as a structural building material to produce safer housing units and increase local craftsmanship?

The technical research is concerned with the question 'how' bamboo could be reinvented in order to produce safer housing produced by local people. Besides, the environmental footprint and the efficiency of production processes in relation to laminated bamboo will be assessed. Research on these topics will be done based on the **TECHNICAL RESEARCH QUESTION**:
How to engineer a glueless laminated bamboo structure in order to change the image of bamboo, from the point of view of kampung residents, as a poor man's building material?

Another four **SUB QUESTIONS** will support the main question:
- What kind of bamboo structures can be relevant to improve construction properties in a low cost way?
- How is the image of bamboo constructed and how can we change it?
- Regarding the existing bamboo construction methods, how can they be used or recombined to improve both the aesthetic and constructive value?
- Which methods of glueless 'all-wood' joining exist and how can they be applied to bamboo?

RESEARCH METHODS

During a three-week fieldtrip in Bandung (Java, Indonesia) information will be gathered via questionnaires, both visual and textual. There will be a set of prepared question and visuals as well as spontaneous conversations obtaining valuable information. Secondly, literature studies will be done to embed this paper within the area of existing research on bamboo. At last, searching for the future of bamboo as a constructive building material in the kampung, experimental research or prototyping will be the most practical approach.

TECHNICAL RESEARCH RESULTS

PHYSICAL PROPERTIES

GROWTH

The word Bamboo comes from the botanical name 'Bambusa', which describes a family of 7-10 bamboo categories. The total amount of species is 1575 including the more wooden species and bamboo herbs. The diagram below indicates how the growth of bamboo species is spread around the world. Compared to the chart you can see that that these continents are all close to the Equator and therefore have a tropical climate. Heavy rain, a lot of sun and a high CO2 level make the optimal climate to grow bamboo.

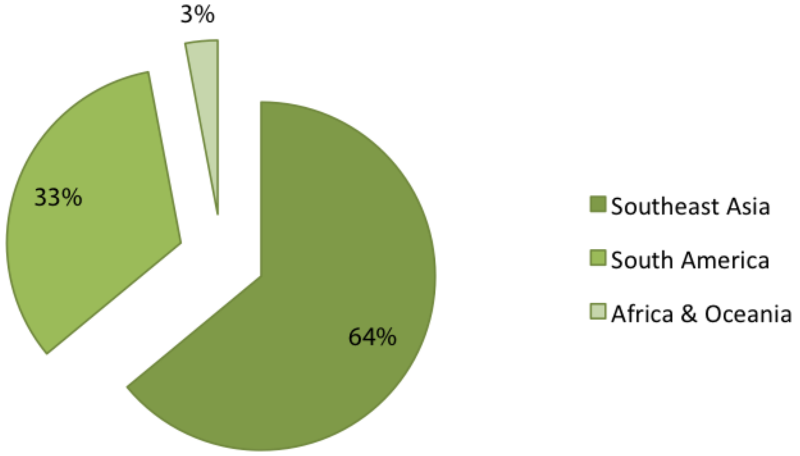

Figure 3 Bamboo growth distribution (Suhaily, Khalil, Nadirah, & Jawaid, 2013, p. 489)

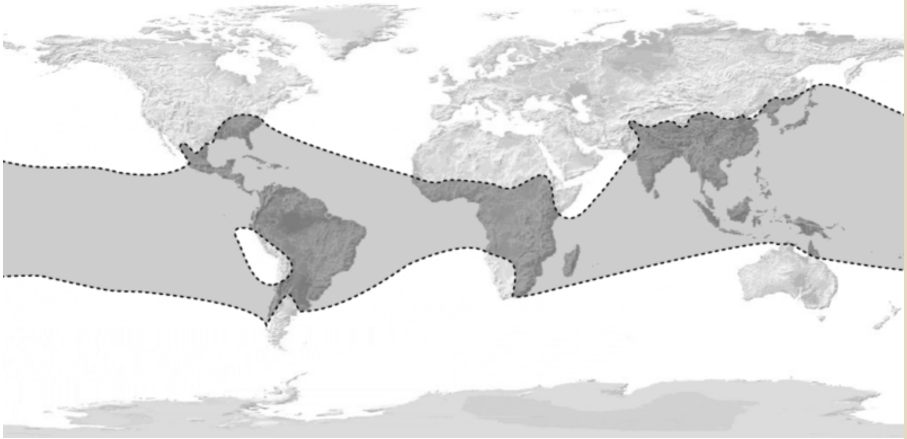

Figure 4 Bamboo growth areas ("Bamboo growing areas," 2014)

Thousands of years ago bamboo was already used in the way we can still see traditional huts/houses nowadays. Techniques how to join bamboo and techniques how to make paper from bamboo can also be dated around the same time. Next to the variety of culm uses bamboo has a soil protective function too. The picture illustrates how this soil regeneration works and that the plant uses it as nutrition. (Suhaily et al., 2013, p. 489)

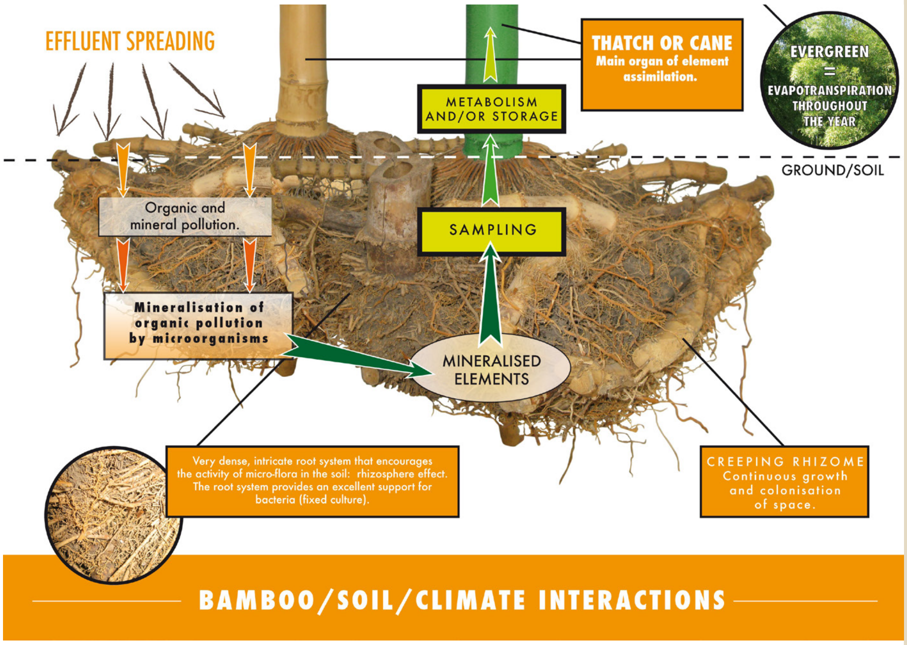

Figure 5 Bamboo soil regeneration (Phytorem, 2012, p. 6)

Knowing the anatomy of bamboo's root system we will continue to analyse its culm anatomy (figure 6). The culm/stem basically exists of nodes (seen from the outside) or diaphragms (seen from the inside) and internodes. Nodes are solid and therefore important for the strength, while internodes are hollow except for a few species (e.g. Guadua amplexifolia). Sizes of internodes, both thickness and length, vary between species and within the culm: shorter and thicker towards the roots, longer and thinner towards the tip. (Schröder, 2011)

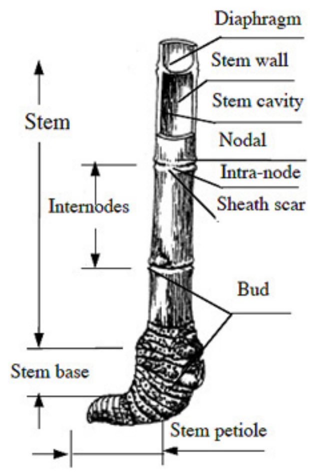

Figure 6 stem anatomy (GuaduaBamboo, 2011)

A story I was told about bamboo says: 'some people will not plant bamboo next to their homes as they think ghosts in the bamboo might kidnap their children' (by: Anzhari). According to other stories I was told it seems like there is multiplicity of superstition in Asia or at least in Indonesia. This turns out to be a potential barrier even if something is technically possible. For Indians bamboo is known as 'wood for the poor people', Chinese say 'friend of the people' and for Vietnamese people bamboo is 'the brother' (Dijk, 1997, p. 1).

The fact that bamboo is a well available product has lead to a culture of seeing bamboo as an easy to replace material. So, for a bamboo cladding it is being used as long as it lasts and replaced whenever the end of life is reached. Another observation, which is part of a habit and comes from the general belief that bamboo is in abundance.

Comparing bamboo (a grass) to other species of 'wood' it gets clear once again that bamboo is the far most sustainable plant to grow and use as a building material. One hectare of 5000 plants can generate 1000 plants a year to be harvested, resulting in a net mass of 15 m3 including losses. A calculation is made that this is enough to build 1 wooden frame house, as drawn in the scheme (figure 7), from this 1ha plantation each year. (Flander & Rovers, 2008, pp. 213-215)

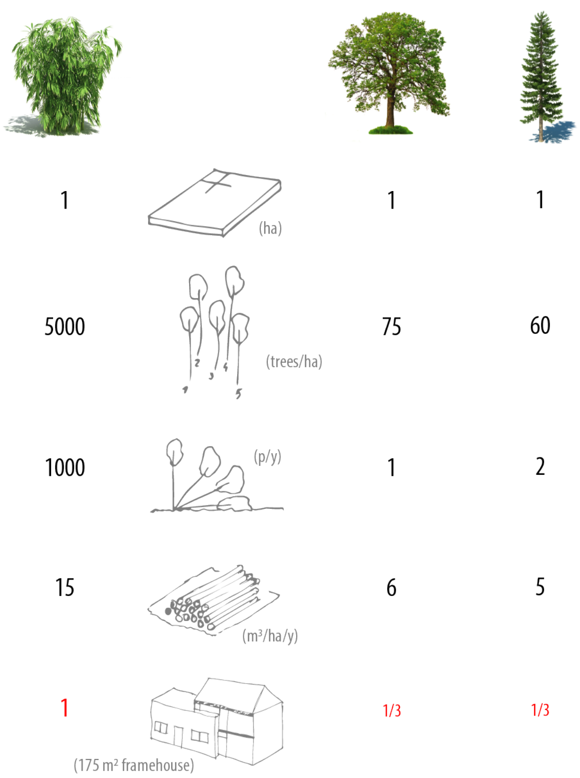

Figure 7 Bamboo growth numbers (own illustration)

It has to be taken into account that bamboo grows on its existing roots and therefore has no need to be replanted. All other wooden species will die after being harvested, which means lumps will be removed and new trees planted. The time to grow fully for bamboo is 3 to 5 years, oak and pine trees respectively need 60 and 40 years (figure 8). Within the same time oak can be harvested ones, bamboo can be harvested 12 times. Besides, bamboo treats the soil so well that we are left with a regenerated plot while oak and pine trees completely destroy the plot (Ripple, 2012).

Harvesting bamboo can be done best in dry season, as the starch (favourite food for pests) level is low at that time. Labelling shoots or taking the innermost culm of a clump can determine the age of bamboo culms, which is useful knowing when to harvest. After being harvested it is important to start a treatment process as soon, though the culms can be stored upright for a few days to get rid of on-going transpiration. This should not last long as there has to be moisture within the culm for further processing. (Garland, 2003, pp. 7-8)

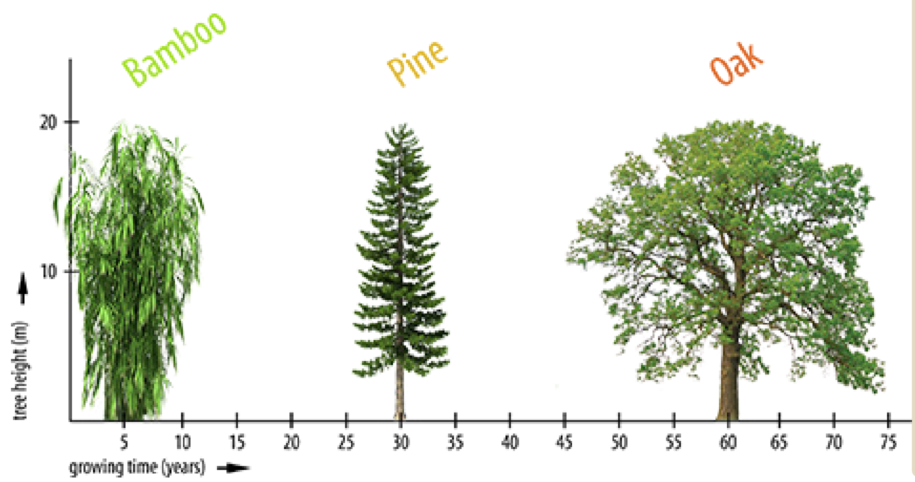

Figure 8 Growth graph (own illustration)

PRODUCTS

Figure 9 lists an overview of bamboo biobased composite materials that can be manufactured nowadays. It's interesting to see combinations of different materials in order to achieve better properties together. The use of all biodegradable products is highly ambitious and maybe not jet economically challenging enough, though these results show a great potential to further develop. For example Flakeboard and MDF can be easily made from waste at the Plybamboo process.

In order to better understand what strengths and weaknesses of bamboo as a building material are they have been listed below.

STRENGTHS:
- Compression (1/3 of tension strength)
- Tension (3 times as strong as in compression)
- Splitting easily along length
- Easy to (wood)work the material
- Ability to laminate
- Different appearances (culm use, fiber use, peeled use, laminated use, crushed use)

WEAKNESSES:
- Low bending strength if not laminated
- Weather sensitive (to be treated)
- Labour intensive to laminated at the moment.
- Splitting easily along length --> hard to make nail joints

Figure 9 Bamboo composites (own illustration)

STRUCTURAL PROPERTIES

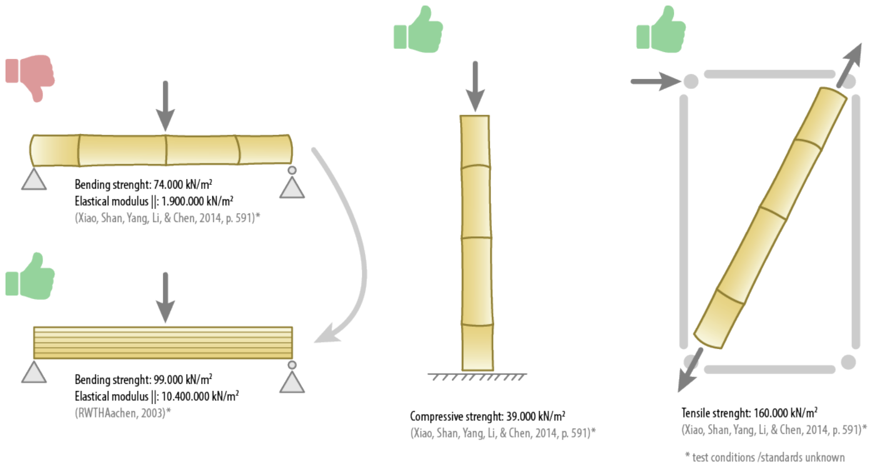

Figure 10 General structural properties of bamboo (own illustration)

kN/cm²	Spruce	Bamboo	Steel
Elastic modulus	1100	2000	2100
Compressive strength	4,3	6,2-9,3	14
Tension strength	8,9	14,8	16
Bending strength	6,8	7,6-27,6	14
Shearing strength	0,7	2,0	9,2

Figure 11 Structural properties compared (Gutu, 2013, p. 316)

ENVIRONMENTAL PROPERTIES

As already mentioned shortly within the introduction, bamboo is an extremely sustainable material due to its capacities of fixating CO_2 and filtering the soil. MOSO (2014) has drawn a comparison between the amount of CO_2 equivalent per kilogram of their products and between CO_2 equivalents per m3 among competing materials. Both diagrams present negative values, meaning bamboo to be CO_2 consuming instead of producing.

Another company called Phytorem is specialized in the use of bamboo for soil purification. They came up with a diagram (figure 14) on circularity, pointing out fast growth, production of dry matter (culms), conversion into biomass (energy production), water treatment and CO_2 conversion. So, bamboo produces energy on one hand and energy is recovered from the bamboos on the other. (Phytorem, 2010, p. 5)

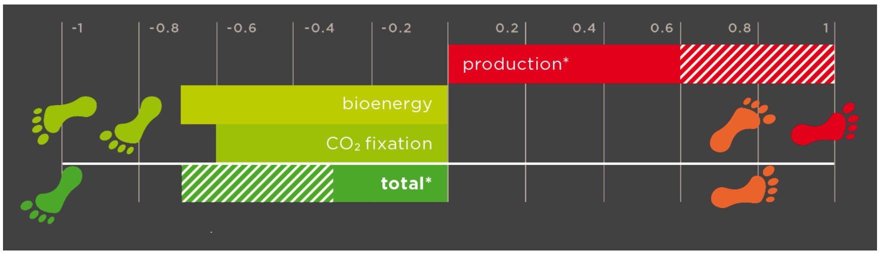

Figure 12 kg CO2 equivalent/kg product (MOSO, 2014)

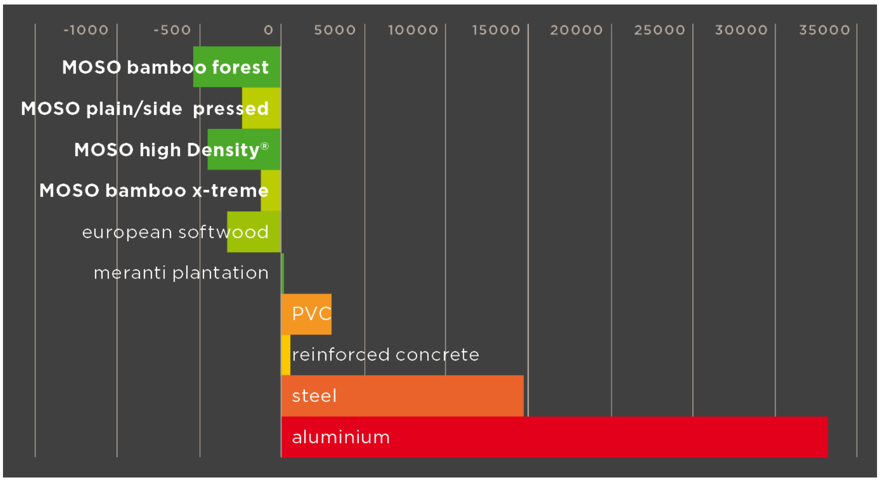

Figure 13 kg CO2 equivalent/m3 material (MOSO, 2014)

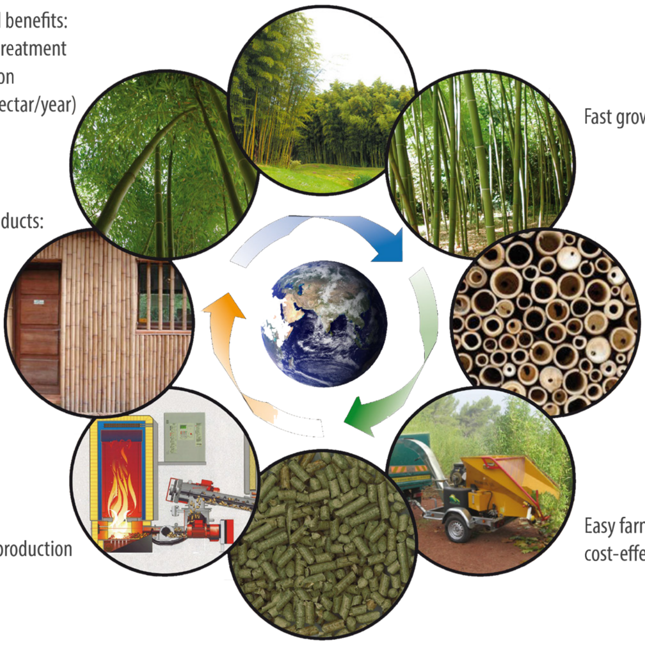

Figure 14 Circularity bamboo (Phytorem, 2010, p. 5)

DURABILITY

In relation to wooden species bamboo lacks certain chemicals responsible for better natural durability. Information on natural durability among different species of bamboo is still scarce. The bamboo culm differs from wooden beams by its cross section, hollow versus massive. In case of a fungi attack the wooden beam, rather then a bamboo culm, looses less strength if 2mm of the outer skin is destroyed. As we know moisture attracts fungi, tropical countries deal with this problem of low durability a lot. We have to note that these problems generally occur in culms, laminated cross sections act different. Figure 15 illustrates three situations using untreated bamboo, which can be related to three different service lives: **1.** 1-3 years; **2.** 4-6 years; **3.** 10-15 years. (Janssen, 2000, p. 52)

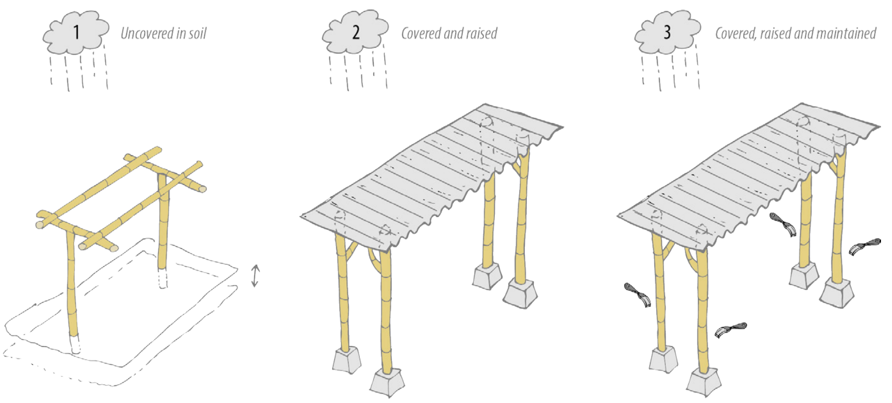

Figure 15 Applications related to service lifes (own illustration)

TRADITIONAL VS. MODERN USE

TRADITIONAL/POOR USE

Regarding the traditional uses of bamboo it can be concluded that the image of bamboo as a temporary structure has been created. Which is not necessarily a bad thing, as poor people will be able to use it as a building material. From these current uses we can derive the embedded strengths of bamboo. Tension as well as compression forces can be taken, while shear forces can only be taken by elements spanning short distances. Though it seems that the recognition of bamboo as a 'poor mans timber' might be problematic in reinventing the material.

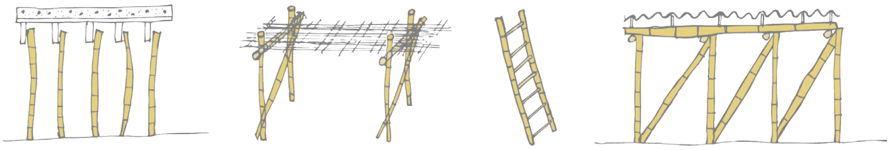

Figure 16 traditional bamboo uses (4 examples) (own illustration)

MODERN USE

Modern uses of bamboo are described by Pablo van der Lugt (2007), who is a PhD, MSc and Eng in architectural engineering and now head of sustainability & innovation at Moso International BV. Figure 17 gives an overview of the most often used applications for bamboo in Western countries nowadays: furniture, sheets and beams, frames and doors, kitchenware and flooring. Van der Lugt initiated a workshop to bring designers together and let them get in touch with bamboo. Designs were executed and bamboo was on the map, open for innovation. Within the coming years it is expected that bamboo will become increasingly challenging against wood. (Lugt, 2007, pp. 84-88)

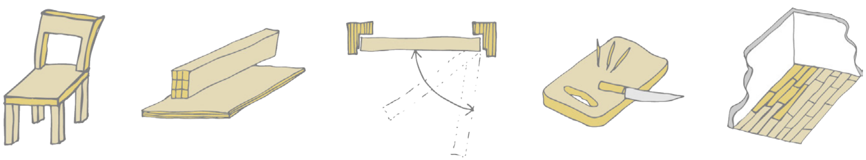

Figure 17 modern bamboo uses (5 examples) (own illustration)

Another analysis on the use of bamboo in both public and private buildings can be found in annex 1. Besides, the reference projects have been categorized by traditional (low-tech) and modern use (high-tech). It can be concluded that modern uses are mostly prestigious or pilot projects whereas traditional uses have more general applications.

THE MARKET

BUSINESS MODELS

Both the traditional and the modern model agree that loans/money is needed for a start up. Within the modern business model planting forests is not integrated as it focuses on creating knowledge resulting in skilled people that can run a workshop/factory. The traditional business model is searching for a direct payback in order to create interest for investors as well as craftsmen. Nevertheless there will be a financial payback within the idea of a 'public workshop', as housing elements will be sold. It would be interesting to know what is the effect of local people engagement on their recognition of bamboo. Meaning to address what are the crucial steps to be taken in the reinvention of bamboo as a valuable building material.

Figure 18 Traditional bamboo business model (Garland, 2003, pp. 27-28)

Design concept: ' **A Public Workshop'**

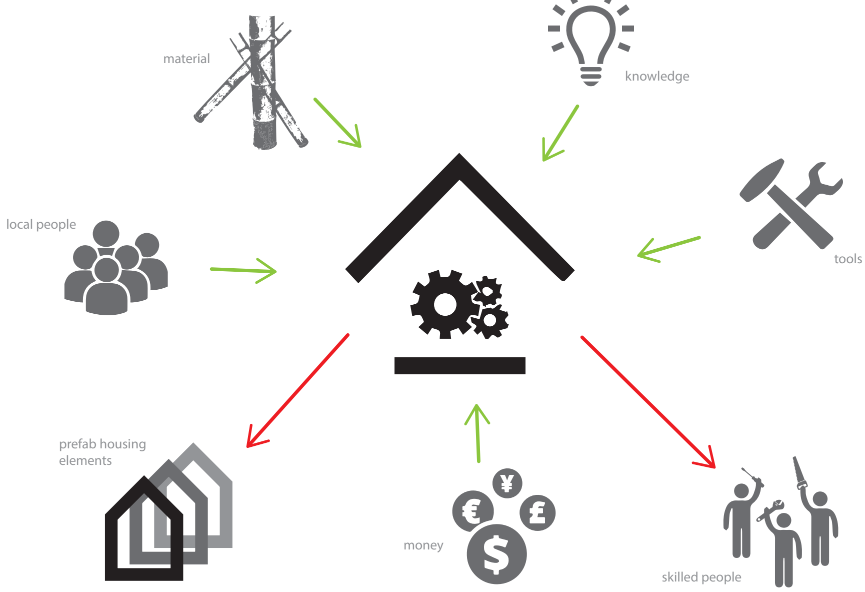

Figure 19 Modern bamboo business model (own illustration)

Although seeking for business opportunities is vital to achieve change we have to incorporate the role of communities, especially in kampung environments. Communities are not asking us to reinvent bamboo, on the contrary. They have a strong desire to build like Western countries propagating concrete and brick. So, a business model should give response to this tendency, maybe trying to relate bamboo to western societies as well. Based on questionnaires a voice of willingness can be extracted whenever they would be supported by means of knowledge and machines.

The proposition of a 'public' workshop relates to a strong community bond that can be further established within a communal workshop. Public means open source, so knowledge will be for free. A chain of knowledge will occur soon, which requires quality management. The value of a workshop should be acknowledged in order to avoid undesired growth, meaning people need to know this is not a place to make money. On the other hand, initiatives to create lucrative business can be established by creating space and funding to start a home shop of factory. Regarding the diagram in figure 20 and many other expectations there will be growth in almost all bamboo industries. For a kampung to think global is unrealistic, so the focus should be local. Interventions in a kampung create enough challenges not to be tackled by bamboo industries solely.

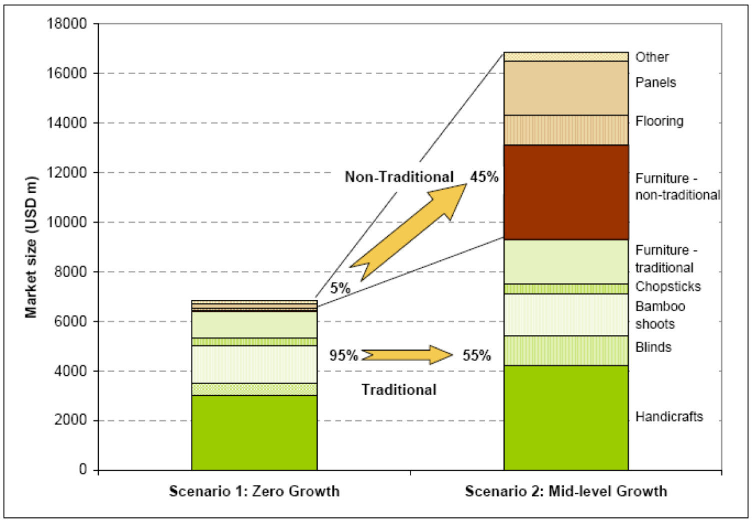

Figure 20 Two global bamboo scenarios (Oxfam-HongKong, 2006)

ANALYSIS

SWOT

A SWOT-analysis (figure 21) was drawn from test results and a market survey among participants from the Dutch bamboo-sector. Most strengths and opportunities arise from the sustainable image of bamboo compared to wood. Weaknesses and threats mainly arise from the fact that bamboo has no certificate, is prone to mould and has high starch content. For outdoor applications laminated bamboo seems to be distrusted by the Dutch market, as only bamboo composites are used outdoors. (Vos, 2010, p. 59)

STRENGTHS	WEAKNESSES
- Decorative material *- Green & trendy image*	*Unpreserved not durable -* *Glue bonds could delaminate -* *Susceptible to surface moulds -*
- Market open for trendy/decorative materials *- Interest in renewable resources* *- Government searches for sustainability*	*No marketing for exterior - applications* *Not (KOMO) certified -* *Image of low durability -* *Market's unfamiliarity -*
OPPORTUNITIES	THREATS

Figure 21 Bamboo SWOT-analysis (Vos, 2010, p. 59)

ADVANTAGES VS. DISADVANTAGES

Although bamboo pretends to be the 'wooden' construction material of the future there are some disadvantages to overcome (figure 22). Preservation is a major issue, whereas the fact that it is shaped by nature is more of an intrinsic property. Besides, you could question wether the natural shape of a culm is destructive in production processes.

ADVANTAGES	DISADVANTAGES
1. Light, strong and versatile	*Requires preservation .1*
2. Environmentally friendly	*Shaped by nature .2*
3. Accessible to the poor	*Low durability --> 5 years lifetime .3*
4. Self renewing resource	*Low structural jointing efficiency .4*
5. Fast growing	*Lack design and building codes .5*
6. Highly productive	*Culm friction in forest --> forest fires .6*

Figure 22 Advantages-disadvantages bamboo (Sharma, Dhanwantri, & Mehta, 2014, pp. 253-254)

PRESERVATION METHODS

PASSIVE

SMART STRUCTURAL DESIGN

The use of overhangs, raised columns and having the structure inside. (Garland, 2003, pp. 7-8)

Figure 23 ZERI pavilion Hannover (N/A, 2000)

ACTIVE

LEACHING

(4-12 WEEKS STORAGE IN WATER)

A traditional process often used by indigenous communities and farmers. In Latin America countries it is usual to transport the bamboos by the rivers as there are lots of remote areas. This journey, executed on bamboo rafts, takes 3 to 4 weeks. Within this time the bamboo becomes less susceptible to insects, however no guarantee for long-term protection can be given. After 4 weeks of immersion one can use the bamboos without further treatment. Immersing for longer then 3 months causes decrease of physical and mechanical properties. The advice will be to chemically treat the bamboo after passing the leaching process. ("Bamboo as a building material," 2002, p. 7)

Figure 24 Leaching bamboo (N/A, 2012)

SMOKING

A preservation technique that uses bamboo resin to smoke the culms. The process intents to create a distasteful skin in order to dislodge insects (Schröder, 2012). Smoke will blacken the culm and cracking might occur. This is the reason some people are in doubt about the durability of this method ("Bamboo as a building material," 2002, p. 7).

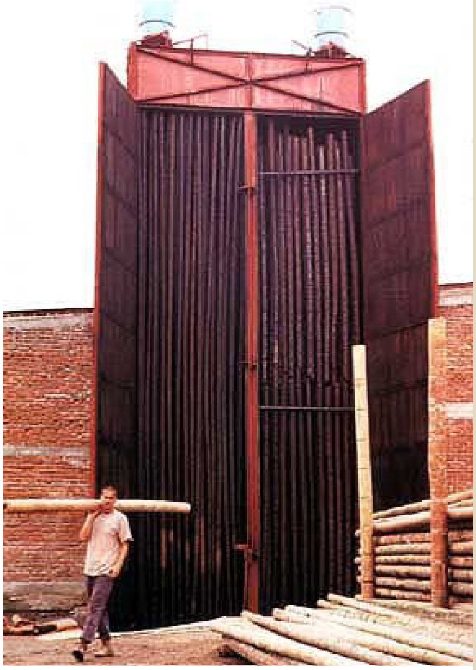

Figure 25 Smoking bamboo (N/A, 2015)

HEATING

Culms are shortly heated up to 150°C in large cylindrical kilns. The bark changes and becomes more resistant against insects. Cracking can easily occur within this process as well. Cooking the culms would be an improvement if it were easy to arrange such a solution practically. ("Bamboo Preservation | Practical Action," 2014, p. 1)

Figure 26 Oven dried bamboo (N/A, 2010)

CHEMICAL TREATMENT

Mostly coating with borax, a sodium borate mineral, are used. The use of insectices, such as DDT and PCP, has to avoided as it is ecologically unacceptable. Borax can be mixed with lime slurries, rangoo oil or other slurries from lime or cow dung. ("Bamboo as a building material," 2002, p. 7)

Figure 27 Chemical treatment (N/A, 2012a)

These methods preserve the bamboo to be protected against insects. Protection against fungi and mould has to be done by avoiding moisture. Therefore nor the diaphragms nor all segments/internodes have to be perforated. Regarding lifetime improvement, preserving bamboo enlarges lifetime by a factor of 4. Untreated bamboo lasts for approximately 2,5 years, treated bamboo around 10 years. ("Bamboo as a building material," 2002, p. 7)

PROCESSING TECHNIQUES

The existence of a variety of bamboo products implicates another variety of production technologies. We will focus on techniques for lamination as they are within the scope of this research. The illustration of 'plybamboo' as shown in figure 2 suggests that several layers of veneer result in a plybamboo plate. Although veneer is a thinner and therefore different product the principle of layering is valid. Layer thicknesses of bamboo, having a diameter of 100-200mm, range from 10mm to 20mm depending on which part of the culm is taken ("Bamboo as a building material," 2002, p. 8). It has to be taken into account that we discuss raw material dimensions. Depending on the process this culm will undergo there are different material thicknesses to be obtained. Next, the processing techniques that exist today will be described.

SPLITTING-SQUARING-LAMINATING

This method can be seen as the 'traditional' method for laminating bamboo. Splitting is done by a set of knifes configured in a star like shape. The culm of approximately 1,5m is then being pressed though these knives by a pneumatic force. The longitudinal grains of bamboo allow the knives to easily cut resulting in almost equal slats. As seen in figure 29 the splitting tool exists of another (central) element, which can be seen as the diaphragm remover. A solid metal cylinder will punch the diaphragm while the knives cut through the node. Nevertheless you will always see a bulge on the inner side of the node due to the fact that the diaphragms are punched instead of cut out. As soon as the splitter arrives at the node the diaphragm breaks loose from the node. In order to obtain nor a flat nor a radial strip post processing is inevitable.

In this case post processing is done by squaring, flattening the slat on all sides using a planer. This operation results in a strait slat having a rectangular cross section. The lamination process then involves putting together a pile of slats in different layers using glue as an adhesive and a press to obtain a flat plate. This plate will be squared and sanded, as the result from the press is a rough plate. Although this process concerns about a plate the process to make a beam is similar.

Figure 28 Splitting machine (N/A, 2003)

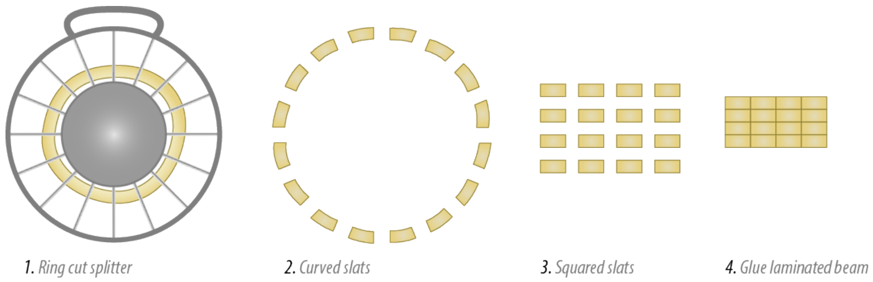

Figure 29 Splitting-squaring method (own illustration)

SPLITTING-PRESSING

The splitting part of this method is equal to the previous method, so we will continue the description of this method from there. The crucial difference compared to 'splitting-squaring' can be noticed in the size of the slats. Slats to be pressed are significantly bigger compared to slats for squaring. These shells, if pressed, will approximately be the height of the beam. By pressing the shells will crack on several points to allow this forced deformation. Afterwards an adhesive will be applied on the different layers, which will be pressed together pneumatically. The rough beam will then be squared on the short edges by a saw or planer. The outcome of this process can be seen in figure 30. Compared to the squaring process the dimension of the cross section is similar only the appearance is different.

An observation I got from this process is the fact that a lot of stress is introduced that has to be taken by the adhesive. Question is whether the adhesive or the bamboo fibers will fail nor in time nor by loading? According to Jorissen & Voermans (Vos, 2010) the limited glue bond strength has no influence on the laminated bamboo. In addition Vos (2009) tells us that the glue bond of Guadua is stronger compared to Moso. The answer to the question only concerns about the strength of the glue bond, while other materials can be weaker then the glue bond. Though in time I might expect delamination due to varying humidity levels that cause expansion and shrinkage.

Figure 30 Crushed bamboo beams (N/A, 2015a)

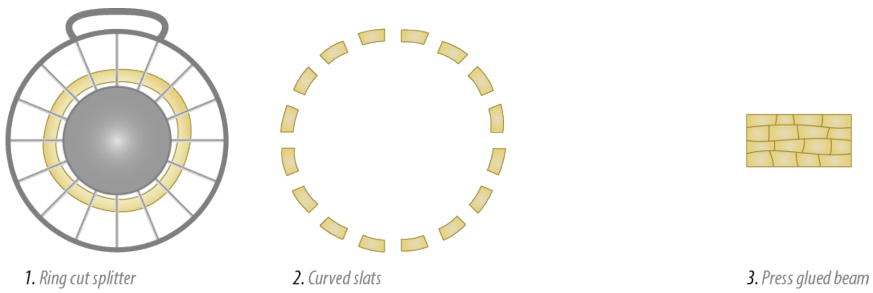

Figure 31 Splitting-pressing method (own illustration)

RADIAL STRIP LAMINATION

A method to lower labour intensity by making use of the radius within the slats obtained from the splitting machine. Due to a lack of knowledge on this method it's hard to recover how they deal with nodes. It seems this requires another step in production, which is flattening or actually curving the surface at the nodes. Furthermore I can imagine both the inner and outer surface need to be prepared before glue can be applied. This method might be a theoretical efficiency improvement that turns out to be less efficient in practice.

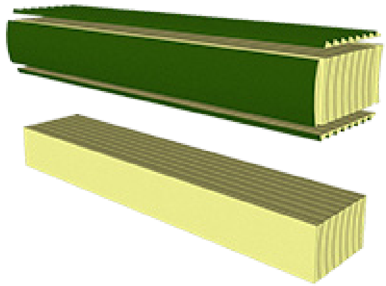

Figure 32 Radial strip lamination (N/A, 2011)

V-GROOVING (CULM UNROLLING PROCESS)

V-grooving can be seen as the method that proves how traditional splitting can be improved. The crucial difference is found in the fact that splitting will not occur. Instead of splitting the culm is grooved by a V-shaped saw blade, which leaves a minimum amount of the culm's section uncut. This keeps the slats together and can be flapped to become a flat stroke. Cracking will occur, although the slats keep connected by un-cracked fibres. Research done by Bakar, Sahrani, & Ashaari (2010) has proved that filling the grooves with an adhesive and adding pressure results in a strait element. The purpose for this element was to be flooring or decorative use, while this technique implies many other applications. For the process to become even more sustainable and accessible for kampung residents the adhesive has to be taken out.

Figure 33 V-grooving result
(Bakar et al., 2012, p. 177)

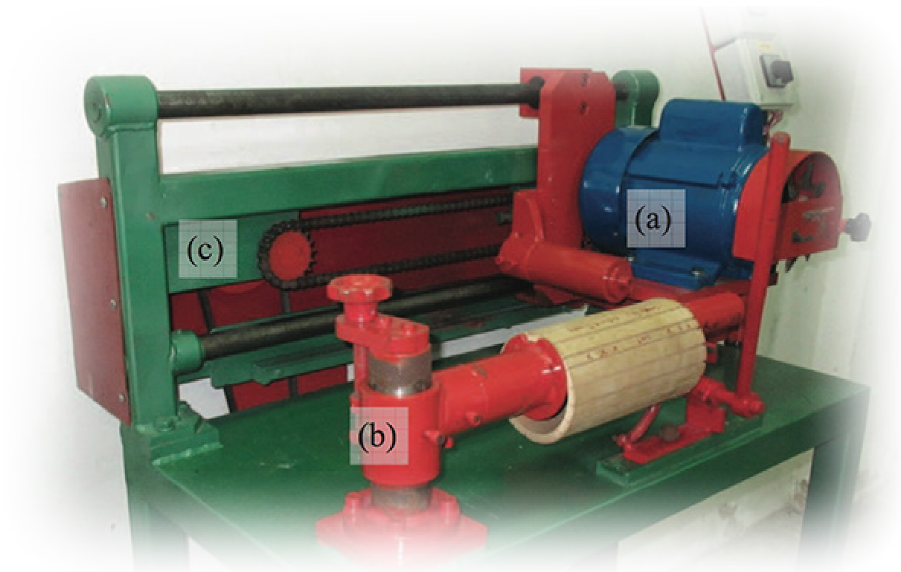

Figure 34 V-grooving machine
(Bakar et al., 2012, p. 175)

The V-grooving method is of specific interest, as it will later be used for prototyping. Prototyping will be done in three stages departing from the raw culm. First the challenge will be how to transform the culm into sheets of slats. This will be done using the V-grooving method, developed by Baker, Sahrani & Ashaari (2012). This method is developed to simplify the traditional lamination method for bamboo. The result is promising although there has to be experimented on layering, creating a real beam or plate. Splitting, flattening and recombining are replaced by cutting grooves while leaving the slats connected. This means an efficiency improvement as three steps can now be done in one. In the next stage there will be several sheets of slats to be combined using a mechanical bamboo joint without the use of glue or other additives. Arriving at the third and last stage it will be the goal to flatten the obtained beam. This proposed process is visualised in figure 35. Research of Bakar et al. (2012) even developed a table indicating the ratio between culm thickness, culm diameter and the grooving angle (annex 2).

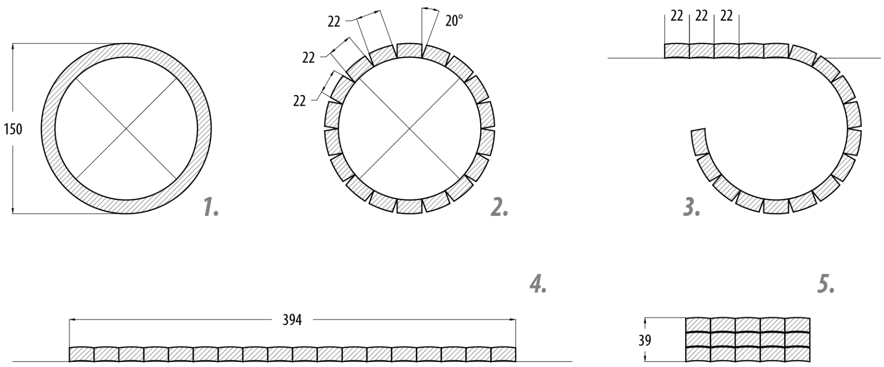

Figure 35 V-grooving process (own illustration)

The 'V-Grooving method and –machine' have been developed to lower labour intensity of the 'splitting-pressing' and 'splitting-squaring' methods. The splitting-squaring method can be used to produce laminated bamboo for decorative use whereas the splitting-pressing method results in a raw product. Regarding the steps to manufacture a laminated sheet by splitting and squaring there are a ten steps to be taken (figure 36). Regarding the V-Grooving method there are only 3 steps to be taken to achieve the same result (figure 35).

Figure 36 'splitting-squaring' process (N/A, 2012a)

PROTOTYPING

The prototyping process started finding a method to imitate the V-grooving machine. Three fundamental functions of the machine were important in doing so: 1. a placeholder for the culm, 2. an 80° V-shaped saw blade or router bit; 3. a sliding mechanism. The result was a reopen able wooden mould to insert the culm, a plunge router having an 80° bit installed and a guiding slot for the copying ring (figure 37).

Having obtained the flattened strips, three variants for mechanical joining were proposed each consisting of 3 layers. The first (top image), a vertical pin connection where the strips were positioned similar to a stretcher bond. Holes would then be drilled alternately, the one in the middle of a segment and the other on the connection of two segments. Over dried pin (having a low moisture value) should then be inserted and expand to equal the moisture concentration of the environment.

The second conceptual model combines vertical pins and horizontal pins that would avoid segments breaking apart, a concern that rose from the first model. Introducing a considerable amount of labour by proposing for this process a third concept should be found.

The last concept tries to combine a horizontal and vertical connection into one joining element/pin. Swallowtail shaped slots will be milled in the strips and a counter shaped pin is then inserted. A contractile effect, obtained by differing the dimension of the slots (bigger) from the dimension of the pin (smaller), provides the amount of friction sufficient for a rigid joint. In the end this concept for joining is used for the prototype.

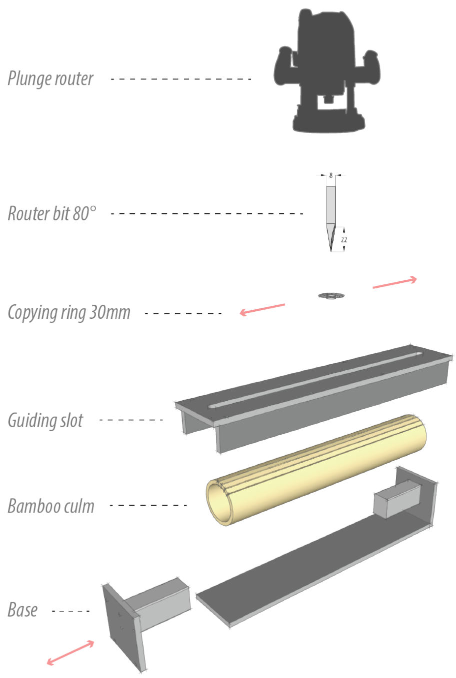

Figure 37 Imitated V-grooving process (own illustration)

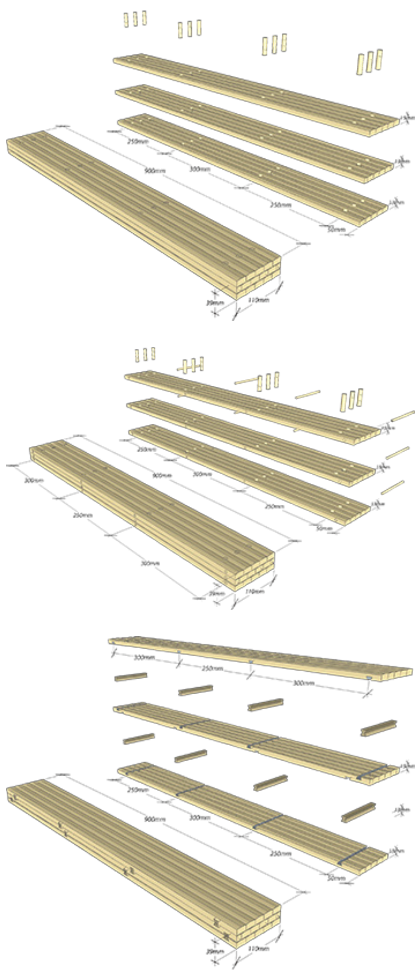

Figure 38 Three mechanical joining principles (own illustration)

Trying to bring theory to practice, prototyping turned out to be an efficient method. A combination of the existing 'V-grooving method' and developing a mechanical alternative for lamination was executed. Both the process and its results are shown in figure 40. Departing from a circular hollow cross section, following the illustrated steps, we have produced a solid rectangular cross section laminated without the use of an adhesive. Mechanical properties of this beam will be investigated by testing in laboratory circumstances. The ISO 13061-(1-17):2014 standard will be followed in order to equally compare result to wooden beams. ISO 13061-(1-17):2014 concerns 'Physical and mechanical properties of wood' divided in 17 parts describing the different properties. The most critical will be part 3: 'Determination of ultimate strength in static bending' (NEN, 2014). The test setup consists of a hinged and rolling imposition and force is applied in one point, situated in the exact middle of the beam (figure 39).

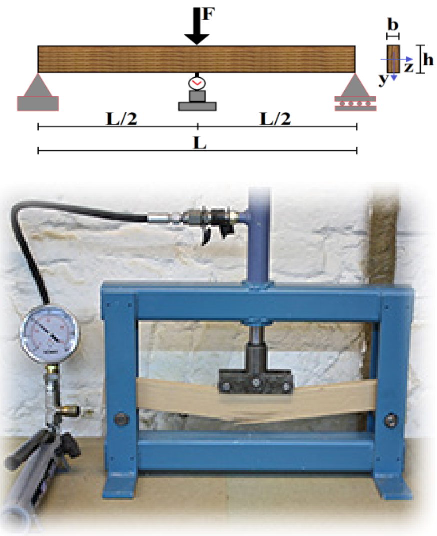

Figure 39 Static bending test (Christoforo, Lahr, Morales, Panzera, & Borges, 2012, p. 167)

Figure 40 Prototyping process (own illustration)

DESIGN RESEARCH RESULTS

MICRO HOUSING

Talking about 'micro housing' we mean housing that maximize usable space, while minimizing footprint. Quantitatively 45m2 floor area is allocated to 1-2 people living in these units. A few synonyms are being used: 'small house', 'tiny house' and 'micro appartment'. For example a definition of 'microappartment' is this: 'apodment or microflat, one room, self-contained living space, usually purpose built, designed to accommodate a sitting space, sleeping space, bathroom and kitchenette (total size: 4-10 m2) These rooms are designed for both futons (traditional Japanese floor matrasses) and pull-down beds. Besides pull-down beds, you can imagine folding desks and tables, hidden appliances etcetera. (Christie, 2013)

Gary Chang, a Chinese architect, designed a 45m2 microappartment using sliding walls. Built-in furniture allowed him to arrange 24 different rooms (figure 41) by using the same wall elements. A kitchen, library, laundry room, dining room, bar and video-game room are some examples of configurations he could make. According to Chang the bed folding mechanism used to be a necessary thing in the past, whereas nowadays we live in larger houses folding mechanisms allow for transformation, flexibility and maximizing space. Though, the city of Hong Kong is described by Chang as a place where home innovations will be crucial to restore social pressure caused by shortage of space for living. His system allows 4 people to live fully facilitated on the one hand and having a spacious room on the other. Using his own apartment as a continuous experiment, Chang is dedicated to upscale his ideas into new multi-unit buildings. (Gardiner, 2009)

Continuing on Chang's experiment it would be interesting to compare his ideas and demands on micro housing to the demands or needs of kampung housing. Minimization of footprint and maximization of functionality seems to be the common ground between these issues. The Chinese example will be both too high-tech and too expansive, though the concept of space utilisation is similar. For a kampung house we expect to design for 16m2 having primitive demands. A set of studies has been done on the optimization of facility integration in a 9m2 housing unit. Living, sleeping, cooking, eating and storage were taken as demands. A family of 2 parents and 4 children will be the residents. Figure 42 schematizes the merge of functions, departing from a full-scale house and merging into a unitized/micro house. The house will be surrounded by 1 meter private outdoor space even if units will be stacked, which implicates the use of balconies. Vertical transportation will occur via stairs departing/arriving from/at the balconies. Another requirement that will be added deals with the structural engineering. Elementary building will be crucial to follow the concept of a 'public workshop' that is discussed as business model earlier. The concept of 'prefab housing' is of specific interest in this. Fabricating a majority of elements in a local workshop will shorten construction time while improving quality. Within the following part of this chapter we will elaborate on this topic.

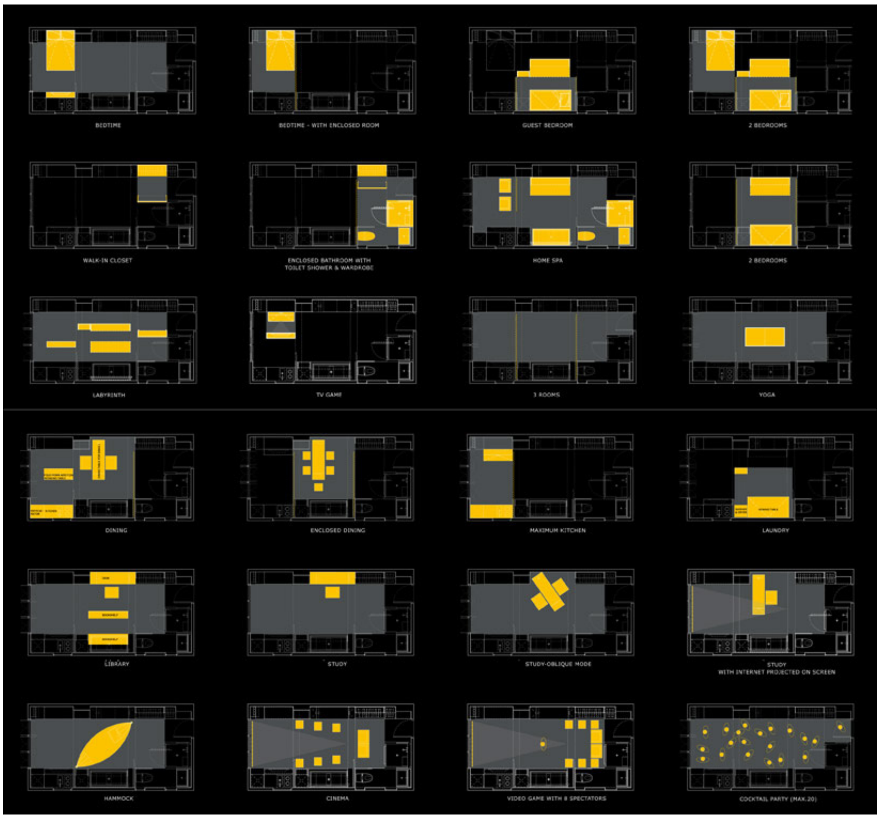

Figure 41 Microappartment configurations (24x) (Jordana, 2010)

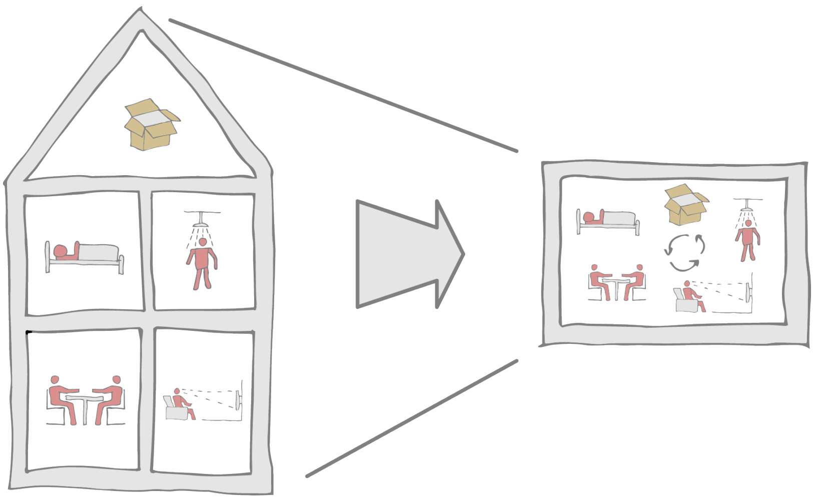

Figure 42 Function merge (own illustration)

PREFAB HOUSING

A definition of 'prefab' is given by Craven (2015): 'prefab is used to describe any type of home that is made from easy to assemble building parts that were manufactured offsite'. Synonyms can be found in the following words: Manufactured – Modular – Factory-built – Factory-made – Pre-cut – Panelized – Mobile.

According to TheFreeDictionary (2015) 'prefabricated' means: 'To manufacture (a building or section of a building, for example) in advance, especially in standard sections that can be easily shipped and assembled'.

Annex 3 presents a chronological overview on the history of prefabricated housing. The timeline brings us back to 1833, when the 'Balloon Frame' was introduced as the first posture of prefab housing. The introduction of 'cut-iron nails' was an improvement regarding building efficiency, as tenon joint could be avoided. Entire wall frames, constructed from posts, beams and bracing, were delivered and nailed together.

Throughout the history of prefabricated housing different styles, typologies and periods of architectural thinking passed by, which reinterpreted the notion of prefab housing repeatedly. Different approaches on form, function, materialisation, scale, context, etcetera can be noticed. An exhibition on this history was held by MoMa (2008), the Museum of Modern Art in New York, combined with a challenge between five contemporary concepts on 'Fabricating the Modern Dwelling'. The exhibition, called 'Home Delivery', challenges these five teams to elaborate on the lessons learned from the past and respond to the needs for the future. Final designs were then built 1:1 on the MoMA's West parking lot (annex 4).

Due to a difference in units, meaning sizes were not fixed, it is difficult to assess all entries wearing the same glasses. However, the use of different production methods and construction techniques can be used to carry out analysis. For example a SWOT-analysis might be useful to compare the projects qualitatively. Another qualitative analysis could be the use of surveys, collecting data from a fixed or random group of people.

There seems to be a close relation between 'micro housing' and 'prefab housing'. Micro housing deals with space efficiency, while prefab housing deals with construction efficiency. A relation between space and construction can easily be drawn, as space is created by construction. For most micro houses there is a need for prefabrication, as lots of functions merge in a tiny space. Innovative solutions for multifunctional usage require ingenuity mostly to be found in complex construction that could better be fabricated in a factory environment. On the other hand, prefab structures do not necessarily imply micro housing.

CONCLUSIONS & DISCUSSION

The driving force for changes in a kampung should be the community. Therefore, community engagement within the process of changing bamboo from a poor men's timber into a self-building material is crucial. Regarding the production of housing concepts of micro housing and prefab housing were discussed. Although the scale of a kampung living is different, sliding wall systems as applied by Chang (Gardiner, 2009) in his 45m2 apartment could improve flexibility of kampung houses too. As micro housing is about a merge of functions we are looking for smart customizable floorplans. Given a space of 9m2, which is assumed to be the interior size of a kampung house, transformability will be the most important objective in designing.

Prefabricated housing was investigated as a response to the current way of construction: self-building or built by a construction team. Prefab housing addresses the need for safer, modular and self-built housing. Safer, as production occurs in a workshop environment providing the right tools and safety measures. Modular, preparing elements of transportable sizes to be assembled on site later. And self-built, following the idea of a 'public-workshop' where local people get skilled to be involved in the production process of their own home or other's. Getting local people engaged providing them with tools and knowledge might even create local craftsmanship that they can use to better their economics. Figure 43 illustrates how this approach can upgrade the value of the material and the kampung both.

The use of bamboo as a construction material is emerging, though not widely accepted yet. According to Lugt (2007) bamboo will become increasingly challenging against wood, talking about West-European countries. In Asian countries quite a different tendency is noticed, as Western construction materials like stone, concrete and steel are preferred. Bamboo, the poor men's timber, is rather avoided due to a lack of knowledge and principal issues related to its poor status. A valuable alternative for using bamboo was found by prototyping. Searching for a glueless lamination method resulted in the beam presented in figure 40. Although official testing should be done the current result is promising and will be further developed. So, an alternative low-tech lamination technique was found, which is applicable for self-building by kampung residents.

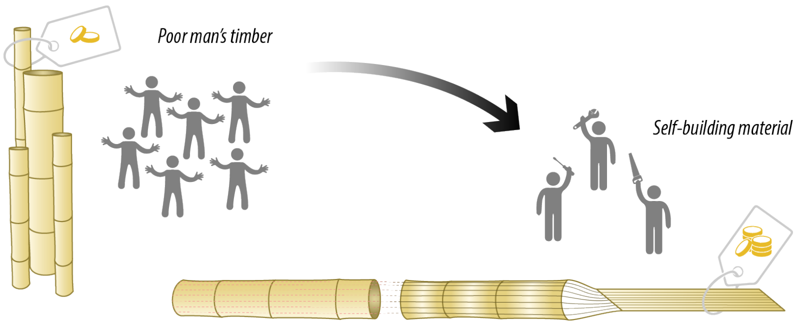

Figure 43 Upgrading bamboo (own illustration)

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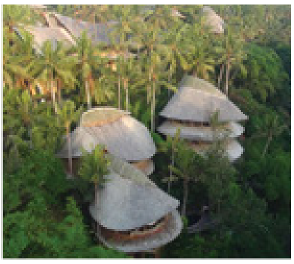
ANNEXES

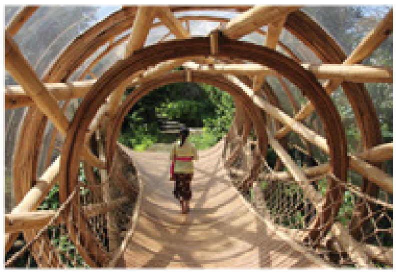
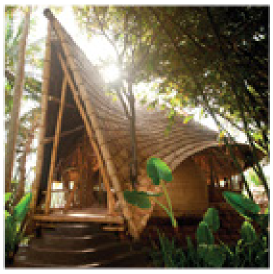
PUBLIC BUILDINGS

LOW-TECH

Low-tech, meaning unprocessed and non-standardized

Bali luxury bamboo village



Bali Green School

Jakarta bamboo Umbrellas

Vietnam thatched dome (bamboo support)

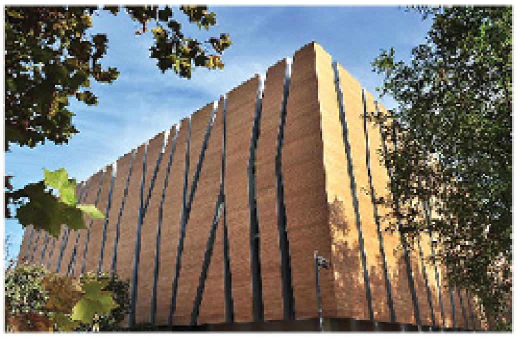

Vietnam toilet block


HIGH-TECH

High-tech, meaning standardized and converted into rectangular sections

Laminated bamboo structure (lamboo.us)

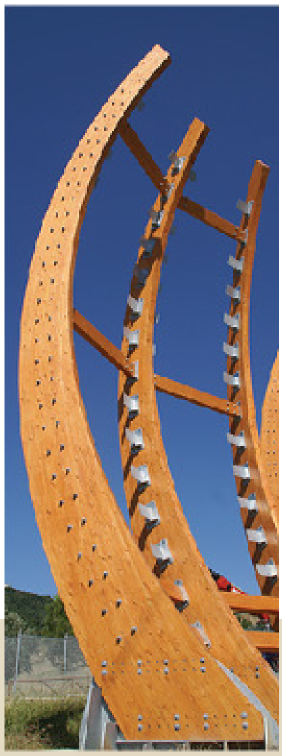
Parking (bamboo cladding)



Car shed (bamboo structure)

Structural bamboo

Curved laminated bamboo



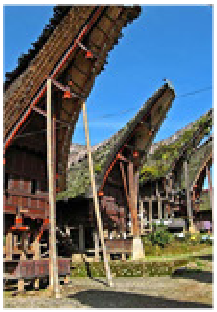
PRIVATE BUILDINGS

LOW-TECH

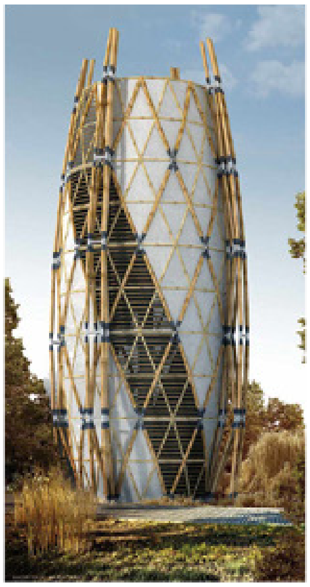
Low-tech, meaning unprocessed and non-standardized

Traditional housing

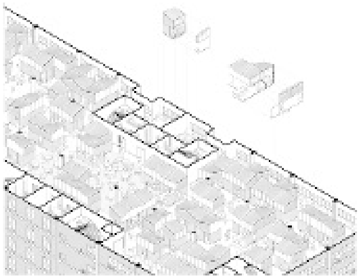




Cocoon housing Bali

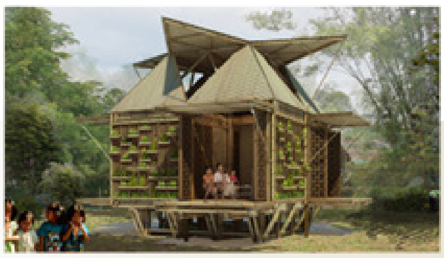
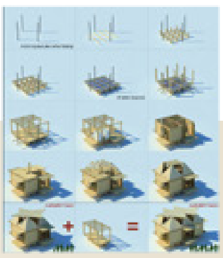


Micro housing Bali

Prefab housing

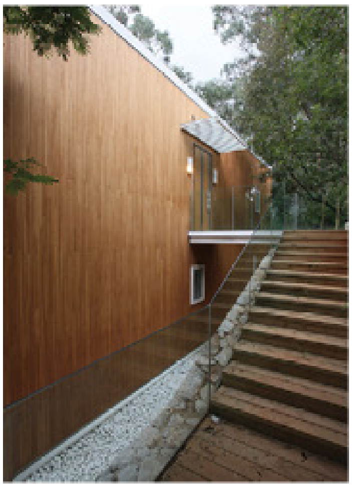

Flood proof housing

HIGH-TECH

High-tech, meaning standardized and converted into rectangular sections

China integer Bamboo House



Crushed Bamboo structural beams


Curved laminated bamboo

Nicaragua bamboo housing

ANNEX 2 GROOVING TABLE (BAKAR ET AL., 2012)

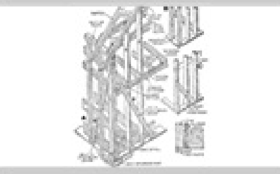
Thick (mm)	Diam. (mm)	Grooving Angle 15°	20°	25°
8	100	11.22	14.96	18.73
	102	11.50	15.32	19.19
	104	11.77	15.68	19.64
	106	12.04	16.04	20.09
	108	12.31	16.40	20.54
	110	12.59	16.77	21.00
	112	12.86	17.13	21.45
	114	13.13	17.49	21.90
	116	13.41	17.85	22.35
	118	13.68	18.22	22.81
	120	13.95	18.58	23.26
	122	14.23	18.94	23.72
	124	14.50	19.31	24.17
	126	14.78	19.67	24.62
	128	15.05	20.03	25.08
	130	15.33	20.40	25.53
	132	15.60	20.76	25.99
	134	15.88	21.13	26.44
	136	16.15	21.49	26.90
	138	16.43	21.86	27.35
	140	16.70	22.22	27.81
	142	16.98	22.59	28.27
	144	17.25	22.95	28.72
	146	17.53	23.32	29.18
	148	17.81	23.68	29.63
	150	18.08	24.05	30.09
9	100	10.93	14.57	18.26
	102	11.20	14.93	18.71
	104	11.47	15.29	19.16
	106	11.75	15.65	19.61
	108	12.02	16.02	20.06
	110	12.29	16.38	20.51
	112	12.56	16.74	20.96
	114	12.83	17.10	21.41
	116	13.10	17.46	21.87
	118	13.38	17.82	22.32
	120	13.65	18.18	22.77
	122	13.92	18.54	23.22
	124	14.19	18.91	23.68
	126	14.47	19.27	24.13
	128	14.74	19.63	24.58
	130	15.01	19.99	25.04
	132	15.29	20.36	25.49
	134	15.56	20.72	25.94
	136	15.83	21.08	26.40
	138	16.11	21.45	26.85
	140	16.38	21.81	27.30
	142	16.66	22.17	27.76
	144	16.93	22.54	28.21
	146	17.21	22.90	28.67
	148	17.48	23.27	29.12
	150	17.76	23.63	29.58

Thick (mm)	Diam. (mm)	Grooving Angle 15°	20°	25°
10	100	10.65	14.20	17.79
	102	10.92	14.56	18.24
	104	11.19	14.92	18.69
	106	11.46	15.27	19.14
	108	11.73	15.63	19.59
	110	12.00	15.99	20.04
	112	12.27	16.35	20.49
	114	12.54	16.71	20.94
	116	12.81	17.07	21.39
	118	13.08	17.43	21.84
	120	13.35	17.79	22.29
	122	13.62	18.16	22.74
	124	13.90	18.52	23.19
	126	14.17	18.88	23.64
	128	14.44	19.24	24.10
	130	14.71	19.60	24.55
	132	14.98	19.96	25.00
	134	15.26	20.32	25.45
	136	15.53	20.69	25.90
	138	15.80	21.05	26.36
	140	16.07	21.41	26.81
	142	16.35	21.77	27.26
	144	16.62	22.13	27.72
	146	16.89	22.50	28.17
	148	17.17	22.86	28.62
	150	17.44	23.22	29.08
11	100	10.36	13.82	17.32
	102	10.63	14.18	17.77
	104	10.90	14.54	18.22
	106	11.17	14.90	18.67
	108	11.44	15.26	19.12
	110	11.71	15.62	19.57
	112	11.98	15.98	20.01
	114	12.25	16.33	20.46
	116	12.52	16.69	20.91
	118	12.79	17.05	21.36
	120	13.06	17.41	21.81
	122	13.33	17.77	22.26
	124	13.60	18.13	22.71
	126	13.87	18.49	23.17
	128	14.14	18.85	23.62
	130	14.42	19.21	24.07
	132	14.69	19.57	24.52
	134	14.96	19.93	24.97
	136	15.23	20.30	25.42
	138	15.50	20.66	25.87
	140	15.77	21.02	26.32
	142	16.05	21.38	26.78
	144	16.32	21.74	27.23
	146	16.59	22.10	27.68
	148	16.86	22.46	28.13
	150	17.14	22.83	28.59

Thick (mm)	Diam. (mm)	Grooving Angle 15°	20°	25°
12	100	10.09	13.45	16.86
	102	10.35	13.81	17.31
	104	10.62	14.17	17.75
	106	10.89	14.53	18.20
	108	11.16	14.89	18.65
	110	11.43	15.24	19.10
	112	11.70	15.60	19.55
	114	11.97	15.96	20.00
	116	12.24	16.32	20.45
	118	12.51	16.68	20.89
	120	12.78	17.04	21.34
	122	13.05	17.40	21.79
	124	13.32	17.75	22.24
	126	13.59	18.11	22.69
	128	13.86	18.47	23.14
	130	14.13	18.83	23.59
	132	14.40	19.19	24.04
	134	14.67	19.55	24.49
	136	14.94	19.91	24.94
	138	15.21	20.27	25.39
	140	15.48	20.63	25.85
	142	15.75	20.99	26.30
	144	16.02	21.35	26.75
	146	16.29	21.71	27.20
	148	16.57	22.08	27.65
	150	16.84	22.44	28.10
13	100	9.81	13.09	16.40
	102	10.08	13.44	16.85
	104	10.34	13.80	17.29
	106	10.61	14.16	17.74
	108	10.88	14.52	18.19
	110	11.15	14.87	18.64
	112	11.42	15.23	19.08
	114	11.69	15.59	19.53
	116	11.96	15.95	19.98
	118	12.22	16.30	20.43
	120	12.49	16.66	20.88
	122	12.76	17.02	21.33
	124	13.03	17.38	21.77
	126	13.30	17.74	22.22
	128	13.57	18.10	22.67
	130	13.84	18.46	23.12
	132	14.11	18.82	23.57
	134	14.38	19.17	24.02
	136	14.65	19.53	24.47
	138	14.92	19.89	24.92
	140	15.19	20.25	25.37
	142	15.46	20.61	25.82
	144	15.73	20.97	26.27
	146	16.00	21.33	26.72
	148	16.27	21.69	27.17
	150	16.54	22.05	27.62

ANNEX 3 'HISTORY OF PREFABRICATED HOUSING' (MOMA, 2008)

1833

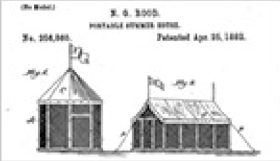


A. Taylor - Balloon frame

1833-1840

H. Manning - Manning Portable Colonial Cottage for Emigrants

1882

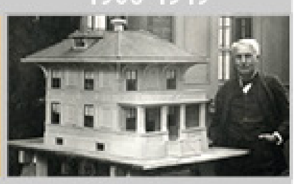


N.G. Rood - Portable Summer House

1892-1995

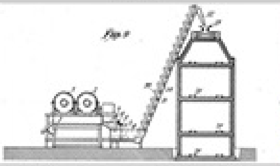
E.F. Hodgson - Hodgson Houses

1906-1919



T.A. Edison - Singel Pour Concrete System

1908

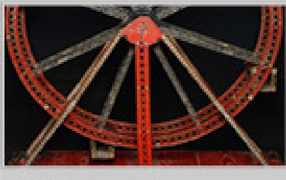


T.A. Edison - Process of Constructing Concrete System

1908-1940

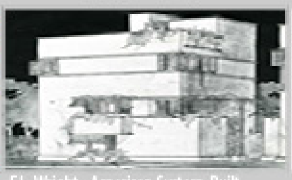
Sears, Roebuck and Company - Sears Catalogue Homes

1911



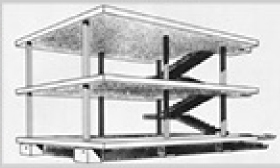
A.C. Gilbert - Erector Set

1911-1917



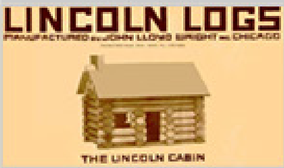
F.L. Wright - American System-Built Houses

1914-1915



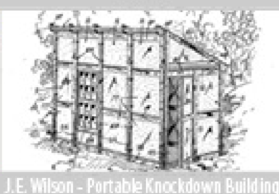
Le Corbusier - Maison Dom-ino

1916-1917



J.L. Wright - Lincoln Logs

1919



J.E. Wilson - Portable Knockdown Building Structure

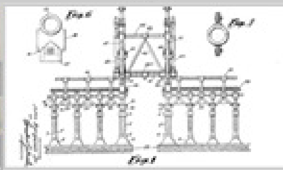
1920

N/A - Buster Keaton's One Week

1922-1923

W. Gropius - Baukasten

1927

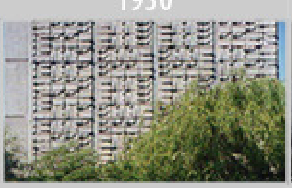


J. Bergesen - Portable Metal Structure

1927

R. Buckminster Fuller - Dymaxion House

1930

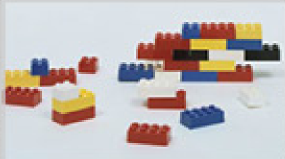


N/A - Plattenbauten

1931-1942

W. Gropius - Copper Houses

1932



O.K. Christiansen - LEGO Building Bricks

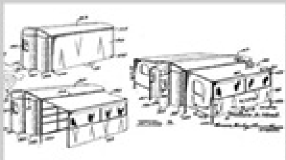
1933-1934

G.F. Keck - Keck Crystal House

1933-1934

H.A. O'Dell - Good Housekeeping Stran-Steel House

1935



W.B. Stout - Portable Building Structure

1936

F.L. Wright - Jacobs House

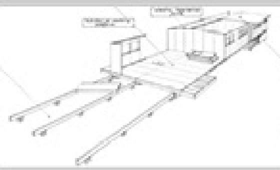
1941

P. Dejongh & O. Brandenberger - Quonset Hut

1941-1952

K. Wachsmann - Packaged House / General Panel System

1942



M. Breuer - Yankee Portables

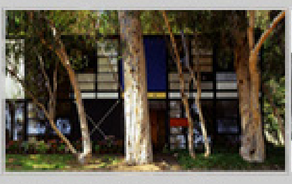
1943

M. Breuer - Plas-2-Point House

1944-1946

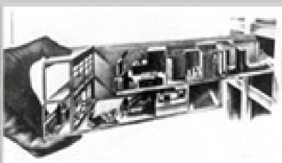
R. Buckminster Fuller - Wichita House

1945-1949



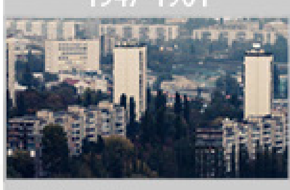
C. Eames - Case Study House no.8

1947-1952



Le Corbusier - Unité d'Habitation

1947-1961



N/A - Khrushchovkas

1948-1950

C.G. Strandlund - Westchester Two-Bedroom Model House

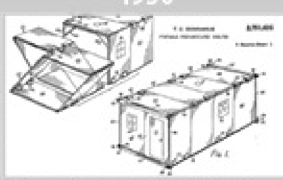
1948-1953

J. Prouvé - Tropical House (Maison Tropicale)

1949

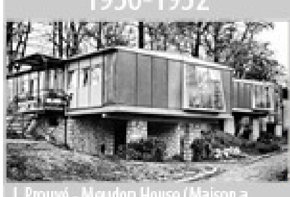
J. Prouvé - House for a Primary School Headmistress, Bouqueval, France

1950



T.C. Donahue - Portable Prefabricated Shelter

1950-1952

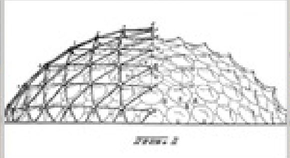


J. Prouvé - Meudon House (Maison a Meudon)

1956

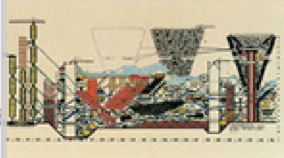
I. Schein - All Plastic House

1957



R. Buckminster Fuller - Geodesic Tent

1962-1964

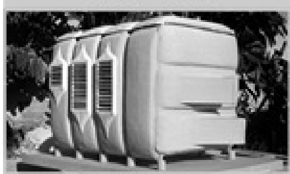


P. Cook - Plug-In City

1962-1967

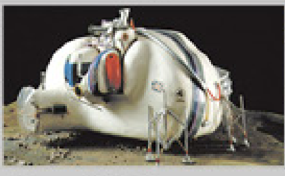
M. Safdie - Habitat '67

1964-1968



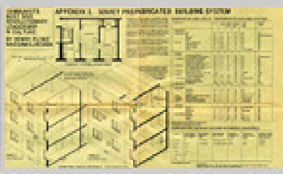
H. D'Acosta & M. Álvarez - Asbestos Cement Housing Module

1965



D. Greene - Living Pod

1965



G. Maciunas - Maciunas Prefabricated Building System

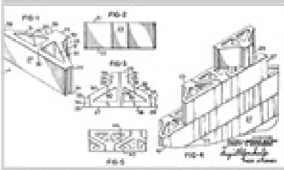
1965-1969

E. Huth & Domenig - Stadt Ragnitz

1965-1972

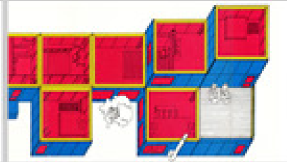
R.J. Dietrich & B. Steigerwald - Metacity Building System (Metastadt-Bausystem)

1967



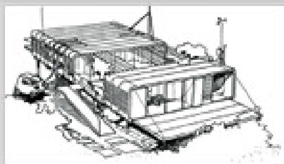
A.L. Koche - Building Block and Wall Made Therefrom

1968-1969



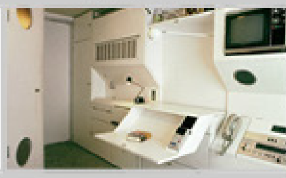
A.J. Diamond & B. Myers - Stelco Catalogue Housing

1968-1971



R. Rogers & S. Rogers - Zip-Up Enclosures Nos. 1 and 2

1968-1972

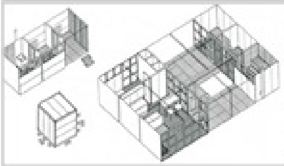


K. Kurokawa - Nakagin Capsule Tower

1968-1978

M. Suuronen - Futuro House

1969-1971



K. Gullichsen & J. Pallasmaa - Moduli 225

1970-1971

P. Rudolph - Oriental Masonic Gardens

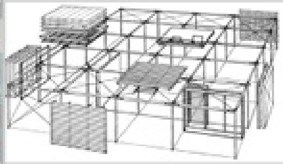
1972-1985

Z. Hecker - Ramot Housing

1982-1984

J. Benthem & M. Crouwel - Almere House

1983

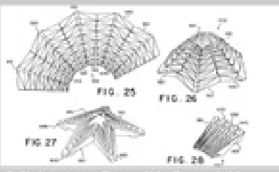


R. Horden - Yacht House

1986-1987

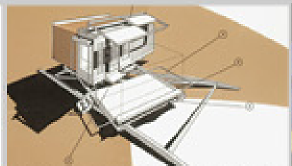
W. Kishi - Kim House

1991



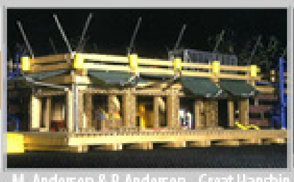
C. Hoberman - Reversibly Expandable Structure

1994



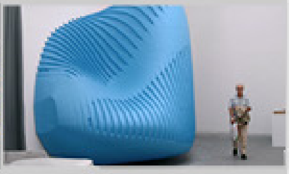
W. Jones - Hesselink Guest Hut/Container House

1995



M. Anderson & P. Anderson - Great Hanshin (Kobe) Earthquake Community Shelter

1997-2002



G. Lynn - Embryological House

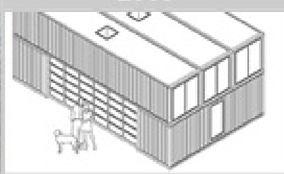
1998

W. Jones - Primitive Hut

1998 - 2000

M. Heikkinen & M. Komonen - Touch House (Laavu)

2000



A. Kalkin - Quik House Variations

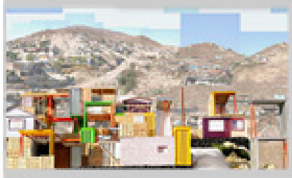
2000

M. Jantzen - M-Vironments/M-House

2004

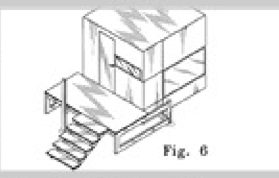
MUJI - MUJI House I by Kazuhiko Namba

2005



T. Cruz - Maquiladora

2007

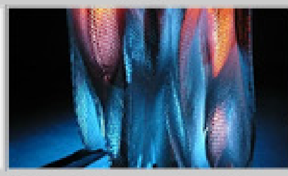


R. Horden - Micro Compact Home

2008

A. Rahim & H. Jamelle - Migrating Formations

2008



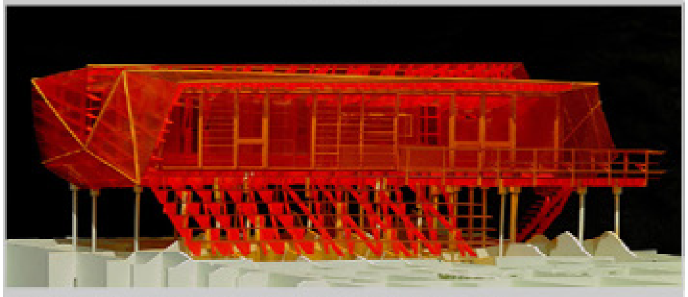
J. Reiser & N. Umemoto - Vector Wall

2008

Kengo Kuma & Associates - Water Block House Fragments

ANNEX 4 HOME DELIVERY:
FABRICATING THE MODERN DWELLING (MOMA, 2008)

Burst*008

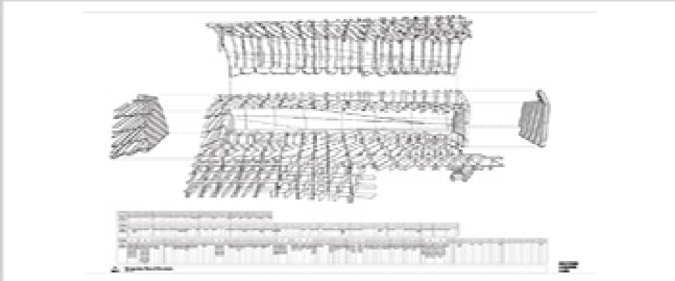


The 'kit' home || 'Prefab isn't about saving money; it's about controlling risk'

Micro Compact Home

'Smart living for a short stay' || 'Modern machine for living'

Burst*008

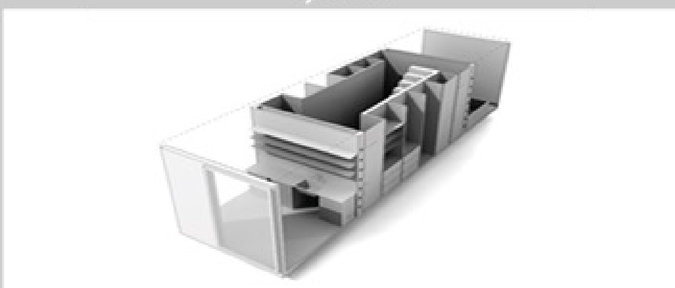


The 'kit' home // 'Prefab isn't about saving money; it's about controlling risk'

System3

Single unit, two space types: 'serving space' & 'naked space'

System3



Single unit, two space types: 'serving space' & 'naked space'

Housing for New Orleans

Highly digital process one day <-> hammering and wedging the next day

Cellophane House

Framework infill with off the shelf entities --> highly customizable

Housing for New Orleans

Highly digital process one day <-> hammering and wedging the next day