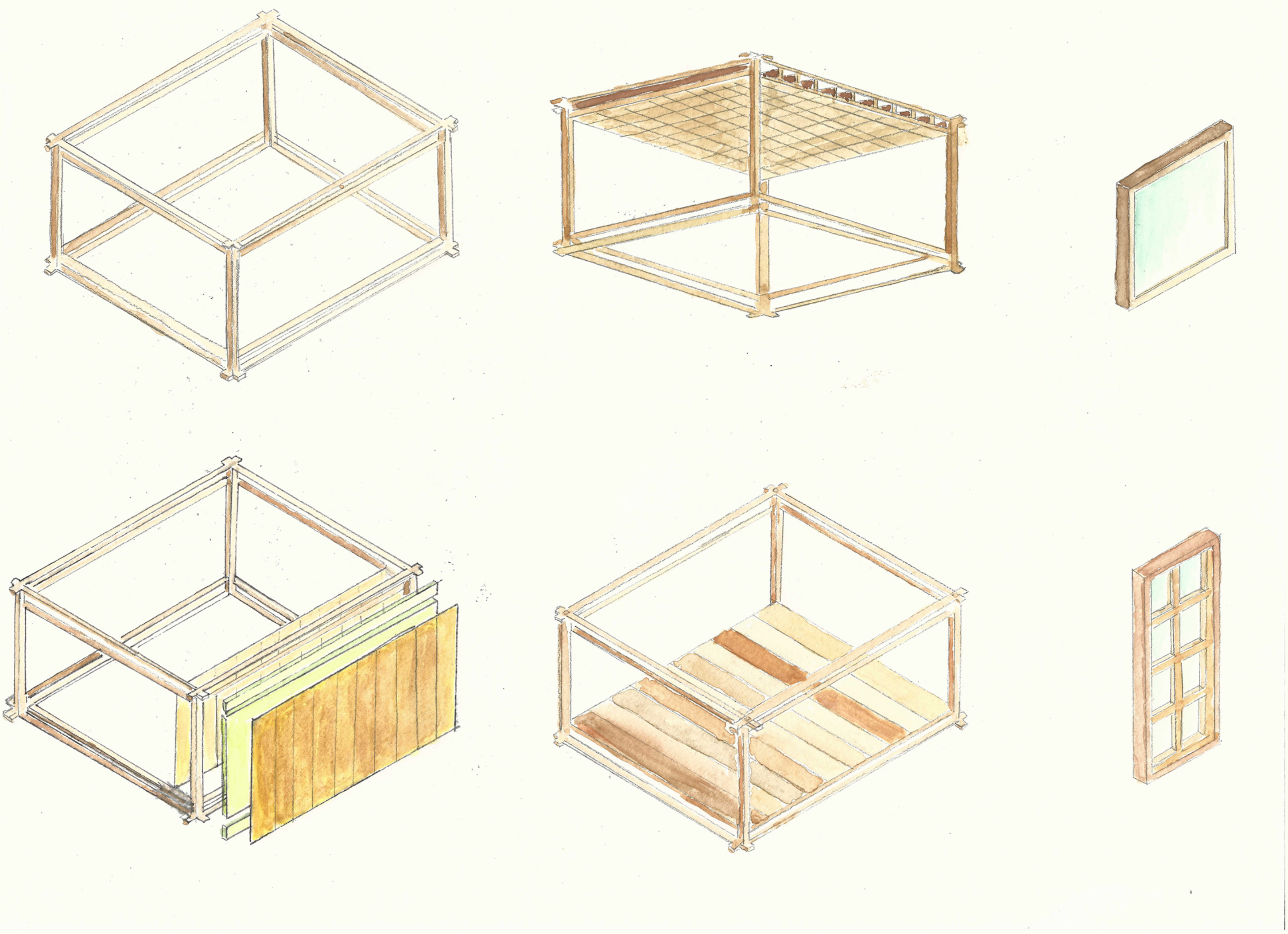
Kooperasi Gotong Royong



Rules and guidelines for construction and material use

1st participant edition

Kooperasi Gotong Royong
Intoduction

The booklet before you serves a summary and justification for the choices in materials that maybe applied in the Kooperasi Gotong Royong.

It consists of three parts:

A) Research Paper: Engineered bamboo for affordable Mass Housing in Semarang

B) Bamboo Engineering overview

C) Renewable material Research

I hope this guide educate you and help you make better informed design decisions.

Mark Keukens

ENGINEERED BAMBOO FOR AFFORDABLE MASS-CUSTOMIZED HOUSING IN SEMARANG

Mark Keukens
Faculty of Architecture & the Built Environment, Delft University of Technology
Julianalaan 134, 2628BL Delft
markkeukens@gmail.com

ABSTRACT

KEYWORDS: *Affordable Housing, Cultivated building materials, engineered bamboo, laminated bamboo, modular, democratized dwelling, vernacular, social structures, traditions, climate adaptation*

I. INTRODUCTION

The world's cities are faced with rapid urbanization and population growth and are in dire need of affordable housing solutions (WEF, 2019). In only 13% of the world's cities, this affordability criterium is met (UN-HABITAT, 2016), while other essential criteria are completely overlooked, namely sustainability and livability. Often the lower and middle-income dwelling solutions provided are low-quality concrete and steel structures (xiao et. Al, 2018) in suboptimal urban sprawl locations, lacking any connection or adherence with the local culture, people or nature (Habibi and Asadi, 2011). This is no different for the city of Semarang on Java, Indonesia, which provides the context for this research. See figure 1 for an example of one of the currently most popular types of housing on offer in Java.

Figure 1. Advertisement for typical 'Type 36' dwelling. (Rumah Dijual, 2019)

We will take a closer look at the significance and urgency of the before-mentioned criteria, starting with the matter of *affordability*: It is estimated that 330 million urban households were living in substandard housing or were financially stretched by housing costs in 2014 (McKinsey Global Institute, 2014). This is projected to rise to nearly 440 million households, or 1.6 billion people, by 2025 – and 2.5 billion people by 2050. Changing demographics, a divergence between living costs and median income, increased land use, urban sprawl, these and more all put pressure on cities globally to provide in an ever-increasing demand for affordable housing. What is more, the problem is worse in developing countries: "Based on median affordability (median price-to-income ratio), cities in less developed countries are found to be significantly less affordable (28% less affordable) than cities in more developed countries" (Kallergis, et al., 2018).

The case for *livability* might be overlooked from a macro-economic perspective, but forcing people to live in places that disconnect them from their sense of self, culture and community causes important values and strengths to be lost and shifts greater parts of the world's population into hyper-individuality. People need to be able to feel at home and grounded in their dwellings and neighbourhoods for them to fully express their (inter)personal potential. The case for sustainability in the building sector should be evident by now, our planet's non-renewable resources are nearing depletion and the built environment is hugely polluting, responsible for 40% of the world's CO2 emissions (UNEP, 2018).

The need for *sustainability* in any project in the built environment should need little explanation. Examining data on climate change, we see that we have to drastically reduce the amount of CO2 that is being expelled into the air to prevent warming of the globe of over 1.5c versus pre-industrial levels and unleashing irreversible chain reactions that could lead to global climate catastrophes (IPCC, 2018). We should also look find ways to remove carbon from the air such as sequestrating the CO2 that is already there back into physical matter (IPCC, 2018, p.14, 342). We also see problematic predictions if we look at the depletion of natural resources (van der Lugt, 2017, p.12). This means we will have to implement alternative renewable resources sooner rather than later. Finally, we can observe that the building industry is responsible for 40% of the world's global CO2 emissions (UNEP, 2018). If we go back to the challenges facing today's cities, we see that there is a great demand for affordable housing. The main materials employed by the building industry at this moment, namely concrete and steel, exacerbate all the before-mentioned problems, their production expels great amounts of co2 and they are finite non-renewable resources. Bamboo is chosen as a material for its properties in carbon sequestration, local cultivation opportunities in tropical areas and structural properties. As a rapid renewable, it's a very viable and welcome alternative to sustainably sourced hardwood as it grows to maturity within 3-5 years and then can be annually harvested without having to destroy the plant itself. This instead of having to wait 30-70 years for trees to mature to then cut them down and having to replant (van der Lugt, 2017). This traditional type of foresting is more damaging for ecosystems than Resilient Bamboo Forestry, a method described by Rabik and Brown (2014) which utilizes and promotes biodiversity as an essential tool as well as a positive side-effect of properly managed forestry. Furthermore, the Rhizospheric network of bamboo's roots can have positive effects on soil and water quality (Emamverdian and Ding, 2017). The strength to weight ratio of bamboo makes it a very attractive choice for a multitude of applications in construction (Lugt, 2017). Engineered or substitutive bamboo deserves special attention for its ability to comply with building code regulations, opportunities for prefabrication and customization and provide a higher grade of fire resistance (Widyowijatnoko, 2019). Furthermore, it negates some of the problems with regards to the vulnerability of joinery in full-culm bamboo construction (Kaminski and Lawrence, 2016).

This paper researches the possibilities of bamboo-based materials to create an *open architecture* that provides answers to the before-mentioned problems. The thesis location in Semarang, Java is a city facing all of the before-mentioned challenges along with some more specific challenges with regards to land subsidence, inundation, floods, urban sprawl and drinking water scarcity. The climate, however, lends itself perfectly for the growth of structurally capable bamboo species.

The research question for this paper is as follows: *"which bamboo engineering and construction techniques are suitable for creating an affordable, livable and sustainable open architecture system?"*

The hypothesis is that engineered bamboo materials belonging to the 'substitutive' category provide the most interesting prospects for the advancement of bamboo as a building material for housing, as they are the most likely to be excepted by the public as well as legislators.

1.1.Challenges for bamboo in the Built Environment

The widespread implementation of bamboo is being held back by a twofold lack of acceptance. The public (recipients) nor the government (legislative entities) have a great understanding of the potential of bamboo as a building material that may resolve some of the essential problems of the 21st century. Through many years of associations with poorly constructed and detailed bamboo constructions (figure 2), the public in tropical areas such as Semarang, has an eschewed view on bamboo as an unsafe, undesirable and unviable building material. People seem to prefer to live as people live in the west, in buildings of concrete and steel (Widyowijatnoko, 2019). Perhaps as a result of this distrustful relationship towards the material, government approval of the material in official building codes is lacking in many countries. Bamboo in its raw form does pose some concerning problems with regards to regulations, standardization and fire resistance. The material has an organic shape, every culm being slightly different in terms of its dimensions and structural properties. Furthermore, the hollow shape of a bamboo culm, especially after its diaphragms have been pierced for treatment, will in case of fire effectively act as a chimney, pulling in air and feeding the fire. There are however many researchers and entrepreneurs who have come up with a plethora of solutions to these issues (Lugt, 2017; Bamcore,2019; Plyboo, 2013; Sharma et. Al, 2015). Governmental approval, however, is still slow, demonstrating that this is not just a matter of science but also of perception (Widyowijatnoko, 2019).

Figure 2. Poor Bamboo detailing and treatment causing splits and rot. Photograph taken by the author on 5th November 2019.

1.2.Strategies for advancing bamboo in the Built Environment

As proposed above, much of the challenges of bamboo implementation lies in the public perception formed by years of association with bad examples. I think it is therefore paramount to have the public (re)discover the incredible potential of this material through inspiring architectural examples which can serve as case studies and provide material for inspiration and education. I propose three categories of bamboo structures and buildings that I think could ameliorate the perception of bamboo as a building material. Firstly, appreciation of the vernacular bamboo architecture of Indonesia might be stimulated, secondly, there are world-famous examples of luxurious bamboo buildings in Indonesia, see the Green School in Bali on

Figure 3 for example. These remain relatively undiscovered by the local Indonesian people, while they did manage to inspire millions of Westerners for bamboo architecture through TED talks and presentations. Finally using state of the art engineering, bamboo culms may be formed into more standardized products, such as the beam by MOSO in figure 4. This allows for a more neutral, modern aesthetic, that people in Indonesia tend to appreciate (Bandarharjo Residents, 2019) furthermore the lamination aids in regulation and fire resistance. Following the classification system proposed at the 8th World Bamboo Congress (Widyowijatnoko and Trautz, 2009), I have divided these typologies into their appropriate categories in table 1.

Table 1. Strategies classified

Proposed Strategy	**Classification World Bamboo Congress**
(re)appreciating the vernacular	Conventional - vernacular
Luxury developments	Conventional - modernized
'Modern' engineered and standardized solutions	Substitutive

Figure 3. Green School, elaborate work of bamboo architecture designed by Ibuku. Photograph taken by the author on 11th of November 2019.

Figure 4. A laminated bamboo beam advertised by Moso International. (Moso, 2019)

II. METHODOLOGY

When dealing with topics as complex as affordable housing and sustainability and facing a context as foreign and intense as Semarang it is paramount to have a research methodological awareness before approaching the field. Elaborating on the methodology, I will explain the methods employed in the research.

Literature studies: Literature studies have been the starting point for this research. A literature review is essential to frame and sharpen one's research questions. (Wang and Groat, 2013, p. 145). It has given me an awareness of the current lines of knowledge available and in development within my field of interest. Furthermore, literature research has also played an essential role in determining the criteria and demands for the material selection in chapter III.

Ethnographic observation: My research question on the acceptation and dissemination of bamboo as a viable building material was to be approached through the ethnographical realms of etics and emics (Pike, 1954). Etics being the physical and material behaviour stream of a specific culture, whereas emics is concerned with the personal significance and reaction in people's minds iteratively reacting to and dictating this behavioural stream (Harris, 1976). Non-participant-observer approaches (Gobo, 2008) were used to conduct etic research, whereas participant-observer methods were employed to elicit emic data. In the etic realm, I have looked into the behaviour stream (Harris, 1976) of people in Semarang and Bali with regards to their ways of building and dwelling as well as their material culture (Lucas, 2016, p. 106) surrounding bamboo. This gave me an idea of the existing informal bamboo economy, its main uses and the condition of the built structures and products. The work was compiled in a booklet (see Appendix) categorizing different construction techniques and uses of bamboo according to the classification framework proposed at the World Bamboo Congress (Widyowijatnoko & Trautz, 2009) For the emic (Harris, 1976, p.332) (Pike, 1954) inquiries of my research, I used a participant-observatory viewpoint: "the researcher establishes a direct relationship with the social 'actors', staying for a period in their natural environment with the purpose of observing and describing their behaviour by interacting with them and participating in their everyday ceremonials and rituals, learning their code (or at least parts of it) in order to understand the meaning of their actions" (Gobo, 2008 p .34) It allowed me to speak to and of the people that were living in the area, about not only their external behaviours and material utterances but more so of their thinking patterns and hidden problems.

Interviews: One of the most essential tools to get an idea on the emic perception of local people and experts on the advancement of bamboo as a building material was to go engage in conversation with them. Unstructured interviews and free-flowing conversations with informants, collaborators and gatekeepers (Lucas, p. 73, 83, 166) were held for this cause. I wanted these conversations to occur in a naturally, harnessing the technique of the free-flowing conversation or unstructured interview, as I felt this could lead me to unexpected outcomes and ideas that lay beyond my frame of reference. Whenever the conversation got to broad or drifted too far into other realms, I just used subtle nudges to guide the conversation back to and around the topic of bamboo building. Amongst others, several lower- and middle-class residents of Semarang, local bamboo dealers, bamboo architects, a harvest and treatment expert, an academic bamboo expert and Indonesian architecture students have been interviewed.

Conference: I was invited by Dr. Ing. Widyowijatnoko to present my preliminary findings at the HabiTechno Conference in Bandung. This platform was a great way to test my findings and the discussion that followed my presentation allowed me to gain reflections and insights by Javanese academia and authorities in the field such as Widyowijatnoko himself.

III. RESULTS

In this chapter, an overview will be given of the state of the art in Bamboo engineered building materials and joinery possibilities. A set of demands and criteria will be used to select applicable and viable solutions for the context and program of the social houses design project in Semarang, Java, Indonesia. The criteria are distilled from literature studies into the different research question operators of *affordability, liveability, sustainability* and *open architecture.* Please see the research scheme in the Appendix.

3.1. Criteria and demands

To help select suitable materials and construction methods for the program of low to middle-income housing in Semarang criteria have been established based on the following concerns:

3.1.1. Affordability

Global population growth and urbanization are putting unprecedented pressure on the demand for affordable housing. To be able to respond to this matter we need to understand and unpack what we mean by affordability with regards to housing. "housing which is adequate in quality and location and does not cost so much that it prohibits its occupants from meeting other basic living costs or threatens their enjoyment of basic human rights" (UN-HABITAT, 2011). "If a house is cheap enough to buy and run, but located far from livelihood opportunities or amenities such as schools, it cannot be said to be affordable" (World Economic Forum, 2019,p.5) When looking at affordability of housing we shouldn't just focus on the costs of buying or renting a house. Other financial factors that come into play are maintenance, services and distance to amenities and services. To achieve affordability in these areas it is important to realize the necessity for density in urban development. Urban sprawl is one of the major contributors toward unaffordability due to the great distance between housing and essential amenities. This means the structure needs to enable enough strength to allow for at least 5 stories of dwelling. The structure then should be:

A) made up of affordable elements B) be easy and fast to construct on-site C) have five stories or more D) be durable E) provide good climatic performance in terms of insulation, ventilation, lighting and acoustics to reduce energy and maintenance costs.

3.1.2. Livability

"In both primitive and traditional societies, the user was directly involved in design and construction process of his dwelling, progressively being part of the whole process. However, together with the need to develop for masses of people; and the materialization of architecture as a professional act, the close tie between the individual and his own environment has weakened, creating a ground for little or no user participation, mainly leading to the emergence of passive users." (Sani, Ulucay and Ulucay, 2011,p.2)

A sense of belonging and user satisfaction between residents and their buildings is important for societal, psychological and sustainable reasons. If these needs are not met it could lead to depression, weakening of the cultural fabric and perhaps abandonment of structurally sound buildings. The ability for a group of residents to have an influence on the design process can greatly increase user satisfaction and social cohesion (Gameren, van den Heuvel and van den Andel, 2012). The ability for people to have influence on the architecture of their house was also one of the reasons for the success of the open architecture of Habraken (1961) ('De Drager: A film about architect John Habraken', 2013)

3.1.3. Sustainability

The reason for choosing bamboo as a base material for the construction of dwellings is its potential in sustainability, through its carbon sequestration and low embodied energy as previously discussed. There are however, many more factors that come into play when it comes to the overall embodied energy of a building as well as its performance.

Logistics: All materials should be available within as short of a range as possible

Engineering: Processing the bamboo into other forms, such as pressed or laminated variants will inevitably cause material loss as well as extra embodied in the form of transport of materials as well as energy in the form of electricity needed to operate the machines. Comparative studies show that further industrialization contributes to a greater environmental impact, with electricity usage and heat energy for cutting and drying, being the most contributive factors (Zea Escamilla and Habert, 2014; Lugt, 2017). Furthermore, lamination requires the use of an adhesive, most of the resins used in current practice release formaldehyde. Formaldehyde is linked to negative respiratory health implications. The resins that were tested in a comparative studies did not expel any measurable levels of formaldehyde after production and the total levels of formaldehyde within a product are tested and controlled by global regulation (Sharma et al., 2015). Still, formaldehyde-free alternatives, such as 'soybond', the soy-based resin utilized by Plyboo (2013), deserve our full attention and further research and development should be done to create formaldehyde free resins that are structurally and financially competitive.

Construction: Regardless of the nature of the materials, construction and detailing in its own right can have a major influence on the sustainability of a building. Some baseline restrictions: the construction has to be modular, meaning it is designed for disassembly, in line with this, only dry joints and connections will be used, meaning no glue between construction elements. Furthermore, the use of materials carrying heavy embodied energy such as steel should be minimized.

3.1.4 Open Architecture

An important contributor to sustainability and livability can be an open architecture as proposed by John Habraken (1961). In this case, a clear, technical, distinction is made between the (load-bearing) *structure* and its *infill*. This way of building implies modularity, allows for more flexibility and adaptability in changes of function and allows users to have more influence on the architecture of their dwelling, increasing their sense of ownership and overall user satisfaction ('De Drager, A film about architect John Habraken', 2013).

3.2. The Indonesian's perspective

What do local people and experts think on the matter?

On-site different types of people were interviewed: Residents of Bandarharjo; one of the poorer neighbourhoods of Semarang, Bamboo Expert; Professor Andry Widyowijatnoko, Bamboo architects; Pak Ketut Arthana, Bamboo factory owners, Local bamboo dealers.

The residents of Bandarharjo were asked if they would consider living in a house constructed out of bamboo. It was interesting to note that nearly all of them responded positively, the only people responding negatively to the question were in a stronger financial position (Bandarharjo Residents, 2019). Much of Western literature on the subject of building with bamboo states there is a prevailing stigma of bamboo being 'a poor man's material' (Lugt, 2017) (Janssen, 2000) (Hidalgo López and Dickinson de Salomón, 2003). Discussing the matter of bamboo perception and acceptance by Indonesian residents at a conference in Bandung, it was noted that acceptance among low-income residents is indeed higher than that of middle- and higher income classes who aspire to live in modern and western buildings (Widyowijatnoko, 2019). This made me shift my focus from just lower to class to also include middle class as a target group. In the same discussion, it was noted that engineered bamboo products probably have a higher chance of being accepted as they have an aesthetic which resembles the western and modern building methods more than traditional bamboo constructions.

The matter of acceptance is dependent on the emic perception of the material. Searching the internet for 'bamboo building' will produce exemplary results in aesthetics and engineering, while walking on the street in Indonesia will provide manifold examples of poor engineering and detailing (Keukens, 2019). Exemplary bamboo architecture such as that of Ibuku and Arte + associates seems to get more attention in the western world than among local residents (Pak Ketut Arthana, 2019) However, there is a slow but steady growing appreciation of the material and more local Indonesian people buy treated bamboo to construct their houses and stores (PT Factory Tour, 2019; Mba Agun, bamboo dealer, 2019).

3.3. Material overview

Based on the criteria discussed in Chapter 2, a set of parameters is established on which the different materials and case studies observed can be rated (see Appendix). The materials in the substitutive category most meet the demands we have earlier discerned.

IV. CONCLUSIONS

As hypothesized, the building materials and construction techniques falling into the category of the substitutives, show the most potential of answering the demands laid out in the research question. Namely the possibility to produce an affordable, livable and sustainable open architecture system. It does this by providing possibilities for prefabrication and customization, reducing construction time spent on site. Furthermore, it allows for standardization, testing and certification of the material, greatly increasing the chance of receiving building code approval. Finally, compressing the material greatly reduces the fire hazard caused by the hollow shape of culms. Lamination of bamboo can also make for strong structural columns and beams, allowing for the creation of a multi-story open architecture. Finally, the modern, standardized aesthetic that can be accomplished in this way of construction could greatly reduce the restraint Indonesian people show in accepting a bamboo-based dwelling.

The findings of this paper recommend the use of a separate carrier and infill system. Therefore a load-bearing structure of laminated bamboo columns and Glubam beams, rafters and roof trusses is recommended. Wall surfaces should be filled in with a hollow wall system similar to Bamcores, for its ease of construction, low weight and great acoustic and thermal insulation as well as fire resistance. Floor finished can be rendered in non-structural bamboo laminates such as Plyboo's soybond-based flooring solutions, chosen for their low environmental impact.

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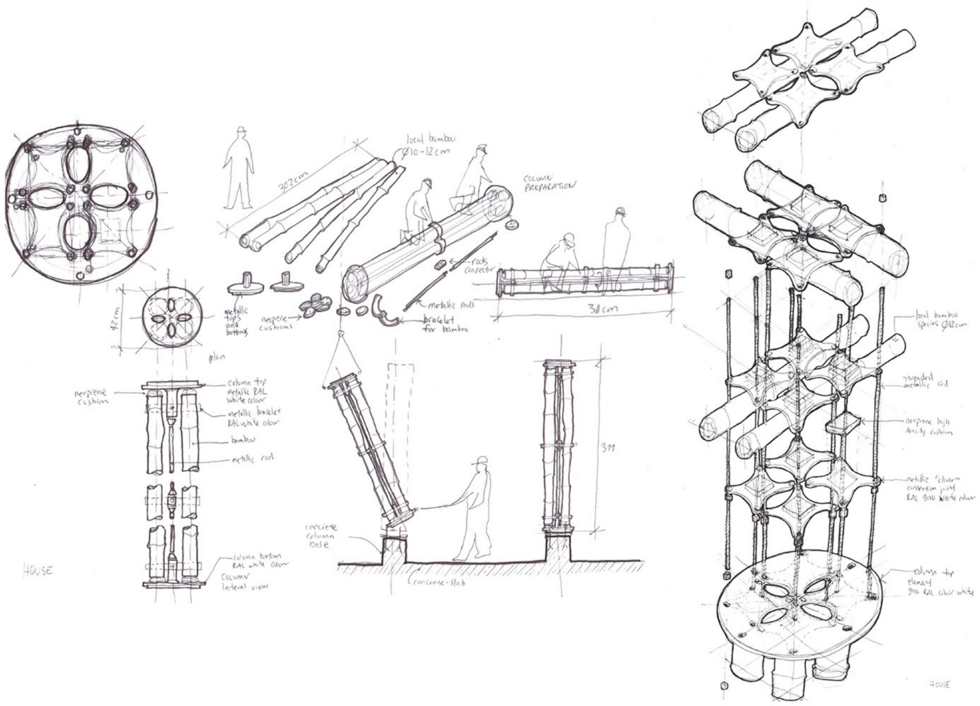
VI. Appendix

Bamboo Engineering
Overview



Bamboo engineering
Intoduction & Justification

The booklet before you represents an overview of the State of the Art of bamboo engineering. It includes constructive elements and a wide range of case studies. It hopes to provide a comparative framework for discussing and selecting certain types of elements for particular purposes. The elements included are categorized according to the offical classification system proposed at World Bamboo Congress nr. 8 (Trautz & Widyowijatnoko, 2013) as follows:

- Vernacular Conventional
- Modernized Conventional
- Substitutive

The elements are rated on a 3 star rating system. This is because this work is a general overview and in depth-analysis on overal production, labour and logistic costs for each element is beyond the scope of this research. Further research into full economic and environmental costs (LCA's) are much recommended.

The principle of material selection is explained on page 68. Conclusions can be found in the accompanying paper: ENGINEERED BAMBOO FOR AFFORDABLE MASS-CUSTOMIZED HOUSING IN SEMARANG (Keukens, 2020)

All images are by the author unless stated otherwise in the form of citations.

Bamboo Engineering
Content

Bamboo Engineering
Rating System

General
The rating sytem is based on a 0-3 scale. This scale is chosen to allow for necessary margin as not all data fields could be exactly gathered so sometimes estimates had to made. The rating reflects a scale within the presented range of products and projects, meaning they reflect and reference on each other. They are always compared to the other products in the same domain, i.e. beams with beams and walls with walls. A certain type of laminated bamboo structure might for example have a far better environmental performance than a steel beam, but since this is not taken into this equation, it might still not recieves 3 stars in this department as it does involve a lot more engineering and embodied energy to produce a laminated bamboo beam versus using a full bamboo culm.

Product/Project affordability
The financial sum of inputmaterials, processing, logistics and labour. Labour is in tropical regions is often less expensive than in other regions.
Environmental performance
Understood as an inverse of the embodied energy or footprint of a product, taking into account, material, processing and logistics
Product lightness
The weight of a product compared to other elements in the same domain. lightness can aid in ease of construction
Ease of production
The inverse of the effort, energy and time needed to manufacture the product.
Ease of construction
The ease with which one can use the product within a building project. Taking into account weight, size, joinery possibilities

Design for disassembly
Is the product designed in such a way that it allows for easy disassembly of the product from its construction?
Strength
The relative strength of a product within that domain. Load Bearing structures often rate between 2 and 3 stars, whereas infills and floorings might score as low as 1 star.
Durability
The expected lifespan or resistance against degradation. Exposed and untreated bamboo is expected to score quite low in this department. Gypsum finishes are expected to need some maintenance.
Fire Resistance
The ability to withstand or retard the spread of a fire. Solid bamboo, just as timber has a charring characteristic in a fire, insulating the material and retarding the spread of fire. Full culm bamboo however has a hollow shape that can act as chimney in the event of a fire, effectively transporting oxygen and feeding the fire. This is why full culm bamboo products and constructions score low and bamboo laminates score higher.
Modern Aesthetic
Important for the possible adaptation of bamboo as a mass market material. The more abstraction from the raw shape of a bamboo culm the higher the score.
Thermal insulation
Only added where relevant, material properties, thickness, airtightness and option for adding insulation taken into account.
Carrier-infill seperation
The degree to which structure and infill in a project is seperated. The ease with which the infill can be altered without having to interfere with the loadbearing structure.
Possibility for multi-story
Not all bamboo based projects have the load bearing capacity to allow for multi-story construction. 1 star means, no capacity, 2 stars represents a limited capacity (2 floors) and 3 stars means a 3+ floor carrying capacity.

Vernacular Conventional
Definition

By Vernacular Conventional structures we understand the structures built by empirical builders (Trautz & Widyowijatnoko, 2009).

In pole construction this mostly comes down to:
- planar (2D) frames, mostly in one layer
- fishmouth and/or rope connections
- compressive or bending stresses

As for split/woven bamboo:
- use of relatively simple shapes
- rendered in mud, lime and/or cowdung

Vernacular Convential
Overview

full culm roof

Product affordability	●●●
Environmental performance	●●●
Product lightness	●●●
Ease of production	●●○
Ease of construction	●●●
Design for disassembly	●●○
Strength	●○○
Durability	●○○
Fire Resistance	●○○
Modern Aesthetic	●○○

This roof structure is made from untreated bamboo culms, damaging its fireresistant properties. It uses bolted connections, which allows for dismantling and easy construction without damaging the culms.

Vernacular Conventional
Load Bearing Structure

Monoplanar frame

Product affordability	●●●
Environmental performance	●●○
Product lightness	●●●
Ease of production	●●○
Ease of construction	●○○
Design for disassembly	●○○
Strength	●○○
Durability	●○○
Fire Resistance	●○○
Modern Aesthetic	●○○

This type of frame, one that is common in informal construction, uses nails to connect bracings to the main posts. This splits the longitudinal fibres of the culms and greatly reduces structural integrity aswell as durability. These frame are commonly made out of untreated bamboo culms, making them susceptible to fast degradation.

Vernacular Conventional
Load Bearing Structure

Bracing members

Product affordability	●●●
Environmental performance	●●○
Product lightness	●●●
Ease of production	●●●
Ease of construction	●●●
Design for disassembly	●○○
Strength	●○○
Durability	●○○
Fire Resistance	●○○
Modern Aesthetic	●○○

Bamboo splits are often used as bracig members. While this is a good choice with regards to strength/ weight ratio and ease of joining, we see here the bamboo used was untreated and nails have been driven in the bamboo, splitting the fibres. The material in itself has a very low embodied energy in this form, but the fact that it will rapidly degrade, negates some of this environmental performance.

Vernacular Conventional
Load Bearing structure

Fishmouth connection

Product affordability	●●●
Environmental performance	●●●
Product lightness	●●●
Ease of production	●●○
Ease of construction	●●●
Design for disassembly	●●●
Strength	●●○
Durability	●○○
Fire Resistance	●○○
Modern Aesthetic	●○○

A fishmouth connection here connects a post to beam, the daigonal members on either side along with the wight of the roof keep the beam in place. This technique requires cratsmanship. If the materials are treated well and connected via bolt-nut or peg-dowel they can make for a durable and modular joint.

Full Culm Wall

Product affordability	●●●
Environmental performance	●●○
Product lightness	●●●
Ease of production	●●●
Ease of construction	●●●
Design for disassembly	●●○
Strength	●●○
Durability	●○○
Fire Resistance	●○○
Modern Aesthetic	●○○
Thermal insulation	●○○

Wall, full culms nailed to top and bottom supportbeams. Bamboo is exposed here to rain (no overhang) and groundwater (no foundation). The nails damage structural integrity of the culms and will also dramatically decrease the durability of the material.

Vernacular Conventional
Ceiling

Weaved ceiling mats

Product affordability	●●○
Environmental performance	●●●
Product lightness	●●●
Ease of production	●○○
Ease of construction	●●●
Design for disassembly	●●○
Strength	●○○
Durability	●●○
Fire Resistance	●○○
Modern Aesthetic	●●○
Thermal insulation	●○○

These traditional mats are weaved from thin bamboo slices. The contrast between blonde and black bamboo source culms allows for variation and decoration. The mats are hand woven, which is a very labour intensive proces. Once produced though, the mats can easily be applied. If used in indoorsettings they can remain in good condition for several decades.

Vernacular Conventional
walls

Weaved wall mats

Product affordability	●○○
Environmental performance	●●●
Product lightness	●●●
Ease of production	●○○
Ease of construction	●●●
Design for disassembly	●●○
Strength	●○○
Durability	●○○
Fire Resistance	●○○
Modern Aesthetic	●●○
Thermal insulation	●○○

A weave of thin bamboo sections is traditionally used to create planar infills like walls and ceilings. It is an easy way, yet offers little rigidity or insulation when compared to other planar materials of bamboo. As an infill material, the low strengh in itself isn’t problematic, but one could foresee damage occuring more easily than in more solid wall systems.

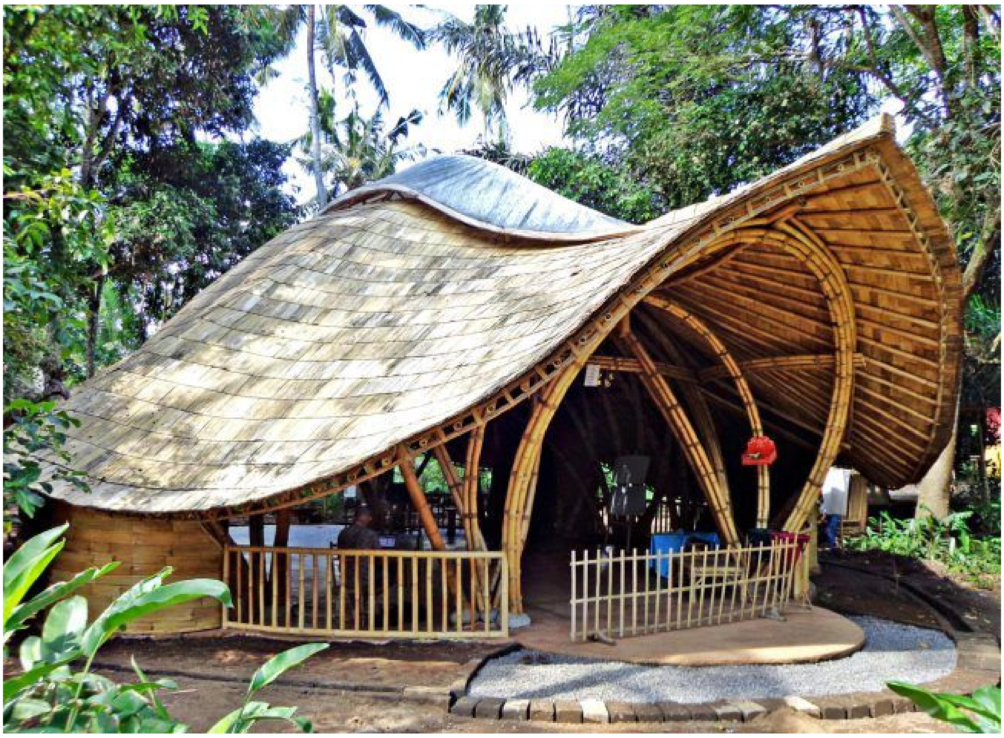
Definition

By Modernized Conventional structures we understand the bamboo structures that are further advanced due to contemporary scientific and engineering approaches (Trautz & Widyowijatnoko, 2009).

In pole construction this mostly comes down to:
- 2D or 3D frames, mostly in more than one layer
- fishmouth and/or nut-bolt connections
- compressive or bending stresses

As for split/woven bamboo:
- use of relatively complex forms
- plastered in mortar

Documentation



Modernized Conventional
Load bearing structure

Quadruple post & Beams

Product affordability	●●○
Environmental performance	●●●
Product lightness	●●●
Ease of production	●●●
Ease of construction	●●●
Design for disassembly	●●●
Strength	●●●
Durability	●●○
Fire Resistance	●○○
Modern Aesthetic	●○○
Thermal insulation	○○○

Three-dimensional multilayered construction with nut-bolt connections. Culms are properly treated and selected based on visual indicators of strength. The treatment and increased number of culms makes this method significantly more expensive than the untreated monoplanar frames we sas before. The strength and quality should allow a long lifespan against a reasonalbe price.

Modernized Convential
Load bearing structure

Reciprocal Tower

Product affordability	●●●
Environmental performance	●●●
Product lightness	●○○
Ease of production	●○○
Ease of construction	●●○
Design for disassembly	●●○
Strength	●●●
Durability	●●●
Fire Resistance	●○○
Modern Aesthetic	●●○
Thermal insulation	○○○

Popular Construction technique to create multi-story loadbearing structures. The technique relies solely on bamboo culms and doesn’t require expensive or environmentally unfriendly connectors. The resulting towers are often found to be easthetically pleasing or spectacular, often being the most photographed elements in the buildings. The bottom of the culms are placed on foundations.

Modernized Conventional
Load Bearing Structure

Roof corona

Product affordability	●●○
Environmental performance	●●●
Product lightness	●●○
Ease of production	●●○
Ease of construction	●●○
Design for disassembly	●●●
Strength	●●●
Durability	●●●
Fire Resistance	●○○
Modern Aesthetic	●●○
Thermal insulation	○○○

This elaborate and spectacular structure is made to handle the load of (semi-) circular roof elements. In contrast to the reciprocal tower this allows for big freestanding spans and open floorspaces. Forces are transfered via full culm members from the roof to a cilinder consisting of a number of vertically connected circles made from laminated bamboo splits. The aesthetic is modern, but still revaels full bmboo culms.

Modernized Conventional
Load Bearing Structure

Rope joinery

Product affordability	●●●
Environmental performance	●●●
Product lightness	●●●
Ease of production	●●●
Ease of construction	●●○
Design for disassembly	●●●
Strength	●●○
Durability	●○○
Fire Resistance	●○○
Modern Aesthetic	●○○
Thermal insulation	○○○

Using ropes to tie together structural elements is probably the oldest technique in bamboo construction. There are many different techniques for tying the bamboo. The technique often needs to be combined with fishmouth cutting for fit and peg and dowel to give a support for the rope to be tied to. The ropeconnection is susceptible to weathering.

Grid Shell

Product affordability	●●○
Environmental performance	●●○
Product lightness	●●●
Ease of production	●●○
Ease of construction	●●○
Design for disassembly	●●○
Strength	●●○
Durability	●●●
Fire Resistance	●●○
Modern Aesthetic	●●○
Thermal insulation	○○○

Steel and wooden gridshell structures were pioneered and presented by Russian Engineer Vladimir Shukhov in 1896. Here laminated bamboo splits are used to create light grid shell structures. The splits are bend connected to a bottom connector ring and than bend over a formwork mold. The splitting and laminating comes at some environmental cost, while the absence of full culms makes the structure slightly more fire resistant.

Modernized Conventional
Load Bearing structure

Gridshell members

Product affordability	●●○
Environmental performance	●●○
Product lightness	●●●
Ease of production	●●○
Ease of construction	●●●
Design for disassembly	●●○
Strength	●●○
Durability	●●●
Fire Resistance	●●○
Modern Aesthetic	●●○
Thermal insulation	○○○

The members of the gridshells are comprised of laminated bamboo splits. This ensures flexibility while the lamination provides extra strengths, The connections here are bolted and then covered with bamboo caps. The glue used to laminate the bamboo splits decreases the environmental performance of the product. Formaldehyde free or biobased resins could help this, but would hurt affordability.

Modernized Conventional
Load Bearing Structure

Riverstone foundation

Product affordability	●○○
Environmental performance	●●○
Product lightness	●○○
Ease of production	●○○
Ease of construction	●○○
Design for disassembly	●○○
Strength	●●●
Durability	●●●
Fire Resistance	●●●
Modern Aesthetic	●○○
Thermal insulation	○○○

This tye of foundation not only serves esthetical purposes, but also serves to increase durability. As we have stated before, bamboo needs to be protected from exposure to rain and groundwater. A bamboo structure is therefor always built on a foundation. Concrete is used underground, but since this is too porous, a riverstone is added ontop and pierced by a rebar, which connects to the concrete filled bottom internode of the culm.

Modernized Conventional
Beams

Rup Rup

Product affordability	●●●
Environmental performance	●●●
Product lightness	●●●
Ease of production	●●●
Ease of construction	●●○
Design for disassembly	●●○
Strength	●●○
Durability	●○○
Fire Resistance	●○○
Modern Aesthetic	●○○
Thermal insulation	○○○

Rup rup is a technique where small V shaped incisions are made, cutting about 1/3rd into the wall thickness of the culms. This allows the bamboo to bend more, but as it cuts into the strongest part of the culm, it does irreversibly harm the structural integrity. If the culms are not properly sheltered, rainwater is very likely to seep in and damage the culms.

Modernized Conventional
Beams

Laminated split beam

Product affordability	●○○
Environmental performance	●●●
Product lightness	●●○
Ease of production	●○○
Ease of construction	●●●
Design for disassembly	●●○
Strength	●●●
Durability	●●●
Fire Resistance	●●○
Modern Aesthetic	●○○
Thermal insulation	○○○

This technique uses rough bamboosplits which are bundled, pegged and roped. This technique foregoes the need for glue or resin It allows the creation of rectangular beam profiles that can curve in the direction of their width. The production of the beams is expensive as its a very labour intensive process. The beams can be connected to culms using ropes, pegs or bolts.

Modernized Conventional
Beams

Lidy Bunch

Product affordability	●○○
Environmental performance	●●○
Product lightness	●●○
Ease of production	●○○
Ease of construction	●●○
Design for disassembly	●●○
Strength	●●○
Durability	●●●
Fire Resistance	●●○
Modern Aesthetic	●○○
Thermal insulation	○○○

A Lidy Bunch is a roped bundle of 'bamboo lidy's'; cilindrical extrusions of bamboo, transfering load from roofrafters to loadbearing culms in a freeform manner, allowing for realization of curved shells and parametricly designed shapes. Compared to the split beams, they can be bent in all directions. The particles here are even smaller than in the split beams, so production is more expensive as a result.

Hybrid Lidy Bunch

Product affordability	●○○
Environmental performance	●●○
Product lightness	●●○
Ease of production	●○○
Ease of construction	●●○
Design for disassembly	●●○
Strength	●●○
Durability	●●●
Fire Resistance	●●○
Modern Aesthetic	●○○
Thermal insulation	○○○

A hybrid form of the lidy bunch, employing bamboo splits at it's core to allow for stiffness along the sidelengths of the splits. It does however limit the flexibility and axis of freedom of the bunch, so combinging different sections might be necessary to attain double curvilinear shapes

Modernized Conventional
Walls

Full culm walls

Product affordability	●●○
Environmental performance	●●●
Product lightness	●○○
Ease of production	●●○
Ease of construction	●●○
Design for disassembly	●●○
Strength	●●●
Durability	●●●
Fire Resistance	●○○
Modern Aesthetic	●●○
Thermal insulation	●○○

A wall made up from treated bamboo culms, with thin finishing of gypsum to close the seems between the culms. The culms are varnished to give them a glossy high quality finish. Neatly crafted fishmouth connections are necessary to obtain a good fit, so craftsmenship is an important factor and expense.

Modernized Conventional
Walls

Woven bamboo wall

Product affordability	●●○
Environmental performance	●●●
Product lightness	●●●
Ease of production	●●○
Ease of construction	●●●
Design for disassembly	●●○
Strength	●●○
Durability	●●○
Fire Resistance	●●○
Modern Aesthetic	●●○
Thermal insulation	●○○

A variant of the tradition woven bamboo wall, using gypsum to fill and close the wall. The gypsum work might need some occasional maintenance or upkeep. Otherwise, when compared to the vernacular weaved wall systems, this one is stronger, more durable and closed to air and insects, while still being lightweight and easy to construct with. The bigger strokes also allow for easier production.

Modernized Conventional
Walls

Bamboo framing

Product affordability	●●●
Environmental performance	●●●
Product lightness	●●○
Ease of production	●●○
Ease of construction	●●●
Design for disassembly	●●○
Strength	●●●
Durability	●●○
Fire Resistance	●●○
Modern Aesthetic	●●○
Thermal insulation	●○○

Similar to the 19th century popular Tudor style, A frame, weave and gypsum technique has been applied here, to create a structurally loadbearning yet relatively lightweight wall system.

Modernized Conventional
Roofing

Plu Plu roofing

Product affordability	●●○
Environmental performance	●●●
Product lightness	●●●
Ease of production	●●○
Ease of construction	●●○
Design for disassembly	●○○
Strength	●○○
Durability	●○○
Fire Resistance	●○○
Modern Aesthetic	●○○
Thermal insulation	●○○

Roofing, partially split and then crushed to flatten the bamboo. The bamboo used is treated, yet it is very exposed to the elements, so it needs to be replaced every at least every 7 years.

Stitched floor mats

Product affordability	●●●
Environmental performance	●●●
Product lightness	●●●
Ease of production	●○○
Ease of construction	●●●
Design for disassembly	●●○
Strength	●○○
Durability	●●○
Fire Resistance	●○○
Modern Aesthetic	●○○
Thermal insulation	○○○

flooring mats, underflooring of sewn bamboosplits, finishing mats of woven bamboo strips. This type of floor finish presents a labour intensive yet low-tech and low embodied energy method of creating even and pleasant floor surfaces. As the material is made up from small splits, yet will be subject to heavy use and it is expected to degrade faster than more solid flooring solutions.

Open Doweled flooring

Product affordability	●●●
Environmental performance	●●●
Product lightness	●●●
Ease of production	●●○
Ease of construction	●●○
Design for disassembly	●○○
Strength	●●○
Durability	○○○
Fire Resistance	○○○
Modern Aesthetic	○○○
Thermal insulation	○○○

Bamboo splits, treated, sanded and tightly doweled to the floor beams. One of the most low-tech and environmentally friendly systems for creating flooring with bamboo. The aethestic might be too 'primitive' for some users and the floor has gaps and seems that might not be desirable for some purposes. The splits are individually connected to floor beams by way of dowel, so the sytem can be disassembled, but isn't very modular.

Modernized Conventional
Stairs

Laminated stairs

Product affordability	●○○
Environmental performance	●●○
Product lightness	●○○
Ease of production	●○○
Ease of construction	●○○
Design for disassembly	●○○
Strength	●●●
Durability	●●●
Fire Resistance	●●○
Modern Aesthetic	●○○
Thermal insulation	○○○

Stairstringer; bamboosplits, bended, doweled and sawed into shape for stairsupport. The fact that the system is connected with dowels and not with glue makes it more environmentally friendly than other laminates, while still achieving similar benefits in strength and freedom of form. A lot of machinework and therefor electiricity is required a structure like this, so that degrades the environmental performance slightly.

Modernized Conventional
Stairs

Full culm stairs

Product affordability	●●●
Environmental performance	●●●
Product lightness	●●●
Ease of production	●●●
Ease of construction	●●●
Design for disassembly	●●○
Strength	●●●
Durability	●●●
Fire Resistance	●○○
Modern Aesthetic	●○○
Thermal insulation	○○○

Stairstringer; full culm connects to stepsupports which carry open laminate doweled flooring. A very simple and low-tech method of creating a strong chair. The full culms have a tendency to be very flammable due to their hollow shape, which can act as a chimney during a fire, therefore this structure doesn't perform well in fire resistance.

Culmsection doorframe

Product affordability	●●●
Environmental performance	●●●
Product lightness	●●●
Ease of production	●●●
Ease of construction	●●●
Design for disassembly	●●●
Strength	●●○
Durability	●●●
Fire Resistance	●●○
Modern Aesthetic	●○○
Thermal insulation	○○○

The outer section of the bamboo culm is used as a framing for doors and windows. it can contain panels of bamboo, glass or wood. The solidity of the culmsections makes them a lot more fire resistant than full culms. In case of fire the sections would start charring in the same manner that timber would. Fire resistance therefor depends upon the flamability of the infill of the frames.

Substitutive
Definition

By Substitutive structures we understand the structures were bamboo is engineered as to replace another material. It is constructed to adapt to other, existing types of construction techniques. (Trautz & Widyowijatnoko, 2009).

We can for example think of:

Pole constructions:
- 3D bamboo (space)frames, where bamboo culms substitute steel members and chords, often used with steel connectors

Split construction
- split bamboo trusses, where splits substitute steel members and chords

Other substitutives:
- laminated bamboo, where it takes upto the construction of laminated timber
- bamboo reinforced concrete, where it replaces steel

Substitutive
Documentation

Substitutive
Load Bearing Structure

Single Truss

Product affordability	●●●
Environmental performance	●●●
Product lightness	●●●
Ease of production	●●●
Ease of construction	●●●
Design for disassembly	●●●
Strength	●●●
Durability	●●●
Fire Resistance	●○○
Modern Aesthetic	●○○
Thermal insulation	○○○

Single Truss made up as follows: bottom chord; single culm, upper chord; double culm, diagonal members; bamboosplits, connected via bolts and nuts. An easy low-tech manner of creating strong and big spans.

Substitutive
Load Bearing Structure

Space Frame

Product affordability	●●○
Environmental performance	●●○
Product lightness	●●●
Ease of production	●●○
Ease of construction	●●●
Design for disassembly	●●●
Strength	●●●
Durability	●●●
Fire Resistance	●●○
Modern Aesthetic	●●○
Thermal insulation	○○○

Spaceframe; full culm orthogonal upperchord-grid bolted to metal nodes, T-joint bolted to full culm diagonal members, connecting to bottom metal nodeconnectors and bottomchord grid. Their is a certain amount of embodied energy into the crafting of the metal nodes. On the otherhand, the substitution of metal for bamboo for the chords and members makes for an ecologically and economically attractive modular structure.

Substitutive
Load Bearing Structure

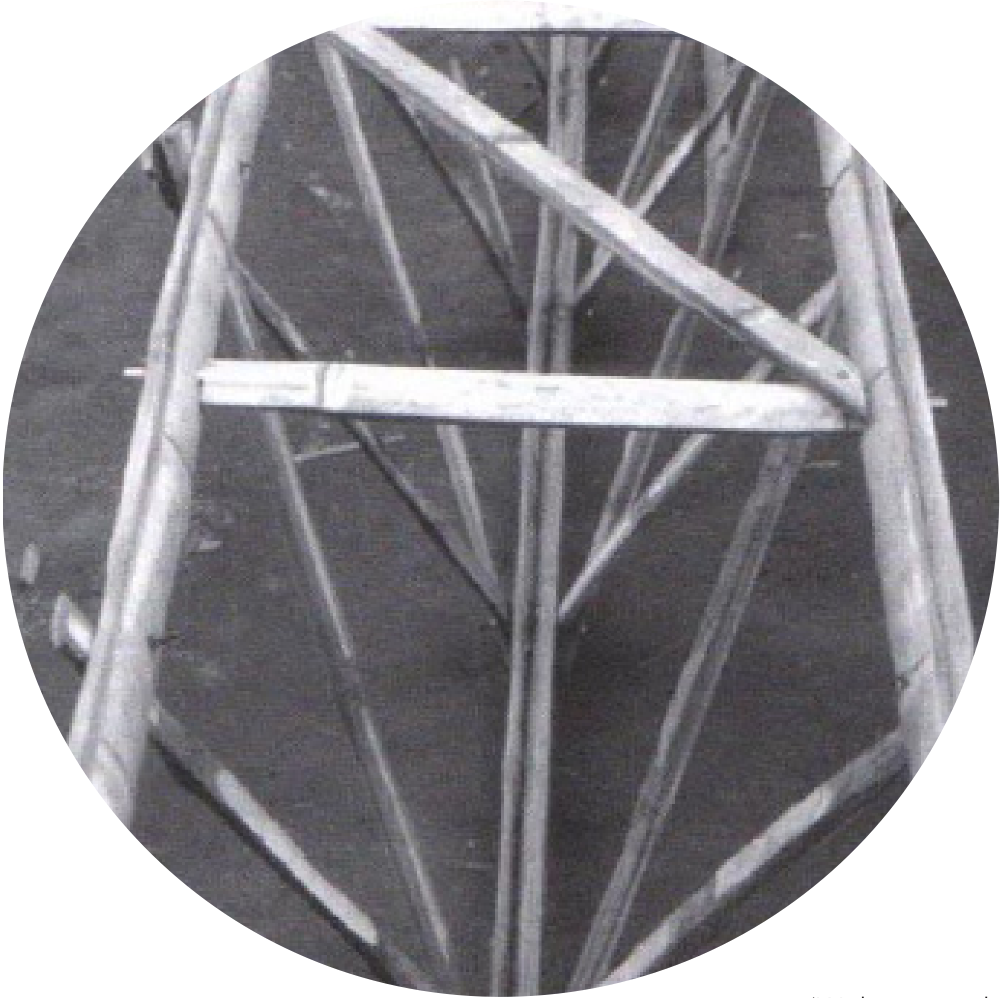


image:
(Widyowijatnoko & Trautz, 2012)

Triangular Truss

Product affordability	●●●
Environmental performance	●●●
Product lightness	●●●
Ease of production	●●●
Ease of construction	●●●
Design for disassembly	●●●
Strength	●●○
Durability	●●●
Fire Resistance	●○○
Modern Aesthetic	●○○
Thermal insulation	○○○

A truss comprised of bamoospilt chords and diagonal members, connected through bolts. A Truss like this provides multidimensional rigidity. However using splits instead of full culms will surely impact the overall strength of the truss. Furthermore the connection of the horizontal arguably members seems as though there is insufficient solid material for the bolts to connect in.

Substitutive
Load Bearing Structure

image:
(Widyowijatnoko & Trautz, 2012)

Bamboo reinforced concrete

Product affordability	●●○
Environmental performance	●●○
Product lightness	●●○
Ease of production	●●○
Ease of construction	●●○
Design for disassembly	●○○
Strength	●●○
Durability	●●●
Fire Resistance	●●●
Modern Aesthetic	●●●
Thermal insulation	●●○

Frames of bamboo splits can in some cases replace metal rebars as reinforcement for in situ concrete castings like walls, floors and roofs. The hard outer silica layer of a bamboo culms is not suitable for this purpose, the more porous inner material of a culm however needs to be used for this purpose. It is labour intensive to make these splits, but being able to substitute metal and allow for a lightweight reinforcement makes up for this.

Substitutive
Load Bearing Structure

Image:
Widyowijatnoko & Trautz (2012)

Laminated truss

Product affordability	●○○
Environmental performance	●●○
Product lightness	●○○
Ease of production	●○○
Ease of construction	●●○
Design for disassembly	●●●
Strength	●●●
Durability	●●●
Fire Resistance	●●●
Modern Aesthetic	●●●
Thermal insulation	○○○

This truss follows the design and principles of traditional wooden rooftrusses, but uses laminated bamboo instead of solid or laminated timber. The main advantages of laminating bamboo is that the material becomes certifieably fire retardant and gets a modern, solid and parametric form.

Image:
Bamcore (2019)

BAMCORE Panels

Product affordability	●●○
Environmental performance	●●●
Product lightness	●●○
Ease of production	●○○
Ease of construction	●●●
Design for disassembly	●●●
Strength	●●●
Durability	●●●
Fire Resistance	●●●
Modern Aesthetic	●●●
Thermal insulation	●●●

Bamcore makes wall panels from a core of crushed culms with two layers of douglas fir veneer to give the panels a smooth and standardized finish. The panels can be made into a lightweight hollow wall system with no need for glue, bolts, or cranes. The walls can carry roofs but not mulitple stories and floors. The panels have recieved all the certificates needed in the USA with regards to performance, safety and fireresistance.

(Plyboo, 2019)

Plyboo

Product affordability	●○○
Environmental performance	●●●
Product lightness	●○○
Ease of production	●○○
Ease of construction	●●●
Design for disassembly	●●●
Strength	●●○
Durability	●●○
Fire Resistance	●●●
Modern Aesthetic	●●●
Thermal insulation	●●○

Used for wall cladding and flooring. This manufacturer is experimenting with soybond as an alternative to normal resins or glues. This makes it into one of the most interesting bamboo laminate products. So far however, there are only architectural and no structural products available. It is interesting to see if the soybased resin could produce laminates strong enough for structural purposes.

Bamboo MDF

Product affordability	●●○
Environmental performance	●●●
Product lightness	●○○
Ease of production	●●○
Ease of construction	●●●
Design for disassembly	●●●
Strength	●●○
Durability	●●●
Fire Resistance	●●●
Modern Aesthetic	●●○
Thermal insulation	●●○

MDF made up from compressed sawdust , covered by a crushed and flattened bamboo veneer layer. The result is slightly more rough than the before-mentioned BAMCORE panels. The strength is also most likely lower, so it's probably only to be used as infill and not as structural elements. The upside however is that it uses only bamboo and a lot of waiste materials at that. It can be relatively easily produced.

Substitutive
Beams

image:
MOSO (2019)

Laminated Beam

Product affordability	●○○
Environmental performance	●●○
Product lightness	●○○
Ease of production	●○○
Ease of construction	●●●
Design for disassembly	●●●
Strength	●●●
Durability	●●●
Fire Resistance	●●●
Modern Aesthetic	●●●
Thermal insulation	○○○

Industialized laminated bamboo beams provide an alternative to masstimber that is potentially more sustainable, if produced in large enough quantities and close to the source of the material. A more sustainable glue alternative is the next necessary step in development to make the product more sustianable. The product can be made in a range of standardized sizes and can easily adapted to conventional construction methods.

image:
Xiao et. al (2008)

GluBam Beams

Product affordability	●○○
Environmental performance	●●○
Product lightness	●○○
Ease of production	●○○
Ease of construction	●●●
Design for disassembly	●●●
Strength	●●●
Durability	●●●
Fire Resistance	●●●
Modern Aesthetic	●●●
Thermal insulation	○○○

The GluBam lamination technique uses laminated mats of bamboo veneer. These bamboo veneer mats are readily available in the United States and are normally used for concrete frameworks. They come 2440x1220x6-30mm size and can be cut into slats and subsequently laminated into beams and columns. GluBam has been used to produce high capacity vehicle bridges aswell as prototype double story housing.

Substitutive
Columns

Image:
Xiao et. al (2008)

GluBam columns

Product affordability	●○○
Environmental performance	●●○
Product lightness	●●○
Ease of production	●○○
Ease of construction	●●●
Design for disassembly	●●●
Strength	●●●
Durability	●●●
Fire Resistance	●●●
Modern Aesthetic	●●●
Thermal insulation	○○○

This laminated column produced by ICTBS, uses the same technique as the GluBam beams, namely laminating strips of bambooveneer. Metal connectors connect different sections to create H, C- or hollow-shaped or solid bamboo columns.
The GluBam method proves very strong as proven by a truckcarrying vehicle bridge using GluBam girders

Substitutive
Infill

SWB cabinets

Product affordability	●○○
Environmental performance	●●○
Product lightness	●○○
Ease of production	●○○
Ease of construction	●●●
Design for disassembly	●●●
Strength	●●●
Durability	●●●
Fire Resistance	●●●
Modern Aesthetic	●●●
Thermal insulation	●○○

Strand Woven Bamboo is a production method using crushed bamboo fibres and resin to create very hard panels, that are similar to hardwood in properties and appearance. The high ratio of resin and the current lack of an environmentally friendly resin, makes this option less attractive from an environmental point of view. On the positive, it allows different types of bamboo to be used.

Case Studies
Conventional Vernacular
Modernized Conventional
Substitutive

Project information

Program: dwelling

Location: Sumba, Indonesia

Architect: -

Area: +-40m2

Sumbanese mbatangu

●●●
●●●
●○○
●●●
●○○
●○○
●●○
●○○
●○○

Description:
The vernacular houses traditionally built on the island of Sumba with their typical high steep roofs, where spirits dwell in their belief, are almost entirely constructed out of bamboo, except for 4 loadbearing timber posts. The construction is effective. The use of timber posts and a roofoverhangs ensures protection of bamboo from rain. The construction is not modular and bamboo is a prominent aesthetic feature on the interior.

ntial

Program: luxury villa

Location: Ubud, Bali

Project information

Program: luxury villa

Location: Ubud, Bali

Architect: Ibuku

Area: +-200 m2

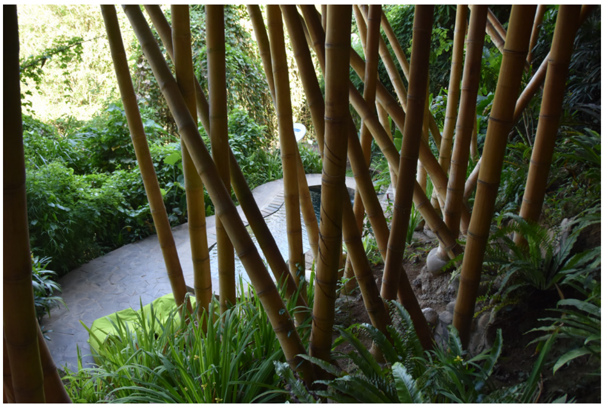
Constructioncosts:
$100,000 +

Project affordability	●○○
Environmental Performance	●●●
Carrier-infill seperation	●●○
Ease of construction	●○○
Design for disassembly	●●○
Possibility for multi-story	●●●
Durability	●●○
Fire Resistance	●○○
Thermal insulation	●○○

Description:

These luxury villas showcase the cutting edge of aesthetical bamboo design. They employ a lot of full culm loadbearing structures combined with lidy bunches and laminated beams. As primarily unaltered bamboo is used, with little addition of other materials, the environmental performance is good, whereas in ease of construction, affordability or fire resistance, the project doesn’t fare well.

ntial



Program: luxury villa

Location: Ubud, Bali

Des

Project information

Program: Housing

Location: Lishui, China

Architect: Studio Cardenas Conscious Design

Area: 320 m2

Energy Efficient Bamboo House

This project is a showcase of a very hightech approach to modernized conventional bamboo. Regarding the eloborate steel joints, we see alot of embodied energy goes into the construction of this building. The joints, however are dry and modular, allowing for easy disassembly. The building shows a strong modularity and carrier-infill seperation.

De

Carrier-infill seperation	○○○
Ease of construction	○○○
Design for disassembly	○○○
Possibility for multi-story	○○○
Durability	○○○
Fire Resistancy	○○○
Thermal insulation	○○○

Project information

Program: private residence

Location: Novato, California, USA

Architect: BamCore

Area: +-200 m2

Assembly time: 15 hours on site (structural walls)

Bamcore Residence

Project affordability	●●○
Environmental Performance	●●○
Carrier-infill seperation	●○○
Ease of construction	●●●
Design for disassembly	●●●
Possibility for multi-story	●○○
Durability	●●●
Fire Resistance	●●●
Thermal insulation	●●●

Description:

This Bamcore Hollow Wall system took only 12 hourse on site to construct. Because of the low weight of the material only a handful of workers and a small forklift were needed to complete the construction. The insulating properties of the hollow wall system outperform normal timberframe walls. Aluminium plates are used to connect the wallparts adding some emboedied energy to the building.

Ease of construction ○○○
Design for disassembly ○○○
Possibility for multi-story ○○○
Durability ○○○
Fire Resistancy ○○○
Thermal insulation ○○○

Project information

Program: affordable housing

Location: Rural Java

Architect: Pak Andry Widyowijatnoko

Area: +-40 m2

Assemble

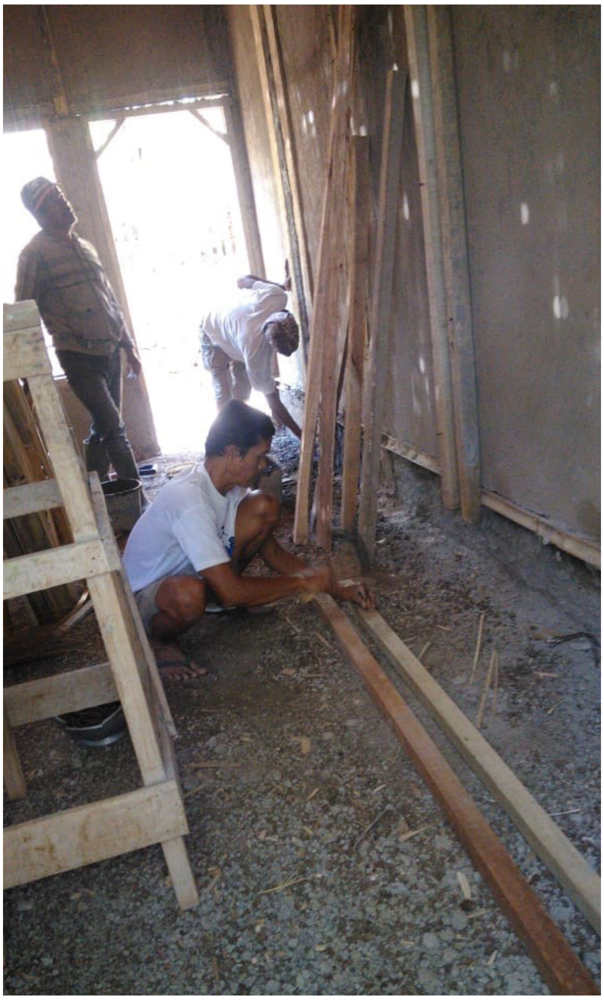
Constructioncosts: $1000

Village dwellings

Project affordability	●●●
Environmental Performance	●●●
Carrier-infill seperation	●●●
Ease of construction	●●●
Design for disassembly	●○○
Possibility for multi-story	●○○
Durability	●●○
Fire Resistance	●●○
Thermal insulation	●○○

These dwellings have been constructed from locally harvested and treated forestbamboo. The gotong royong principle for shared labour was harnessed, so labourcosts were kept to a minimum. The walls consists of bamboomats finished with a layer of mortar.

ntial



Project affordability	○○○
Environmental Performance	○○○
Carrier-infill seperation	○○○
Ease of construction	○○○
Design for disassembly	○○○
Possibility for multi-story	○○○
Durability	○○○
Fire Resistancy	○○○
Thermal insulation	○○○

Des

Substitutive

Project information

Program: family home

Location: California, USA

Architect: ICTBS

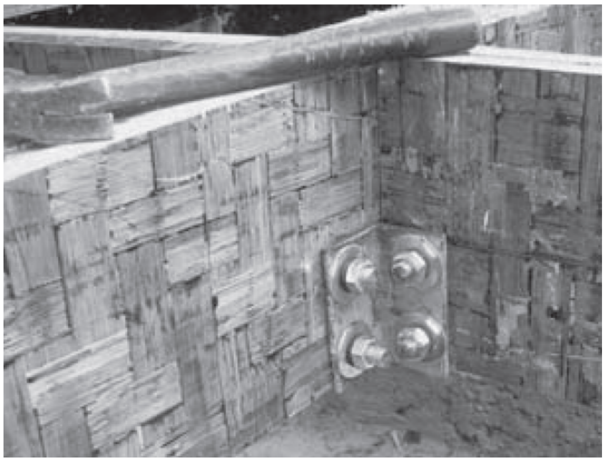
Area: 260 m2

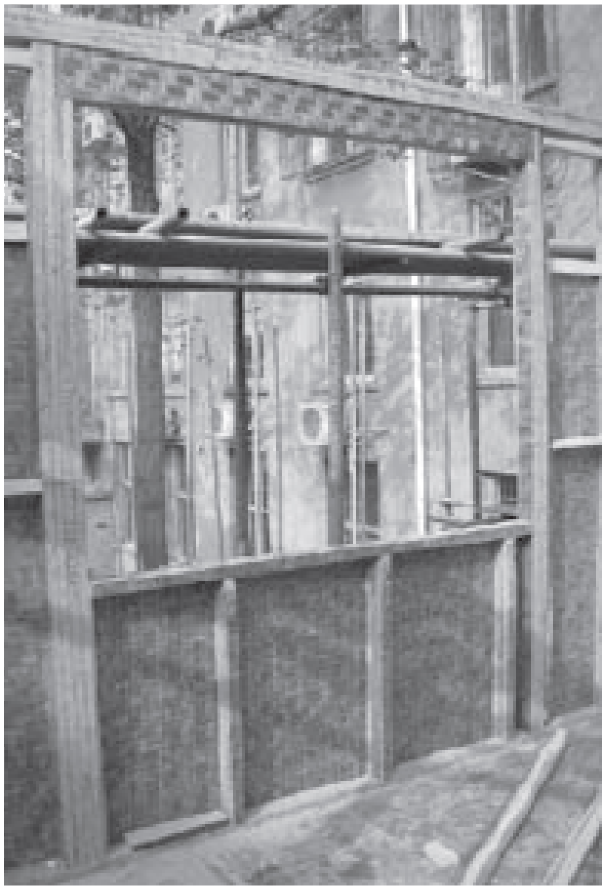
2-story Bamboo House

Project affordability	●○○
Environmental Performance	●●○
Carrier-infill seperation	●●●
Ease of construction	●●●
Design for disassembly	●●●
Possibility for multi-story	●●●
Durability	●●●
Fire Resistance	●●●
Thermal insulation	●●○

Description:

This building was erected following existing U.S. building code. It is a platform frame building using, GluBam laminated columns, studs, joists, and trusses. Bamboo veneer sheets are used for flooring, wall infill and roofing purposes.





Project information

Program: housing prototype

Location: Bandung, Indonesia

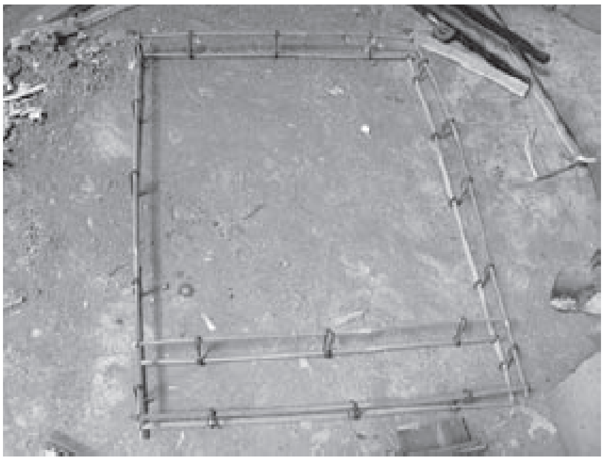
Architect: Widyowijatnoko

Area: 25 m2

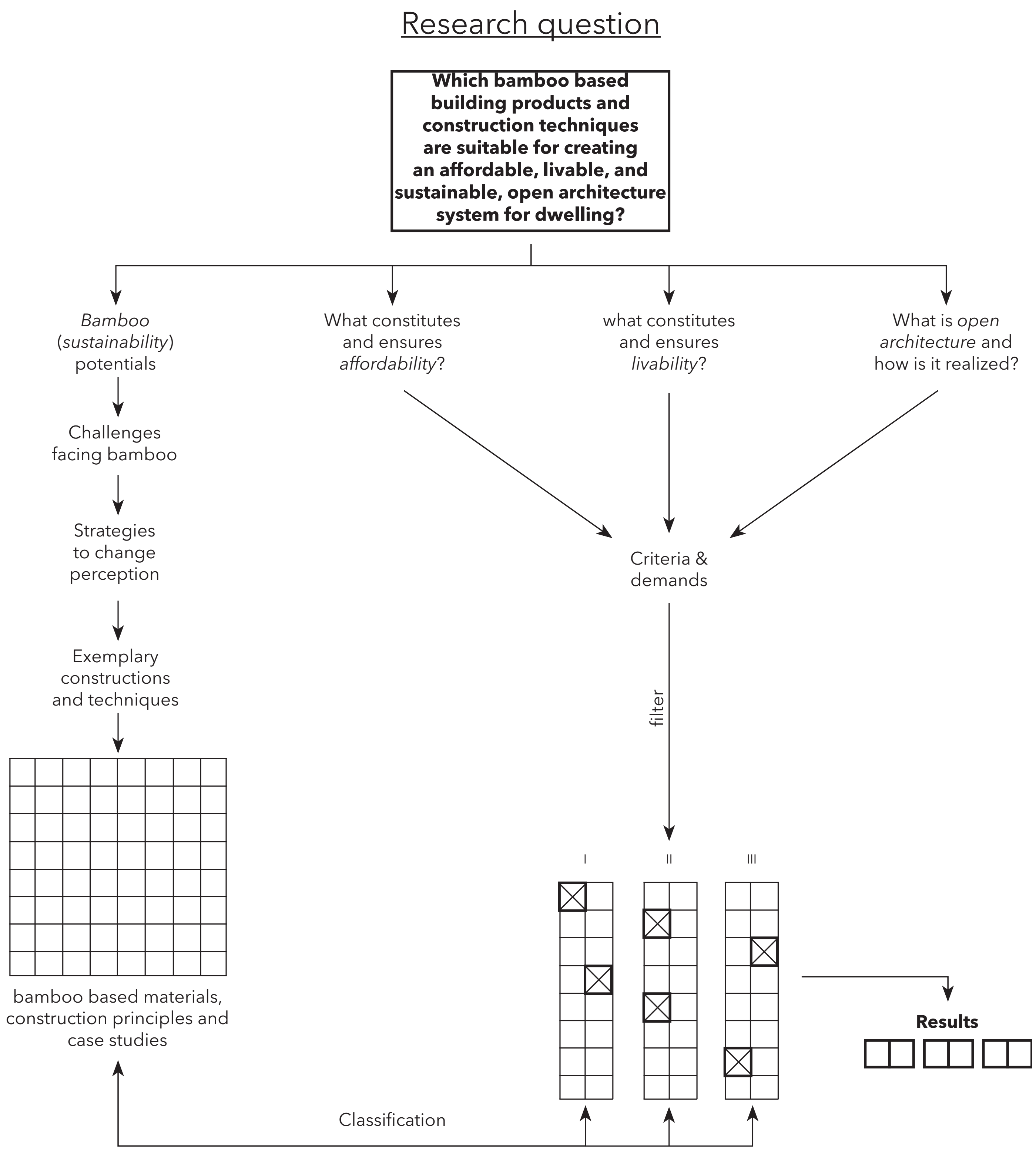
Prefab Bamboo RC house

Project affordability	●●○
Environmental Performance	●●○
Carrier-infill seperation	●●○
Ease of construction	●●○
Design for disassembly	●○○
Possibility for multi-story	●○○
Durability	●●●
Fire Resistance	●●○
Thermal insulation	●●○

Description:
This design is made to showcase the use of bamboo reinforced concrete to create light, low costs architectural elements, such as wall panels, door- and windowframes. The structural columns and beams of this structure are made with conventional steel-reinforced concrete. The roof is made up of full bamboo culms. This deign shows how bamboo can subtly be implemented to increase affordability and sustainability of prefab houses.



Research Scheme

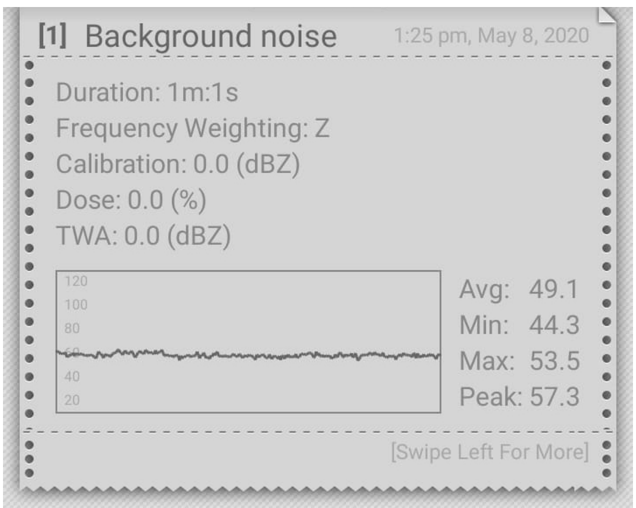


Material Research

Insulation, Ventilation and Translucency

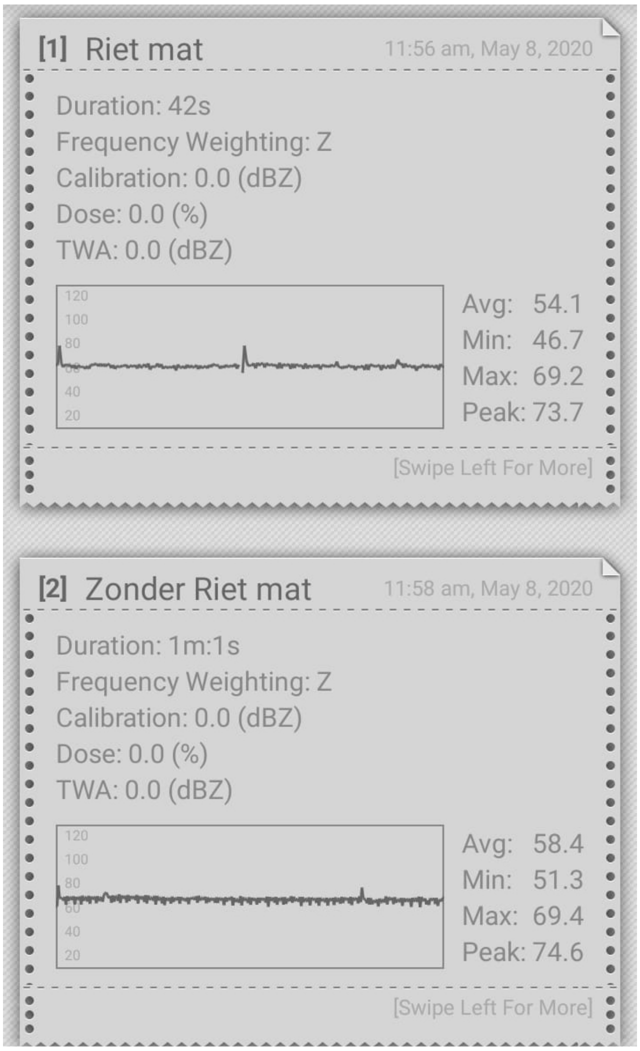
Test Setup

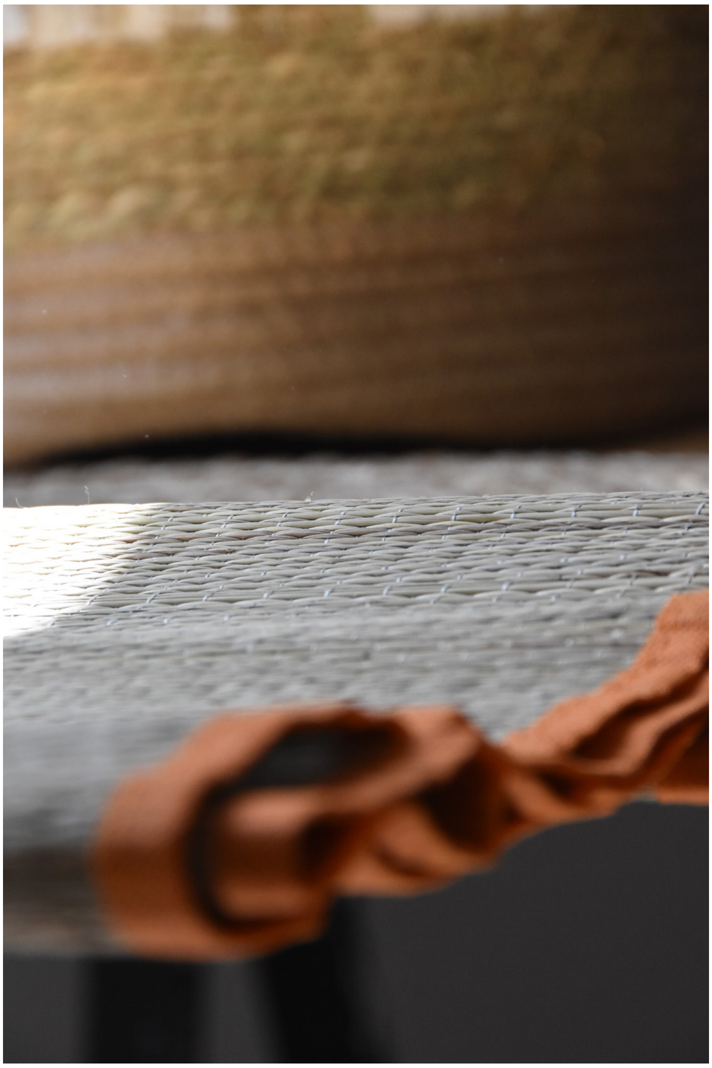
Calibration
Background Noise

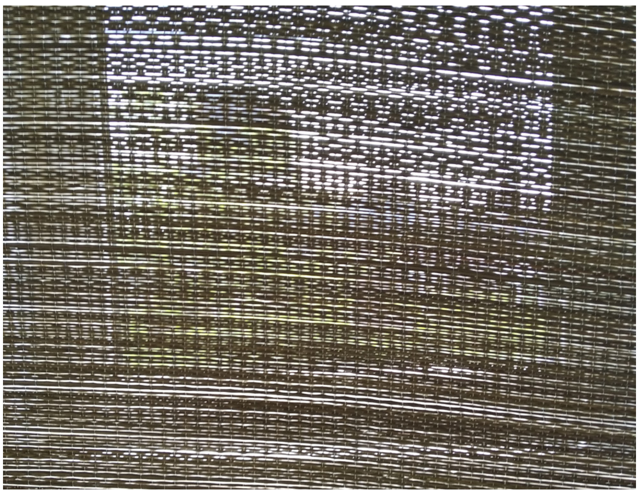


Average noise level: **49,1**

Thatch
(Phragmites australis)



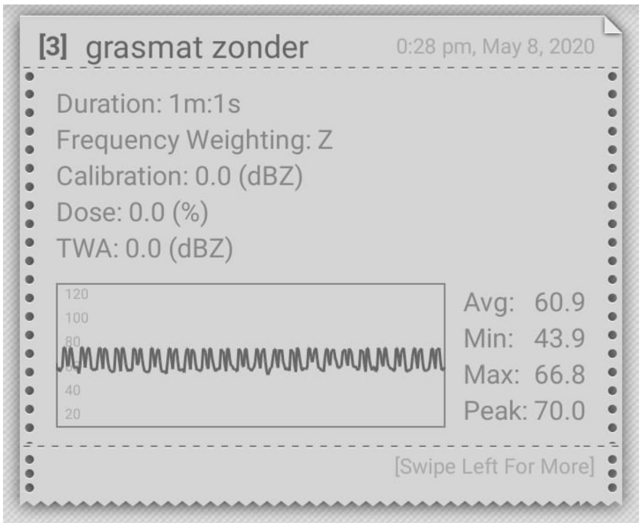


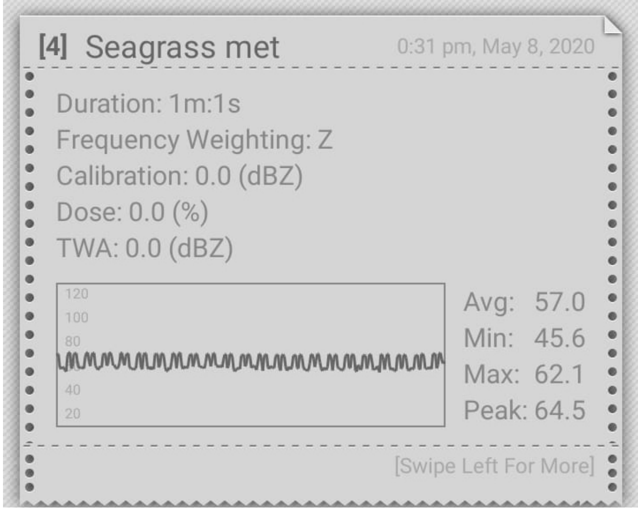


Noise Reduction: 54,1 - 58,4 = -**4,3 dB**

Sound Insulation
Ventilation
Translucency

Seagrass
(Zostera marina)

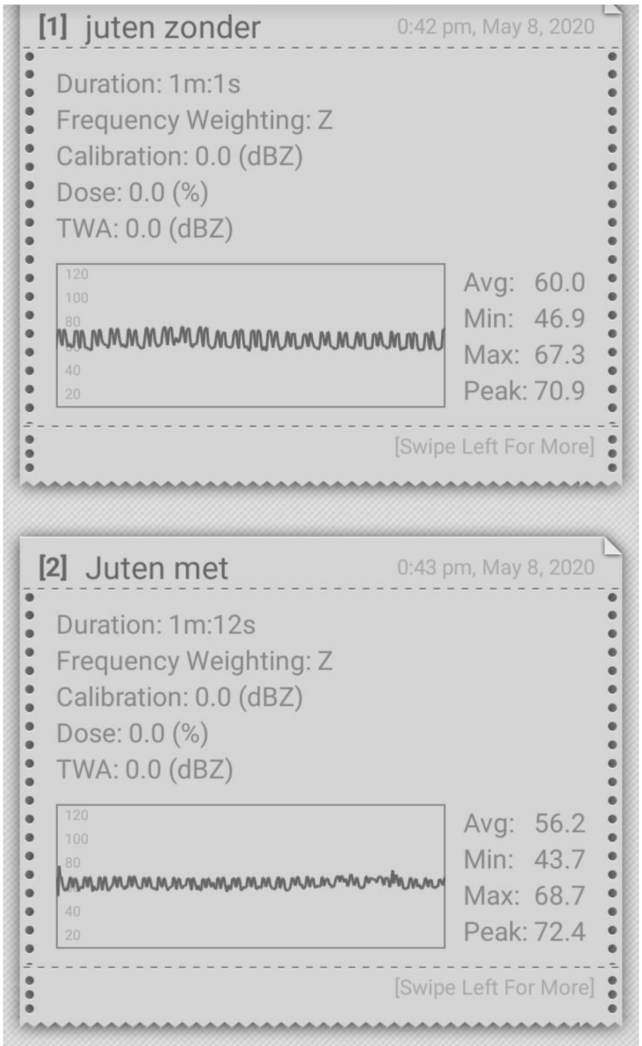




Noise Reduction: 57,0 - 60,9 = **-3,9**

Sound Insulation ●●○
Ventilation ●●○
Translucency ●○○

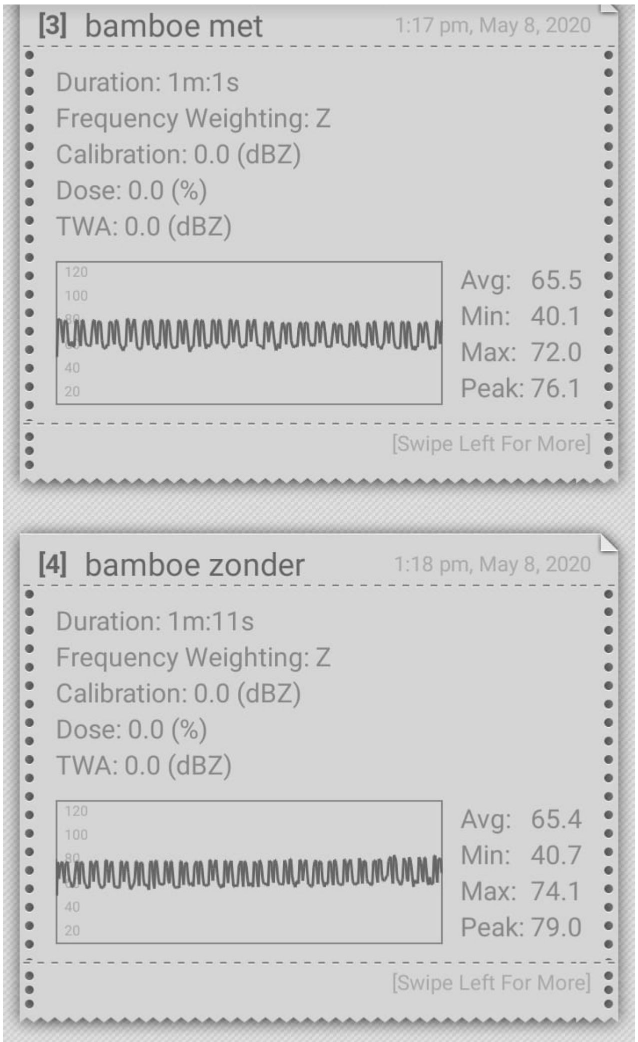
Jute
(Corchorus Olitorius)

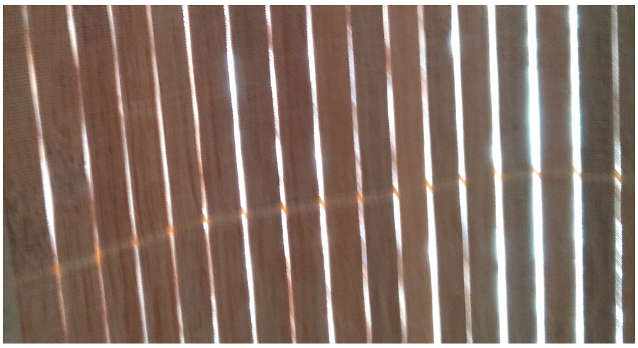


Noise Reduction: 56,2 - 60,= **-3,8**

Sound Insulation
Ventilation
Translucency

Bamboo
(Bambusa textilis)

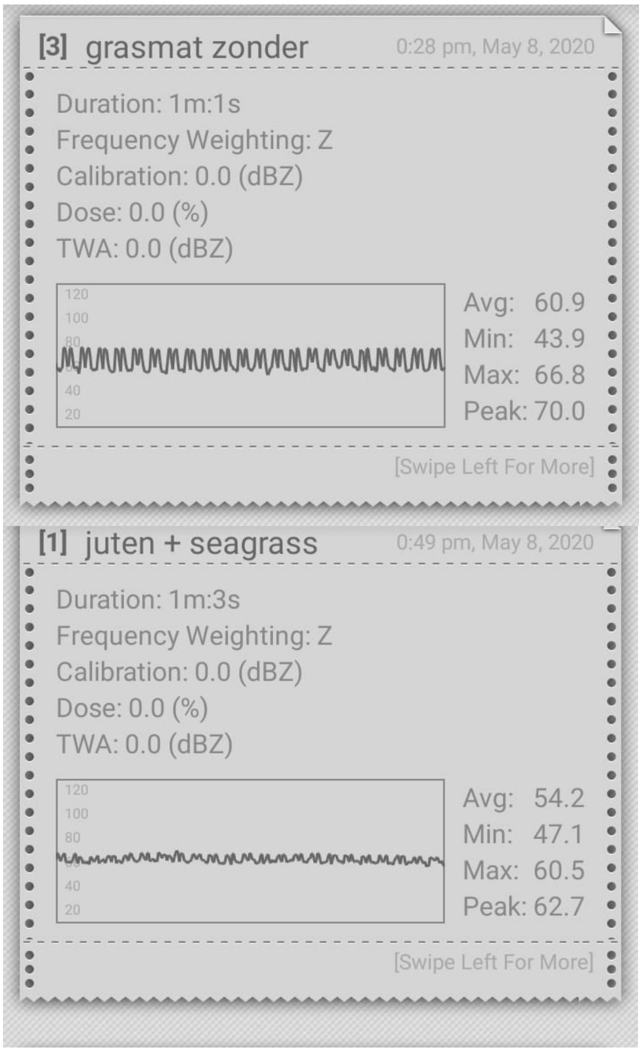


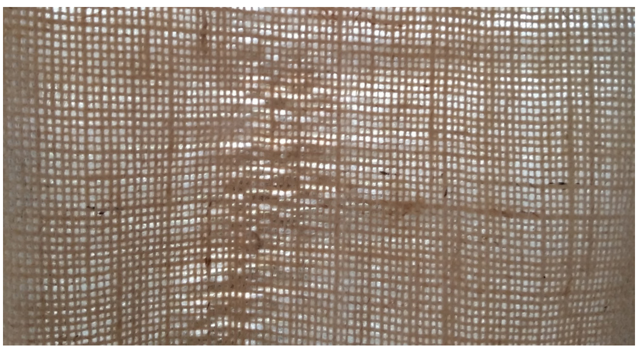


Noise Reduction: 65,5 - 65,4 = **+0,1**

Sound Insulation
Ventilation
Translucency

Layered Materials
Jute and Seagrass

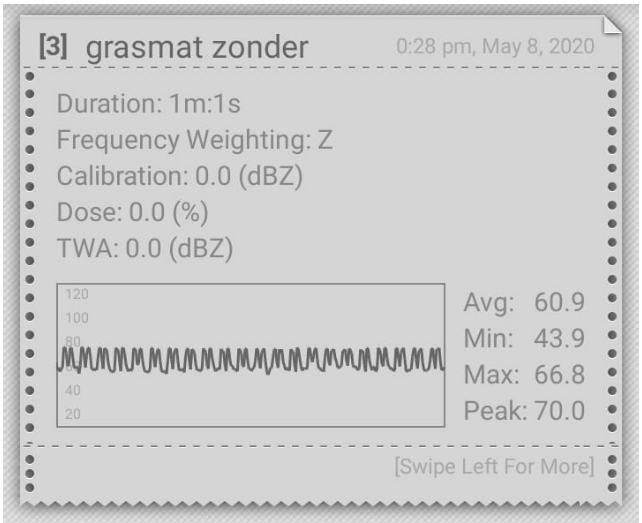


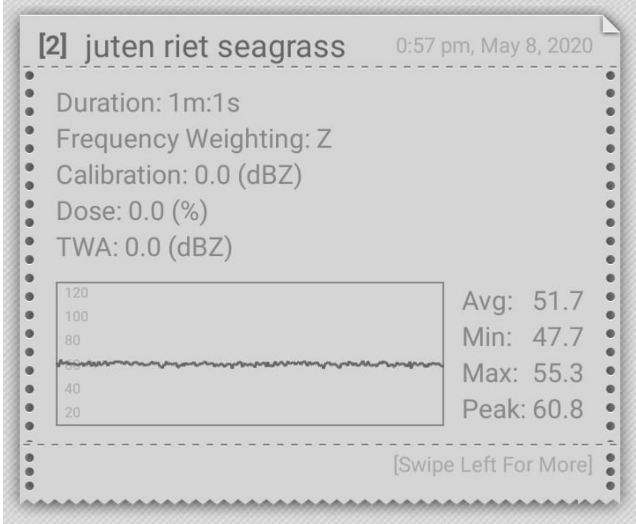


Noise Reduction: 54,2 - 60,9 = **-6,7**

Sound Insulation
Ventilation
Translucency

Combinations
Jute, Thatch and Seagrass





Noise Reduction: 51,7 - 60,9 = **-9,2**

Sound Insulation
Ventilation
Translucency

Conclusion

1. A layering of different weaved natural materials helps to significantly reduce noise levels (**-9,2 dB**) and almost bring them down to normal room level
(**51,7 vs 49,1**).

2. The materials used in this this are all of very fine grain. A more spacious weave and more **distance** between layers could possible increase ventilation significantly

3. Jute and **Seagrass** seem promising when combined, they perform well together and have the **best balance** and overall performance between the three quality parameters.