Exploring the Potential of Bamboo as a Didactic Alternative Construction Material

"Living School" for the Community of Tongova Mews, Tongaat

Kanji Yoshimura

Dissertation submitted in partial fulfillment of the
Requirements for the degree of Master of Architecture to the
School of the Built Environment and Development Studies
University of the KwaZulu-Natal
Durban, South Africa
December 2017

Supervisor: Mrs. B Horner
Dissertation Document 2017

DECLARATION

Declaration for this document to be original to author unless otherwise stated. All References, samples, citations, ideas are referenced to standards. University of Kwa-Zulu Natal being the only examining school.

Student Name
Kanji Yoshimura

Date

DEDICATION

To my mother and late father who gave me a name and a chance to live in South Africa. Thank you for your thoughts, moments, and patience.

ACKNOWLEDGEMENTS

To everybody that has contributed towards the conceptualising and writing of this dissertation document, I am forever grateful.

Bridget Horner
Thank you for making the school of architecture the way it is; allowing us to think, without giving away the possible answers, yet providing us with right path information when needed.

UKZN, Staff
Thank you for always being there.

To my superior and colleagues, thank you for your inspirations and support during my years at UKZN, I am honoured to have studied with you.

Family / Friends
I love you all.

ABSTRACT

There is a current trend in architectural design of being conscious of the global environment and how this connects locally to a particular building site, especially in the selection of materials. Being a renewable and versatile resource, bamboo provides a cheap and effective solution as a construction material. Bamboo can be a rapid and continuous source of resources that can assist rural communities within developing countries using every part of the bamboo plant. Additionally bamboo has the benefit of being an agent of reforestation and positive socio economic empowerment.

This research explored the process and usage of bamboo as a construction material. Global examples of bamboo structures were explored, examining how this material is used from structural details to intricate form-making. Furthermore, biological properties of bamboo were assessed through collected samples by the researcher to conceptualize details for the making of the 'living school'.

The 'living school' is a development in which the spaces constructed out of bamboo would become an example of tectonic assembly, allowing communities to see the assemblages of parts to inspire experimentation in order to expand upon their knowledge of creating spaces using this material. The building could become a didactic tool for teaching of the potential of bamboo without formal instruction. This research will focus on how construction technologies could speak for themselves and transmit knowledge in a passive manner rather than by active methods of formal instruction to teach and transmit knowledge.

PART ONE
DISSERTATION DOCUMENT

TABLE OF CONTENTS

CHAPTER ONE | RESEARCH BACKGROUND AND METHODOLOGY

1.1. Introduction

This research is focused on the exploration of the potential for the bamboo plant to be used in construction as an alternative to conventional construction materials. The properties of bamboo structures will be explored, and in particular the capacity for bamboo to be a didactic construction material: one where structures on their own can teach others how to use the material and replicate building techniques. The aim of this research is to develop a conceptual and practical framework for the concept of the 'living school' - in which bamboo plants are grown and processed into construction materials, and techniques for bamboo construction are taught by teachers with the aid of the didactic properties of the school structure. The 'living school' is for the community of Tongova Mews, Tongaat.

1.2. Background

Rural communities rely heavily on their environment to sustain their way of living in providing construction materials, herbal medicine and fuel. The forest contains biodiversity which enriches the culture of those that coexist with their natural environment. In developing countries, populations are increasing and too are the demands for resources. Dimick (2014) states that sub-Saharan Africa is experiencing an exponential growth of population, with a growing concern that indigenous natural cycles are not able to produce enough resources to meet their demands. Many activities result in the deforestation of natural environments, with built-up areas increasingly encroaching into rural areas. This is supported by Rosenberg (2012), who contends that “the majority of the population (70%) in Sub-Saharan Africa use wood fire to prepare their meals” (Fig 1.1.). Industries that rely on the same natural resources and are contributing to the increasing rate of deforestation, including those involved in activities “such as land clearing by farmers, commercial logging, construction of dams, roads and mines” (Agyei, 1998: 1).

The land degradation phenomenon (Fig 1.2.) which threatens large parts of Africa, this happens when the biological and economic productivity of land is lost, mainly through human activities (Rosenberg, 2007). Land degradation thus creates chain reactions including drought and other associated environmental issues. Small to large scale farming enterprises are affected to such a large extent that often they are unable to continue production. In the long term, this results in rise of food costs from fundamental water system being difficult to purify, with the excessive silting of eroded soil entering rivers and dams. People leaving their homestead because the land is no longer able to sustain them are called "environmental refugees"(Dunn, 1989: 1). To counter the effects of land degradation huge cost factors are known to be considered together with introduction of sustainable usage of resources.

Fig 1.1. Collection of Firewood for Fuel

Fig 1.2. Land Degradation

Water and sanitation is another serious issue that affects the livelihood of rural, and also urban communities. “A safe and sustainable water supply, basic sanitation and good hygiene are fundamental for a healthy, productive and dignified life” (International Fund for Agricultural Development, 2017: 4). Water consumed or used by people become contaminated and requires processing before it can be fed back into the water supply, or into nature. Lack of sanitation facilities and poor sewage treatment works across South Africa are seen as initial form of pollution (Erasmus, 2017). Water that is more heavily contaminated which is unfit to water edible crops may be fit for use in farming of plants used for renewable construction or energy resources.

Bamboo has been gaining attention globally as a low impact material that offers many benefits to humanity and the environment. Compared to 20 year maturing age for the average timber, bamboo matures in five years. As long as the root system remains intact, the same plot of land will produce a constant yield annually. Bamboo can provide practical and rapid solutions for a number of natural resource and poverty challenges; the plant has proven its effectiveness for restoring damaged land and ecosystems, combating climate change through carbon sequestration, avoiding deforestation, and boosting rural livelihoods (Friederich, 2017).

The environment plays a vital role in people’s life; they can inform and become a part of their learning process. This includes, not only academic education, but knowledge on sustainable systems that can be comprehended so as to allow people to replicate what they have observed. This thesis has explored how bamboo could become an alternative renewable resource to build infrastructure that teaches through its construction detailing.

1.3. Motivation for the study

This research sets out to investigate the potential of bamboo as an alternative construction method for rural community development and to establish a system, wherein people create a close symbiotic relationship with bamboo in a living environment, which could become part of their everyday life. The research aims to contribute towards the knowledge of bamboo construction in South Africa and possibly become part of literature for future researchers in this field.

It is suggested that Africa has an enormous potential to grow and produce more products from plants such as bamboo (Bystriakova, Kapos and Lysenko, 2004). Therefore, small scale farming should be encouraged as it empowers people by allowing them to benefit from their immediate environment. To achieve this, knowledge on small scale farming methods and renewable resources, such as bamboo, should be introduced and disseminated in South Africa. Also, African economic growth and development will depend fundamentally on increased agricultural and rural productivity, thus; spreading the knowledge of renewable resources will have long term benefits for South Africa (Steyn, 2012).

The Bamboo industry creates multiple trades (from construction to craft) that use the plant in various ways to create different products which can assist the communities to develop a sense of identity and independence (Fig 1.3. and Fig 1.4.). According to the United Nations Environmental Programme (UNEP), there are approximately 2000 different uses of bamboo, some of which are commercially produced, with considerable income being generated from from these products (Musau, 2016). Skills development is a crucial factor in the bamboo industry since it is a labour intensive material, from harvesting, treatment, construction to craft it has the potential to involve a large number of possible employment; also being a hands on material, there would be no need to invest in heavy machineries which could not be affordable to the general public. Bamboo will help developing nations where resources are scarce and environmental issues are directly related to the growth of populations.

Bamboo can be a renewable material which, if grown locally, can reduce the carbon footprint of construction (Calkins, 2009). Increasing available knowledge about bamboo as an alternative construction method will challenge people to re-consider it as a viable material with which to build, preventing the need to transport long distances or deplete a range of natural resources.


Fig 1.3. Bamboo House by H&P Architects


Fig 1.4. Bamboo Weaver

My personal motivation for this research topic stems from having seen bamboo used in the livelihood of people in Japan and how it has been incorporated into every aspect of daily life. Its versatility was more apparent in previous decades, where people had to make the things they needed. In the modern era, craftsmanship with bamboo is fading away as people became more interested in products that save time and money. I believe that there is value in developing the art of bamboo craft in South Africa, which may be a transformed version of the craft that adopts elements from international experts as well as incorporating uniquely South African characteristics. In South Africa, I first noticed bamboo plants growing on the sides of highways and wondered what they were used for, only to realise that they are considered as yet another invasive species that everybody wants to get rid of. I believe that there is enormous potential in utilising this naturalised resource to benefit people and the environment.

1.4. Problem Statements

Rural communities often have limited access to readymade construction materials, which makes it hard for them to build structures without the aid of external organisations and finances. At the same time water usage and its treatment are crucial for the livelihood and wellbeing of communities. This research focuses on rural development through the use of bamboo as a strategy towards creating self-sustaining communities and regards the potential of bamboo as both a renewable resource and didactic alternative construction material.

Moreover, there is a lack of information regarding bamboo construction in South Africa, with bamboo agriculture and use in construction having not been formalised or standardised. Hence, there is a need to investigate the types and quantity of bamboo available locally and their biological properties as well as examples of how it is currently being used in construction and how it can be used in future.

1.5. Aim and Objectives

Aim

The aim of this research is to explore the construction and related didactic potential of bamboo as an alternative renewable building material in KwaZulu-Natal Province, South Africa.

Objectives

1. To understand the biological properties of bamboo and the treatment processes necessary to use it as a construction material.

2. To explore bamboo construction techniques from indigenous to modern construction examples from around the world.

3. To contextualise the information gathered by developing construction techniques and principles that are site specific to suit South African conditions.

1.6. Definition of Terms

The following terms are used to describe various aspects of bamboo in this research:

Chromated Copper Arsenate (CCA) - is a wood preservative treatment commonly used in timber which is also applicable for bamboo preservation (Anthony and Lebow, 2012).

Community - A gathering of people living and working together within a reachable distance. Inhabitants with similar social and religious background, sharing common heritage or interest. A sense of belonging is often portrayed by identifying participation towards a common goal (Hystad and Carpiano, 2012).

Culture - Collective and shared knowledge of particular behaviour patterns that are improved by socialization. Culture is derived from the Latin word "colere", which means to tend the earth and grow, or cultivation and nurture (Zimmermann, 2015). Cultures are forever evolving, since needs and demands will always change and conflicts will arise. Acceptance for change and improvement makes for a resilient culture.

Culm - Used extensively in this document to refer to raw bamboo poles. This is the jointed stem system which characterise this perennial evergreen grass family (Bamboo Botanicals, 2017).

Didactic - Meaning to design or intend to teach, didactic persons will over incline to preach to others while didactic buildings will display their capabilities, offering a visible choice of methodology for others to see. "Didaktikos", is a word from Greek origin which means "apt at teaching." It comes from the word didaskein meaning to teach. Something didactic does just that, teaches or instructs (Merriam-Webster, 2017).

Lashing - Term used in bamboo construction to tie the separate culms with thread / rope (Schroder, 2009).

Laminated Bamboo Lumber (LBL) - this refers to the split and planed bamboo culms that are glued together to make a rectangular profile (Rittironk and Elnieiri, 2007).

Living School - Expanding modular building methodology that uses the nature of bamboo plants to aid the scheme. The word “living” would be used to represent a system that utilises human activities for the growth of bamboo plants.

Rhizome - A root-like structure, generally of the grass family. This is also a name for a philosophy which takes from the characteristics of roots to develop a conceptual framework (Olivier, 2015).

Tactile - The sense of touch of the human body which makes connections between people and physical objects and resources, regarded as the “tectonic language of buildings” (Pallasmaa, 2005: 54).

Tectonic - Tectonic is a term which originates from the Greek word "tekton", referring to the carpenter and builder. Tecton is closely associated with another Greek word “techne”, which addresses skills of an artisan to craft. Tectonic is referred to as science and art of construction. Tectonic composition is a "syntactical form of the structure which explicitly resists the action of gravity" (Frampton, 1995: 27).

Vernacular - Primitive indigenous architectural response to their climate, landscape and available resources, a reflection of cultural history from a particular civilisation (Rudofsky, 1964).

1.7. Delimitation of the Research Problem

The researcher is aware of the broad subjects that exist within and around this area of study. These subjects range from environmental, water and sanitation to socio-economic topics which may divert away from the main research objective in the discipline of Architecture. A framework is needed to focus the study in order to carry on this investigation. This research does not go into depth with regard to the economic or environmental impacts of bamboo as a construction material. However, the research will focus on bamboo as a material, and related processes and construction techniques. The proposed 'living school' will be examined from the point of view of the construction material. Thus, the focus will remain on the cycle of growth and development of structures made using bamboo and didactic spread of knowledge regarding construction techniques.

The research explores what opportunities exists for the use of bamboo as a construction material that could have the potential to be didactic through tectonics. It is making the assumption that learning can be conveyed through the art of construction.

1.8. Research Questions

1.8.1. Key Question

What is the construction and related didactic potential of bamboo as an alternative renewable building material in KwaZulu-Natal Province, South Africa?

1.8.2. Secondary Questions

1. What are the biological properties of bamboo and what treatment processes are necessary for it to be used as construction material?

2. What indigenous and modern techniques are available for bamboo construction?

3. How to contextualize details and principles that can be applied to building with bamboo in South Africa using local skills and materials?

1.9. Research Methods

This is a descriptive, exploratory study using a qualitative approach to explore sustainable architectural practice through the use of bamboo as a main construction material. The didactic properties of architecture are of main research interest whereby this research questions the ability of structures to teach through their construction. The study will consist of both primary and secondary data (published works), the latter will be analysed and interpreted to form the literature reviews which will elaborate on the relevant theories and practices dealing with the bamboo plant and 'living school'.

Objective 1 and 2 are addressed through literature reviews, online journals, websites and books. Keywords that were used to drive the search for literature were: ‘didactic properties of bamboo’, ‘tectonics’, ‘critical regionalism’, ‘wabi-sabi’, ‘tactile qualities and culture of bamboo’, ‘examples of bamboo construction’, ‘large span coverage with bamboo’, ‘bamboo joinery techniques’, ‘community involvement in bamboo construction’, ‘fully furnished bamboo house’. The above materials were searched for within Google search engine (Google.com), Google Scholar, World Cat Library (https://www.worldcat.org), as well as UKZN electronic (http://library.ukzn.ac.za) and physical library.

The literature and document review assist with obtaining information on the current practices relating to bamboo constructions, so as to understand the biological properties of bamboo (Objective 1), literature would be sourced related to the characteristic, productivity, treatment and water usage of bamboo in order to develop the foundation for the concept of the 'living school'.

In order to explore bamboo construction techniques (Objective 2), literature will be sourced that demonstrates structures which exhibit principles of tectonics in their architecture, and which depict critical regionalism. These structures will form a series of precedent studies which will contribute to a set of achievable design details that can be applied in South Africa (Objective 3 - details).

As Primary data, two industries that manufacture and distribute bamboo products will be examined. This was done to address the Objective 1 and 3 of this research, interviews were held with specialists who are involved in the bamboo industry in Africa - in growing, processing, selling and construction using bamboo.

1.9.1. Sampling Method

Primary data was collected by the researcher, analysed and synthesised to develop a practical understanding of functions that would be incorporated in the 'living school'. In order to gain understanding of the current practices that deals with bamboo, three distinct phases were identified 1) growing, 2) processing, construction and 3) distribution. These phases are the target samples which the researcher has aimed to investigate, the selection of participants has been conducted according to the specialists who deal with the above phases.

The selected precedent studies are i) Fumba Town Development in Tanzania and ii) Brightfields Natural Trading Company in Cape Town. First being, Fumba Town Development, they grow and processes their own construction material (laminated bamboo lumber), to make their prefabricated residential unit for their scheme. This research has particular interest in the growing and processes of bamboo that this precedent study was chosen. Second is Brightfields Natural Trading Company, whom are a bamboo product supplier in Cape Town, they are one of the leading companies in South Africa that they were chosen to find out the current usages and appropriate locally available species of bamboo, their processes, showroom, storage and offices were of interest in the findings during the interview.

These information assist with developing principles relevant to 'living school' (Objective 3 - principles), growing, manufacturing process of converting bamboo into a durable construction material and their distribution.

1.9.2. Data Collection Methods

To address Objective 1 and 3, three interviews were developed. i) an open ended questionnaire for Fumba Town Bamboo nursery, ii) a similarly open-ended questionnaire for

Fumba Town Laminated Bamboo Lumber processing plant, iii) a semi-structured interview questionnaire for Brightfields Natural Trading Company. These are focused interviews for the collection of selected samples.

Telephonic interviews were conducted with Fumba Town development and with Brightfields specialists, these were held with three specialists: Fumba Town nursery specialist **Vuai Mkoko Hassan**, Fumba Town Laminated Bamboo Lumber (LBL) factory project manager **Akief el Mauley**, and bamboo product supplier **Graham Dunbar** from Brightfields Natural Trading Company. Digital images and descriptions of processes within Fumba Town Development and Brightfields Natural Trading Company have been requested and were received digitally from those interviewed, to supplement the responses to the questionnaires.

1.9.3. Data Analysis

Collected questionnaire answers were transcribed and supplemented with notes taken, photographs were collected from the interview processes, and from information sent subsequently this data was arranged in logical order. This will be formalised into categories based on each step in the manufacturing process, from the bamboo plant to a final structure.

A summary and an analysis of the primary data gathered from the interviews will be presented in chapter 5. This section depicts the process of manufacturing using bamboo, from a raw form to a processed product. Development of the details and sketches would be documented in chapter 6, in the recommended design guide. This section focuses on the physical development of details that can be applied to the proposed 'living school' development for the community of Tongova Mews in Tongaat.

1.10. Conclusion

This chapter provides the background, guidelines and limitations of how the research will be conducted and sets the framework for the rest of the documentation. The research will be focusing on bamboo, the process of making it into a construction material and its application in construction. Furthermore, this research has a key interest in the physical configuration of bamboo buildings. The researcher will examine the physical properties of bamboo construction to understand the didactic nature of this material which allows one to observe and apply construction techniques.

Bamboo has shown to be a sustainable and viable construction material in various places, being labour intensive to grow as it requires constant attention, but having considerable benefits, in both financial and material ways. Innovative construction methods need to be found to address growing population demands, and to reduce the negative consequences of growing populations and expanding urbanisation. Within the context of the global bamboo industry, this study aims to explore its suitability as a construction material in South Africa by establishing which species are available, whether they can be used for construction, and if so how this can be achieved. This background chapter outlines the context for the study, and is followed by Chapter 2, which provides the theoretical and conceptual framework for the research.

CHAPTER TWO | THEORETICAL AND CONCEPTUAL FRAMEWORK

This chapter details the theories and concepts that informed the development of this study. The Theories of **Critical Regionalism** and **Tectonics** in architecture are followed by the concepts of **Rhizome** and **Wabi Sabi**. Each of these theories characterise the various elements of bamboo construction and, in the context of bamboo, combined together to form one framework.

Bamboo has been used for centuries as a construction material, often being used in simple construction modes that typically exhibits qualities of **Tectonic** architecture. The versatility of bamboo allows for it to express different cultural practices such as weaving but also to be used in new ways and to be incorporated into modern applications. This process of assimilation being aligned with the principles of **Critical Regionalism**. The ability of bamboo plants to grow and spread rapidly, and the efficient dissemination of the knowledge of how to use it (aided by its didactic properties), means that it is a good example of a **Rhizomatic** concept. Bamboo is also seen as a humble material which does not require complex industries for its manufacture. It is an impermanent material that is regarded as plentiful and environmentally efficient. The use of bamboo, to replace more complex materials, is in line with the principles of **Wabi Sabi**.

In the process of identifying a starting point, the theory of Critical Regionalism is introduced to highlight the importance of focusing on a localised identity and relevant materials in construction methodology, and to make the point that to create a unique culture one has to consider the tactile quality of materials (Frampton, 1996). Bamboo buildings often display irregular tactile qualities, due to the physical attributes of each culm and because the various component are manufactured using different processes. Bamboo is a labour intensive material, and the process required to make a bamboo building itself can become a specialised trade for local craftsmen.

Tectonics in architecture is explored to develop an understanding of the role of didactic architecture in bamboo structures, and is expressed in the physical appearance of structures. The visibility of the logical composition of materials will allow an individual to understand how elements form connections and build upon this knowledge (Frampton, 1996). The biological profile of the bamboo plant with visible junctions is an example of how information could be transferred visually and inspire others to create their own examples.

Rhizome is a philosophical concept that provides the principles for the spread of structure and knowledge regarding this alternative construction material. The concept of rhizome is inspired by a root structure, such as that of the bamboo. Gilles Deleuze and Felix Guattari (1987) explain the root expands its connections horizontally, creating multiple new shoots without hierarchy. The root structure may be broken at any point and each piece may sprout new shoots. The multiplicity of the bamboo plants is reflected in the physical transfer of structure and information regarding bamboo construction across continents.

Wabi Sabi is a case study from Japan that represents the core philosophical framework to the research. It establishes the ethical guidelines and principles of space making using bamboo, and it speaks about the impermanence of beings and objects, and that everything weathers (Durston, 2006). Bamboo, being more vulnerable than other materials, requires careful consideration regarding its application. Understanding this aspect of Wabi Sabi and bamboo enable the incorporation of design details that consider the transience of the materials and occupants.

2.1. Critical Regionalism

Modernism (emerged early 20th century) in architecture was a rejection of classicism (late 8th and early 9th centuries), where ornamentation was eliminated and replaced by function shaped buildings (Sudjic, 2006). Conversely, the emphasis with postmodern architecture became more inclined towards visual aesthetics rather than their function (Frampton, 1983). Thus, postmodern architecture can be considered as an exaggeration of the classical order combined with modern technology (Figure 2.1).

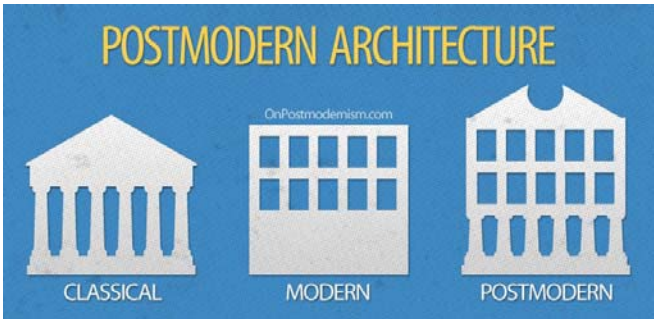


Fig 2.1. Classical, Modern and PostModern Movement

Until the advent of concrete reinforcements, spanning large openings was a challenge with limited materials, this now being possible with reinforced concrete beams that can span 20 meters. The scale of architecture has been influenced to extend beyond their natural capabilities and host far greater demands. However, modern technology has allowed architecture to become close to being a fully automated process, with less and less people are getting involved in the creation of spaces. The advances of modern technology in construction is largely a result of universalisation; this being a process whereby available technology, products and habits of people become standardised throughout the world (Ricoeur, 1961; 276). Universalisation is a result of the progress of humankind but at the same time it is also a threat to traditional cultures (Fig 2.2.).

The concept of universalisation can be further expanded by optimised technology, which is an acknowledged objective in the construction industry where the aim is for materials to be used most efficiently in order to create and recreate the same standard building products. Where building products are predetermined to be used in a certain manner, this generally determines the outcome of the building (Frampton, 1983: 16). An example of this is the concrete construction block and corrugated iron sheeting, which are products of optimised technology that are used extensively in the South African building industry (Fig. 2.3.).

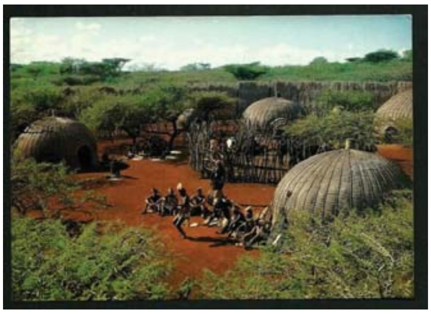


Fig 2.2. Traditional Zulu Kraal

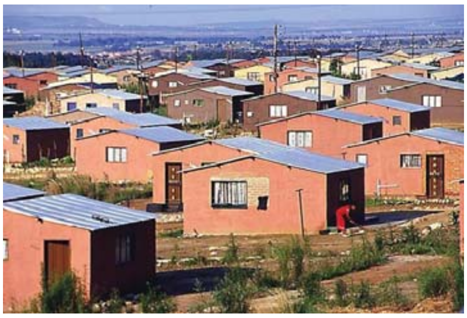


Fig 2.3. User-Manufactured Low Cost Housing Solutions

Unfortunately, universalisation in construction techniques has meant that the use of local materials by region, and the variety of construction techniques across regions, has been reduced. This research will argue that this reduction in the use of local materials and construction styles can result in people no longer identify with their structures as being linked to their region or their culture which can negatively impact their cultural identity.

2.1.1. Towards a New Vernacular

By addressing unique characteristics associated to a specific region or location, critical regionalism aims to reintroduce local elements into architecture that have lost its local identity in the progress of civilisation (Frampton, 1983). Critically regional responsive architecture gains inspiration from the topography, quality of natural light and cultural practices from a particular site. Thus, it can be concluded that "critical regionalism is a bridge over which any humanistic architecture of the future must pass" (Tzonis and Lefaivre, 1981: 178).

In order to reach this goal, there is a need to reconsider the aims and principles that drive universalisation. Thus, critical regionalism assists in the mediation of universal techniques and optimised industrial/post industrial technology in order to reintroduce the local identity of a specific region. "The case can be made that critical regionalism as a cultural strategy is as much a bearer of world culture as it is a vehicle of universal civilisation" (Frampton, 1983: 21).

Since critical regionalism is not about reviving vernacular but rather considering their relevance in creating a new architecture/vernacular, awareness of "critical self-consciousness" (Frampton, 1983: 21) is required. Critical regionalism emphasises the reinterpretation of local characteristics without direct adaptation of traditions (Beyazh, 2015). This is articulated by Ricoeur (1965: 277), who noted that "there is (exists) a paradox: how to become modern and return to sources; how to revive an old, dormant civilisation and take part in universal civilisation".

Vernacular buildings around the world display the uses of traditional materials and skills to create a landscape unique to their location, which in turn contribute to the local character and culture of the region (Fig 2.4.). Depending on the climatic conditions and available materials, people will aim to make the best use of the available materials to create comfortable habitat zones and solve the problems that they face. The combination of differing regional conditions, craftsmen and various available materials generates a variety of innovative solutions that will contribute to the collective pool of universal techniques (Frampton, 1983).

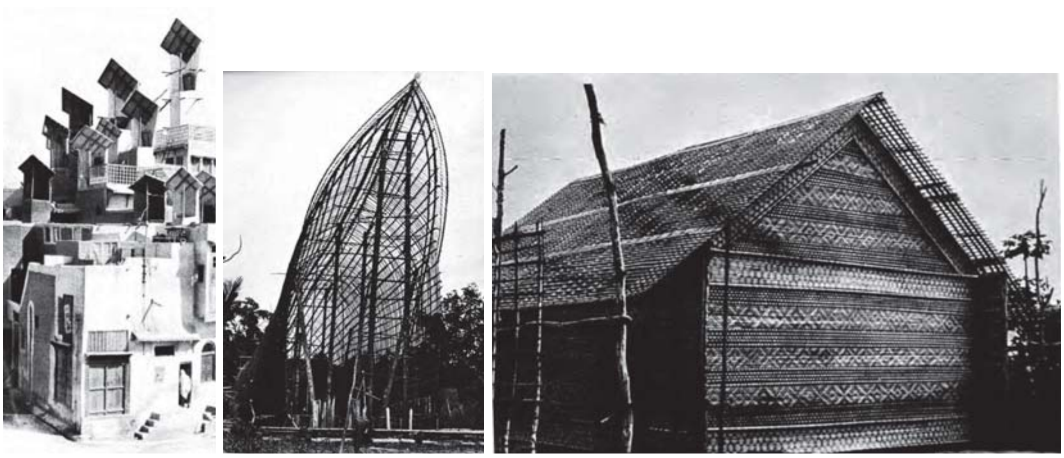


Fig 2.4. Series of Pictures from *Architecture without Architects* by Bernard Rudofsky 1964

2.1.2. Tactile and Light Implementation Towards a Place Based Architecture

Many early modern art galleries showcased art work under controlled artificial lighting that provided a standard space in which the pieces were displayed. However, the aura that the pieces possess becomes diluted from there being lack of natural spectrum of light. However, the use of natural light is unfathomable as direct sun rays on the art pieces are to be avoided to minimize their deterioration. Therefore, ambient natural lighting should be incorporated to exhibit art pieces together with the changing quality of time and season (Fig 2.5. and 2.6.).

Relating this concept to architecture, buildings are considered as a "place-conscious poetic - a form of filtration compound out of interaction between culture and nature, between art and light" (Frampton 1983; 27). This quality not only applies in the display of art but as a reflection of a place and culture, thus; it relates to architecture.

Fig 2.5. Kimbell Art Museum

Fig 2.6. Louis Kahn

“As buildings lose their plasticity, and their connection with the language and wisdom of the body, they become isolated in the cool and distant realm of vision” (Pallasmaa, 2005: 31).

Critical regionalism enhances the architectural journey, not only visually, but by creating a structure that engenders a distinct quality in its tactile composition. Incorporating designs that pay tribute to the elements of culture and history of a region, and using locally familiar materials, connects people to the structures around them physically. “Natural materials express their age and history, as well as the story of their origins and their history of human use.” (Pallasmaa, 2005: 31).

The act of weaving is regarded as the start of ethnic cultures around the world and in bamboo buildings the materials are woven in various scales . When structures are built by local residents using their hands, the connection between people and the structure becomes woven in the same way as the structure around them. Bamboo, having the capacity to transform into various products (both structural and as a partition of spaces), allows for its diverse application, with many artisans working in particular trades of the construction industry. As Frampton notes (1983: 29), the tactile and the tectonic together have the capacity to transcend the near appearance of the technical in much the same way as the place-form has the potential to withstand relentless onslaught of global modernisation.

2.2. Tectonics in Architecture

As buildings have evolved around civilisations, they represent the need and aspirations of each community in their respective eras. As time passed and civilisations evolved, the progression of technology occurred which has allowed for spaces to be constructed to not only accommodate our basic needs, but for other expressions of comfort, art as well as higher level needs (Schwarzer, 1993).

The use of the term tectonic in architecture dates back to 1830, when Karl Otfried Muller published a German article titled "Handbook of the Archaeology of Art" (Frampton, 1996: 4). In this article, Muller refers to the aesthetics of objects as being derived from need and comfort. Their process is tectonic in nature, with the biggest creation being architecture, which mostly through necessity rises high and can be a powerful representation of the deepest feelings"" (Frampton, 1996).

2.2.1. Tectonic Thoughts

Heidegger (1954) argues that foundation is the first intent of architecture, with the phenomenological essence of such a space/place depending upon the concrete, which clearly defines nature and its boundaries. Placements of stones on the surface of the earth defines a plane of ownership and an intention to build upon a space, the action of foundation laying initiating the possibility of buildings. "A boundary is not that from which something stops, but, as the Greeks recognised, the boundary is that from which something begins its presencing" (Heidegger, 1954: 332)(Fig 2.7.).

With that being said, a significant figure in developing the theoretical framework for the tectonic field is Gottfried Semper who, with strong influence from Muller, published "*Four Elements of Architecture*" in 1851. This book questions the neoclassical primitive hut theory as an initiative of dwellings, as proposed by Abbe Laugier (1753).

The primitive hut theory was conceptualised after Semper saw a physical Caribbean hut at the Great Exhibition in 1851. Semper's idea for a primordial dwelling was categorised in four elements with two main types of construction. The four elements are 1) Earth work, 2) Hearth, 3) Framework/roof and 4) Lightweight enclosing membranes (Fig 2.8.). The two types of constructions are i) Tectonics of the frame and ii) Stereotomics of the earth work (Frampton, 1996: 5). Semper (1851) believed that the theory of tectonics is deeply related to the behaviouristic practice of humankind.

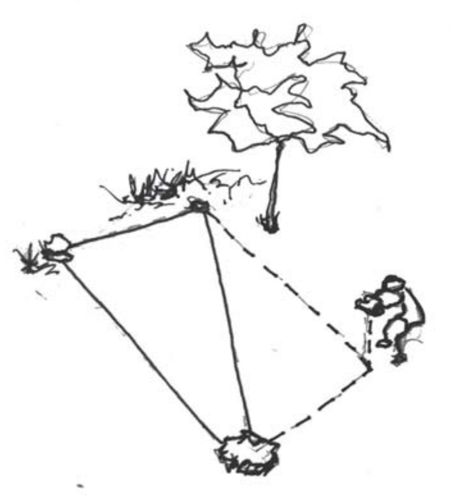


Fig 2.7. Ownership of Space and Intention to Build

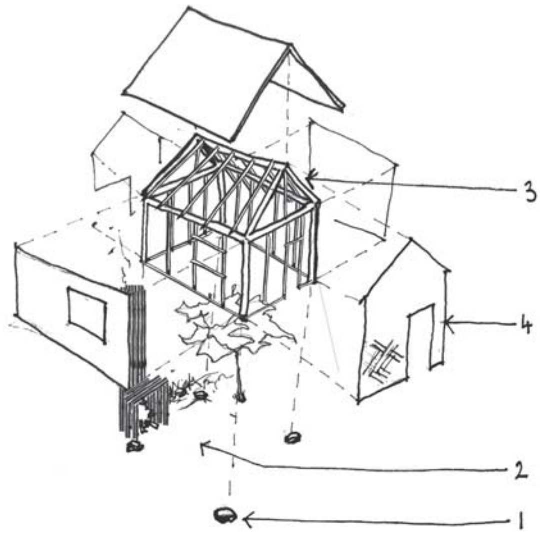


Fig 2.8. Four Elements of Architecture

The construct of the primordial dwelling distinguishes between the qualities of different materials and contends that optimal selections are made to achieve the best results for each component (Semper, 1851). Timber (or bamboo), which has a high tensile quality, would be used to create the framework. This framework is regarded as a space defining component of the sky. Stone / Earth works as a compressive element (appropriate for the foundation) defines a surface on the earth. Frampton (1996) argues that Semper's theory's validity lies in vernacular buildings throughout the world, showing signs of the "four elements"; depending on the culture and climate, and while the use of materials might vary, the fundamentals remain intact.

Tectonics makes use of the properties of individual materials to create bigger and stronger combined structures. Threads are gathered, from a raw material, to combine the individual properties into one element that can withstand a far greater load (Fig 2.9.), with one of Semper's element of architecture being the *light weight enclosing membrane* and this is achieved by weaving of these threads. Clothing defines the culture of people, with Semper (1851) likening the dressing of buildings to that of people's clothing. Materials such as bamboo, with their tactile woven quality, allow the identity of people and their culture to carry through to the construction of their spaces (Frampton, 1996). Finally, knots are regarded as the primordial form of joints, they are created by making the thread tangle amongst itself to create an irregular piece within their composition; knots allow for the possibility of various joinery to occur, this is also considered a form of weaving.

Fig 2.9. Threads Making a Surface

Karl Botticher defines tectonics in architecture as a simple formulation of a building, in which the spaces are clearly defined by their function in that they are visual in their form (Schwarzer, 1993: 267). Botticher focused on the necessity of spaces and activities that creates building form, using the phrase "dynamic and infinite universe of forces" (Schwarzer, 1993: 267). Architectural space is intimate, to which people respond both socially and physically. Tectonics deals with the issues related to construction, their structure, function and symbolism. Tectonics allows architectural interventions to be created that signify natural and cultural progression which Botticher refers to as the "ontological principle in the conception of buildings" (Schwarzer, 1993: 267).

Schwarzer (1993) states that the German aesthetic philosophy in the 1840s, used to judge and analyse objects, took an interest in tectonic theory. Architectural aesthetics of that time was heavily dependent on ornamentation, with the mechanical properties of structures being only a framework for its decoration. Ornaments were detached from utility and had no relevance to the people that used them. However, Botticher proposed that the "essence of architecture lies in functional needs and constructive force" (Schwarzer, 1993: 268), leading the value of artistic aesthetics to a focus on physical connection of human culture and buildings. To summarise, Botticher argued that the symbolism of architecture, which represents function and form, should be the target of aesthetic judgment. Therefore, Botticher's tectonic theory became a mediational ground for the fusion of ornaments and structure.

2.2.2. Didactic Architecture

‘Didactic’ is a term that is often used in education, and means that something is designed and intended to teach or instruct others (van Wesemael, 2001). Something that is didactic makes moral observations or statements that convey instruction and information as well as pleasure and entertainment (van Wesemael, 2001). Tectonics in architecture creates visible structures both in form and function. Their details are exposed, which provides opportunities for others to recreate or improve on a detail made present. Therefore, Didactic architecture is a passive characteristic and implies that an object can influence how others perceive, and build spaces (van Wesemael, 2001).

The tactile resilience of the place-form and the capacity of the body to read the environment in terms other than those of sight alone suggest a potential strategy for resisting the domination of universal technology (Frampton, 1983: 28). Tactility of the building is of importance to the built form, as the first impression would be of visual sensation. The other senses will reinforce the perception of the building, such as the aroma of materials and sensation of touching. Bamboo can create specific tactile effects since their biological profiles require crafting in order to create a surface or junction.

Materials with different properties are placed in logical order to achieve the optimal results. The types of material used, and how they are connected becomes the decorative nature of the structure. The act of joining is a form of tectonics in architecture where details are exposed, allowing didactic learning opportunities for occupants by observing the construction (Fig 2.10.). Instructive architecture is that which reveals its own process of existence, and by understanding something is to understand how it is made (Frampton, 1995).

The structure is exposed where the act of joining is meaningful. Theory and techniques of construction exist within its appearance, such that "architecture denies intellectualisation; the power of architecture is in its physicality" (Frampton, 2001: 377-387). Construction with raw bamboo material generally leads to structures where the junctions, details and techniques utilised in the process can be observed.

Fig 2.10. Bamboo as a Didactic Construction Material

2.3. Rhizome

Rhizome is a philosophical concept furthered by Giles Deleuze and Felix Guattari (1987) in a text titled “A Thousand Plateaus: Capitalism and Schizophrenia”. The authors reflect that every existence is interconnected through a rhizomatic system rather than a tree structure, to which the world often tends to relate. Deleuze and Guattari (1987) argue that the traditional thinking of knowledge and power could be seen as a hierarchical society, onto which an image of a tree could be transposed. From a single point the structure of society will develop into divided roots forming ranks.

Olivier Bert (2015) states that in botanical terms, a rhizome is a kind of root structure (Fig 2.11.) that spreads horizontally under the surface, producing shoots and roots from each node. These nodes may be broken at any point, with each node continuing to produce similar or adapted versions of the plant continuously. Although they may be disconnected, they are all interconnected through a system. “Rhizome is an organism of interconnected living fibre that has no central point, no origin, and no particular form or unity in structure” (Mambrol, 2017).

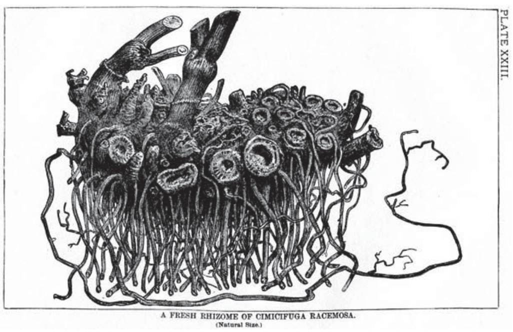


Fig 2.11. Rhizomatic Plant

2.3.1. Heterogeneous Multiplicity

Deleuze and Guattari (1987) explained the principles of a rhizome as connectivity and heterogeneity. The exterior relations formed between multiple beings create a rhizome structure of irregularities. “Any point of a rhizome can be connected to anything other, and must be. This is very different from the tree or root, which plots a point and fixes an order” (Deleuze and Guattari, 1987: 7).

The insects are seen as “assemblages” that allows an increase in the dimensions of the rhizome. This increase in dimensions or connections are regarded as the “multiplicity” of the rhizome. Deleuze and Guattari (1987) regard multiplicities as different from a simple multiple of the one. “A multiplicity has neither a subject nor an object, only determinations, magnitudes, and dimensions that cannot increase in number without the multiplicity changing in nature (the laws of combination therefore increase in number as the multiplicity grows) (Deleuze and Guattari, 1987: 8).

In Deleuze and Guattari’s view, the world wide web is seen as a modern example of the rhizome concept. Connections are made simply by inputting a keyword in the search bar and clicking a link in order to open a portal to all other connected entities from that particular site. The web pages could resemble a node that is expanding and creating connections with other nodes. At any point, servers could be shut down but the internet will still function and expand as they will modify another replacements wherever the need exists. “A rhizome may be broken, shattered at a given spot, but it will start up again on one of its old lines, or on new lines” (Deleuze and Guattari, 1987: 9). The horizontal spread of rhizomatic plants is regarded as a non-hierarchical system that allows new connections to be made by any available points. “All multiplicities are flat, in the sense that they fill or occupy all of their dimensions” (Deleuze and Guattari, 1987: 9). Although there exist multiple dimensions, the planes are always consistent and accessible.

The horizontal spread of rhizomatic plants are seen as a non hierarchical system which allows new connections to be made by any available points. Fig 2.11 is a conceptual sketch of the nature of the rhizomatic system where the 2 dimensional layers are infinitely possible to be anywhere along the z axis into the page, at any point the lines are able to connect to each other and they hold no order for their existence, they simply exist.

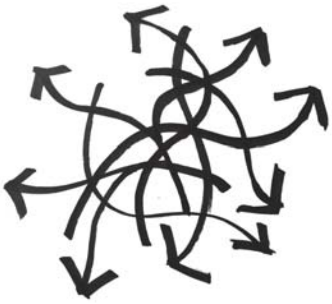


Fig 2.12. Rhizome Concept Sketch

By way of an example, “A book has neither object nor subject” (Deleuze and Guattari, 1987: 3). Books are an assembly of lines, movements in time, the contents and their process of being are the same. What goes around the exterior and in the relationships the book forms is the realities of multiplicities. “A book exists only through the outside and on the outside” (Deleuze and Guattari, 1987: 4). Likewise, “a Rhizome has no beginning or end; it is always in the middle, between things, interbeing, intermezzo” (Deleuze and Guattari, 1987: 25). There exists no singularity in this world, everything is interconnected in the actions and reactions of multiplicities that dependant upon each other. Thousand plateaus is a platform which allows for the forever expanding, changing society we live in. Traditional thoughts and knowledge could be seen as an image of the tree, however, at any moment ,a tree structure could morph into a rhizomatic structure. This is reflected by “the book is not an image of the world. It forms a rhizome with the world, there is an apparel evolution of the book and the world” (Deleuze and Guattari, 1987: 11).

As a rhizome structure holds no linear order, inspiration is the only necessary ingredient to spark the multiplicity of a new construction technique using a bamboo plant in South Africa (Fig 2.13.). Bamboo structures are available around the world, connecting ideas from various continents would signify the rhizomatic spread of this construction technique. The ancient relationship that people have had with construction using raw materials resonates strongly. Although use of bamboo is not widespread in South Africa, it seems familiar in that it has been adopted in the past, and spreads quickly biologically and has many industrial applications. South Africa can be another shoot of the rhizomatic spread of this material and information on its use. “We have been aided, inspired, multiplied” (Deleuze and Guattari, 1987: 1). This research will connect the future to a past from other continents, and as such, the rhizome will continue to expand.

Modern applications of bamboo could vary from those used in the past, as the technology currently available is very different from that of 100 years ago. While biological and didactic properties of bamboo have two dimensions in which the spread of bamboo is rapid, technology and innovation in the area of construction and material manufacturing can aid its spread in yet a third dimension."The tree imposes the verb "to be," but the fabric of the rhizome is the conjunction, and… and… and…" (Deleuze and Guattari, 1987: 25).

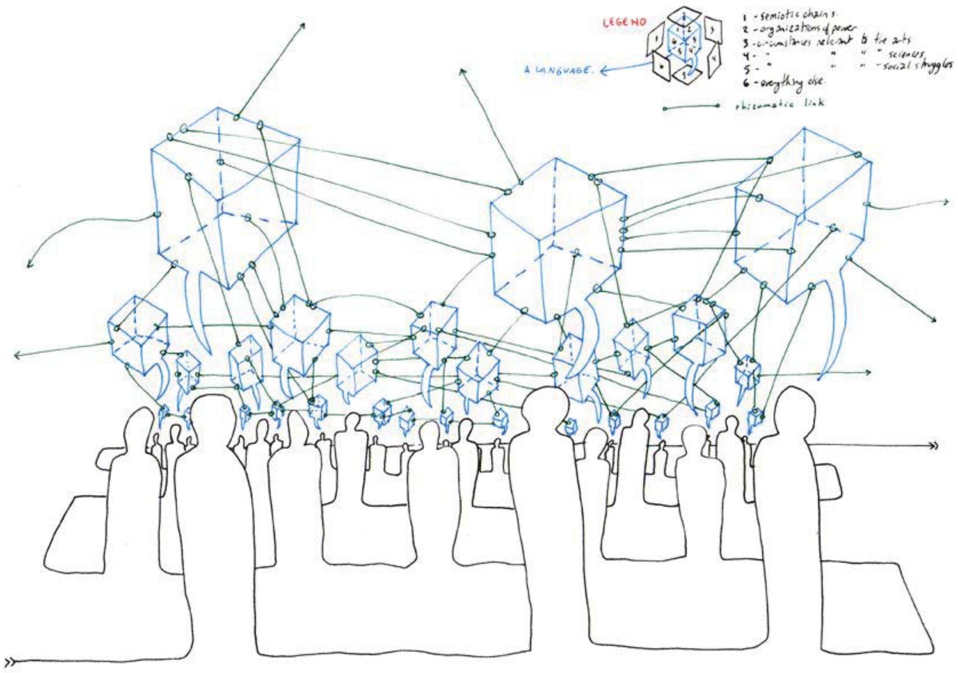


Fig 2.13. Multiplicities by Marc Nugui

2.4. Wabi-Sabi

Wabi Sabi developed in 15th century Japan together with the spread of the way of the tea (茶道). The mannerism of participants in tea ceremonies towards the physical space used for the ceremonies were carefully executed. An egalitarian approach to the selection of construction materials developed, with extensive use of bamboo being made as it was abundantly available.

Having its root in Zen Buddhism, Wabi Sabi is a philosophical concept that seeks beauty in everyday moments and objects from the passing of time. The word Wabi-Sabi is composed of two characters, 侘 (Wabi) a conscious state of mind to seek contentedness from the bare minimum or insufficiency, and 寂 (Sabi), which implies that with the passage of time, one is able to appreciate the tranquil property of existing objects, transiency. (Fig 2.15.)
"Wabi-Sabi is a beauty of things imperfect, impermanent, and incomplete. It is a beauty of things modest and humble. It is a beauty of things unconventional" (Koren, 2008: 7).

The philosophical lesson to be taken from the principles of Wabi-Sabi are that structures can be imperfect and transient or temporary, and still serve their purpose. Construction with raw bamboo materials has these characteristics, with every bamboo pole having unique natural properties that can be assigned to various parts of a building. The concept behind the Wabi Sabi tea ceremony is an inspiration for the approach to the 'living school' (introduced later) and its proposed usage of bamboo materials. When building with bamboo, the physical properties of bamboo need to be considered to design details for a building. The use of bamboo as a construction material must be accompanied by an appreciation that it will age and fade, and individual pieces can be replaced over time (Fig 2.14.).

Fig 2.14. Window Detail

Fig 2.15. Rock Garden

2.4.1. The Way of Tea

The drinking of tea is told to have started as Buddhist monks drank it to stay awake and focus during their meditation. Later on, drinking of tea was adopted by aristocrats in their tea tasting games (Fig 2.17.), which expanded and developed into a ritualistic act that even emperors practiced. There are various examples over many generations of specialised rooms and architecture designated for the practice of tea.

Zen Buddhism was introduced to Japan from China together with the way of tea, which became closely connected to the Japanese culture heritage and is a large part of the everyday life. The tea ceremonies were held in designated rooms attached to the main complex of buildings, with the journey of the ceremony beginning the moment the premises is entered, and continued until the room is vacated; an approach through a garden space being considered part of the experience.

Sen no Rikyu (1522-1591) (Fig 2.16.), who was a personal tea master of Nobunaga (a warlord) and his successor Hideyoshi, developed philosophical and religious frameworks, including that around the way of the tea ceremony (Young, 2004). Rikyu favoured austerity, with an emphasis upon the aesthetic concepts of Sabi (the patina that comes with age) and Wabi (things that are simple, natural, and imperfect (Young, 2004: 62). All the qualities from the motion of serving the tea to austerity of the tea room designs had the essence of Wabi Sabi. As the warlords castles grew, Rikyu's tea rooms became smaller, as he was constantly eliminating the unnecessary (Young, 2004).

Fig 2.16. Sen no Rikyu

Fig 2.17. Tea Ceremony

Rikyuu believed that tea should be simple and available for everyone from all socioeconomic classes, as seen by his simplistic designs that used locally sourced and inexpensive materials (Handa, 2013). He did this in response to the pretentious tea room designs used for the extravagant tea ceremonies that were exclusively held by and for the wealthy. Rikyu taught that tea ceremonies do not require ornamentation, and that the instruments used must not overpower the ceremony.

He developed a style for the tea house called Sou An (grass hut)(Fig 2.18. and 2.19.), where the spaces are simple and there is an extensive use of raw and natural materials. The walls are woven bamboo with mud plastering that gives them texture, with tea powder being mixed into the plaster in some instances. By having a small tea room, three tatami mats (4.86 sqm), the visitors are able to take a close look at the fine details of every aspects of the tea room. The entrance to the tea rooms were often so small that guests had to crawl inside, and were too small for a samurai to carry their swords which they had to leave outside, this being the symbol of equality within the tea rooms.

Fig 2.18. Sou An Style Tea House

Fig 2.19. Sou An Style Tea Room

The windows were designed to restrict the amount of light entering the space, and skylights were incorporated for different explorations of light. Nature and the seasons were a big part of Wabi Sabi, in that buildings and gardens are designed to enjoy the different views that the seasons bring. A tea master showed humility by choosing abundant locally available materials to host tea ceremonies, believing that upon the act of drinking tea, everyone was equal, with anyone being able to perform a ceremony if they desired. The use of transient materials, such as bamboo, for ceremony structures has the effect of emphasising the importance of the current moment, and that the structure is sufficient for housing the current need. The structures become more closely linked with people's lives, in that they need to be maintained and replenished on an ongoing basis.

CHAPTER THREE | BAMBOO BIOLOGICAL PROPERTIES AND PREPARATION

This chapter focuses on the bamboo characteristics, life cycle for harvesting and treatment procedures necessary for the use in construction. These would be combined through integrated “living” system which calculates our daily use of water and ultimately feeding the bamboo plant. This chapter provides foundational understanding of how the 'living school' would operate.

3.1. Anatomy, Characteristics and Productivity

Bamboo (Bambusoideae) belongs to a grass family (Poaceae), a family which includes rice, reed, maize and other similar cane-type plants (Lynn, 2016). Being a member of the grass family, cutting of the plant does not kill it but rather stimulates the plant to grow by making space for new shoots to appear. Figure 3.1. Explains the anatomy of bamboo which is characterised by the jointed stem system called culm which are hollow, with fibres that are more dense on the outer layers, providing a water resistant layer on the surface. The culm has segments with solid joints called nodes (diaphragms) where branches and roots are able to grow, these joints strengthen the culm while the segments in between are called internodes (Bamboo Botanicals, 2017). Circular in profile, the culm tapers from the base to the top. Fig 3.2 shows that the internodes' spacing decreases towards the culm base where it allows for concentrated roots and new shoots to grow (Schroder, 2011).

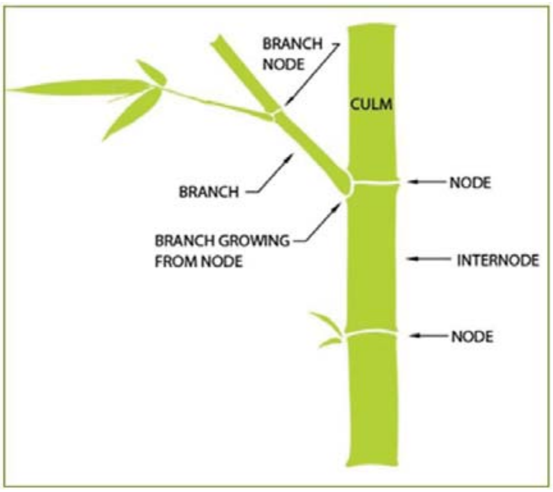


Fig 3.1 Anatomy of Bamboo Culm

Fig 3.2 Bamboo Culm Cross Section

Depending on the bamboo species, the thickness of the culm wall varies. Bamboo plants that grow in Africa's lowlands are one of the few solid bamboo species (Rosenberg, 2012). Bamboo rhizome and root systems in general can be divided into two categories, running (monopodial) (Figure 3.3) and clumpers (sympodial) (Figure 3.4). Clumping bamboos are usually found in tropical regions while running species are found in cold sub-tropical regions. Running bamboos could be regarded an invasive species as the root system can expand one to five meters per year and some can reach 30 meters in height, outcompeting indigenous plants (Friederich, 2014). Giant runners such as Moso (Phyllostachys Pubescens) grown in cold subtropical regions, such as East Asia, and are widely used in the construction industry (flooring, panels, laminated products) and for many other applications. The bamboo types that grow in Africa are not as invasive (clumping) as those found in colder climates (Rosenberg, 2012).

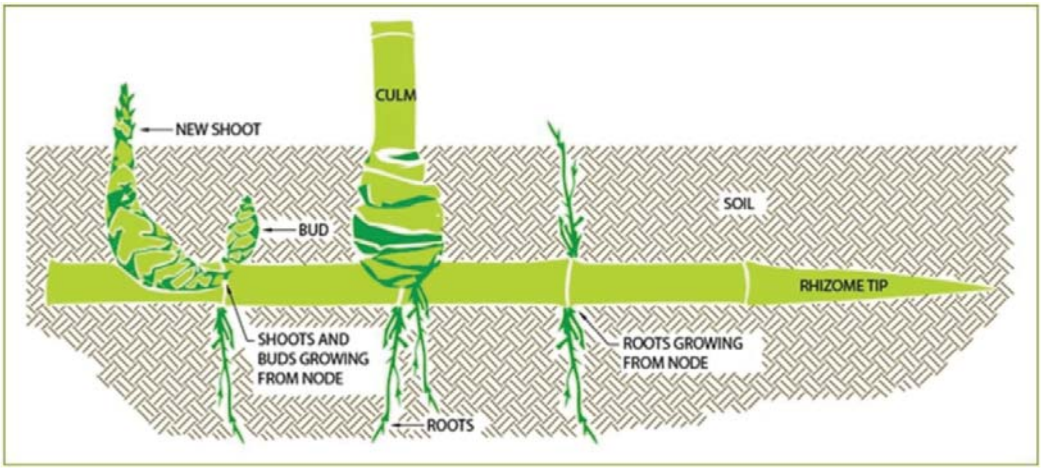


Fig 3.3. Running (monopodial) Bamboo

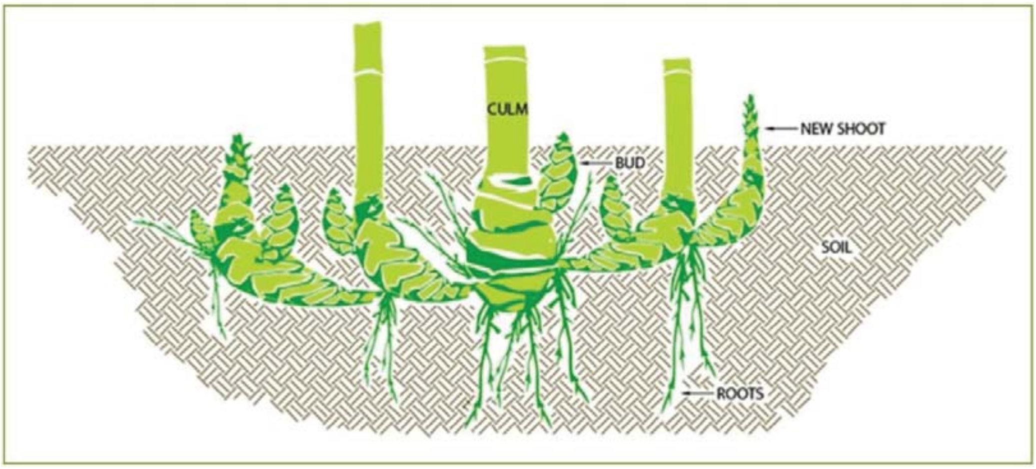


Fig 3.4. Clumping (sympodial) Bamboo

Bamboo plants require watering during their initial period of planting, but once they are matured they are able to self-sustain in their given environment (Friederich, 2014).

Kleinhenz and Midmore (2000) assume water consumption for mature bamboo plants suitable for commercial plantation to be approximately nine to 13 litres a day. A bamboo rhizome system spreads horizontally and will not go deeper than 600mm of depth below the surface, minimising the threat that the plant will deplete underground water resource (Lewis Bamboo, 2017). This is in comparison to some of the alien species introduced to Africa, such as Eucalyptus trees, which may reach 30 to 50 meters below ground and use 100 to 1000 litres of water per day, and Pine trees, which can use from 50 to 600 litres of water per day (Greeff, 2010). Bamboo can survive with an average rainfall of approximately 500mm/year (Friederich, 2014), and as the average annual rainfall for South Africa is 464mm/year (World Weather and Climate Information, 2016), there is a considerable opportunity for this plant to be introduced widely in the region (Figure 3.5). In addition bamboo can absorb carbon dioxide and release 35% more oxygen than trees (Laidler, 2003).

Bamboo and reeds are the oldest building materials in the tropical/subtropical region of the world (McClure, 1972). Bamboo is known to have more than 1400 species, with indigenous species in Asia, Africa Central and South America (Fig 3.6), most of which are not suited for construction, with selection of the right species for construction (giant woody bamboos) being essential (Yeasmine et al., 2015).

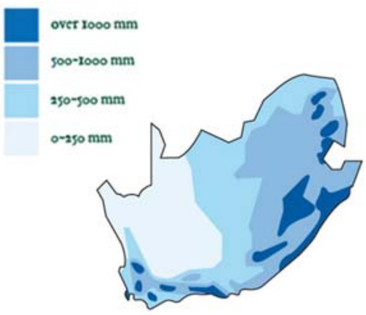


Fig 3.5. Rainfall Across South Africa

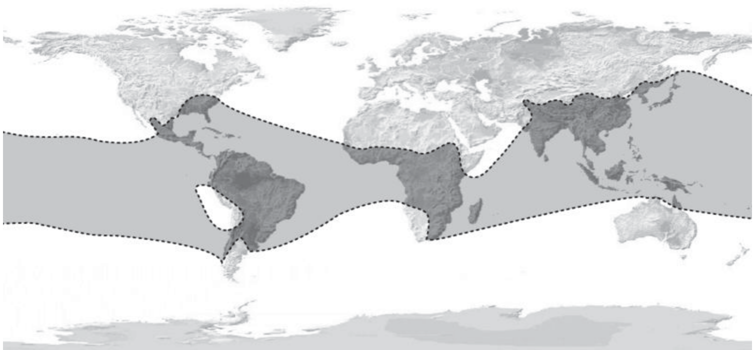


Fig 3.6. World Distribution of Bamboo, Tropical / Sub Tropical Regions

Bamboo flowering is a rare phenomenon that happens every 20 to 120 years depending on the species. When a bamboo flowers, it triggers all divided and related siblings to flower and produce seeds simultaneously (Jaquith, 2016). This flowering happens at a global scale and is often a potential sign of death of those particular bamboo species. To assume the possibility of this phenomenon, aged bamboo plants will decay in order for seedlings to receive space, sun, nutrients and water to grow in the place of the mother plants. "As with all plants, flowering and reproduction from seed is necessary for the survival and spread of the species" (Jaquith, 2016: 1-5).

Bamboo requires few nutrients, making it possible to grow on soil that is inhospitable for other plants and at the same time rehabilitating the soil to allow for future growth. Its roots leach heavy metals from the soil, bind the ground and draw water closer to the surface (Rosenberg, 2012). Allahabad of India is a prime example of restoration of degraded lands using bamboo, with the topsoil being extracted to create clay bricks for many decades (Fig 3.7.). After closing of the factory, local communities were left with a barren land, until 1997, when INBAR and a local Non-Governmental Organization, Utthan used bamboo in a pilot project of just over 100 hectares that turned red earth into a green oasis (Friederich, 2014)(Fig 3.8.). They set up a bamboo nursery where they sold bamboo seedlings to the local farmers after explaining their benefits. The locals saw the rapid growth of the bamboo rehabilitating the land, which enabled for other crops to be harvested around them, soon many followed and started to plant bamboo. The water table rose by seven meters within first five years (Rosenberg, 2012). In 2007, the initial investment had rehabilitated 85000 hectares of degraded land that supported 90 000 local households, for which Utthan was awarded the Alcan Prize for sustainable development (Friederich, 2014).

Fig 3.7. Allahabad and its Effect of Brick Industry

Fig 3.8. Successful Bamboo Reforestation

Bambusa Balcooa (clumping) is a giant woody bamboo species originating from India and was introduced into South Africa in 1660 for paper pulp production (Zyl, 2013). This species has naturalised over the years and is grown across the South African landscape (especially in Durban), commonly found along river edges. Average culms range from 12 to 22m long and 60 to 150mm in diameter (Schroder, 2012) and can be used in a wide variety of purposes ranging from food, construction to the industrial supply of raw material.

In Bangladesh, healthy single Bambusa Balcooa clumps produce three to four mature culms per year. One hectare plantation with 5m x 5m spacing of 400 clumps will have an annual production of 1200 to 1600 culms (Alam, 2016). One Green Village house (300 sqm) in Bali uses 1200 bamboo culms, 8100 running meter, for its construction (IBUKU, 2015).
8100m / 22m = 368.2 culms / 3 culms annual harvest = 123 plants =300sqm
Therefore, it can be conceptualized that one bamboo plant, producing 3 culms, is able to

make 2.4 sqm of floor coverage annually, this is the case for using bamboo for all aspects of the building.

3.2. Harvest and Cycles

Regular harvest is necessary for a productive bamboo grove, as the old and fallen culms may interfere with the growth of new shoots (Fig 3.9. and Fig 3.10.), for which timing is important. Knowing how and when to harvest bamboo is important to maximise the productivity of the plant. Incorrectly harvested bamboo will be more attractive to biological degrading organisms (Schroder, 2012) and will therefore deteriorate faster, as it has a high concentration of sugar (starch) which fungi, borers and parasites feed on. By applying the right applications and procedures, the content level of carbohydrates can be minimised allowing for naturally more resistant culms (Schroder, 2012).

Fig 3.9. Abandoned Bamboo Forest

Fig 3.10. Bamboo Shoot

Harvesting of bamboo culms needs to consider 1) its life, 2) annual, 3) moon and 4) daily cycles, as follows:

1) Culm life cycle: New bamboo shoots will grow during the rainy season, reaching their full heights in the first few months, after which they do not increase in size, with the culms reaching maturity in three to five years. Unlike trees, the culms do not produce toxins to protect themselves, and can therefore become affected by mold and fungus soon after maturity (Humanitarian Bamboo, 2009). By the time it reaches the 7th year, the culms will start to lose its strength, causing them to fall naturally. Therefore making it optimal to harvest them in their 3rd to 5th year of age, depending on the species. Harvest and clearing of old culms will allow adequate lighting and nutrients for new shoots to grow.

2) Annual cycle: Self propagating rhizome structures will grow culms, creating a network of multiple culms all producing shoots every year. The bamboo accumulates and stores nutrients for their new shoots that appear during the rainy season. At the end of the dry season, the culms are full of nutrients and energy for the shoots, as well as potential food for biodegrading organisms. Shoots appear with the rainy season drawing on all the nutrients, making it is advisable not to harvest during this time, as the felling action could harm or destroy the new shoots (Schroder, 2012). In addition, the high moisture content of the culms during the rainy season can result in post harvest cracks.The most recommended period of harvesting would be after the complete growth of new shoots and the beginning of the dry season (Schroder, 2012).

3) Moon Cycle: Although many scientists are sceptical about what they refer to as "peasant knowledge"(Schroder, 2012), there is a theory that the moon has an effect on the water mass in plants and many indigenous civilisations acknowledge and practice activities that coincide with this cycle. "During the waxing (crescent) moon the majority of the plant's vital fluids are active in the leaves, and while in waning (menguante) the liquids remain in the roots" (Bellavista, 2017). Detailed studies have been conducted in Columbia that show that the starch content is minimal in-between waning gibbous and the last quarter from the gravitation of the moon (Schroder, 2012).

4) Daily cycle: Photosynthesis for any plant occurs during the day, when the bamboo will produce its highest levels of sugar in the sap at midday. Therefore it is best to harvest bamboo culms before sunrise and after the sunset (Humanitarian Bamboo, 2009).

Considering all the cycles together will allow to assist in determining the optimal condition and timing for harvesting a naturally resistant durable raw bamboo construction material.

The bamboo culms should be cut on top of nodes close to the ground, pockets will collect rainwater which will rot and damage the plant rhizomes (Fig 3.12 and Fig 3.13). The starch and moisture content of the culm can be reduced by leaving the felled culm resting vertically on other culms for 4 weeks and placed on top of a stone as direct contact with soil should be avoided. Leaving the branches and leaves intact allows transpiration to occur, as the parenchyma cells continue to live after the plant has been felled (Fig 3.14). The leaves and culm will fade in colour, indicating that the starch content is being used up, this method allows the culm to dry slowly therefore lessening the possibility of cracks (Schroder, 2012).

Fig 3.11. Incorrect Felling Practice

Fig 3.12. Correct Felling Practice

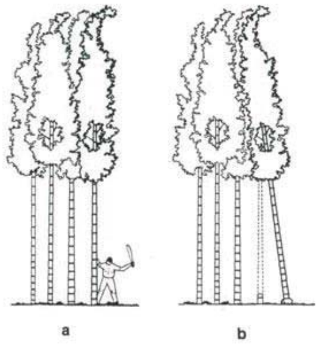


Fig 3.13. Post Felling Transpiration

3.3. Treatment of Bamboo Culms

There are number of traditional remedies and treatments for bamboo (untreated they would need replacing every two to three years), although the time will vary with different species (Schroder, 2012), it is possible to achieve substantial building life span if they are treated. In india, a CCA-treated low-cost bamboo house can be found stable even after forty years of usage (Kumar, Shukla, Dev and Dobriyal, 1994).

There are a few treatment methods to preserve raw bamboo culms to make them more durable for construction purposes. There are two types of preservation methods, these being natural (traditional) and chemical, although among the chemical methods there are options to use more natural preservatives. Natural method includes leaching (submerging culms in running streams) and smoking. Chemical methods include fixing (CCA) and non-fixing types (boron, borax and boric acid). Boron, Borax and Boric acid are the main treatment types for bamboo preservation, often referred as Octabor, being less toxic and naturally occurring in nature (Schroder, 2012).

There are a few ways to apply these preservatives, some methods requiring the use of machines (pressure pumps) and others using structures (vertical soak diffusion and boucherie method) to hold the bamboo in position with the preservatives being diffused using gravity (Fig 3.15.). Another technique requires a pool (Fig 3.16) to submerge the bamboo within the chemicals (this can take up to 40 hours), also during the post felling transpiration barrel of preservative could be placed at the butt end of freshly cut bamboo (Fig 3.13.) which the leaves acts as a natural pump, this method will require 3 weeks (Janssen, 1995). As for a fixing type application of CCA, High pressured pump systems are advisable (Schroder, 2012).

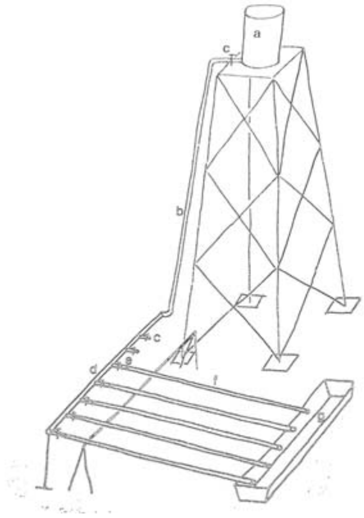


Fig 3.14. Boucherie Method using Gravity

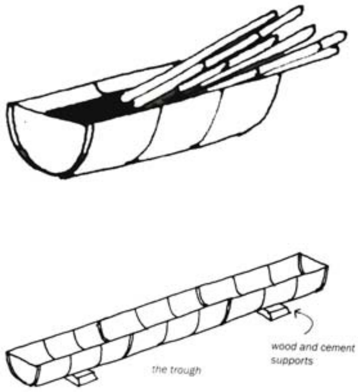


Fig 3.15. Extendable Welded Half Cut Oil Barrels

3.4. Incorporated Living Bamboo Systems

Bamboo can produce a micro ecosystem that human activities can directly contribute to and benefit from the growth of the plant. Being a part of the grass family, bamboo can consume large amounts of nitrogen, this characteristic being useful for applying grey / black water channelling. Human habitation requires water and daily activity revolves around the usage of water. By having a septic tank system with the soakaway pit channelled towards bamboo plants, the plants will not require irrigation as long as people use water. The water will allow the plant to grow.

'living school' (Fig 3.16. and Fig 3.17.) is a term introduced to represent a system that channels daily used water to grow construction materials. Erasmus (2017) states that the average South African household daily water usage is 235 litres, which would be sufficient to grow 18 plants producing 43.2 sqm of floor coverage every year. As the plants' shallow root structure that spreads sideways, this result in the moisture content of soil and the groundwater table to being elevated instead of depleted, the pollutants would be drawn before they seep. This is the primary reason why bamboo are commonly seen along river edges, as they do not reach below one meter underground.

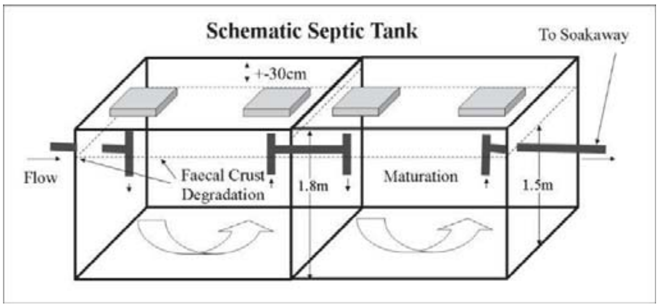


Fig 3.16. Schematic Septic Tank

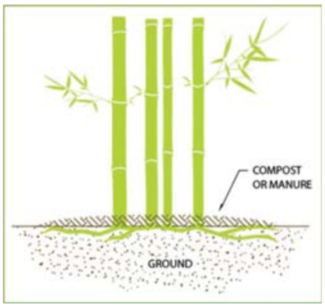


Fig 3.17. Bamboo Fertilisation

It is suggested for a 7500 litre septic tank system for 6 people (Bio Systems SA, 2017). This 7500 litre tank system is calculated to take 250 litre of water usage every day for the duration of the facial matters to degrade. According to Bio Systems SA (2017), faecal materials takes 18-21 days to degrade anaerobically, septic tank chambers will process the continuous input simultaneously overflowing the bio degraded solution out into soak pits. The volume is the main concern therefore it is possible to provide multiple tanks in order to meet the need, JoJo tanks offer wide range of septic tanks from 1250 - 6000 litres (JoJo Tanks, 2017).

There are other examples of how bamboo can co-exist closely with human activity in rural settings. Small check dams are micro structures that can be built from bamboo, where if they are placed in gullies and channels they can redirect streams and prevent the water erosion from going deeper along the same path. Spreading of the stream water can assist with irrigating nearby crops. These are among the many potential useful applications of bamboo structures in rural settings.

3.5. Conclusion

This chapter outlined the biological properties of bamboo and their growth characteristics as well as procedures to prepare them for use in construction and to incorporate them into systems of living. As a fast growing member of the grass family it has a number of benefits with its roots staying close to the surface. Also the available bamboo for construction in South Africa is a clumping variation which are seen as manageable species for forest management, the running bamboo are difficult to contain in a specific location as they will freely expand endangering indigenous species.

The following chapter will review the use of bamboo in construction in successful examples around the world.

CHAPTER FOUR | EXPLORATION OF BAMBOO CONSTRUCTION THROUGH PRECEDENTS

This chapter explores bamboo construction techniques, from indigenous to modern construction examples, from around the world. Bamboo, with its distinct biological properties requires craftsmanship in the processes of using it in construction. An argument proposed in this research is that observing most bamboo buildings, even in still images, makes their structure understandable i.e. it is possible to infer much of the information required to recreate them from observation alone. The theoretical and conceptual framework set out previously speaks of the wider spread of the tectonic technologies used in bamboo construction. This chapter is divided into three categories of bamboo construction relevant to this research, namely bamboo joining techniques, its use in large span structures and how it is used in community projects.

4.1. Bamboo Joining Techniques

This section deals with various methods to connect bamboo with other materials or to other bamboo sections. The physical connections of bamboo are explored in order to demonstrate the didactic properties of bamboo when used as a construction material.

4.1.1. Plugin Connections

Plugin connections are found in many (ancient) bamboo structures, as using nails on bamboo can lead to splits which deteriorate the structural integrity of the bamboo, often being secured with lashing to keep the structure in place (Minke, 2012). These connecting elements could be achieved using split bamboo, also possible to use modern steel products, such as steel tension clamps. The junctions needs to be carefully considered, as they are not meant to take the stress but to allow the culm pieces to maintain their shape so that the structure as a whole distributes the load. The downfall of these connections would be that the piece that connect the junction uses only a single point on which the plugin and not the culm’s full diameter to support the load. Fig 4.1 shows a lashing and plugin technique that can be used to keep a structure in place. These methods require careful placement of the holes and positioning of the plugin to achieve the best results, and should be placed on natural bamboo nodes to ensure that they contribute to the strengthening of the junction.

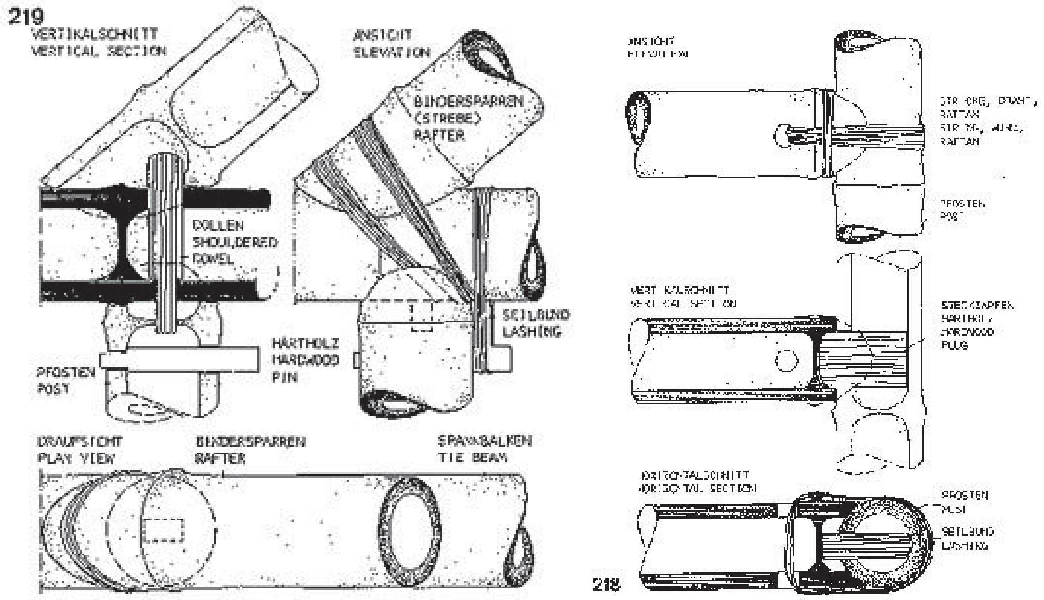


Fig 4.1. Bamboo Plugin Connections

It is possible to carve out bamboo joints with a simple saw, hammer and chisel but the profiles must be flush with each other to transmit the load efficiently. As bamboo culms are natural, they are irregular in shape, hollow and tapering, causing difficulties in the crafting process. For this reason, it is necessary to develop skills for bamboo joinery which would become a specialised trade (Ricoeur, 1961: 276). Fig 4.2 displays basic culm ends that could be used for joining the various parts of a bamboo building.

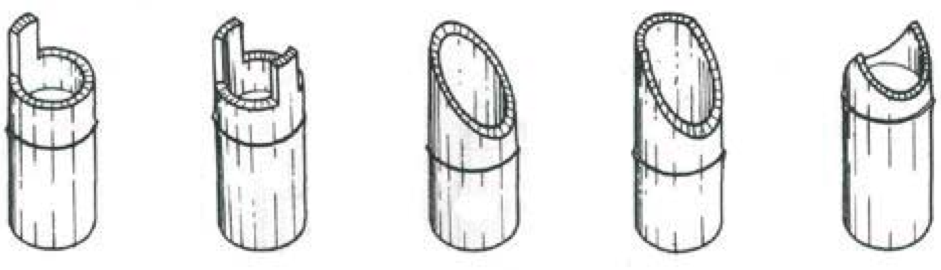


Fig 4.2 Variety of Ends to Suit Different Junctions

Schroder (Schroder, 2009) states that the process to create a standard of construction for bamboo is to develop a universal joining system that would allow bamboo to be used widely in modern construction (affordable housing), and that the detail must make sense and become simplified, which would aid the spread of didactic knowledge of bamboo construction. Fig 4.3 and Fig 4.4 are a comparison of similar joinery techniques using bamboo wedges and modern steel tension clamps, which follows the discussion of findings from Simon Velez regarding bamboo construction in Columbia (Minke, 2012). He incorporates concrete in the later example to create a reinforced junction that is capable of achieving a far greater span of structures.

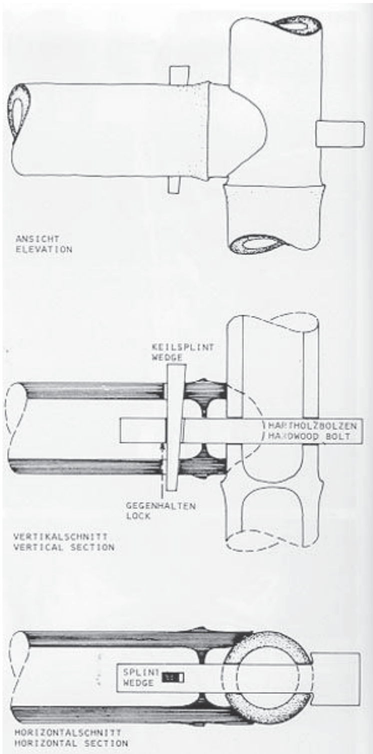


Fig 4.3. Plugin Connection

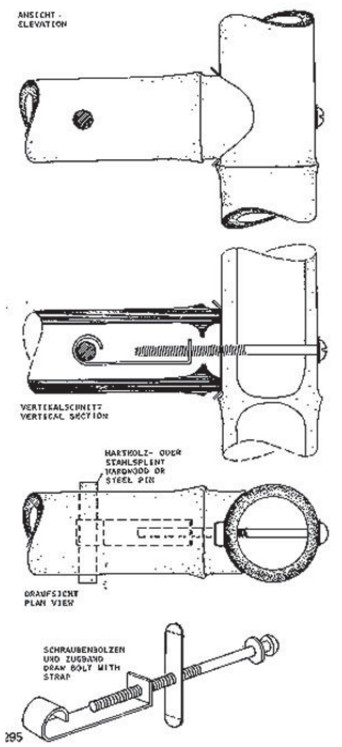


Fig 4.4. Plugin Connection (Steel Tension Clamp)

4.1.2. Injected Mortar

Bamboo is often perceived as a poor man’s timber due to its abundance in the East and in South America (Yeasmine et al., 2015). However, after Simon Velez discovered methods of creating junctions by filling the cavities with mortar and inserting steel rebar or thread, the opportunity for bamboo construction has become accessible for public application (Fig 4.5). This joinery method for bamboo has allowed Velez to use bamboo as a permanent structural element in his architecture. He has been practicing for over 40 years and his projects range from residential to large public commercial structures. In the Hanover Expo in 2000, he designed a 2000 sqm pavilion achieving 40 meters in diameter, first built in Manizales Colombia, for Zero Emission Research Initiative (ZERI) Foundation, which was the first bamboo building to receive a building permit in Germany. Fig 4.6 is an elevation of the ZERI Pavilion, which is a combination of timber and bamboo, where Velez applies similar principles to achieve his structures (Minke, 2012).

Fig 4.5. Injected Mortar Method used in the Philippines

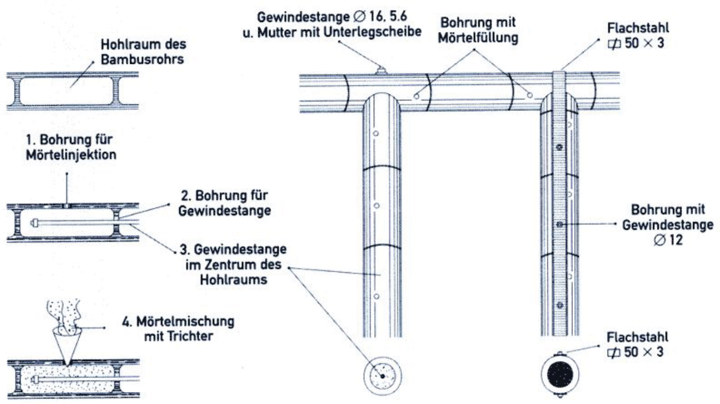
Fig 4.6. Zero Emission Research Initiative Pavilion

For the base of his structures, Velez usually mounts the columns onto a concrete foundation from where all the other elements branch off. Fig 4.7 shows the combined columns (bolted timber poles) connected to a concrete foundation, with the aid of steel rebars embedded in the columns. Fig 4.8 is a detail for when connecting bamboo and timber using an embedded rebar system (Velez, 2000). In order to join the bamboo to another material, Veles fills the bottom of the bamboo with mortar which has a steel rebar or thread embedded in the culm. Lateral bracing incorporates nuts and bolts in which the joining culms are filled with cement mortar after application, to ensure that the junctions are solid connection points. Velez demonstrates tectonics in his architecture by combining the tensile bamboo material with compressive concrete, the result of which gives him a medium for various junctions to be attached.

Fig 4.7. Combined Columns to Concrete Foundation

Fig. 4.8. Detail for Bamboo and Timber Connection

Fig 4.9 shows technical details and methods to inject mortar into bamboo. The far right example with steel strips are important details that are used to connect the separate structures, especially over the highest points. Velez is fond of using a symmetrical system, where load distribution is clear and defined, which results in him designing in sectional views that are often reflected throughout the structure. Fig 4.10 shows his famous sketch designs that he made on gridded paper (Velez, 2000).



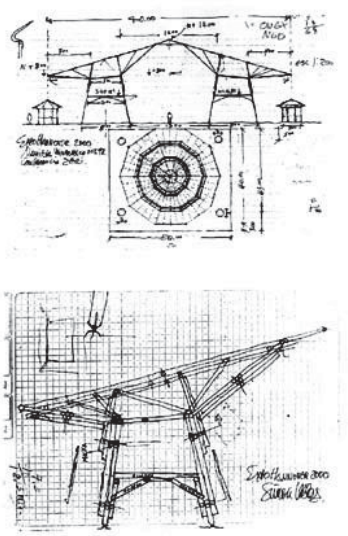


Fig 4.9 Technical Details from ZERI Pavilion Construction in Germany

Fig 4.10 Sketch Section and Plan of Pavilion

For the detail of the arch, Velez uses the natural curve of the bamboo root which is combined and carved to fit a horizontal culm piece. This is then bolted with injected mortar and thus further supports the floor and the roof as shown in Fig 4.11. He uses heavy elements such as tiles for the roof and cast concrete for the floor in order to solidify the structure to withstand the heavy winds of Columbia. Fig 4.12 and Fig 4.13 are interior and exterior photographs of the ZERI Pavilion where the injected mortar has been applied to all connections (Minke, 2012).

Fig 4.11. Arch Detail

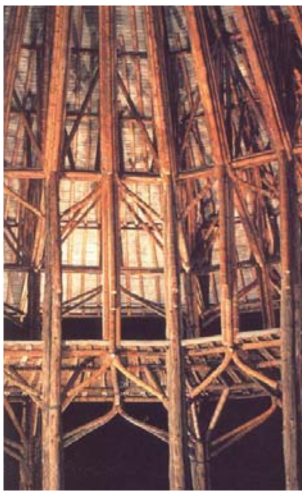


Fig 4.12. Interior

Fig 4.13. Exterior Corridor

4.1.1. Steel Products

The combination of bamboo with other technologies will allow for a greater span to be traversed, with interesting details that emerge from their joinery. Fig 4.14. is a connection made by Shoei Yoh that employs steel tubes to apply bolts, with the inserted steel tubes inside the bamboo culm absorbing the pressure of the tightening of bolts which may otherwise crack the bamboo (Yoh, 1989). Fig 4.15 shows the use of steel tube to allow for additional steel elements to be welded within, which could be attached to another connecting member thereby extending the design to feature a variety of other kinds of connections.

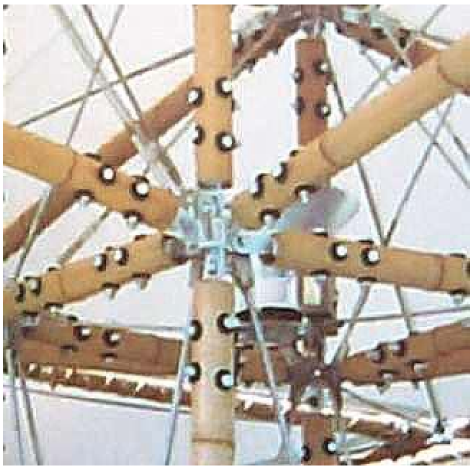


Fig 4.14 Steel Tube and Bolt Junction, Shoei Yoh 1989

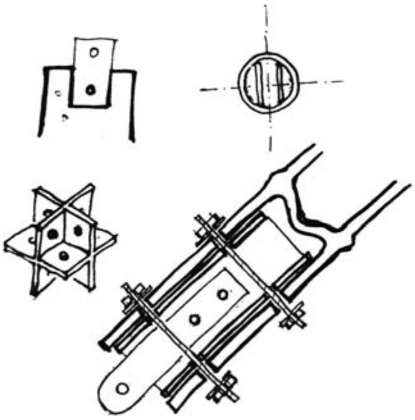


Fig 4.15 Junction Detail nts

Fig 4.16 is a connection by the Renzo Piano Building Workshop in 1997 in which the bamboo culms are connected to designed steel junctions and bound by wire (Buchanan, 1997).The load for this junction may all need to be in compression, acknowledging the tendency of bamboo to split when fractured, additional binding elements could be required over the plate and end of the culm for additional support.

Fig 4.16 Bamboo Junction from Renzo Piano Building Workshop 1997

These connections would require a manufacturing process to create each connective piece, resulting in the structure details being able to be standardised. By standardising and testing such joint elements, it may be possible to acquire building codes regarding public use of bamboo in construction. However, these joints would result in a high cost of manufacture since they will require some level of engineering to produce.

4.2. Large Span Coverage

Bamboo is often associated with small structures with limited span (Minke, 2012), the following important examples explore the potential of bamboo as a material that can span a great distances, either with or without steel products.

4.2.1. Bridge

Fig 4.17 is a bamboo bridge for Crosswaters Ecolodge (Tan et al., 2015) created by Simon Velez, an example of the few public bamboo structures that exist in China. Its heavy tiles and big overhangs suggest that this bridge is designed for permanence, reflecting a traditional method of construction that is infused with modern technology. Bamboo bundled arches connect the two engineered concrete bases. Injected mortar and bolts have been applied improving the overall stability of the bridge compared to traditional methods of using rope and allowing it to span a greater distance. Fig 4.18 depicts the repeated sequence of the structure to support the roof so that what is seen on the initial concrete pillars are repeated on the bundled arch, creating an organic shape from a static profile.

Fig 4.17 Bundled Combined Culm Arch

Fig 4.18 Entrance View

The bundled bamboo arches, made from combined culms, take on the form of a single member which the rest of the structure seems to be in tension towards the middle. The combination of multiple culms effectively achieves the structural distribution of load. The culms of different length are put together with bolted injected mortar and a metal strip to give extra support. Fig 4. 19 shows the interior view of the footbridge suspended from the bundled arches.

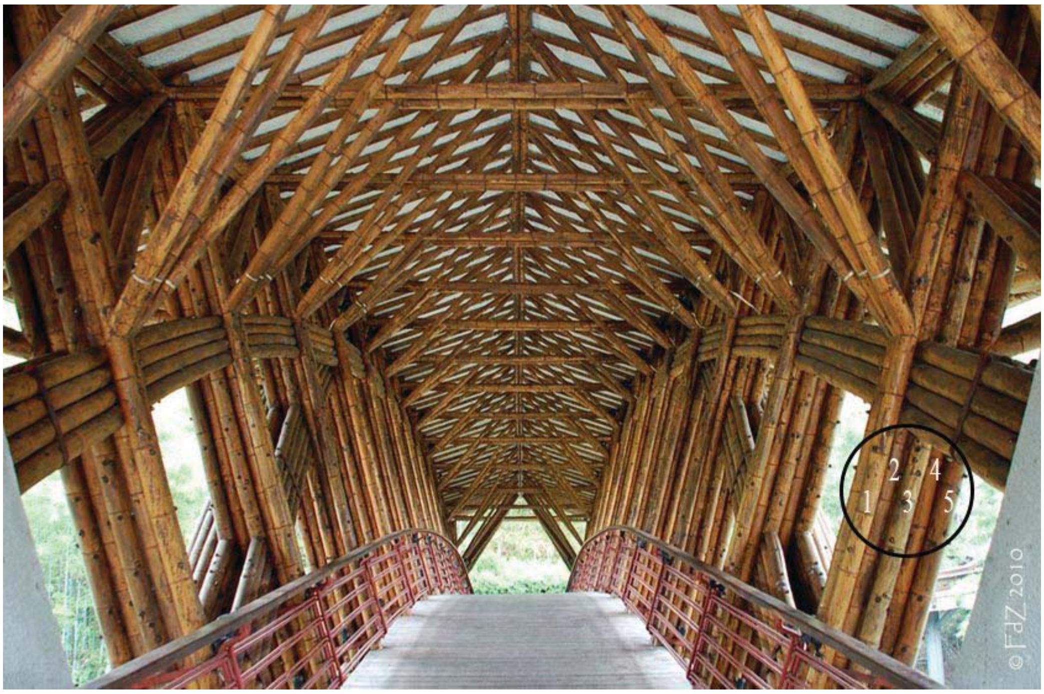


Fig 4.19 Internal View Showing Details for the Connection of Bundled Arch and Suspended Walkway

The suspending structures appears to have 5 layers of culms (8 in total), with the crossing bundled arches going between the layers. The top arch consists of 2x4 vertical culm bundles that intersects the suspended structure on the second and fourth layer from the interior. The bottom arch has four vertical culms intersecting on the third layer (note how they meet towards the centre) and main dominant bundle on the fifth (exterior) that consists of many culms to make a combined arched profile, as is visible in Fig 4. 17. The combined profiles allow for overlapping of the layers that are bolted with injected mortar at various intervals to maintain their shape. This is an example of weaving of small elements combined to make a structural membrane (Tan et al., 2015).

Fig 4. 20 shows the suspended support structure of the footbridge, combined culms on either edges which are connected through the injected mortar with bolts on horizontal and vertical section from vertical suspending members (8 combined culms).

Fig 4.20 Support Structure of Bridge

4.2.2. Bamboo Sports Hall for Panyaden International School

Built in Thailand in 2017, this structure is an example of contemporary use of bamboo, enclosing an area of 782 sqm shown in Fig 4.21 and capable of accommodating 300 students with multi-purpose usage (Zuraini et al., 2017). This structure is an extension to the existing earth and bamboo constructed school and can cater for various ball games and has a stage at the top where it is possible to host functions and a gallery on the first floor for spectators. The structure is open, allowing for natural ventilation with the details of the structure being exposed to exhibit the craftsmanship of the building. As shown in Fig 4.22, the design is based on cultural Buddhist teachings, and takes its inspiration from the lotus flower that is split in half and the flower layers become the roof.

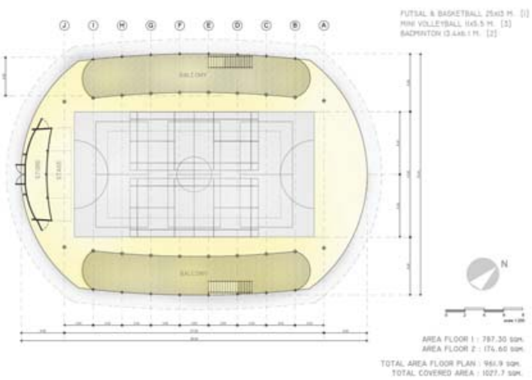


Fig 4.21. Plan

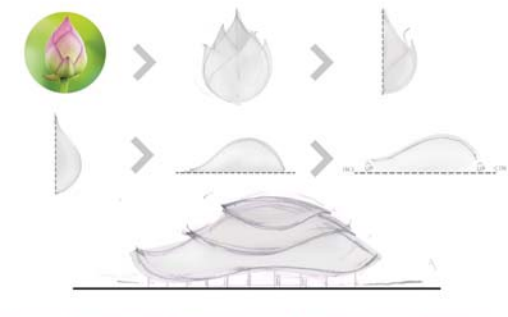


Fig 4.22. Concept Development

Fig 4.23 and Fig 4.24 is The Panyaden International School, which commissioned this structure, was aiming for the building to have a low carbon footprint. Since the sports hall is constructed purely out of bamboo, this was achieved, even after taking into consideration the carbon emission during the curing and transportation of the material and the actual construction. Borax salt solution, which has no toxic chemicals, was used to treat the well-aged bamboo, with the hall being expected to last 50 years (Zuraini et al., 2017).

Fig 4.23. Internal space

Fig 4.24. Exterior View

With help from two engineers, they developed a prefabricated truss system that can span 17m without relying on steel reinforcement. This building as shown in Fig 4.25 and Fig 4.26 represents a cultural heritage of bamboo craftsmanship and is unique to this specific location. Made from locally available bamboo materials, its shape is designed after a regional emblem, the lotus flower. This buildings contemporary use of a local material is a good example of critical regionalism (Zuraini et al., 2017). This is an important case study in the use of bamboo to create a structure, with a significant span (17 m). With a coverage of this size accommodating a large scope of designs and use is possible, thereby illustrating the potential of this material to be used more centrally in larger structures.

Fig 4.25. Variation of Arches Made by Different Size Bundles

Fig 4.26. Stairs Detail

The assembly of materials is visible in the final structure, showing the didactic nature of tectonic architecture. In order to achieve tight curves, smaller bamboo is used, while the compressive elements use bigger culms. According to the load estimation, one or more culms are put together to carry the weight. By showing clearly how each of the components are connected, opportunities for didactic learning for future expansion or restoration are made possible.

4.2.3. Warehouse

A warehouse in Indonesia made by Asali Bali Engineers uses a prefabricated modular bamboo frame (Fig 4.27) that spans 16 meters (and is capable of spanning 20 meters) (Baig, 2016). Every detail has been carefully designed and seven load tests have been administered and passed to assess the strength of the structure. The bamboo culms used to make these frames were selected carefully with respect to their size and straightness, and were cured and treated with traditional Balinese knowledge, and took eight craftsmen two months to complete.

Fig 4.28 shows how foundation posts were cast prior to the floor slabs, with two steel rebars extruding from the form boards indicating that there is a pre-drilled hole in the embedded mortar of the bamboo culm, which would be epoxied when assembled.

Fig 4.27. Prefabricated Structure Leveraged using Crane

Fig 4.28. Engineered Foundation Posts

The frames were carefully leveraged with a 22 meter crane mast. Fig 4.29 showing the trusses being braced with rafters and secondary structural components tied with sash cords, this modular system allows for future expansion onto the structure. The post seems to have double culm layer that are bound by lashing with horizontal member separating the vertical culm (Fig 4.30).

Fig 4.29. Leverage Operation using Crane

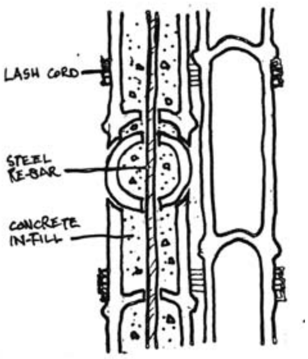


Fig 4.30. Junction Detail nts

A steel cladded roof is fixed with self tapping screws directly onto the bamboo, this detail is also achievable with wire threading holes in corrugation and around lateral culms (Schneidereit, 2000), this is an application of modern products onto the bamboo (Fig 4.31). The truss system is braced with additional steel tension elements (Fig 4.32.) which allows for a design to consist relatively few culms being used to achieve such a large span (Baig, 2016).

Fig 4.31. Warehouse Interior

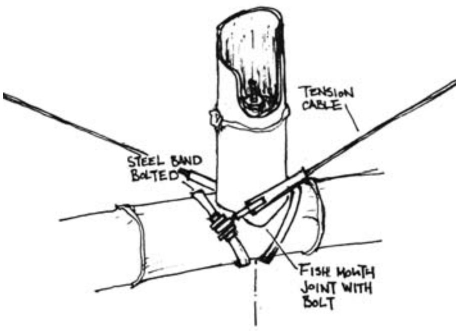


Fig 4.32. Junction Detail nts

4.3. Community Involvement

This section describes examples of structures built of bamboo with community involvement. The involvement of local people and materials to create a structure becomes an unique culture and this process is seen as a representative of critical regionalism (Frampton, 1983), structure having elements that are tactile which complement its climate and site. The involvement of local people creates a tactile bond between the community and the structure that they have created.

4.3.1. Hand Made School in Bangladesh

Fig 4.33. depicts a school that was built by Modern Education and Training Institute (METI), an NGO from Dipshikha in Bangladesh (Lepik, 2010). The focus of this construction was on creating a space for team-based education, making use of locally available resources, and developing skilled labour and knowledge to further progress the communities. The building was hand built by local craftsmen, pupils and teachers who collaborate with European volunteers. The main goal was to involve the students to help create the school in which they were going to be studying, including to plaster the mud walls which would keep them cool during their schooling life (Fig 4.34).

Fig 4.33. Hand Made School

Fig 4.34. Mud Plastered Wall

Anna Heringer and Eike Roswag designed the building, working closely with the local community (Fig 4.35), which includes the properties of various materials. The mud and rammed earth construction on the ground floor allows for a solid mass that insulates it from the heat of the sun, and the lightweight bamboo on the first floor sits on top (Fig 4.36), creating a well-ventilated space, both sections being allocated to best suit their properties (Lepik, 2010). Tectonics in architecture makes use of various properties that the materials possess, this is seen with tensile bamboo frames resting on a compressed earth works.

Fig 4.35. Mud / Rammed Earth Construction

Fig 4.36. Bamboo Frame on Top

The region is rich in vernacular construction techniques, specifically earth and bamboo, with information about modern techniques and materials (damp proofing) not having been exposed to the public. Construction of vernacular buildings therefore results in structures that require a high degree of maintenance, with structures failing within 10 years (Lepik, 2010). Improving the rural quality of living will prevent the rapid in-migration of residents towards urban regions that do not have the infrastructure to accommodate them.

Development in the rural settings are sometimes easier than in urban areas, with respect to the cost of labour, as well as to land and the availability of natural resources, which can be cheaper and more plentiful than in urban centres. This school aims to raise awareness about available resources in the region and demonstrates how to incorporate modern design details in order to enhance the life expectancy of traditional construction methods (Fig 4.37, 4.38 and 4.39). This was all done with the involvement of the local community members so that the information could be spread and repeated in the future (didactic). All of the factors make this case study an example of critical regionalism.

Fig 4.37. Deep Eve and Structure

Fig 4.38. Floor Structure

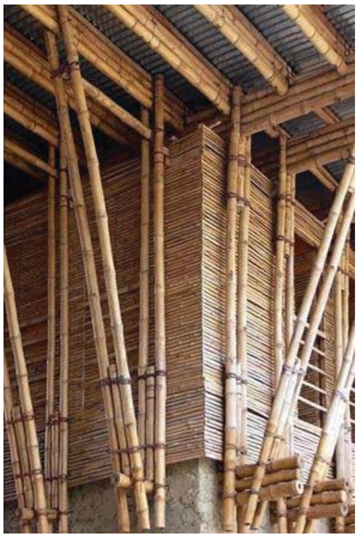


Fig 4.39. Lightweight Bamboo Frame

The enclosure elements being used for the upstairs part are lateral bamboo panels that represent tactile elements from the local culture. The openable windows suggests the use of timber frames with hinges, and the small bamboo slats form the surface of the facade. The span of the roof is possible to create with the four bamboo culms piled on top of each other. In addition, extending the eaves was achieved through angular supports that are spaced with additional culm interlocking the floor beams, which protrude out of the mud walls (Fig 4.38.).

The bamboo culms are put together by a steel pin lashed with nylon chords (Fig 4.40.), this detail is applied throughout the structure and is the most important detail for this construction. Compared to the injected mortar method discussed previously, the nylon chords seems to act as the bolt keeping the culms from separating and also splitting. From every junction to column detail, the building is put together considering the tectonic shape of combining singular bamboo culms to create a profile that could weave on different layers to support its load.

Fig 4.40. Steel Pin Lashed with Nylon Chords

Fig 4.41 demonstrates a three meter load test of the floor detail supports, five spacing gaps indicate the structural elements to be at 600mm lateral centres, the junctions being put together with steel pin and nylon chords. Spacing of the supporting elements appears very frequent, but this is appropriate considering the natural properties of bamboo, this being an example of structural requirements for a straight edged bamboo building type. Fig 4.42 is the process of the floor structure being made on the ground before assembly.

Fig 4.41. Load Test of Three meter Span

Fig 4.42. Floor Assembly on Ground

This structure is made largely from cheap and accessible materials, mud and bamboo, assembled with methods to meet the needs directly and minimalistically, this could be regarded as a philosophy example of Wabi Sabi.

As indicated by the architects the project has successfully set the foundation for the spread of construction technology, Fig 4.43 is an expansion of the school being made beyond the initial construction. This can be seen as the spread of knowledge in line with the rhizome concept with aid of didactic potentials of bamboo.

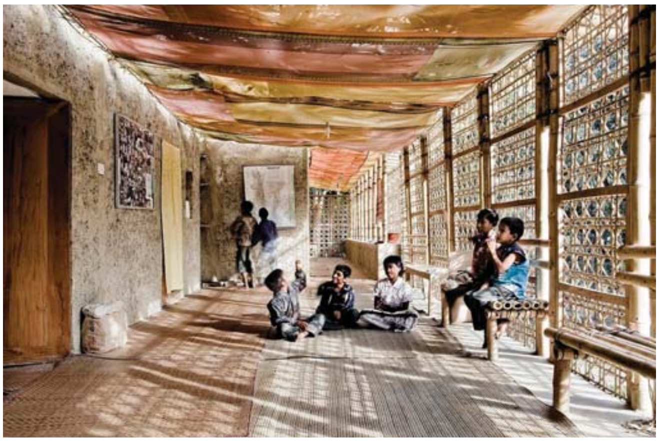


Fig 4.43. Skills Development to Create Necessary Spaces

4.3.2. Simon Velez and Communities

Simon Velez involves as much labour as possible in his projects, as he believes in an intense use of labour and not machines, thus offering important positive by-products for social development within communities in developing nations. Fig 4.43 is Simon Velez explaining the process of injection mortar with builder for an interview (Restrepo et al., 1993).

Fig 4.44. Simon Velez and Builder Creating Injected Motor Junction

Bamboo building construction can be done without the use of electricity and with only simple hand tools. Therefore people with minimum capital or limited specialised skills are able to construct spaces for themselves (De Beer and Bareis, 2000). Using this material makes construction accessible to the unprivileged members of society, who can gain livelihood from handcrafted skills that can become their pride and honour. With relatively simple training and clear guidance, a person can assist with advanced bamboo structures. Valez's use of a large labour contingent, rather than machinery, promotes a tactile relationship between a community and the structure that they contribute to building (Restrepo et al., 1993).

Valez's joinery uses mortar and other materials, as although bamboo is versatile and strong, there are limitations and downfalls to using it alone, and materials of different properties need to be considered alongside it to reinforce. This is an example of critical regionalism, wherein there is a use of new technology with old materials in order to create something new that pays tribute to old techniques.

4.4. Tactile Implementations

The following are examples of structures that are built to suit their environment, and in their design they pay tribute to regional materials and characteristics. The walls of the structures are made to have the texture of bamboo culms, which further speaks to key elements in the theoretical framework, specifically in that they use tactile characteristics of local materials to create structures that are regional and familiar.

4.4.1. House for Trees

Designed by Vo Trong Nghia, house for trees is a project that has strong message in greenifying the city to incorporate nature into the urban design of Vietnam (Stevens, 2014). Bamboo is an abundant and cheap material in Vietnam, and is often used in the firm's designs. House for trees is similar to giant pot plants for vegetation in the city, where grey and storm water is designed to be channelled through to feed the plants (Fig 4.46). These bamboo structures have created micro environments within the big city, the intention behind the design being to alter the perception of the built environment to accommodate more green technology into their planning. Completed in 2014, this 226 sqm building is located amongst many rows houses in Ho Chi Minh City ,and crowds the area (Stevens, 2014). Being the only trees in the area, these structures and the trees on them stands out amongst the still buildings around them. Concrete form work is created by bamboo culms as seen in Fig 4.45, where an imprint of the bamboo is made into the concrete to create a more durable compressive material, this transforms the original information so that it lasts longer than the original form, this being a particularly interesting feature that could be developed further. Modern day stone (concrete), having compressive characteristics, is well suited for the foundation of structures, which could have bamboo structure on top of the memory textured foundation. This would add another possibility of a multi storey bamboo building using raw and processed shapes.

Fig 4.45. Culm Formwork Cast Concrete   Fig 4.46. Excess Rain Water Conduit to Trees from Other Buildings

Private zones are designated on the first floor and public functions occur on the ground floor, with the plan utilising the site well and openings connecting the ground floor areas while keeping them apart. The structure creates a tropical way of living, with the feel of there being natural elements integrated into the design (Fig 4.47).

In these structures, five concrete boxes with various heights were arranged on the edge of the site (Fig 4.48), which reflect the bigger scale of the city around them. The negative spaces formed are representative of the in-between spaces formed in cities. Although the project is built in a residential scale, it is possible to envision a cityscape applying the same principles and shapes at a larger scale.

This structure is an example of critical regionalism because it draws inspiration from both natural and modern elements, their tactility and its relationship with the city. Urbanisation has transformed the cities of Vietnam from diverse tropical forests to a densely developed islands of buildings. Only 0.25% of Ho Chi Minh City is covered with vegetation, with pollution from motor vehicles and the dense distribution of buildings, making the city difficult to live in. The younger generations are losing their connection to nature, which has a close relationship to the country's cultural heritage. This building displays signs for "architecture of resistance" (Frampton, 1983: 25), in that the tactile implementation of bamboo (which is a cultural plant) is used in conjunction with a modern material (concrete) to represent shapes of the city to address a problem.

Fig 4.47. Interior Finish

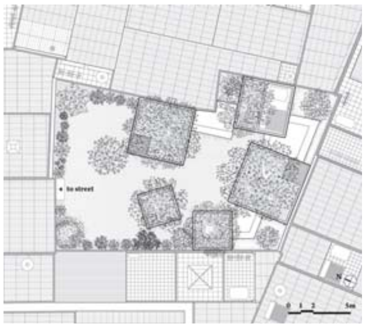


Fig 4.48. Context and Site Plan

4.5. Furnished Bamboo House

The structure described in this section are further examples of how bamboo, due to its versatility, can be used to create structures with finishing done almost entirely with this material. They are examples of critical regionalism with didactic nature, in that they make use of specific tectonic features to complement the physical features of the bamboo material.

4.5.1. Green Village House in Bali

World famous green village house in Bali, designed and built by IBUKU, is a fine example of a fully furnished bamboo building (Fig 4.49). The IBUKU team consists of local artisans who became specialised in bamboo construction, as well as engineers and architects who supported the fundamental design whose designs evolve around scaled structural model making. They have done over 50 bamboo buildings, with sustainability amongst their main principles, and offer tours and construction workshops that are open to the public (Green Village, 2017). As seen in Fig 4.50 bamboo material is possible to build more than a single storey, in this example they utilised the full length of the culms without combining the vertical elements radiating from the center.

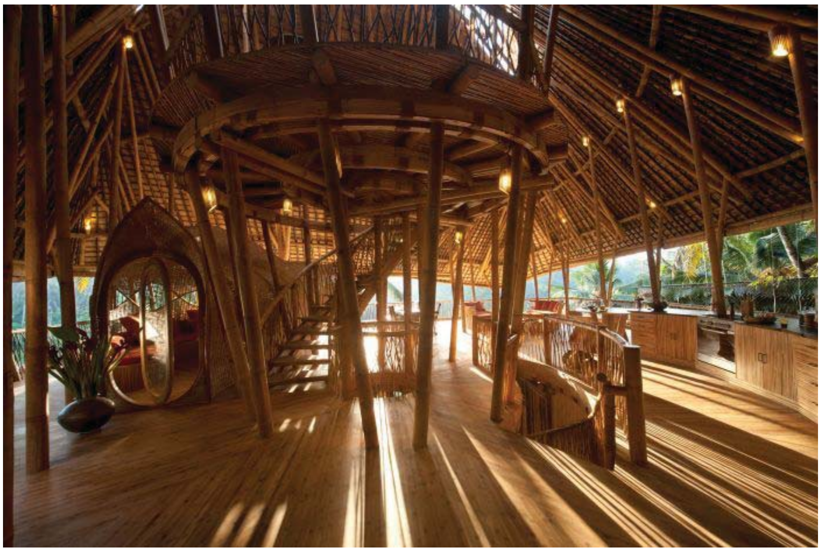


Fig 4.49. Green Village House

Fig 4.50. Multi Storey

The traditional artisans have been influenced by the international architects to produce this handcrafted building that is unique to its location and has successfully incorporated a tactile quality the whole body will experience (Green Village, 2017). It is a wall-less structure with deep eaves that allows for a panoramic views of the forest, allowing light to play on various surfaces. The irregular column placements are anchored by the floor structure, stabilising the whole building. In principle, double ringed (in and out of columns), small strips of bamboo are tied with rope in order to create a flexible beam that is able to wrap around complex shapes. These are further sandwiched by culms on which strips of bamboo are laid to create a floor. The visibility of structure allows for didactic learning to occur, the roof seems to follow a logical order of linking the separate columns diagonally, creating a spiral effect often seen in IBUKU's designs (Green Village, 2017).

Bamboo is used extensively for decorating every aspect of this building, all ornaments being different in the way they are crafted. These kind of buildings are possible for countries such as Bali, that have a deep cultural history of people that have dealt with bamboo for centuries. The stimulation of an international taste has created a new kind of culture that incorporates sustainability, which is directly related to the crafting of the local hands.

As the nature of bamboo to continuously produce new culms every year, this village house is being built as the materials grow. As mentioned previously the 300 sqm house using 1200 bamboo culms would be of this kind and is changing the landscape creating a unique culture of hand woven buildings.

CHAPTER FIVE | PRECEDENT STUDIES OF BAMBOO CONSTRUCTION INDUSTRIES

This chapter addressed Objective 3, which is to contextualise the information gathered by developing construction techniques and principles that will suit South African conditions. To explore the potential of bamboo as an alternative construction material in South Africa, the precedent studies below examine the industry around bamboo as a materials for construction.

The first precedent study is that of a project in Tanzania named Fumba Town Development, which uses bamboo as their main construction material. The project includes a nursery and a factory, from which they manufacture materials to create prefabricated residential units using laminated bamboo lumber. Their vision is to harvest all the necessary construction materials from their nursery, which correlates with, and has inspired, the concept of the 'living school' in this research.

The second precedent study conducted is of a company that supplies bamboo and natural products in South Africa. This was done to establish the potential bamboo species available for use as a construction material in the country and to obtain insight into the current state of the bamboo industry from people who work within the industry.

5.1. Fumba Town Tanzania

Fumba Town Development is a construction project where they intend producing prefabricated residential units using bamboo as the main construction material. Semi-structured interviews were conducted (telephonically) with professionals who are involved in various parts in this process. Akif El Mauly is a manager of the bamboo lamination factory and explained the steps needed to create bamboo laminates, while Vuai Mkoko Hassan is a botanist who manages the nursery for their development.

The linear process of transforming bamboo from growing to processing them into a construction material, and the spaces (constructed out of raw bamboo culms) necessary to process them, is a valuable example that aids in the conceptual development of the 'living school'.

5.1.1. Location

Fumba Town is a project in Zanzibar, Tanzania where the whole town is a project, in which the main construction material is bamboo (Mauly & Hassan, 2017). Their vision is to develop a sustainable building construction method that will assist with the housing needs in East Africa. Started in February 2016, they are in the process of developing a bamboo processing factory and nursery. They are producing laminated bamboo lumber that will be used to create prototypes of their prefabricated residential units to be located in Fumba Town (Mauly & Hassan, 2017).

5.1.2. Justification

The development project uses locally sourced bamboo for their construction materials and all of its processing is done on site. The development of skills and technology was a main objective in the Fumba Town project, this being facilitated by German specialists who pass on their skills and conduct the phases of the development, these being curing, treating and processing the bamboo (Mauly & Hassan, 2017).

The application and incorporation of raw bamboo into modern construction is a difficult process, as the natural profile in harvested material is round, hollow, exhibits tapering and has irregularities. Circular profiles are difficult to adjust to suit standard construction plans due to the nature of their junctions. With modern technology, a rectangular profiled laminated bamboo lumber has been produced that has properties similar to those of steel. While being environmentally friendly, the cost performance turned out to be four times that of conventional lumber and 1.6 times that of laminated lumber (Rittironk&Elnieiri, 2007).

The Fumba Town project involves the introduction of a supply chain to create bamboo construction materials, which are then used on site (Mauly & Hassan, 2017). The objective of the consultation with Fumba Town was that it would assist in answering some key questions regarding what is necessary to introduce bamboo as a construction material into a region. Additionally, this research aims to identify methods of processing the material and various stages of treatments gives insights into how a 'living school' development could be established.

5.1.3. Growing Bamboo for Construction (Nursery)

Fumba Town is growing bamboo to increase the amount of renewable resource to supply their scheme, their species (Dendrocalamus Asper) that was brought from China in the early 1900s having adapted well to the climate in the region and being suitable for construction. As indicated in Chapter 2, bamboo is relatively easy to propagate, the rhizome structure allowing it to grow shoots and roots from each node (Hassan, 2017). In the preparation of the nursery, simple earth work is done to bury the cutting of fresh bamboo. After 3 weeks, roots will appear followed by their shoots. Moisture is necessary for the rooting process. Therefore, soil needs to be watered regularly (Fig 5.1.) (Hassan, 2017).

Fig 5.1. Series of Photographs showing the Propagation Techniques used by Fumba Town

There are many ways to propagate the bamboo, and they require attention during their initial years of planting (Hassan, 2017). Once the plant is about a year old in their given environment, as long as the area receive adequate rainfall, bamboo can survive and will not require further fertilisation or irrigation. One bamboo culm will be cut into several pieces with nodes attached (Hassan, 2017). The culms contain energy which allows them to regrow, the colours often indicate their content. During the period of initial cutting (variation may occur from different species), the bamboo culm will slowly lose its colour. So it is important to use freshly cut culms which include nodes. Root hormones could be used to increase the success rate of the process, when fresh cuttings are made, and during their transportation, the culms may be submerged in a container with diluted root hormones. This would give extra stimulation for the culms to grow roots (Hassan, 2017).

A further 3 weeks are given for the plants to expand their roots and then they are separated into bags for distribution and planting purposes (Fig 5.2.). The seedlings need to be covered in some form of shade in order to prevent them from drying out as shown in Fig 5.3. (Hassan, 2017).

Fig 5.2. Individual Bags for Distribution and their Storage

Fig 5.3. Shade provided by palm leaves on structure

It is recommended that planting of the culms is done during the rainy season. The success rate of seedling rooting will largely be dependant on the timing and careful placement of the plant, as the seedlings need water to survive (Hassan, 2017). As long as there is a steady source of water the plants will live. The seedlings are sold to the general public during the rainy season.

In nature a single bamboo plant may multiply down the river, during a flood a bamboo culm may break off and get washed downstream, if a node is covered by soil, it will root and start a new plant (Hassan, 2017). This is strictly in the case of the clumping bamboo species, which is the kind to be used in this scheme for the manageability of the forest cover. Running species will be invasive and could become a threat to existing indigenous vegetation. A thought would be to locate the nursery along a stream, provided that shade is available (from existing vegetation) and that there would be no need for irrigation.

Fig 5.15. shows the shelter created for the nursery was developed in response to a need and in doing so, they have incorporated their traditional method of creating a coverage and in that they used a single bamboo culm to support the structure (back right corner). This could be the fusion of a process to create a new vernacular for local architecture that has the capacity to be available for the general public.

The ceiling detail for the nursery shelter displays woven palm leaves, which suggests the existence of a tactile culture that makes use of available resources (Fig 5.4.), as Fumba Town is a project that started in early 2016, the bamboo they have planted will only be harvested in five years' time (Hassan, 2017).

Fig 5.4. Nursery Shelter

Fig 5.5. Woven palm leaves

5.1.4. Preparing Bamboo for Construction (Laminated Bamboo Lumber Factory)

The general construction in Tanzania uses block and mortar construction, similar to that of South Africa, this method being commonly used for general construction. They have incorporated the use ceramic floor tiles in their bamboo structure to achieve acceptance amongst the general public, together with fire and waterproofing so this additional element makes these units more durable for everyday use (Mauly, 2017).

The Fumba Town Development has a linear production line from the bamboo plants to their final product, with all the spaces being required to create these units being made from bamboo (Fig 5.5.). Containers are used as safe storage, between which the spaces are the covered with bamboo structures. The big areas that need covering use bamboo truss systems that are anchored by concrete columns (Mauly, 2017).

The concrete columns are spaced according to the calculation of the span of a combined bamboo truss systems, which becomes the basis of the space coverage using bamboo (Mauly, 2017). In this way, the structural process is in fact “living” together with the growth and harvest of bamboo culms. The bamboo resources available are not yet at the level required to support this scheme on an ongoing basis. Therefore the development of the nursery is as important as the spaces being made on the LBL factory construction site.

Fig 5.5. Spaces Necessary Being Created by Bamboo and Modern Technologies

From their existing resources, the bamboo culms are harvested, punctured and submerged in seawater for three weeks. This process is called “leaching”, the objective being to drain out the starch content from the culms, which could also be achieved with a running stream. The application of boric acid is done after this process. The vessels in the culms are open and will allow for the treatment to seep through. The culms are then kept in the solution for a week (Mauly, 2017).

After treatment the culms are then sun dried for a week. The rotation of the culms are necessary every 2 hours since the rapid drying from one side will cause cracks (Fig 5.6.). The culms are then stored in a well ventilated and shaded space to mature (Fig 5.7.). In some cases they could leave the culms for 2 years so that all that remains is a cured skeleton structure (Mauly, 2017).

Fig 5.6. Sun Drying of Culms

Fig 5.7. Curing and Maturing of Culms

The matured bamboo are split into segments (Fig 5.8.), which are planed and sanded to create strips which are combined together with glue to create the laminated bamboo lumber (Fig 5.9.). In line with the concept from tectonics in architecture, the small profiles are put together in order to create a shape that could withstand far greater load than that of a singular profile. The overlapping of the layers is visible (possibly sanded to remove glue), giving clues into how this was achieved. With the conditions in Tanzania being hotter than Germany, a point made among the engineers is that the drying speed of the glue differs significantly (Mauly, 2017).

Fig 5.8. Split and Planed Bamboo Culms

Fig 5.9. Hand Operated Lamination Press

Fig 5.14. displays the external view of a building which hosts the lamination process, they made use of two shipping containers with a raw bamboo culms to make the truss. This process of creating their necessary spaces using the material itself is the core understanding of the creation of a school that teaches through its construction.

Fig 5.14. Exterior View of the Bamboo Lamination Building

Fumba Town will use LBL for their construction, including the guard house for the factory, which is being made in the dry-wall method (Mauly, 2017). Since they are still waiting for the bamboo plants to mature, they are currently using locally sourced timber to create this example (Fig 5.10. and Fig 5.11.).

Fig 5.10. Interior of Guard House with Fireproofing   Fig 5.11. Exterior of the Guard House in Process

Being closer to the tropical band, Tanzania is very hot and humid, with the design of the building needing to accommodate insulation by incorporating air pockets. The guard house shows a gap between the roof and room and once completed, the hot air will be ventilated naturally; thus keeping the rooms cool (Mauly, 2017). In the image below, of the prototype of their bamboo Townhouse (Fig 5.12.), the floor is suspended, which allows for cool air from beneath to be circulated into the structure (Fig 5.13.). In Fig 5.12. shows the units having a window allocated at the top of the bottom pitch roof which allows for light and ventilation of heated air.

Fig 5.12. Prototype of their 2 Bedroom Townhouse   Fig 5.13. Interior Ventilation Detail

5.1.5. Evaluation and analysis

Bamboo construction in Tanzania is limited, as there is an image of the material being related to poverty, with the development in Fumba Town making an effort to counter the existing ideology by creating a modern product made with bamboo. According to the developers, they do not have sufficient bamboo to supply their scheme. Therefore propagation process of bamboo is in place at their nursery which will be ready in 5 years.

Their objective will be to develop a facility, using their existing resources, which would be able to process the expected annual harvest. Their vision is to have a production line capable to create all aspects of their building using LBL and currently prototypes of individual components were being made.

The Fumba Town’s process of harvesting, treating and using the bamboo to create their own spaces are directly inline with the 'living school' development. Their facilities would grow together with the annual harvest and ultimately providing resources for their housing development.

5.1.6. Conclusion

Fumba town is creating a product using bamboo in its processed form, the end-product being a dry wall construction that people may not realise is made from bamboo . This is intentional, in order to be able to sell the final products to people who may have a negative view of bamboo and would not want to identify the raw bamboo shape with their homes. However, the laminated bamboo lumber requires more culms to produce the same square meter coverage. The tectonic properties of bamboo are lost and opportunity of didactic learning is not visible, and the process of making spaces does not incorporate any kind of weaving or tactility, rather involves hammering nails of standard white boards. The 'living school' development will acknowledge and learn from the initial spaces that Fumba Town has created, specifically its processing factory and nursery, from which they create their more modern processed construction materials.

5.2. Brightfields Natural Trading Company

Brightfields Natural Trading Company is a South African business that specialises in various environmentally friendly products, including sisal, seagrass natural fibre mats and a wide variety of bamboo products. Brightfields currently target a higher-end market of consumers, specifically those who are ecologically conscious. Their bamboo products largely entail using raw culms for outdoor fencing, and processed (laminated bamboo) for components of buildings, including flooring and counters (Dunbar, 2017). They also have an exterior durable decking product that are made out of compressed bamboo chips. Interview was conducted with Brightfields manager Graham Dunbar.

5.2.1. Location

Brightfields is one of the leading bamboo manufacturers in the country, and have a showroom (Fig 5.16.) and head office in the industrial neighbourhood of Woodstock, Cape Town. Although being far from the growing regions of bamboo, Cape Town has few varieties (including Bambusa Balcooa) grown in their environment (Dunbar, 2017). Deleuze and Guattari (1987) states, if a plant has been able to successfully multiply at various locations the land between are within range of the rhizomatic possibilities. This means that the applicable region for the 'living school' will reach all the way to the furthest point in Africa.

Fig 5.16. View of Brightfields Showroom and Products

5.2.2. Justification

Brightfields sells products from processed bamboo boards, but also makes use of raw bamboo poles for some of their projects (Dunbar, 2017). They are currently using imported bamboo that is processed at source or sometimes as culms and shipped to Cape Town. However, they want to simplify their business model and use locally sourced raw materials, as well as use their own equipment to produce bamboo products for South Africa.

Brightfields sells seedlings, and while it may not be a big part of their profits, they are doing so in order to promote knowledge of bamboo, which will eventually increase its use in the building industry. This is an example of how bamboo as a material relates to the concept of a Rhizome, whereby the use of bamboo is able to spread biologically in natural systems, in commercial systems (sale of seedlings) and in conceptual systems via advances in techniques and knowledge of how to use bamboo in practice.

For bamboo to be introduced as a construction material in South Africa, an industry needs to be developed around it. This involves local growers and distributors, while those who work with bamboo need to continually develop techniques for preparation and construction. However, for this industry to grow, greater public awareness about the use and benefits of bamboo are required. Brightfields is a company that is actively developing techniques for bamboo use in construction and in their operation; they are working to increase public knowledge and awareness of bamboo. South Africa will need more companies like this if the bamboo industry is to grow.

5.2.3. Industry and material

According to Brightfields, bamboo products are more expensive than similar commercially available products in South Africa, and while it is very easy to handle and does not require working with heavy machinery, it is still a new concept in the country. Bamboo is a labour intensive plant and the cost of harvesting in South Africa currently could be equivalent to importing the bamboo from abroad (Dunbar, 2017). New methods to harvest bamboo in a more efficient way would need to be developed in order to reduce the costs and make it competitive to use locally grown bamboo. Another difficulty with bamboo plantations is that there can be complications with issues related to land ownership and funding for farming that can make new ventures difficult to initiate (Dunbar, 2017).

Currently, most of the bamboo used in construction in South Africa is largely imported from China, where the thriving industry has farms that cover more than 20 million hectares and efficient labour force (Dunbar, 2017). Phyllostachys Pubescens is the species of bamboo that is commonly imported from China, and is usually already processed into planks prior to import (Dunbar, 2017).

The most common bamboo species available in South Africa are Bambusa Balcooa and Dendrocalamus Asper, which have been planted commercially in Pietermaritzburg and Durban North (Dunbar, 2017). These two species from South Africa can both be used in furniture and as a construction material. Balcooa being more irregular in their shapes than Aspers, which grows in more straight culms. Balcooa can be difficult to process e.g. symmetric planing machines can struggle with the irregular shapes (Fig 5.17.), which has resulted in some manufacturers (including Brightfields) prefer to use Aspers. For fencing, Sudo Japonica, also known as ‘Tonkin Bamboo’, can be used, and is also used for spear-fishing poles due to their flexibility and strength (Dunbar, 2017).

The life expectancy of bamboo structures has been known to exceed 10 years in some cases, depending on the weather conditions, as well as processing and treatment. Its life expectancy can be improved by making sure that the bamboo pieces do not retain or get exposed to water, and when used in construction it should never the touch soil as it will attract insects and absorb moisture (Dunbar, 2017). Insulation, as well as fire, wind and waterproofing, could be achieved by incorporating other materials in addition to bamboo.

Insects can be an issue for bamboo material storage and hamper its use as a construction material. The wood boara is an example of an insect that has been known to consume bamboo, and treating it with borax salt and boric acid can assist in preventing insects from eating it, although it is time consuming to treat full culms (Fig 5.18.) (Dunbar, 2017).

Laminated bamboo lumber is strong and would be able to motivate for the possibility of using bamboo for larger sized complexes. Laminating means that even species that are not otherwise suited to construction can be made into usable boards e.g. Beema a species of bamboo that has the wall thickness three times of regular bamboo (Sugets et al, 2015).

Fig 5.17. Balcooa Bamboo Slats

Fig 5.18. Boara Attack

5.2.4. Brightfield processes

Brightfields is mainly using bamboo mainly for exterior fencing and cladding, while the imported processed boards are increasingly being used for flooring, kitchen countertops as well as cupboards. For outdoor decking, Brightfields uses compressed high-density bamboo boards that are suitable for exterior spaces (Dunbar, 2017). Their bamboo is not yet used for structural purposes but rather for cladding items within and around the household, such as countertops (Fig 5.19.) and furniture (Fig 5.20).

Brightfields have not yet tried to use bamboo as a load bearing material, for which they would require approval. Having previously worked with sandbag houses that are cladded with bamboo, they are considering putting through a proposal for a housing scheme using container cladded with bamboo (Dunbar, 2017).

Fig 5.19. Options for Bamboo Countertop and Side Panel

Fig 5.20. Bamboo Furniture

Brightfields employ a technique to counter the curved properties of the bamboo culm when they combine the processed imported boards (Fig 5.21.). The fibres are dense on the outside and fine on the inside, and therefore when laminating boards, it is important to alternate the direction of the strips to prevent warping (Fig 5.22.). If the adjacent strips are all in the same direction then the board will curve towards the side with less density. They also find that the best method to combine the separate bamboo poles for fencing is to drill the bamboo and thread them with lengths of wire. For insect treatment, Brightfields process the culms into strips, of 2.4 m which are ideal for their process and products, before treating them (Dunbar, 2017).

Fig 5.21. Bamboo laminates using South African Bamboo

Fig 5.22. Curve Occurring after Lamination

Technology can make a significant difference in the time required to prepare the materials. For example, Brightfields require a machine that can heat-treat bamboo, with which the culms are treatment with chemicals, and therefore increase the level of production. Brightfields is currently investing in machinery to process the bamboo so they can localise their whole operation (Dunbar, 2017).

5.2.5. Evaluation and analysis

There is a lack of bamboo plantations and processing factories in South Africa, which makes it more expensive to process than it does to import the processed products from China. While bamboo products are seen as being environmentally friendly, there is an environmental cost to importing them (shipping), and until a local industry is established, it will not reach its full potential as a environmentally friendly alternative to modern construction materials.

No examples were found of the raw bamboo culms being used in construction in South Africa, nor were any building standard or codes for bamboo construction found. In the absence of these building standards, bamboo can only be used for cladding, counter cupboards and exterior fencings. Brightfields have worked on housing schemes where there was extensive use of bamboo in and around a frame made of different material that bear the load. This is perhaps a necessary interim step towards building structures, where bamboo is utilised as a core material. Bamboo seedlings have been found to grows in Cape Town, which is not a recognised bamboo growing region in terms of climate (Dunbar:2017).

5.2.6. Conclusion

Brightfields are among the few bamboo distributors in South Africa who want to use naturalised local species rather than imported alternatives. They believe in local bamboo manufacturing and they are investing in machinery that will allow them to create bamboo products at competitive prices locally. They believe that this is the direction that the industry will take. If more bamboo is grown and manufactured locally, this will reduce the cost of working with its products, which increase the variety of associated materials and their application of bamboo as a construction material. Brightfields indicated that Durban has a more suitable climate to cultivate bamboo due to its subtropical climate in which the plant is known to thrive. The confirmation that bamboo is viable for growth in the Durban region motivated the research to conduct the research in a nearby area.

CHAPTER SIX | CONCLUSION AND RECOMMENDATIONS

6.1. Introduction

Bamboo is regarded as environmentally friendly material that grows rapidly and requires minimal resources to grow. It has land and forest restoration capabilities, and can use processed wastewater as a source of nutrition. As a result of these properties, a community that lives closely with bamboo can benefit from its characteristics and by-products, including having access to an annual harvest of construction material. Such a symbiosis between bamboo and people can create a higher level of self-sufficiency in a community that can lead to social change and improved welfare.

The bamboo plant is known to be resilient and to grow and spread rapidly. These characteristics are also true of bamboo as a construction material, where the accessible and didactic nature of bamboo building techniques drive the spread and adoption of bamboo in construction. Internationally there are numerous examples of critically regional structures that utilise locally available bamboo, and create functional structures with local character. These examples include some which involve the communities directly in the design and construction of the structures.

Although use of bamboo has not yet been widely adopted, bamboo has naturalised in South Africa, with a number of naturally occurring species that are suitable for construction; renewable resources are only efficient if they are utilised to their full potential. The bamboo technology is not yet known in South Africa (especially in the rural context), details and treatment methods needs to be developed to create a standardised building material which would assist in the wide application for modern construction.

Skills development is one of the biggest challenges and opportunities in expanding the bamboo industry. There are many areas of work surrounding the trade and use of bamboo, from forest management, treatment, construction and craft-making. As with other industries, the expansion of the bamboo industry will create a demand for more skilled jobs, this demand being beneficial for socio-economic empowerment.

It is important to ensure that bamboo culms are correctly harvested, well cured and treated if they are to be used in construction, as this will determine the lifespan of the building. Some bamboo structures in China have been found to have lasted for over a century when well cared for. These examples suggest that, with a little technological investment, it is possible to create long lasting structures, and that using modern technology in bamboo construction will also make it possible to achieve more demanding structure types.

6.2. Recommendation

Bricks and blocks in construction are trusted amongst the general public for their durability, however commercial products are often expensive and heavy to transport. It is therefore difficult for people living in rural areas, who may have limited financial resources and may not have their own means of transportation, to construct their spaces from these materials.

Bamboo is a strong and versatile construction material, which can be grown and treated rurally with limited cost. Bamboo is relatively light for its surface area and relatively easy to transport. Bamboo can therefore be used as a preferred alternative to traditional materials in many situations. Nevertheless there are hurdles to the growth of the bamboo industry in South Africa, which include:

i) the misconception of bamboo and its water usage
ii) the reputation of bamboo as a cheap material
iii) the cost of growing and processing locally, as opposed to importing finished material
iv) the challenges around initiating farming of bamboo - such as land ownership, licence and lack of funding (grants) for agriculture in bamboo
v) the lack of knowledge, skills and technology locally in construction using bamboo
vi) the absence of a history and culture of bamboo construction

These can be overcome but there needs to be continued education about bamboo in rural and urban contexts, by both individuals, companies and other industry participants, that aims to alter mind-sets.

Another misconception is that constructing with bamboo means that whole structure needs to be built exclusively from bamboo. There are of course aspects of a building where it is not possible to replace conventional materials with bamboo (such as foundations, earth works). Another example, it would very difficult to create a secure safe room using only bamboo. It is possible to incorporate existing resources, such as shipping containers, for safe keeping. Buildings are made up of distinct parts each with their specific purposes, for which appropriate materials are selected to fulfil various roles.

The concept of a 'living school' emerged from the connection of the various properties and advantages that bamboo offers, and the challenges that need to be overcome and for the spread of bamboo as a construction material. The concept is that a space can be created from bamboo that is itself a processing facility for bamboo material into construction materials, and that teaches people to the skills of bamboo construction techniques through the architecture.

The space is made possible by the biological properties of bamboo, and would aim to educate people by amplifying the natural didactic properties of bamboo. The concept would serve as an example within a starting industry for what is possible, and ultimately it can inspire other similar ventures.

The structure is a living example of how to use bamboo to build and to craft - the school will grow annually with each years harvest, and so too will the knowledge and reach of the participants. The component parts of the structure will be visible, and teachers will make use of this as a visual aid to spread information on how to use bamboo to build. Other bamboo products can be incorporated into the output of the school and into daily functions - furniture and utensils made from bamboo will be utilised to demonstrate the various uses of the material. Over time, a culture of building using bamboo will be developed and is aimed to contribute to the conscious identity for residents in that they will become more empowered to craft their spaces using their own hands and resources.

6.3. Details for Suggested Design Guide

This section focuses on the physical development of details that can be applied to the proposed 'living school' development for the community of Tongova Mews, Tongaat. This is an example of the 'living school' concept that aims to use existing bamboo resources (naturally found in the area), or the scheme can be initiated from an initial structure containing an ablution block (Fig 6.1), septic tank and bamboo plants.

Calculating water usage (which is a function of the number of people that make use of the ablution facilities) is necessary in order to acquire an adequately sized septic tank. Bamboo cuttings (Fig 6.2) are to be planted at the septic tank outlet for their initial rooting period, and after roots have developed, the bamboo plants can be transplanted during the rainy season. This is to be done within the regions where there is more than 500mm annual rainfall, while regions with less waterfall will require the plants to remain near the outlet. The bamboo plant requires five years to mature, during which time there will be an initiation period to develop a nursery and treatment facility, and after which the occupants can expect an annual harvest of materials with which to expand.

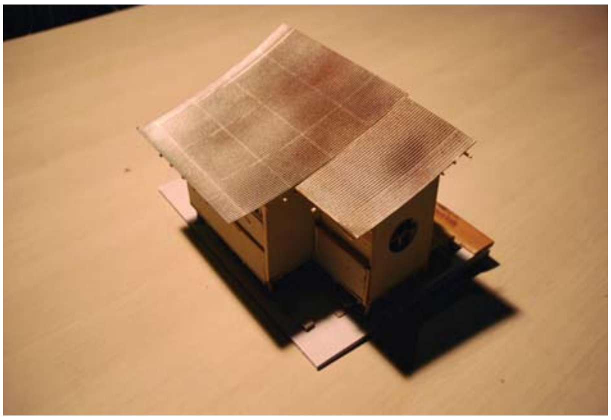


Fig 6.1 'living school' Initial Development: Ablution Block

Fig 6.2 Bamboo Propagation

The strength of the scheme lies in the fact that people use water in their daily activities, with the initial development suggesting that the used water be directed towards growing construction materials (Fig 6.3). The ablution block will contain all the necessary information regarding bamboo construction (visible repeatable construction details), and by the time the structure starts to fail, new resources will be harvested, treated and applied to maintain the structure. This is the start of an expanding modulated building, with a school of thought to use bamboo as an alternative construction material as much as possible in each phase. These structure details will not be assessed by engineers and specialists yet (for this particular documentation), they are simply ideas which need to be developed further before actual implementation can be carried out.

Fig 6.3 Water Channelling to Grow Construction Material and Energy Generation

6.3.1. Tools and Process for Construction

Fig 6.4 shows the tools required to harvest and process bamboo, namely a pruning saw, panger knife, hammer and chisel. The harvesting, treatment and curing process is not the focus of this section however, it will focus on the tools used and the processes required for construction. Fig 6.5 shows the process of splitting the bamboo into smaller segments that would be applied to various parts of the structure. The fibres of the bamboo plant run vertically, this being a necessary characteristic to consider when dealing with the material in construction applications.

Fig 6.4 Basic Tools

Fig 6.5 Splitting of Culms

Figure 6.6 displays the various size culms that could be harvested from the full length culm of Bambusa Balcooa species that is commonly found in Durban. The tapering nature of the culms allow for the harvest of pieces with a variety of diameters from a single culm. From the base (far right) to the branches, every part of the culm is usable for a variety of applications. The samples depicted were harvested at different times, with the base being the most recent to fade in colour as the starch content decreases over time, starch being necessary for the propagation of rhizomes.

Fig 6.6 Various Size Culms Possibly Harvested from a Single Culm

6.3.2. Foundation

It is necessary to elevate the bamboo from the ground level to avoid it having direct contact with soil, as this will cause deterioration and will attract insects that will consume the material. There are various options to elevate culms off the ground, including stones, brick and use of concrete. Concrete appears to be the optimal selection due to its permanence, flexibility and wide use in construction. As a mode of construction, a structure on stilts is chosen to ensure the use of the minimal number of commercial products. Conventional construction requires that a trench is dug, based on the building profile, which is then filled with concrete on top of which bricks are laid to the surface. The 'living school' development requires a flexible foundation system, after the ablution block it may develop into a variety of typologies.

Spans of bamboo become bases of the modular construction, which determine the grid system of which a reinforced concrete pillar is casted using a bamboo formwork. Split bamboos are drilled and bolted to the form of shutter boards that will be reused continuously to create a pillar above the ground (Fig 6.7 , Fig 6.8), the length and width of which may be adjusted by selecting and adding appropriate sized culms. This method will allow the building to take place on any kind of landscape. To connect the bamboo and foundation, Simon Velez’s injected mortar method should be used (Fig 6.9). The moisture content of the wet cement expands the culm (absorbing moisture) causing it to split if the cement is cured in the expanded profile where the culm tries to return to its original state, making it necessary to apply a steel clamp (Fig 6.10) during the curing process.

Fig 6.7 Split Culms

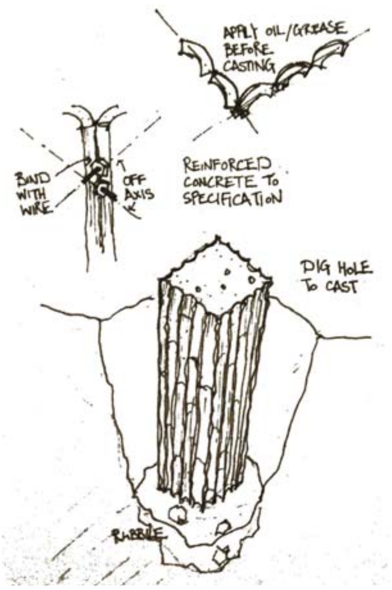


Fig 6.8 Split Culm Formwork Concrete

Fig 6.9 Injected Mortar Rebar

Fig 6.10 Steel Clamp

Holes need to be drilled into the foundation to insert the embedded rebar, with their size being determined by how many culms would be using that particular foundation . It is important to apply mortar or to adjust the culm end (before injection) to create a flushed junction. If the area does not have electricity, a steel tube with an inner diameter of the steel rebar could be casted in the foundation.

6.3.3. Floor

For the floor, 100mm diameter culms to be used at 600mm intervals to form a mesh like structure were injected mortar and rebar (pin joints) can be used on the corner elements, creating a 3 x 3 meter span. On this main structural membrane, 50mm diameter culms to be applied at 300mm intervals, which hosts the split culms laid on top, upon which surface heavy duty tiles could be applied on grout mortar. Thatching twine ropes could be bundled and used as lashing for all crossings of the culms. Fig 6.11 Shows the above explained floor structure membrane, with progress floor finishing. Fig 6.12 demonstrates the method to be used to expand the floor structure, with additional concrete pillars needing to be casted to continue the expansion.

Fig 6.11. Exposed Floor Structure

Fig 6.12. Expansion of Floor Modular

Regarding the corner detail, the x and y axis of the floor membrane culms only allows for vertical weaving to be inserted diagonally. Tectonically, the result requires connecting the outer horizontal culms directly above, with another vertical culm that is attached to the diagonally inserted anchor (Fig 6.13.), which becomes the main structural support for the roof.

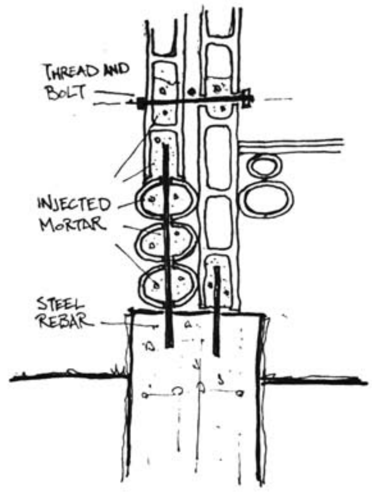


Fig 6.13. Diagonal Section View of Typical Corner

6.3.4. Column and Beam

Simon Velez's injected mortar method is so versatile that it could be applied to any part of the bamboo culm, with a connection being possible with the aid of steel products. A principle that can be used in tectonics is of multiplication of similar elements that can be combined in a form of weaving to withstand a greater load. Fig 4.14 is an example of where the culms are being connected with thread and bolt injected with mortar. This is done in this way to prevent the thread from creating pressure that will split the bamboo culms, this cross section being applicable in both horizontal and vertical use, only the connected nodes are injected with mortar. Fig 6.15 explores the possibility of connecting the circular profile culms together. The crossing of the thread axis is resolved by varying heights within the injected culm, with additional steel bars being applicable as the size of the columns increase.

.

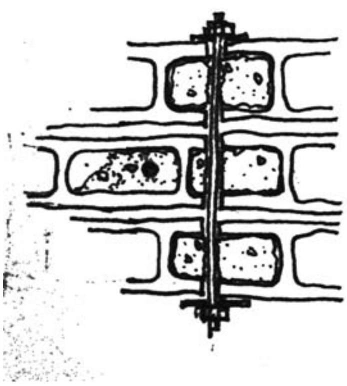


Fig 6.14. Section of Combined Culms

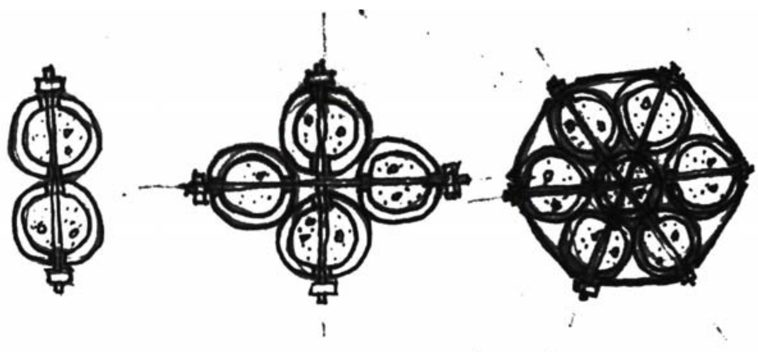


Fig 6.15. Variation of the Combined Culms Associated to their Load

To connect the vertical and horizontal members, crafting the ends is necessary to create a stable, efficient load distributing point of the structure, which can again be connected using the injected mortar method. Fig 6.16. Shows the possibility of creating these junctions with simple tools, angles were first sawed off then adjustments made using a chisel.

Fig 6.16. Carving of Culm End to Make Fish Mouth Joint

For use in high density structures, the culms may be combined to create a larger scale of the original culm, and may be bound with steel flat bar bolted at their ends. The combination of various lengths will allow for a larger combined distance to be spanned, with the bolted flat bars being needed at various intervals to hold them in place. Another technique to consider is to invert the culms while joining them, which will create nodes that will form an uneven surface upon which the steel bar will be fixed. This should result in non-sliding junctions that the combined beams will connect to. For a grouping of combined beams that are supporting large individual culms, each culm in the grouped column needs to be crafted to profile.

6.3.5. Roof

The roof structure will consist of a similar application of culms to the floor. There are many options for roofing, and the application will depend on the use of the building in its context. For a temporary shelter, it may be sufficient to use half split bamboo culms (Fig 6.5) with internal nodes removed and the culms overlapped each other. A waterproofing layer needs to be applied over the under structure of 50 mm diameter culms at 300mm spacing, which will result in a few extruding over the edges to tie over the interconnected roofing profile.

Corrugated sheeting is one of the preferred methods for roofing in Africa (Fig 6.17), possible with optional insulation (crushed bamboo wall) beneath it for the thermal comfort of the building. Wire can be used to connect the structure and the corrugation, while areas with strong winds would require tiles that will add stability to the structure. Tensile or tarpaulin membranes are also a possible solution for the roof, and can be attached to a bamboo skeleton, which will mean that less structure for the roofing is required, which will be a temporary or interim solution.

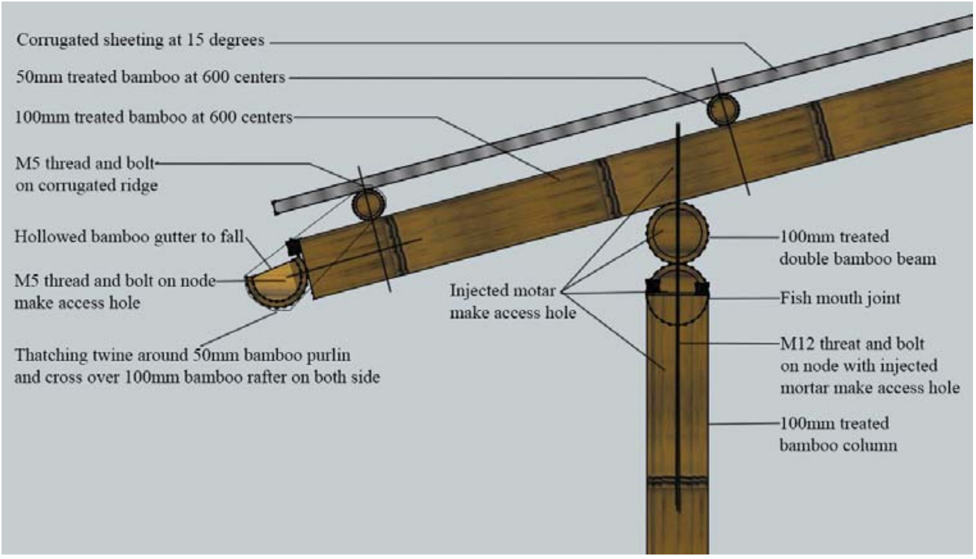


Fig 6.17. Typical Roof Detail nts

6.3.6. Wall

The walls will consist of exterior and interior finishes, with the exterior ones providing protection against weather and the internal walls adding stability to the structure. These walls can be woven, many patterns could be applied. Both the exterior and interior walls should be modulated to allow for a production line in their construction. Culms of bigger dimensions are used to create a frame, with smaller culms being inserted. The exterior will consist of frequent members, the gaps within which will provide a surface for plastering. The interior can incorporate a decorative weave pattern consists of split bamboos that are inserted in between the modulated frames (Fig 6.18).

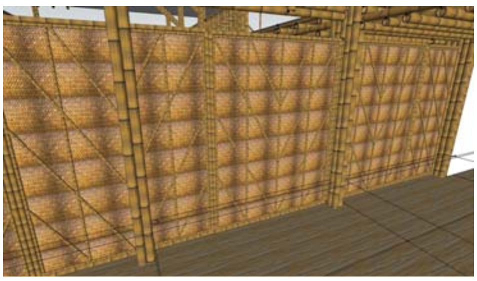


Fig 6.18. Modulated Wall Panels

6.3.7. Window / Door

Bamboo laminates can be used in order to apply a glazing edge, with the bamboo grains allowing for vertical splits that taper in nature. Fig. 6.19. shows the rectangular profile obtained from splitting circular culm, with these strips being filled and sanded to provide workable planks for glue lamination (Fig 6.20). Instead of using a router to engrave the profile, during the lamination process, the profiles are made by gluing (Fig 6.21). The door hinges can be screwed to the laminates and to the structure, steel flat bars attached around the culms to form a junction to connect, with the culms used for the door frames needing to taper upwards (Fig 6.22).

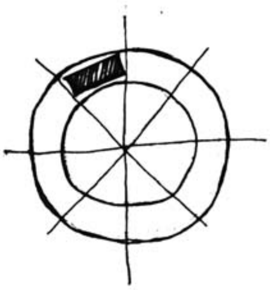


Fig 6.19. Rectangular Profile

Fig 6.20. Rectangular Profile from Splitting

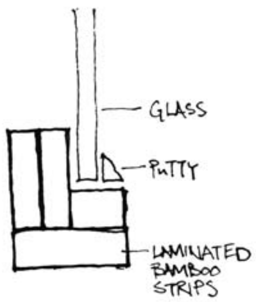


Fig 6.21. Laminated Bamboo Profiles

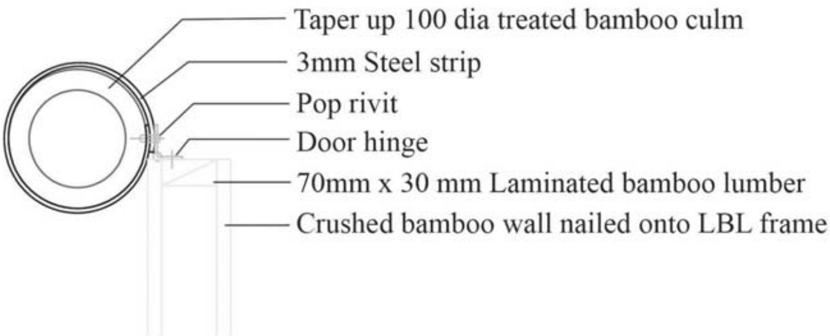


Fig 6.22. Door Hinge Detail nts

6.4. Conclusion

The above details are applicable to the 'living school' development where all the production and their products determine the outcome of the building and surrounding landscape as the years go from the initial development. This is a process to create a new kind of tactile culture which utilises this naturalised resource to form an independent / self sufficient rural communities within South Africa. Since a building code for bamboo does not exist in South Africa, standardisation of these junctions and details are of importance for the wide general application this scheme has thought a bamboo could do.

Although the 'living school' development essentially can start from the creation of an ablution block, it is necessary to have an existing forest (to source initial materials and plants) in reachable distances. Therefore it is important to identify existing bamboo forests within South Africa and furthermore, the discovery of durable construction species (woody bamboo) will become the start of the multiplicity of this rhizomatic plant and bamboo construction techniques.

Bamboo samples used in the above chapter was harvested from a single clump of a Bambusa Balcooa in upper highway region of Durban. In search of a forest the researcher has identified a specific location where there are approximately 50 Bambusa Balcooa plants grown along a stream, this was a discovery in Tongaat. There was a sense of serenity despite being right next to a main road leading into Tongaat from the national highway, there is an unique history with the development of this forest and it would be discussed in Part Two of this research.

Part Two of the thesis will focus on the 'living school' for the community of Tongova Mews in Tongaat, Kwa-Zulu Natal, which aims to utilise an existing bamboo forest to inspire the spread of this renewable, didactic bamboo technology.

LIST OF FIGURES

http://juanisasa.com/blog-wabi-sabi-the-art-of-imperfection/, Online (Accessed September 2017)
Fig 2.16 Sen no Rikyu. Source:
http://www.urasenkeboston.org/chado, Online (Accessed September 2017)
Fig 2.17. Tea Ceremony. Source:
http://tokubooan.jp/archives/1400, Online (Accessed September 2017)
Fig 2.18. Sou An Style Tea House. Source:
http://blog.ht-atelier.com/?eid=145552#comments, Online (Accessed November 2017)
Fig 2.19. Sou An Style Tea Room. Source:
http://www7b.biglobe.ne.jp/~chinke/tabuchi.html, Online (Accessed November 2017)

Fig 3.1. Anatomy of Bamboo Culm. Source:
http://www.bamboobotanicals.ca/html/about-bamboo/bamboo-growth-habits.html, Online (Accessed June 2017)
Fig 3.2. Bamboo Culm Cross Section. Source:
http://www.bamboobotanicals.ca/html/about-bamboo/bamboo-growth-habits.html, Online (Accessed June 2017)
Fig 3.3. Running (monopodial) Bamboo Root. Source:
http://www.bamboobotanicals.ca/html/about-bamboo/bamboo-growth-habits.html, Online (Accessed June 2017)
Fig 3.4. Clumping (sympodial) Bamboo Root. Source:
http://www.bamboobotanicals.ca/html/about-bamboo/bamboo-growth-habits.html, Online (Accessed June 2017)
Fig 3.5. Rainfall Across South Africa. Source:
http://www.waterwise.co.za/site/water/environment/situation.html, Online (Accessed September 2017)
Fig 3.6. World Distribution of Bamboo Tropical / Subtropical Regions. Source:
http://www.wri.org/blog/2014/02/bamboo-secret-weapon-forest-and-landscape-restoration, Online (Accessed June 2017)
Fig 3.7. Allahabad and its Effect of Brick Industry. Source: INBAR, 2014. Greening Red Earth II(Screenshot). https://www.youtube.com/watch?v=6UU0ahKBj6Q, Online (Accessed June 2017)
Fig 3.8. Successful Bamboo Reforestation. Source: INBAR, 2014. Greening Red Earth II(Screenshot). https://www.youtube.com/watch?v=6UU0ahKBj6Q, Online (Accessed June 2017)
Fig 3.9. Abandoned Bamboo Forest.
Source:https://www.takano-bamboo.jp/english/photo_gallery/index_10.html, Online (Accessed June 2017)
Fig 3.10. Bamboo Shoot. Source: http://www.masterfile.com/search/en/spring+rain+bamboo, Online (Accessed June 2017)
Fig 3.11. Incorrect Felling Practice. Source:
https://www.guaduabamboo.com/cultivation/when-and-how-to-harvest-bamboo, Online (Accessed June 2017)
Fig 3.12. Correct Felling Practice. Source:
https://www.guaduabamboo.com/cultivation/when-and-how-to-harvest-bamboo, Online (Accessed June 2017)
Fig 3.13. Post Felling Transpiration. Source:
https://www.guaduabamboo.com/cultivation/when-and-how-to-harvest-bamboo, Online (Accessed June 2017)
Fig 3.14. Boucherie Method using Gravity. Source:
Janssen, A, J, J. 1995. Building with Bamboo - A Handbook. Warwickshire: Intermediate Technology Publications. 10.
Fig 3.15. Extendable Welded Half Cut Oil Barrels of Above Example. Source:

Lengen, V, J. 2008. The Barefoot Architect - A Handbook for Green Buildings. California: Shelter Publications. 338-339.

Fig 3.16. Schematic Septic Tank. Source: http://www.biosystemssa.co.za/urgent/septic%20sewage%20systems/how-a-septic-tank-works, Online (Accessed Nov 2017)

Fig 3.17. Bamboo Fertilisation. Source: http://www.bamboobotanicals.ca/html/bamboo-care/fertilizing-bamboo.html, Online (Accessed Nov 2017)

Fig 4.1. Bamboo Plugin Connections. Source: http://bambus.rwth-aachen.de/eng/reports/connect/bolt/bolt.html, Online (Accessed Nov 2017)

Fig 4.2. Variety of Ends to Suit Different Junctions. Source: http://bambus.rwth-aachen.de/eng/reports/connect/bolt/bolt.html, Online (Accessed Nov 2017)

Fig 4.3. Plugin Connection. Source: http://bambus.rwth-aachen.de/eng/reports/connect/bolt/bolt.html, Online (Accessed Nov 2017)

Fig 4.4. Plugin Connections (Steel Tension Clamp). Source: http://bambus.rwth-aachen.de/eng/reports/connect/bolt/bolt.html, Online (Accessed Nov 2017)

Fig 4.5. Injected Mortar Method used in the Philippines. Source: http://www.architectureindevelopment.org/project.php?id=298, Online (Accessed Nov 2017)

Fig 4.6. Zero Emission Research Initiative Pavilion. Source: http://bambus.rwth-aachen.de/eng/reports/zeri/englisch/ , Online (Accessed Nov 2017)

Fig 4.7 Combined Columns to Concrete Foundation. Source: http://bambus.rwth-aachen.de/eng/reports/zeri/englisch/, Online (Accessed Nov 2017)

Fig 4.8. Detail for Bamboo and Timber Connection. Source: http://bambus.rwth-aachen.de/eng/reports/zeri/englisch/, Online (Accessed Nov 2017)

Fig 4.9. Technical Details from ZERI Pavilion Construction in Germany. Source: http://bambus.rwth-aachen.de/eng/reports/zeri/englisch/, Online (Accessed Nov 2017)

Fig 4.10. Sketch Section and Plan of Pavilion. Source: http://bambus.rwth-aachen.de/eng/reports/zeri/englisch/, Online (Accessed Nov 2017)

Fig 4.11. Arch Detail. Source: http://bambus.rwth-aachen.de/eng/reports/zeri/englisch/, Online (Accessed Nov 2017)

Fig 4.12. Interior. Source: http://bambus.rwth-aachen.de/eng/reports/zeri/englisch/, Online (Accessed Nov 2017)

Fig 4.13. Exterior Corridor. Source: http://bambus.rwth-aachen.de/eng/reports/zeri/englisch/, Online (Accessed Nov 2017)

Fig 4.14. Steel Tubes and Bolt Junctions. Source: http://bambus.rwth-aachen.de/eng/reports/connect/bolt/bolt.html, Online (Accessed Nov 2017)

Fig 4.15. Junction Detail nts. Source: http://bambus.rwth-aachen.de/eng/reports/connect/bolt/bolt.html, Online (Accessed Nov 2017)

Fig 4.16. Bamboo Junction from Renzo Piano Building Workshop. Source: http://bambus.rwth-aachen.de/eng/reports/connect/bolt/bolt.html, Online (Accessed Nov 2017)

Fig 4.17. Bundled Combined Culm Arch. Source: https://www.flickr.com/photos/13523064@N03/5371912960, Online (Accessed Nov 2017)

Fig 4.18. Elevation View. Source: https://eclecticeast.com/2013/10/10/crosswaters-ecolodge-striking-architecture-in-china/, Online (Accessed Nov 2017)

Fig 4.19. Internal View Showing Details for the Connection of Bundle Arch and Suspended Walkway. Source: http://viewthrumygloballens.blogspot.co.za/2010/07/bamboo-bridge.html, Online (Accessed Nov 2017)

Fig 4.20. Support structure of Bridge. Source: https://scentsofkate.wordpress.com/2011/02/07/scents-of-bamboo/, Online (Accessed Nov 2017)

Fig 4.21. Plan. Source: https://www.archdaily.com/877165/bamboo-sports-hall-for-panyaden-international-school-chiangmai-life-construction, Online (Accessed Nov 2017)

Fig 4.22. Concept Development. Source: https://www.archdaily.com/877165/bamboo-sports-hall-for-panyaden-international-school-chiangmai-life-construction/5987b972b22e38643200010a-bamboo-sports-hall-for-panyaden-international-school-chiangmai-life-construction-concept-sketches-01, Online (Accessed Nov 2017)

Fig 4.23. Internal Space. Source: https://www.archdaily.com/877165/bamboo-sports-hall-for-panyaden-international-school-chiangmai-life-construction, Online (Accessed Nov 2017)

Fig 4.24. Exterior View. Source: https://www.archdaily.com/877165/bamboo-sports-hall-for-panyaden-international-school-chiangmai-life-construction, Online (Accessed Nov 2017)

Fig 4.25. Variation of Arches Made by Different Size Bundles. Source: https://www.archdaily.com/877165/bamboo-sports-hall-for-panyaden-international-school-chiangmai-life-construction, Online (Accessed Nov 2017)

Fig 4.26. Stair Detail. Source: https://www.archdaily.com/877165/bamboo-sports-hall-for-panyaden-international-school-chiangmai-life-construction, Online (Accessed Nov 2017)

Fig 4.27. Prefabricated Structure Leverage using Crane. Source: https://www.designboom.com/architecture/asali-bali-engineered-bamboo-structure-bali-02-03-2016/, (Accessed Nov 2017)

Fig 4.28. Engineered Foundation Posts. Source: https://www.designboom.com/architecture/asali-bali-engineered-bamboo-structure-bali-02-03-2016/, Online (Accessed Nov 2017)

Fig 4.29. Leverage Operation using Crane. Source: https://www.designboom.com/architecture/asali-bali-engineered-bamboo-structure-bali-02-03-2016/, Online (Accessed Nov 2017)

Fig 4.30. Junction Detail nts. Source: Author Sketch

Fig 4.31. Warehouse Interior. Source: https://www.designboom.com/architecture/asali-bali-engineered-bamboo-structure-bali-02-03-2016/, Online (Accessed Nov 2017)

Fig 4.32. Junction Detail nts. , Author Sketch

Fig 4.33. Hand Made School. Source: http://www.spatialagency.net/database/how/subversion/sanjeev.shankar, Online (Accessed June 2017)

Fig 4.34. Mud Plastered Wall. Source: http://www.akdn.org/architecture/project/school-rudrapur/, Online (Accessed June 2017)

Fig 4.35. Mud / Rammed Earth Construction. Source: http://www.designaddict.com/blog/2010/02/24/School-handmade-Bangladesh, Online (Accessed June 2017)

Fig 4.36. Bamboo Frame on Top. Source: https://www.archdaily.com/51664/handmade-school-anna-heringer-eike-roswag, Online (Accessed June 2017)

REFERENCES

Book

Bell, B. Wakeford, K. 2008. *Expanding Architecture - Design as Activism*. New York: Bellerophon Publications Inc.

Bruce Mau Design. OWP/P Architects. VS Furniture. 2010. *The Third Teacher - 79 Ways You Can Use Design to Transform Teaching & Learning*. New York: Abrams Publisher.

Buchanan, P. 1997. *Renzo Piano Building Workshop (Book 3)*.London: Phaidon

Bystriakova, N. Kapos, V. Lysenko, I. 2004. *Bamboo biodiversity: Africa, Madagascar, the Americas*. United Kingdom, Cambridge: UNEP-WCMC/INBAR.

Calkins, M. 2009. *Materials for Sustainable Sites - A Complete Guide to the Evaluation, Selection and Use of Sustainable Construction Materials*. Hoboken, New Jersey: John Wiley & Sons, Inc

Deleuze, G. Guattari, F. 1987. *A Thousand Plateaus: Capitalism and Schizophrenia, transl. Massumi, B*. London: University of Minnesota Press.

Dunn, M, G. (ed.). 1989. *Exploring Your World: The Adventure of Geography*. Washington, D.C : National Geographic Society.

Durston, D. 2006. *Wabi Sabi - The Art of Everyday Life*. United State: McNaughton & Gunn, Inc.

Frampton, K. Kudo, K. 1997. *Japanese Building Practice From Ancient Times to the Meiji Period*. New York: Van Nostrand Reinhold.

Frampton, K.1983. *Towards a Critical Regionalism: Six Points for an Architecture of Resistance*. In: Foster, H. ed. The Anti-Aesthetics, Essays on Postmodern Culture. Port Townsend: Bay Press. pp.16-30.

Frampton, K. 1995. *Studies in Tectonic Culture : the Poetics of Construction in Nineteenth and Twentieth Century Architecture*. Cambridge, Mass : MIT Press.

Heidegger, M. 1954. *Poetry, Language, Thought*. Translated from German by A, Hofstadter. 1971. New York: HarperCollins Publishers Inc.

Janssen, J,J,A. 1995. *Building with Bamboo: A Handbook*. Warwickshire. Intermediate Technology Publications.

Jones, L, D. 1998. *Architecture and the Environment.* London: Laurence King Publishing.

Koren, L. 2008. *Wabi Sabi for Artists, Designers, Poets and Philosophers*. Point Reyes: Imperfect Publishing.

Kronenburg, R., Lim, J. and Chii, W. (2003). *Transportable environments 2*. London: Spon Press.

Laugier, A, M. 1753. *Essai sur I'architecture*. A Paris: Chez Duchesne.

Lengen, V, J. 2008. *The Barefoot Architect - A Handbook for Green Buildings*. California: Shelter Publications.

Lepik, A. 2010. *Small Scale, Big Change: New Architectures of Social Engagement*. New York: Museum of Modern Art.

Mann, H,T. Williamson, D. 1973. *Water Treatment and Sanitation: Simple Methods for Rural Areas*. London: Intermediate Technology Publications.

McClure, F, A. 1966. *The Bamboos- A Fresh Perspective*. Cambridge, Massachusetts: Harvard University Press.

McClure, F, A. 1972. *The Use of Bamboo and Reeds in Building Construction*. New York: United Nations Publications.

Minke, G. 2012. *Building With Bamboo: Design and Technology of a Sustainable Architecture*. Basel: Birkhauser, p.132.

Pallasmaa, J. 2005. *The Eye of the Skin - Architecture and the Sense*. West Sussex: John Wiley & Sons Ltd.

Ricoeur, P. 1961. *Universal Civilization and National Cultures - History and Truth*, trans. Kelbley, A, C. Evanston: Northwestern University Press. Pp. 276-7.

Rudofsky, B. 1964. Architecture Without Architects, A Short Introduction to Non-Pedigreed Architecture. New York: Museum of Modern Art

Tierney, L. 1999. Wabi Sabi - *A New Look at Japanese Design*. Layton: Gibbs Smith Publisher.

Tzonis, A. Lefaivre, L. 1981. *The Grid and the Pathway: an Introduction to the Work of Dimitris and Susana Antonakakis - with Prologomena to a History of the Culture of Modern Greek Architecture. Architecture in Greece*, 15:164 -79.

Velez, S. 2000. *Grow Your Own House*. Germany:Vitra Design Museum

Villegas, M. and Arango Restrepo, E. (1990). *Tropical bamboo*. New York: Rizzoli, pp.41-46.

Watt, A,B. 1984. *Septic Tanks and Aqua-privies from Ferrocement*. London: Intermediate Technology Publications.

Wright, L.,F., 1939. *An Organic Architecture of Democracy*. London: Lund Humphries & Co. LTD.

Yoh, S. 1989. *Construction of a geodesic dome of bamboo*. Japan: Keio University

Young, D. Young, M. 2004. *Introduction to Japanese Architecture*. Hong Kong: Periplus Editions Ltd.

Journal

Denan, Z., Awang, A., Mazlan, M., Majid, N., Rahim, Z. and Sanusi, N. (2017). The Implementation of Environmental Education and Green Programs in Schools to Achieve Sustainability. *Advanced Science Letters*, 23(7), 6261-6265.

Eggener, L, K. 2002. *Placing Resistance: A Critique of Critical Regionalism*. Journal of Architectural Education. 55:4. 228-237

Handa, R. 2013. *Sen no Rikyū and the Japanese Way of Tea: Ethics and Aesthetics of the Everyday.* Architecture Program: Faculty Scholarly and Creative Activity. Interiors 4:3 Bloomsbury Publishing. 229-247

Hystad, P. Carpiano, M, R. 2012. *Sense of Community - Belonging and Health - Behaviour Change in Canada*. J Epidemiology & Community Health. 66:3. 277-83

Kleinhenz, V. Midmore, D. 2000. *Estimating Water Usage of Bamboo*. [Online] Department of Natural Resources & Environment and Rural Industries Research & Development Corporation, Access to Asian Vegetables , Issue 28 (1-2). 1-2.

Kumar, S., Shukla, K.S., Dev, I., Dobriyal P.B., 1994. *Bamboo Preservation Techniques: a review*. INBAR Technical Report No. 3. International Network for Bamboo and Rattan, New Delhi, India.219-222 and 226-235.

Rittironk, S. Elnieiri, M., 2007. *Investigating laminated bamboo lumber as an alternate to wood lumber in residential construction in the United States*. Proc., 1st Int. Conf. on Modern Bamboo Structures, Taylor & Francis, Abingdon, U.K., 83-96.

Schwarzer, M. 1993. *Ontology and Representation in Karl Botticher's Theory of Tectonics. Journal of the Society of Architectural Historians*. Vol 52 (3/9). 267-280

Sugest, S., Kardiansyah, T. and Hardiani, H. 2015. *Bamboo as Raw Materials for Dissolving Pulp with Environmental Friendly Technology for Rayon Fiber.* Procedia Chemistry, 17, 194-199.

Tan, T., Xia, T., OFolan, H., Dao, J., Basch, Z., Johanson, K., Novotny, J., Ozeki, M. and Smith, M. (2015). Sustainability in Beauty: An Innovative Proposing-Learning Model to Inspire Renewable Energy Education. *The Journal of Sustainability Education*.

Yeasmin, L. Ali, N. Md. Gantait, S. Chakraborty, S. 2015. *Bamboo: An Overview on its Genetic Diversity and Characterization*. 3 Biotech. 5(1), 1-11. doi:10.1007/s13205-014-0201-5

News Paper

Musau, Z. 2016. *African states must lay roots for bamboo boom*. Sunday Tribune, Business Report, 12 June, p.3

World Wide Web

Anthony, W, Ronald. Lebow, S. 2012. Guide for Use of Wood Preservatives in Historic Structures. [ONLINE]. Available from: https://www.fpl.fs.fed.us/documnts/fplgtr/fpl_gtr217.pdf. [Accessed: 23rd November 2017]

Agbor, J. 2012. *Poverty, Inequality and Africa's Education Crisis*. [ONLINE]. Available from: https://www.brookings.edu/opinions/poverty-inequality-and-africas-education-crisis/. [Accessed: 4th June 2017]

Agyei, Y. 1998. *Deforestation in Sub-Saharan Africa*. [ONLINE]. Available from: http://web.mit.edu/africantech/www/articles/Deforestation.htm. [Accessed: 20th November 2017]

Alam, K, M. 2016. *Bambusa Balcooa (PROCEA)*. [ONLINE] Available from: http://uses.plantnet-project.org/en/Bambusa_balcooa_(PROSEA). [Accessed: 27th June 2017]

Bamboo Botanicals. 2017. *Bamboo Anatomy and Growth Habits*. [ONLINE] Available from: http://www.bamboobotanicals.ca/html/about-bamboo/bamboo-growth-habits.html. [Accessed: 27th June 2017]

Bamboo Botanicals. 2017. *Fertilizing Bamboo*. [ONLINE] Available from:

http://www.bamboobotanicals.ca/html/bamboo-care/fertilizing-bamboo.html. [Accessed: 5th November 2017]

Bean, C. Russo, J, M. 2014. *Eucalyptus Globulus*. [ONLINE] Available from: http://wiki.bugwood.org/Eucalyptus_globulus. [Accessed: 27th June 2017]

Bellavista, F. 2017. *Moon Management.* [ONLINE] Available from: http://www.fincabellavista.com/moon-management/. [Accessed: 29th June 2017]

Berg, D, V, S. Spaull, N. 2017. *SA Education: The Poorest Choice*. [ONLINE]. Available from: https://mg.co.za/article/2011-04-08-sa-education-the-poorest-choice/. [Accessed: 4th June 2017]

Beyazh, M. 2015. *Six Points for an Architectural Resistance*. [ONLINE] Available from: https://mbeyazli.wordpress.com/2015/05/29/six-points-for-an-architectural-resistance/. [Accessed: 24th September 2017]

Bio-Systems SA. 2017. *How a Septic Tank Works.* [ONLINE] Available from: http://www.biosystemssa.co.za/urgent/septic%20sewage%20systems/how-a-septic-tank-works. [Accessed: 5th November 2017]

Department of Higher Education and Training. 2014. *National Policy on Community Colleges*. [ONLINE]. Available from: http://www.dhet.gov.za/Adult%20Education%20and%20Training%20Programmes/Call%20for%20Public%20Comments-%20Draft%20National%20Policy%20on%20Community%20Colleges.pdf.
[Accessed: 4th June 2017]

Dimick, D. 2014. *As World's Population Booms, Will Its Resources Be Enough for Us?* [ONLINE]. Available from: https://news.nationalgeographic.com/news/2014/09/140920-population-11billion-demographics-anthropocene/. [Accessed: 20th November 2017]

Dube Trade Port, 2014. *THE BEEMA BAMBOO TO ENERGYPROJECT.* [ONLINE] Available from: https://www.iea.org/media/technologyplatform/workshops/southafricabioenergy2014/THEBAMBOOTOENERGYPROJECT_Summary.pdf. [Accessed: 19th June 2016]

Elman, K. 1994. *Frank Lloyd Wright and the Principles of Organic Architecture*. [ONLINE]. Available from: http://www.pbs.org/flw/legacy/essay1.html#top. [Accessed: 6th March 2017]

Erasmus, D. 2017. *Eighty - Seven Litres of Water or Less Per Day*. [ONLINE] Available from: https://www.farmersweekly.co.za/opinion/blog/letter-from-the-editor/eighty-seven-litres-of-water-or-less-per-day/. [Accessed: 5th November 2017]

Friederich, H. 2014. *Bamboo for Land Restoration*. [ONLINE] Available from: https://hansfriederich.wordpress.com/2014/05/31/bamboo-for-land-restoration/. [Accessed: 26th June 2017]

Friederich, H. 2017. *Can Bamboo Help Africa Shift to a Green Economy.* [ONLINE]. Available from: http://www.landscapes.org/can-bamboo-help-africa-shift-to-a-green-economy/. [Accessed: 31st May 2017]

Greeff, L. 2010. *South Africa, Thirsty Alien Trees in a Water Scarce Country*. [ONLINE] Available from: http://wrm.org.uy/oldsite/bulletin/153/South_Africa.html. [Accessed: 27th June 2017]

Green Village. 2017. *Tours.* [ONLINE] Available from: http://greenvillagebali.com/visit/. [Accessed: 8th November 2017]

Humanitarian Bamboo. 2009. *The Right Time to Harvest.* [ONLINE] Available from: http://www.bamboocraft.net/forums/showthread.php?t=3582. [Accessed: 29th June 2017]

IBUKU. 2015. *Green Village*. [ONLINE] Available from: http://arqa.com/en/architecture/green-village.html. [Accessed: 27th June 2017]

INBAR(International Network for Bamboo & Ratten), 2016. *New Bamboo Charcoal Technologies Promise to Jump-start Africa's Bioenergy Sector, Slow Deforestation and Fight Climate Change*. [ONLINE] Available from: http://www.inbar.int/2011/12/new-bamboo-charcoal-technologies-promise-to-jump-start-africas-bioenergy-sector-slow-deforestation-and-fight-climate-change.[Accessed: 19thJune 2016]

International Fund for Agricultural Development. 2017. *Rural Water, Sanitation, and Hygiene*. [ONLINE]. Available from:https://www.ifad.org/topic/innowat/tags/water/2100102#1. [Accessed: 20th Nov 2017]

International Tree Foundation, 2012. *Burning Bamboo.* [ONLINE] Available from: http://internationaltreefoundation.org/articles/burning-bamboo/. [Accessed: 19th June 2016]

Jaquith, N. 2016. *Flowering Bamboo Presents an Opportunity*. [ONLINE] Available from: http://www.bamboogarden.com/when%20bamboo%20flowers.htm. [Accessed: 28th June 2017]

JoJo Tanks. 2017. *Septic Tanks*. [ONLINE] Available from: https://www.jojotanks.co.za/product/storage-tanks/sanitation-storage-tanks/septic-tanks. [Accessed: 5th November 2017]

Kennedy, F,J. 2002. *An Overview of Natural Building Techniques*. [ONLINE]. Available from: http://www.networkearth.org/naturalbuilding/overview.html. [Accessed: 24th April 2017]

Laidler, K. 2003. *The Bear's necessity: Bamboo 'corridors' could save pandas and the planet*. [ONLINE] Available from: https://www.theguardian.com/environment/2003/mar/20/research.science. [Accessed: 23rd June 2017]

Lester, S. 1999. *An Introduction to Phenomenological Research*. [ONLINE]. Available from: https://www.rgs.org/NR/rdonlyres/F50603E0-41AF-4B15-9C84-BA7E4DE8CB4F/0/Seaweedphenomenologyresearch.pdf. [Accessed: 15th May 2017]

Lewis Bamboo. 2017. *How does Bamboo Grow*? [ONLINE] Available from: https://lewisbamboo.com/how-bamboo-grows/. [Accessed: 27th June 2017]

Little, D. 2003. *Institutions, Inequality and Well-being Distributive Determinants of Capabilities Realization*. [ONLINE]. Available from: http://www-personal.umd.umich.edu/~delittle/RURDEV%20v3.htm. [Accessed: 15th June 2017]

Lynn, C. 2016. *Bamboo Evolution and Classification: Recent Advances.* [ONLINE] Available from: http://www.worl
SA History, 2015. *KwaDukuza Timeline*. [ONLINE] Available from http://www.sahistory.org.za/places/kwadukuza-timeline. [Accessed: 1st March 2017]

Mambrol, N. 2017. *The Philosophical Concept of Rhizome*. [ONLINE] Available from: https://literariness.wordpress.com/2017/04/26/the-philosophical-concept-of-rhizome/. [Accessed: 26th September 2017]

Olivier, B, 2015. *What is Rhizome in Deleuze and Guattari's Thinking?* [ONLINE] Available from: http://thoughtleader.co.za/bertolivier/2015/06/15/what-is-a-rhizome-in-deleuze-and-guattaris-thinking/. [Accessed: 26th September 2017]

Rosenberg, E. 2007. *Land Degradation*. [ONLINE]. Available from: http://www.enviropaedia.com/topic/default.php?topic_id=147. [Accessed: 30th May 2017]

Rosenberg, T. 2012. *In Africa's Vanishing Forests, the Benefits of Bamboo*. [ONLINE] Available from: https://opinionator.blogs.nytimes.com/2012/03/13/in-africas-vanishing-forests-the-benefits-of-bamboo/. [Accessed: 27th June 2017]

Sreekanth, P. 2017. *Modern bamboo architecture*. [ONLINE] The Archi Blog. Available from: https://thearchiblog.wordpress.com/2011/09/25/modern-bamboo-architecture/. [Accessed: 19th July 2017]

Scheer, J. 2001. *Preservation of Bamboo*. [ONLINE] Available from: http://www.greenhomebuilding.com/QandA/bamboo/preservation.htm. [Accessed: 23rd June 2017]

Schneidereit, S. 2000. *Bamboo as a Building Material*. [ONLINE] Available from: http://bambus.rwth-aachen.de/eng/reports/buildingmaterial/buildingmaterial.html. [Accessed: 23rd June 2017]

Schroder, S. 2009. *Bamboo Joints and Joinery Techniques*. [ONLINE] Available from:https://www.guaduabamboo.com/working-with-bamboo/joining-bamboo. [Accessed: 20th November 2017]

Schroder, S. 2011. *Bambusa Balcooa*. [ONLINE] Available from: https://www.guaduabamboo.com/species/bambusa-balcooa. [Accessed: 27th June 2017]

Schroder, S. 2011. *Bamboo Stem Anatomy*. [ONLINE] Available from: https://www.guaduabamboo.com/identification/bamboo-stem-anatomy. [Accessed: 27th June 2017]

Schroder, S. 2012. *When and How to Harvest Bamboo*. [ONLINE] Available from: https://www.guaduabamboo.com/cultivation/when-and-how-to-harvest-bamboo. [Accessed: 27th June 2017]

South African Institute of Race Relations. 2013. *South Africa goes with the urbanisation flow*. [ONLINE]. Available from: http://irr.org.za/reports-and-publications/media-releases/Urbanisation%20-%2022_Jan_2013.pdf/ [Accessed: 4th June 2017]

Stevens, P. 2014. *vo trong nghia architects stacks house for trees in vietnam*. [ONLINE] designboom | architecture & design magazine. Available from: https://www.designboom.com/architecture/vo-trong-nghia-architects-house-for-trees-vietnam-06-19-2014/. [Accessed: 23rd May 2017]

Steyn, P. 2012. *Developments, Challenges and Opportunities in Africa*. [ONLINE]. Available from: http://www.werksmans.com/legal-briefs-view/developments-challenges-and-opportunities-in-africa/. [Accessed: 4th June 2017]

Sudjic, D. 2006. Modernism: *The Idea Just Won't Go Away*. [ONLINE] Available from: https://www.theguardian.com/artanddesign/2006/jan/29/architecture.modernism. [Accessed: 24th September 2017]

The Environmental Literacy Council. 2015. *Renewable Energy*. [ONLINE] Available from: http://enviroliteracy.org/energy/renewable-energy/. [Accessed: 12th May 2016]

United Nations Environmental Program, 2009. *Buildings and Climate Change- Summery for Descision Makers*. [ONLINE] Available from: http://www.unep.org/sbci/pdfs/SBCI-BCCSummary.pdf. [Accessed: 11th November 2016]

Zimmermann, A, K. 2015. *What is Culture? Definition of Culture.* [ONLINE]. Available from: https://www.livescience.com/21478-what-is-culture-definition-of-culture.html. [Accessed: 13th June 2017]

Zyl, v, J. 2013. *Buy Bamboo South Africa*. [ONLINE] Available from: http://sabamboofarmer.blogspot.co.za/. [Accessed: 27th June 2017]

Dissertation

Richard, J, M. 2013. *Assessing the Performance of Bamboo Structural Components.* Ph. D. The University of Pittsburgh.

Interview

Dunbar, G. (2017). *Brightfields Natural Trading Company - Cape Town*.

Hassan, V. (2017). *Fumba Town Development Bamboo Nursery - Zanzibar*.

Mauly, A. (2017). *Fumba Town Development Laminated Bamboo Lumber Factory - Zanzibar*.

APPENDICES

Appendix A

Brightfields Natural Trading Company Interview with Graham Dunbar

Q1. What species of bamboo are suitable for construction? And are these species available in South Africa?

Q2. Where does the bamboo for construction in South Africa come from?

Q3. What would be the life expectancy of bamboo structures?

Q4. How could the life expectancy of bamboo be improved by its design detail?

Q5. How could insulation be achieved, fire, wind and water proofing in a bamboo construction?

Q6. Are there any specific issues that can occur when dealing with bamboo as a construction material - e.g. susceptibility to insects?

Q7. How does bamboo construction compare to that of using more common materials and methods available in South Africa?

Q8. What types of structures is bamboo currently being used for, and is there an aim to construct a larger variety of structures from bamboo in future?

Q9. Could bamboo be used for all components of a building?

Q10. Are there any issues regarding approval of use of bamboo as a construction material, as opposed to other types of timber or materials?

Q.11 In your experience, what is the best method to combine the separate bamboo poles e.g. bolts, ropes?

Q12. Could you estimate how many vertical storeys one could support in a structure made out of with raw bamboo poles?

Q13. What do you think are the kind of technologies that would need to be developed to allow for multi storey structures made of bamboo?

Q14. What do you think is necessary to support and accelerate the adoption of bamboo as an alternative resource for space and craft making for South Africa?

Appendix B

Fumba Town Bamboo Nursery Telephonic Interview with Vuai Mkoko Hassan

Q 1. What are the necessary steps required to set up a bamboo nursery?

Q 2. What is the vision and purpose of the bamboo nursery?

Q 3. What are the steps to grow and cultivate bamboo?

Q 4. How often does it need to be watered for it to grow?

Q 5. Does bamboo need additional fertilisers to grow?

Q 6. Does growing bamboo require a special indoor facility?

Appendix C

Fumba Town Development Laminated Bamboo Lumber (LBL) Factory Telephonic Interview with Akif el Mauly

Q 1. What is the process of creating a LBL?

Q 2. What kind of equipments are used?

Q 3. How is the production line setup?

Q 4. How much bamboo is needed to create one LBL?

Q 5. How long does it take to create one LBL?

Q 6. What products can be made from LBL?

Q 7. How does the climate conditions in Tanzania affect the process of making LBL?

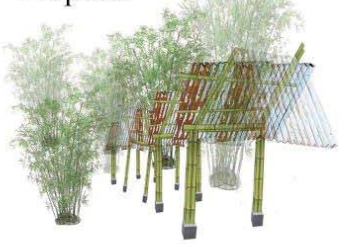
Appendix D

Presentation

Problem Statement

Communities, in the rural context, often have limited access to ready made construction materials which makes it hard for them to build facilities without aid of external organisations and finances.

Proposal



Expanding modulated building with the annual harvest of bamboo

Aim

The aim of this research is to explore the construction and related didactic potential of bamboo as an alternative renewable building material in KwaZulu-Natal Province, South Africa.

Objectives

1. To understand the biological properties of bamboo and the treatment processes necessary to use it as a construction material.
2. To explore bamboo construction techniques from indigenous to modern construction examples from around the world.
3. To contextualise the information gathered by developing construction techniques and principles that are site specific to suit South African conditions.

Benefits

Accessible Housing

Waste Water Treatment

Socio Economic Empowerment

Energy Generation

Reforestation

Exploring the Potential of Bamboo as a Didactic Alternative Construction Material

"Living School" for the Community of Tongova Mews, Tongaat

Kanji Yoshimura 208512966
16 January 2018

PART TWO

DESIGN REPORT

TABLE OF CONTENTS

CHAPTER ONE | "LIVING SCHOOL" FOR THE COMMUNITY OF TONGOVA MEWS, TONGAAT

1.1. Introduction

PART ONE of this research document focused on the bamboo plant, the processes required for it to become a construction material and its application. The concept of a 'living school' is derived from the characteristics of the bamboo plant and related preparation processes, and represents a vision to assist rural communities who have limited resources with which to construct their living spaces. PART TWO of this research further expanded on this concept by analysing the possible history of bamboo in Kwa-Zulu Natal Province, and Durban in particular, with respect to its origin, availability and the possibility of using it to create a 'living school' that could potentially have a substantial positive impact in the future. The justification of selecting Tongaat as the site for the 'living school' development is discussed, and descriptions provided of the client organisations that are currently operating in the area that will provide resources and contribute to the development. Following the project brief, this chapter expands on the programme of the 'living school' development and the master plan, which will consider the various phases required for its construction. The details will be discussed under the schedule of accommodation, and the design of the 'living school' development for the community of Tongova Mews will be summarised.

The project includes various skills development facilities for the bamboo trade to create a new industry within the area using a local renewable resource and thereby eliminate the need for long-distance transport.

1.2. History of Tongaat and Bamboo

The town of Tongaat has a strong relationship with bamboo that originates from the history and the development of the sugar industry in 1800s (Richardson, 1982). This has influenced the unique bamboo resource seen in the nearby city of Durban, and which this research has tried to incorporate into the design. The development of the 'living school' in Tongaat is intended to trigger a chain reaction, wherein the spread of didactic bamboo technology, which creates a unique tactile culture in the form of a handmade community, continues throughout the rest of the local area. In relation to the annual rainfall of South Africa, Figure 1.1 shows bamboo growable regions in South Africa. Fig 1.2 shows the site in Tongaat and its relation to Durban.

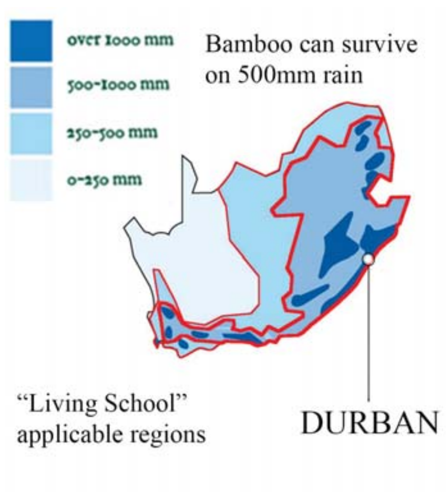


Fig 1.1. Bamboo Growable Region in South Africa

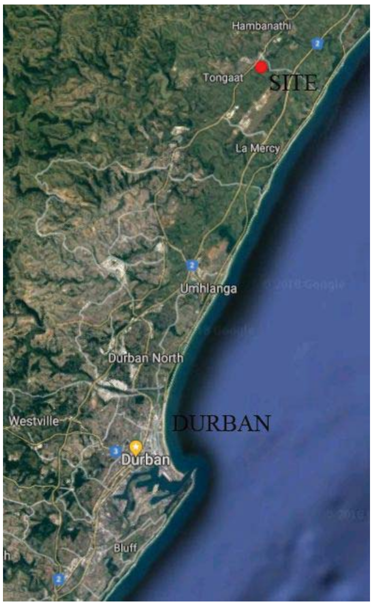


Fig 1.2. Tongaat and Durban

Indian migrant labourers were brought from India to South Africa in 1860 by the British as an organised system of cheap indenture labour to work on the sugarcane plantations that were being developed along the Natal coastline (Moodley, 1981). (Figure 1.3) In return for their passage, the labourers worked for five years, after which they had to select one of three options: 1) renew their contract and continue to work as labourers for rations, 2) immigrate and get paid wages that would not be sufficient to cover their accommodation, taxes or living expenses, or 3) return to India (Badassy, 2002). Additionally, the reluctance and resistance of black African labourers to work as sugarcane field workers catapulted the need for indentured labourers and thus this systematic operation worked successfully for the British colony of Natal.

Many indentured labourers chose to stay in the port city of Durban and later moved throughout the province, their way of living has been compromised but still practice their culture and religions (Vahed and Waetjin, 2013). Jhandi prayer flags (Figure 1.4) hang on bamboo poles in front of homesteads as a practice of their belief in the residential areas of Tongaat. Hall (2011) argues that plants often hold a sacred significance in Hinduism through a strong relationship with a deity or divine being, and gives an example of bamboo, being used by the Hindu god Lord Krishna for his flute (Hall, 2011).

Fig 1.3. Indian Indentured Labourers

Fig 1.4. Jhandi Prayer Flags using Bamboo Poles

Due to its significance in the Hindu religion, bamboo plants were intentionally transplanted to various locations within Durban. Tongaat is located about 37 km from Durban, being one of the oldest Indian communities due to the development of the sugar industry (Koen, 2015). Figures 1.5. and 1.6. are of the daily market located in the heart of Tongaat, which depicts the cultural history and character of a farming community. The gable end of the building depicts a farming scene from the 1860s, with a male figure (wearing a turban) harvesting sugarcane, these clothes being typically of that worn by Indians during this era (Badassy, 2002).

Fig 1.5. Tongaat Daily Market

Fig 1.6. Tongaat Daily Market Gable Showing History of the Sugar Industry

1.3. Site Selection and Analysis

Tongaat was chosen as a potential site for the 'living school' for its available and abundant source of bamboo that is currently not being utilised (other than religious purposes). It can therefore be cultivated as a construction material and grown for use by the rural communities around the area. The specific site is located at the southern side of Tongaat, as indicated in Figure 1.7, being located along the M43 Watson highway, which is the main access route from the N3 highway that connect Durban with the northern part of the province. Tongaat has a growing industrial centre and is surrounded by sugar cane fields, owned by the Tongaat Hulett, which has been involved in the industry since 1892 (Tongaat Hulett, 2016). 90% of the population of Tongaat are Indian (42 555), some of trading businesses are based on communal living which has been passed on through generations (Shaikh, 2014).

With the construction of King Shaka International Airport (2010) and the adjacent Dube Tradeport, which is an industrial area nearby, and the development of Mount Moreland, there is a need for housing in the area for the growing workforce (Mount Moreland Inkonjane, 2013). The intention of locating the ‘living school’ at Tongaat is that there is an established resource of suitable bamboo for the growing construction market in an era of environmental awareness and concerns about the sustainability of human habitation practices.

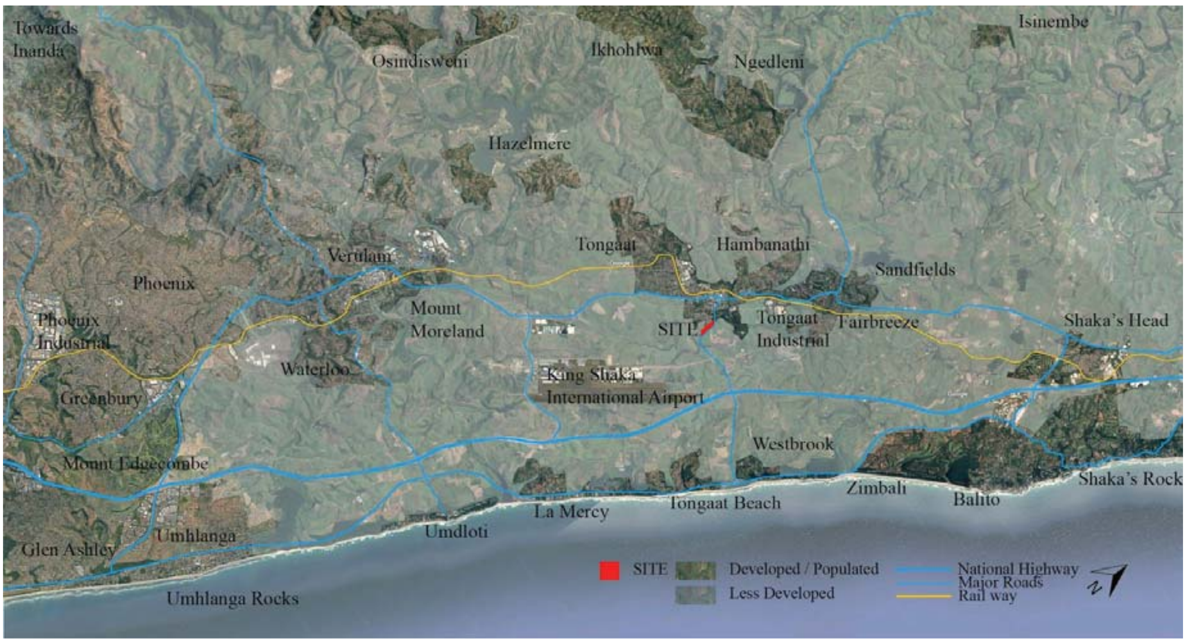


Fig 1.7. Greater Site Context

By virtue of their requirement to sustainable practice, 'living school' housing schemes are required to have independent black water treatment systems that grow bamboo, which will spread as more resources become available for them to feed off, thereby increasing its availability. Planning towns and suburbs therefore needs to accommodate the land available for bamboo to spread to treat the black water as more people make use of this system. Water courses need to be utilised to channel the water into the soil in order to grow bamboo. Examples such as floodplains can be considered for growing bamboo, as they are unsafe locations for human habitation.

1.4. Client Organisations

Tongaat area have been identified as possible ‘living school’ locations due to the presence of suitable bamboo and land suitable for habitable development, these being owned by Tongaat Hulett, the eThekweni Municipality and the Dube Tradeport Corporation. The existing bamboo resources in the area are located within the properties owned by three enterprises.

Tongaat Hulett (Fig 1.18)

Tongaat Hulett is an agriculture and agri-processing business, their focus is on sugarcane and maize, and have a considerable land portfolio within KwaZulu-Natal Province (KZN), having been established in 1860 (Tongaat Hulett, 2016). The existing natural bamboo resource in Tongaat are largely located on the land owned by Tongaat Hulett. They are actively involved in many development projects that they may show interest in allowing the scheme to access this existing resource. Furthermore, due to the newly developed Dube international airport, there is a need for development of housing solutions on these land for the growing population.

Ethekwini Municipality (Fig 1.19)

The selected site is divided by Hlawe river, with half the land being owned by Tongaat Hulett and other by the eThekweni Municipality. The municipality has the potential to extend the boundaries of this scheme, as the 'living school' addresses water and sanitation issues, low cost housing needs, socio-economic empowerment and reforestation using the bamboo plant. The ‘living school’ principals are suited for municipality’s social development programs and will be able to provide practical solutions throughout rural communities in South Africa (eThekwini Municipality, 2016).

Dube Tradeport Corporation (Fig 1.10)

A business entity of the KZN Provincial Government, the Dube Tradeport Corporation runs a 3 000 ha infrastructure project called the Dube Tradeport Special Economic Zone, which was established to promote local and international trade, and is located at the King Shaka International Airport (Dube Tradeport, 2017). There is a natural bamboo resource area located at the site of the proposed landing strip of the Dube Tradeport 60 years master plan (Dube Tradeport, 2017). There is a need to investigate its use and inform the project of this stabilised natural resource that can be used to make products from a renewable resource that could be used locally and exported abroad.

Fig 1.8. Tongaat Hulett

Fig 1.9. eThekwini Municipality

Fig 1.10. Dube Tradeport

1.5. Brief

The aim or intention of the 'living school' is to create a local industry in Tongaat that uses the area’s bamboo resources as construction material and would ultimately support the implementation of the 'living school' concept towards other rural areas/settings within South Africa. This is a pilot project to test the bamboo structures in preparation and anticipation of applying for a building code for the material. Shipping containers will be used for safekeeping of the sponsored tools and materials, and as the resources grow, the project will sell bamboo products to acquire further funds in order to acquire additional equipment and materials necessary: tools, preservative, steel, cement, septic tanks.

Once construction begins on the identified site, a clear distinction of spaces will be necessary to prevent the loss of tools and resources:

- The general public will have open access to the distribution and entertainment facility,
- Identified persons who are interested in the bamboo industry will have access to the trial workshop spaces,
- Crafters and related professionals, and will have access to the private lockable spaces.

The above spaces would become a hub for innovation, and use of the bamboo resource, and associated technology and processes required to make these spaces, this is part of the skills development course that will lead to the emergence of bamboo construction specialists after the completion of the 'living school' for Tongaat. These specialists in turn will be able to demonstrate and instruct other rural community members to create their own 'living school' projects. Each specialist would be responsible for the five year initiation period of setting up the initial ablution facility, planting new plants and developing the bamboo treatment facility, there after the communities are able to construct spaces for themselves. This process would be repeated, providing foundational initiatives for different rural communities to gain access to bamboo resources, as well as the knowledge about how to use them. Skills development and training to use bamboo as a didactic alternative construction is one of the main objectives of the 'living school'.

1.6. Master Plan

There are approximately 50 bamboo plants on site and more are available upstream towards the King Shaka Airport, since there are already available bamboo resource and municipal sewer system installed in the area, this particular ‘living school’ is able to start the harvesting, treating and curing the bamboo for construction without growing the plants. Its development will occur in six phases, with the initial phase establishing a nursery (to propagate the bamboo for distribution and increase its resources), bamboo treatment and craft facility. Figure 1.11. is a 1:2 000 context model that represents the proposed 'living school' for the community of Tongova Mews in Tongaat, existing infrastructure and resources are indicated, as well as the sites for each of the six phases indicated below:

- Phase 1. Establishment of the bamboo nursery, treatment, curing and craft facility.
- Phase 2. Distribution and entertainment facility.
- Phase 3. Community hall and recycling center.
- Phase 4. Bamboo lamination factory.
- Phase 5. Treatment and curing facility to cater greater resources upstream.

- Phase 6. Example of the new housing scheme from the 'living school' development, progressive in a way that the occupants using the above infrastructures could live and work.

Fig 1.11. Context Model of Implementation Phases

White objects represent the current built environment, brown objects represent the newly built from bamboo; red markings depicts the existing bamboo resources on site (50 bamboo plants making approximately 120 sqm of floor coverage per year). The above phases follow the order of the development of the 'living school', rough estimation of 5 years is given for phase 1 since there are no infrastructure to mass treat the culms. As the plants mature in the process of phase 1 (Nursery) the process would speed up, with a successful plantation of 400 bamboo plants occupying 1 hectare land space (these are total sum of 22 households using the septic tank system), 960 sqm of additional floor coverage would be produced annually.

Figure 1.12 is the master plan of the site with the locations of the activities at each of the six phases being indicated, with Figure 1.13 showing site photos associated with some of the features. Red highlighted zone in Figure 1.12 is mainly on Tongaat Huletts land, with the area being divided by the Hlawe River, and total land area, inclusive of existing bamboo forest, measure approximately 28 500 sqm.

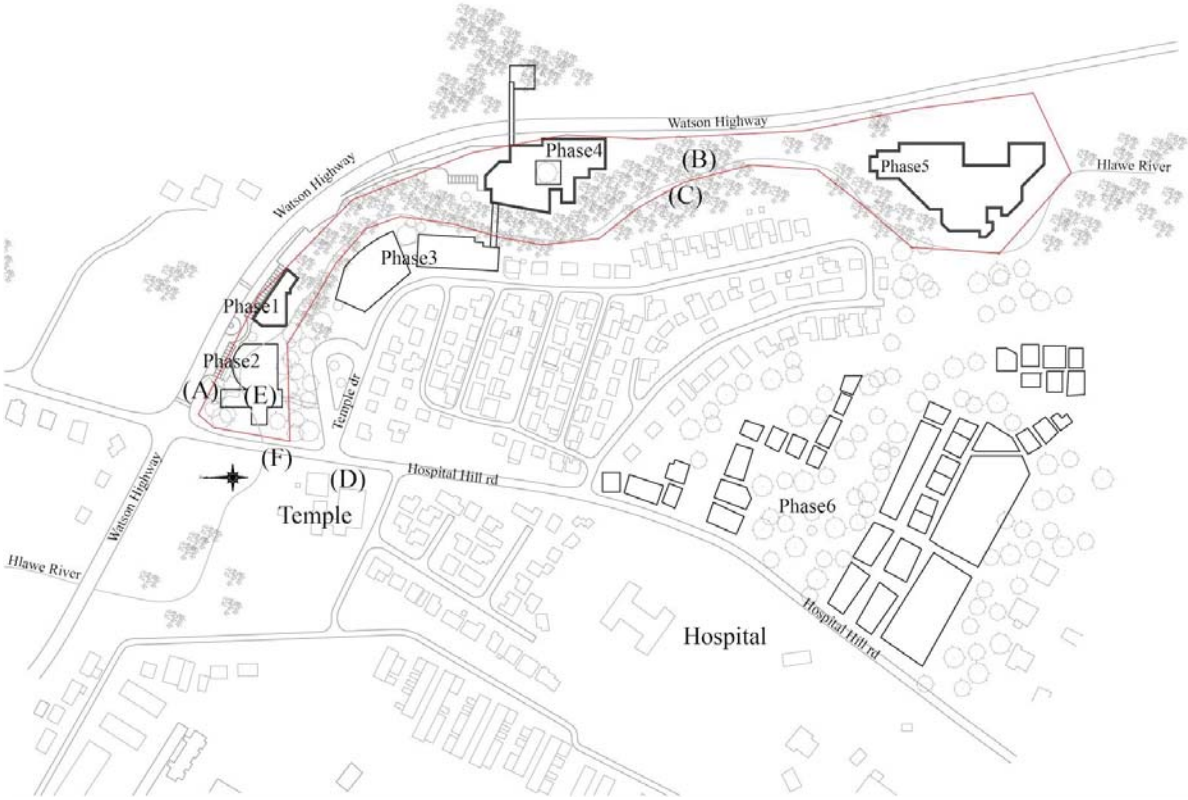


Fig 1.12. Master plan of Construction Phases nts

(A) Welcome Board

(B) Existing Bamboo Grove

(C) Scale of Bamboo

(D) Temple

(E) Footbridge

(F) Bridge Over Hlawe River

Fig 1.13. Series of Site Photos

1.7. Schedule of Accommodation, Phase 1 and 2

Phase 1 and 2 of the development are designed to demonstrate visually the process and application of the bamboo nursery, treatment, curing, craft and distribution which is necessary for every 'living school' proposal. The design details are applicable to the rest of the development and it is intended for these details to improve as skills and new technologies develop, these particular facilities would be designed to suit this site. Their scale would be determined by the amount of bamboo plants available.

Phase 1: Nursery, Treatment, Curing and Craft Facility

River Level		
Spaces	**Description**	**sqm**
Machine Room / Tools Storage (20 inch Container)	Mechanical pumps are used to pump river water into a filtration system for various applications, including the Boucherie gravity diffusion of preservative solutions into fresh cut bamboo culms. Hand operated tools for harvesting and adjusting bamboo culms are kept in a lockable container, shelves to be made from harvested bamboo.	14
Furnace (Vertical 40 inch Container)	Three layers of fireproof bricks would be laid within the vertically placed container concealing the fire that would be generated during the production of bamboo charcoal (use of bamboo species not durable for construction, harvested from the region), hot shower being a byproduct of this heat. This vertical container is supported by the horizontal containers with all corners bolted.	2.6
Storage of Burnable Bamboo Offcuts (20 inch Container)	During harvesting / crafting process of bamboo, considerable amount of burnable biomass is generated. These are to be stored and when the chamber for the bamboo charcoal is full, they are to be burnt to carbonise bamboo (packed in oil barrels).	14
Boucherie Gravity Feed Yard	Exterior yard, near river edge is utilised to apply preservative chemicals to fresh cut bamboo culms, these chemicals are collected after treatment which is to be reused. This method requires the bamboo to be freshly cut (must be treated the day of harvest) for the fibers to permeate the treatment chemicals to replace the original sap (average two hours per culm). The harvested culms may be submerged in the river during the waiting period of the process.	

Bamboo Culm Storage	50 plants will produce (single plant, 3 - 4 culms of average 22m) 150 - 200 culms, cut in thirds for storage = 900 - 1200 culms. Diameter of culm max 150mm, area = 0.07sqm x 1200 culms = using max 84 sqm to store 1200 culms. Horizontal and vertical storage methods are used for various size diameter of the treated culms, these are to be organised according to their size.	88
Bamboo Culm Access Platform	First raised platform to be built which can access the horizontally stored culms. The horizontally stored culms require rotation once a week to cure in a straight profile. The bamboo culms are cut and split here to be used in other extended spaces.	65
Craft Room	Extension of above, a covered space, which is connected by a staircase which will eventually join all the levels.	75
Bamboo Nursery	The rhizomes are propagated along the river edge and packed in rice bags for distribution.	58
Security / Information	As the development grow and there are visitors with cars this would be a necessary installment, but as a start all the tools and resources are secured in lockable containers so this would be the last development in phase 1.	12
	Total	**328.6**

Elevated Floor Levels		
Spaces	**Description**	**sqm**
Ablution / Shower	Increase in number as development grows	70
Kiosk	Daily amenities and lunch.	17
Stock Management Office (40 inch Container)	Managing of stock and initial public assistance. This office will make necessary raw supply orders for the development of this scheme, staff will also register their daily attendance.	16
Bamboo Charcoal Chamber with Access Deck	Six oil barrel are to be filled with bamboo and a fire would be made from offcuts during production. These charcoals may be sold and used in phase 2 for the preparation of foods (pizza oven).	8
Temporary Storage	Delivered raw materials to be registered on the system and stored in **Raw Material Storage**.	11
Raw Material Storage (40 inch Container)	Cement, steel products, preservative chemicals, lamination glue, corrugated sheeting and glass are organised in their categories, shelves to be made from harvested bamboo.	29

Split and Cut Bamboo Processing Floor	Adjusted bamboo culms are further processed to become building components. Hand operated vice for laminated bamboo lumber is used for creation of straight edged components, doors and windows. Wall panel frames are crafted, large scale furniture and big surface weaving is done in this space.	150
Temporary Completed Product Storage	Crafted products are tested of their quality and durability before their application or distribution. All the elevated level productions are gathered in this space before they are dispatched to phase 2.	80
Craft Space First Floor	Small scale furniture production and medium scale weaving.	100
Craft Space Second Floor	Small scale product production.	80
Circulation	Stairs, ramps and corridors	100
	Total	**581**

Phase 1 Total Floor Area	**909.6**

Phase 2: Distribution and Entertainment

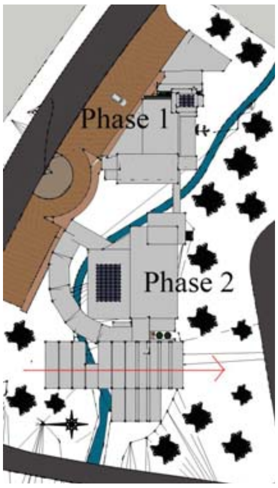
Elevated Floor Level		
Spaces	**Description**	**sqm**
Private Office	Head of distribution.	12
Retail Distribution Office	Management and distribution of completed products from phase 1.	40
Meeting Room and Storage	Discussion space for clients and project members.	64
Ablution and Storage	Disabled, male, female ablution and cleaning storage.	30
Restaurant / Bar	Upper level entertainment.	180
Circulation	Stairs, ramps and corridors	120
	Total	**446**

River Level		
Spaces	**Description**	**sqm**
Completed Product Storage	Storage of completed products from phase 1. One 40 inch container and two 20 inch containers are used to store the products.	55
Open Show Room Space	Display of completed products (mainly furniture) to be used and stored daily from the storage spaces, standard products may be fixed onto the structure to eliminate need of storing. This space is also used to do experience workshops for small scale bamboo crafts.	350
Coffee Shop	Small scale items are displayed together with	64
Ablution and Storage	Disabled, male, female ablution and cleaning storage.	30
Lockable Craft / Retail Space	Sales and production of small scale bamboo crafts and related arts.	63
Food Court	Entertainment public space of river level.	200
Food Stalls and Kiosks	Supply of food and beverage for river level entertainment.	111
Circulation	Stairs, ramps and corridors	240
	Total	**1113**

Phase 2 Total Floor Area	**1559**

1.8. ‘Living’ Process

This section is referring to the nature of this scheme which depicts a growing modulated building together with the annual harvest of bamboo. The most important infrastructure would be the treatment tower which will allow for a systematic application of preservatives to raw bamboo culms. Within phase 1 of the development there are order of development necessary to utilise this existing naturalised resource to its maximum potential, phase 2 host the distribution of the created products (Figure 1.15) and entertainment facilities for visitors. Figure 1.14 shows phase 1 and 2, red arrow is an elevated platform over the existing footbridge seen in E of the site photos in Figure 1.13, bamboo seedlings to be planted amongst natural vegetation considering their orientation and spacing (the clumping bamboo species are able to co-exist with indigenous plants), in place of other deep rooted water thirsty alien species- let the rhizomes spread.



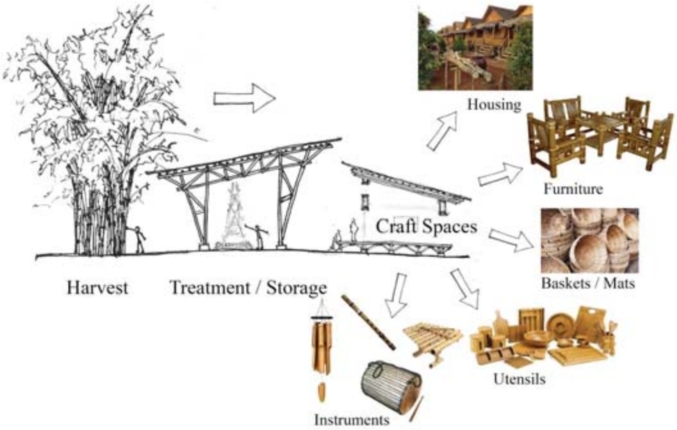


Fig 1.14. Phase 1 and 2 Roof Plan nts

Fig 1.15. Living School Process

Phase 1: Initial Development

40 and 20 inch containers are utilised to ensure the safe storage of tools and chemicals, inner container level to be elevated by 20 inch container on the lower back with cast concrete footings to the front (Fig 1.16). Retaining wall to be made with paving and parking to be progressively built according of the phase of development. Method chosen for the treatment of bamboo culms is a gravity fed boucherie method (Fig 1.17) which allows mass treating of culms, 2 hours of application to feed chemicals to a freshly cut bamboo during harvesting season (the culms may be kept in the stream to extend the applicable timeframe but advisable to only harvest what could be treated that day)(Janssen, 1995). The initial treatment of the bamboo to make the vertical access could use traditional leaching methods for post and roofing members while structural components (stairs and floors) will be treated with butt treatment and chemical pool method (short length culms in half cut welded oil barrels).

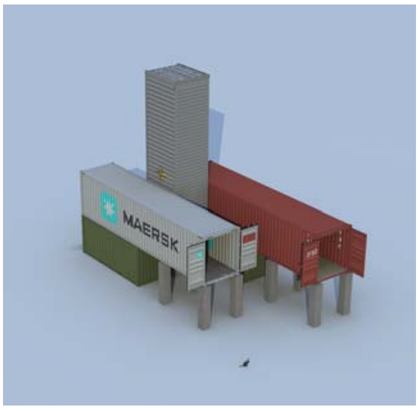


Fig 1.16. Initial Containers

Fig 1.17. Development of Boucherie Tower

Fig 1.18 is a ground floor plan of initial containers installed on site with a vertical circulation corridor/stairs of 1300mm width (the entire building would be composed of bamboo culms at 600mm centers with their finishing edges).

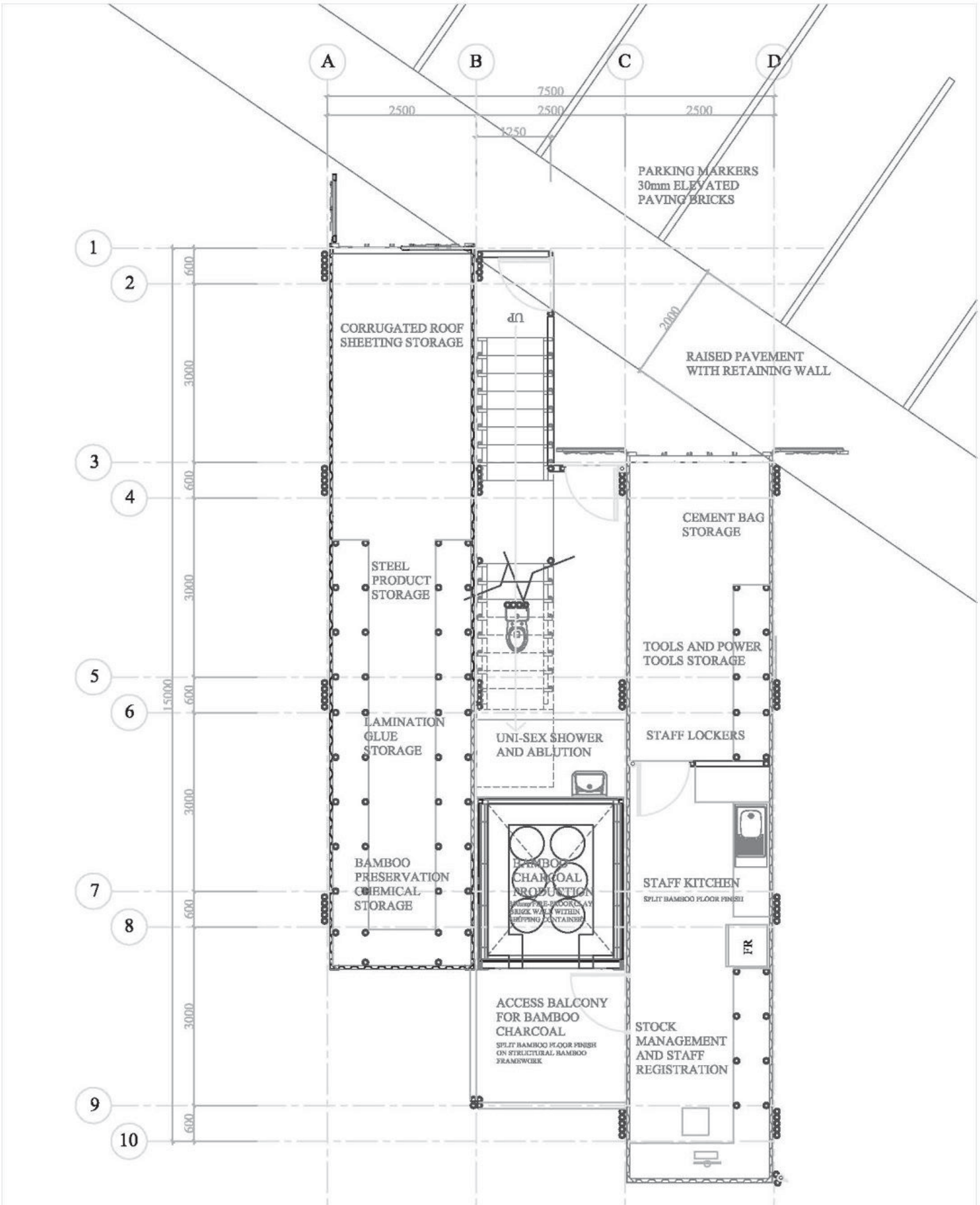


Fig 1.18. Initial Containers Plan nts

Fig 1.19 is a 3D representation of the boucherie tower water system which also shows the furnace on the river level. The water is pumped using a solar system installed on top roof of the tower.

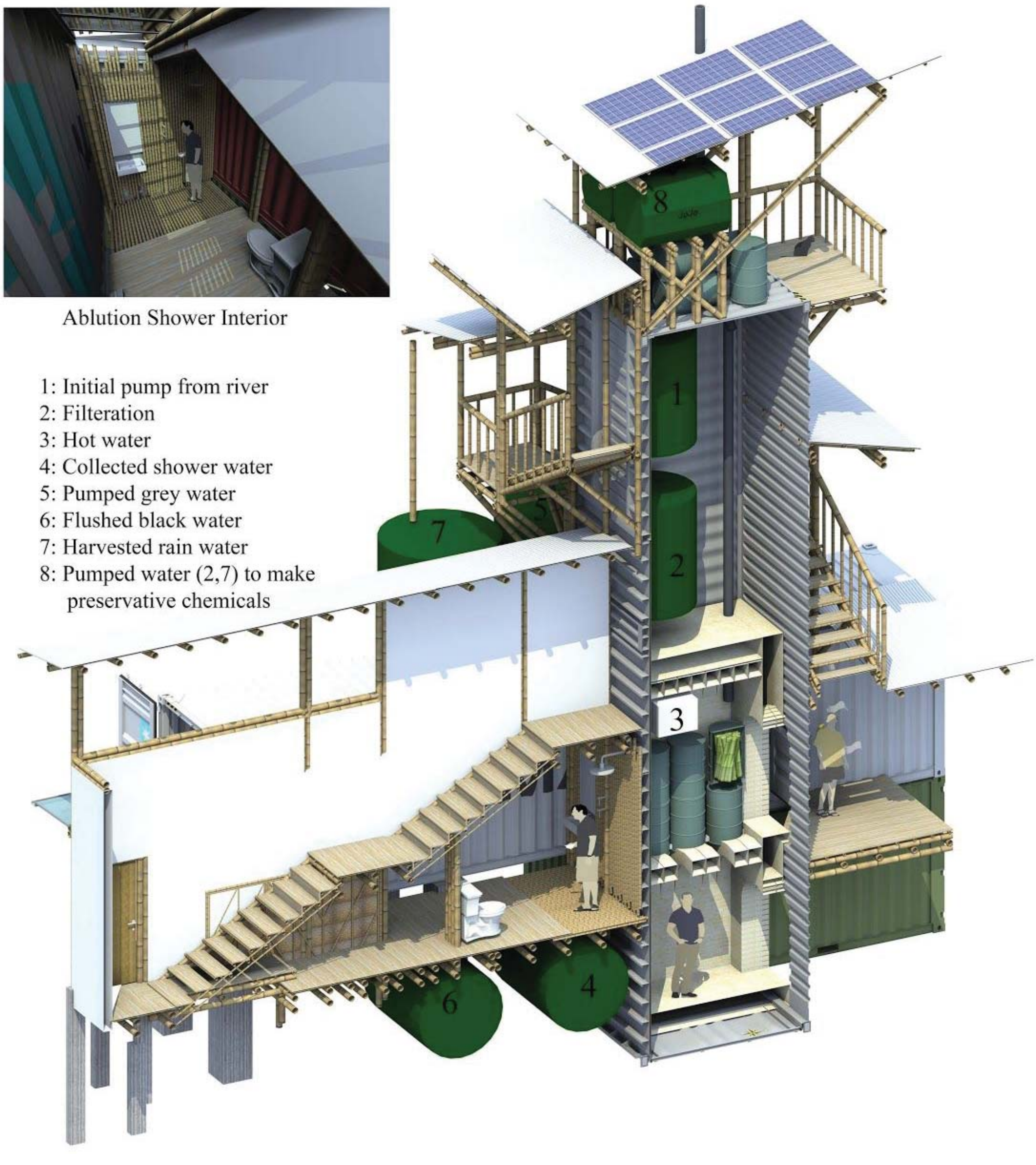


Fig 1.19. Boucherie Tower Water System

Fig 1.20 is a 2 dimensional representation of above together with details. Treatment chemicals are mixed with water on the top level (900 litre jojo tanks) which has a valve to release the solution 12m below, the connection point at the bottom may split into few ways possibly treating multiple culms at a time. This would require calculation (fall x water mass and resistance of culm vessels respect to their length) to maximise the treatment of the available species of bamboo present on site.

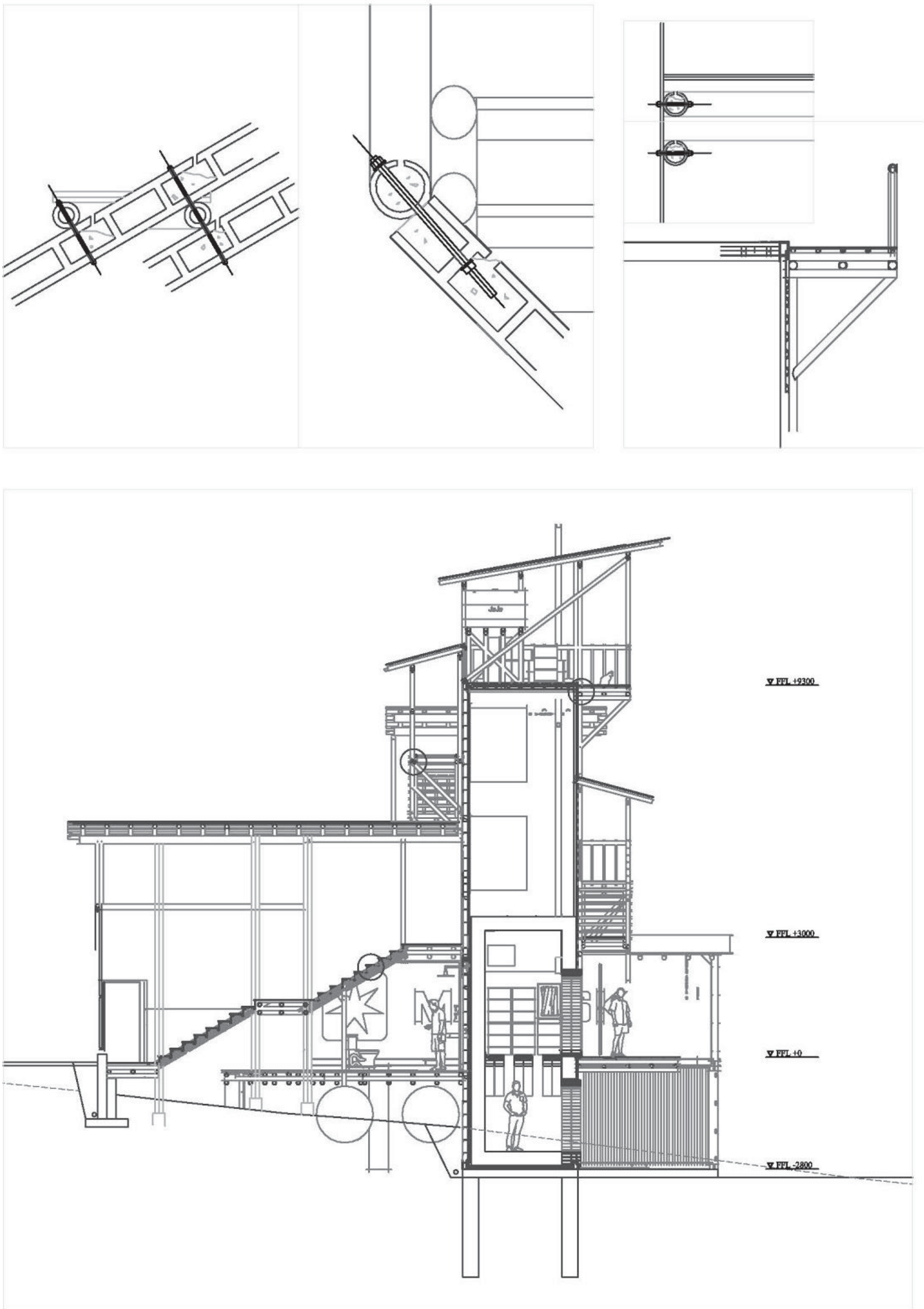


Fig 1.20. Boucherie Tower Section Details nts

Fig 1.21 is a 3D representation of the completed phase 1 development without the main roof and Fig 1.22 shows the progression from phase 1 to phase 2. This passive experience of building with this material is aimed to develop skilled artisans who could further transmit the knowledge on how to use this available grass to build possibly needed spaces throughout the region.

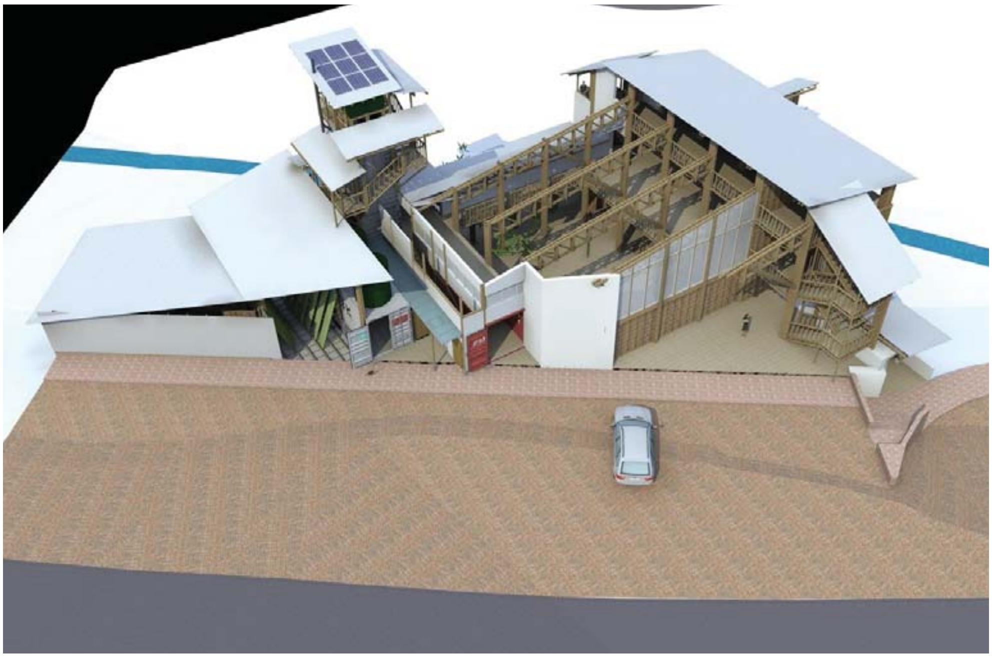


Fig 1.21. Phase 1, Treatment and Craft Facility

Fig 1.22. Progression of Phase 1 to Phase 2 Physical Model

1.9. Design Development

Biological shapes and properties of bamboo has inspired the functions / detailing of this scheme, based on an ideology to be created with minimal influence from advanced technologies (heavy machinery) that this development could be built entirely with simple tools and techniques. Fig 1.23 is a structural study model made from 3mm bamboo skewers at scale 1:30 (each representing 100mm dia culms), since the culms taper in real life, the columns and beams are segmented (alternated in directions) and combined to make a straight profile. Heavy load points will be injected with mortar after the bolts are in place.

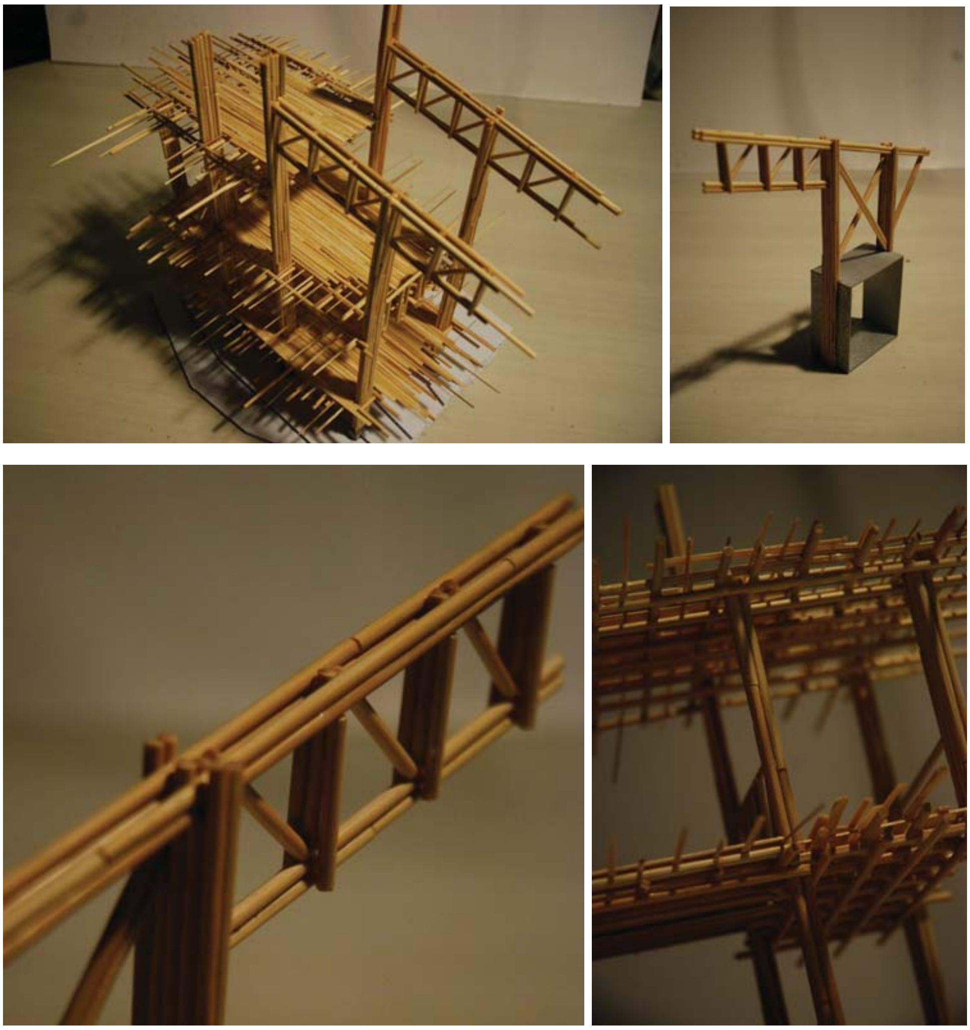


Fig 1.23. Structural Study Model

This method of construction allows short elements to weave in and out of the separate building components that makes a progressive building that grows with the annual harvest of bamboo. Fig 1.24,25,26 are floor plans representing the completed phase 1 and 2.

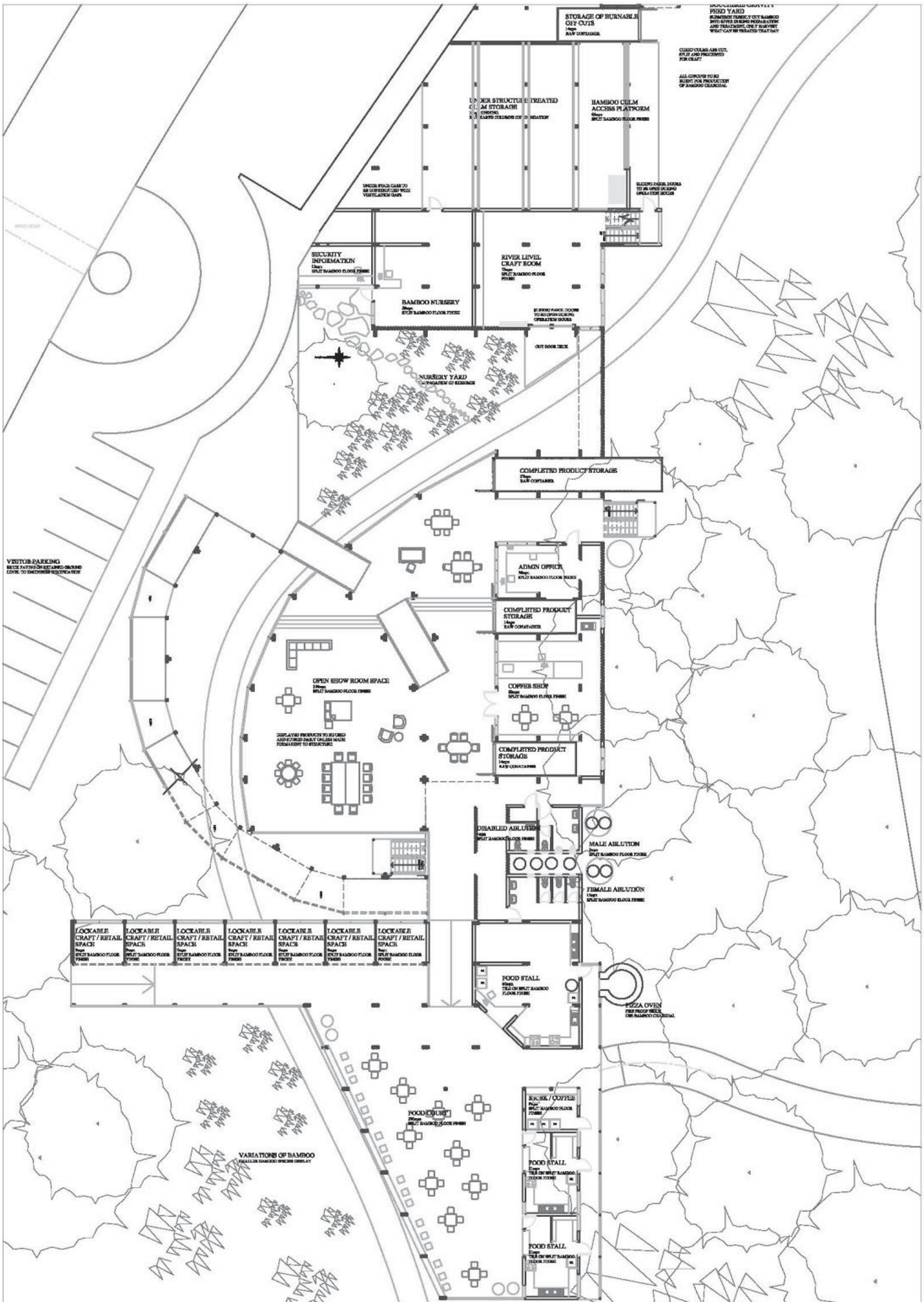


Fig 1.24. River Level Plan of Phase 1 and 2 nts

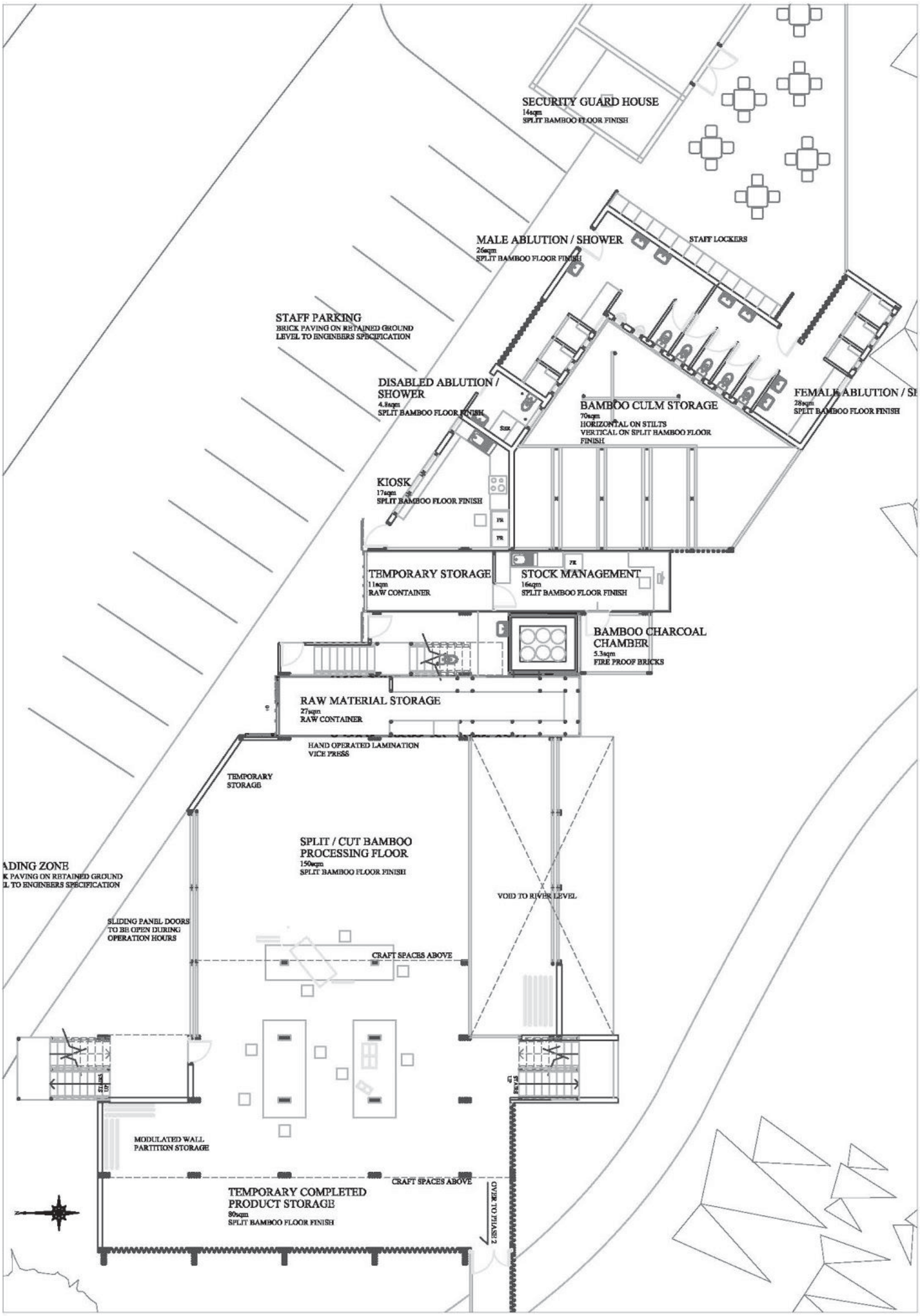


Fig 1.25. Phase 1 Elevated Floor Level nts

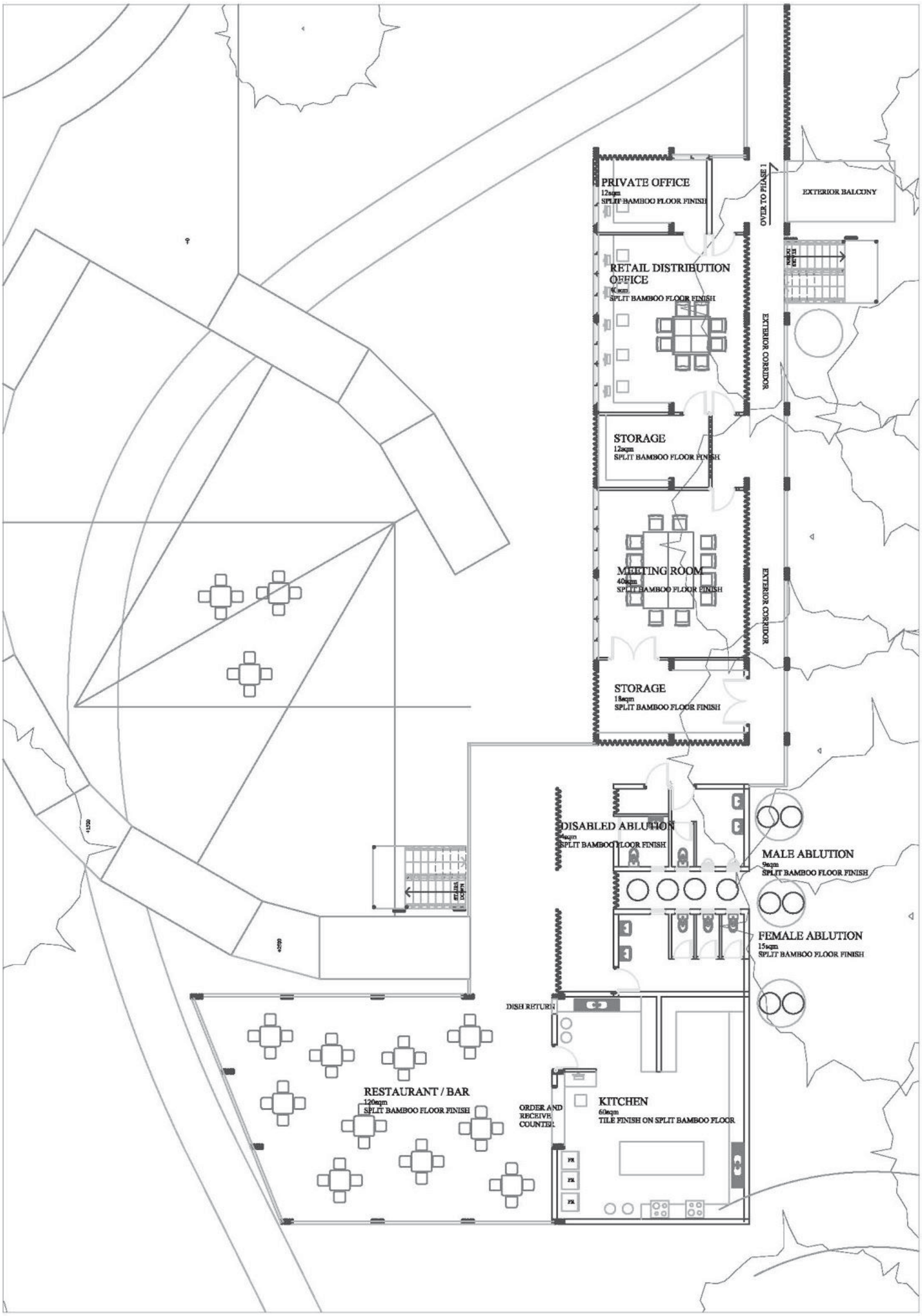


Fig 1.26. Phase 2 Elevated Floor Level nts

Figure 1.27,28 shows elevations of the development, this development will constantly be mended replacing old unstable components (some places may need design improvements based on their weathering speed) with newly grown, harvested and treated bamboo culms to extend the lifespan of its structure, undercover and treated bamboo could last 40 years.

Fig 1.27. North Elevation nts

Fig 1.28. West Elevation nts

Fig 1.29 displays a site section going through phase 1 and 2, elevated floor levels are connected by a river crossing bridge that creates a straight process line of production from harvesting to the distribution of crafted products.

Fig 1.29. Site Section nts

Fig 1.30 are sections of phase 1, the 5 combined culm columns are spaced at 3600mm centers and the floor structures are composed of 600mm centers allowing the combined columns to sit in tune with the modulated structural span of bamboo.

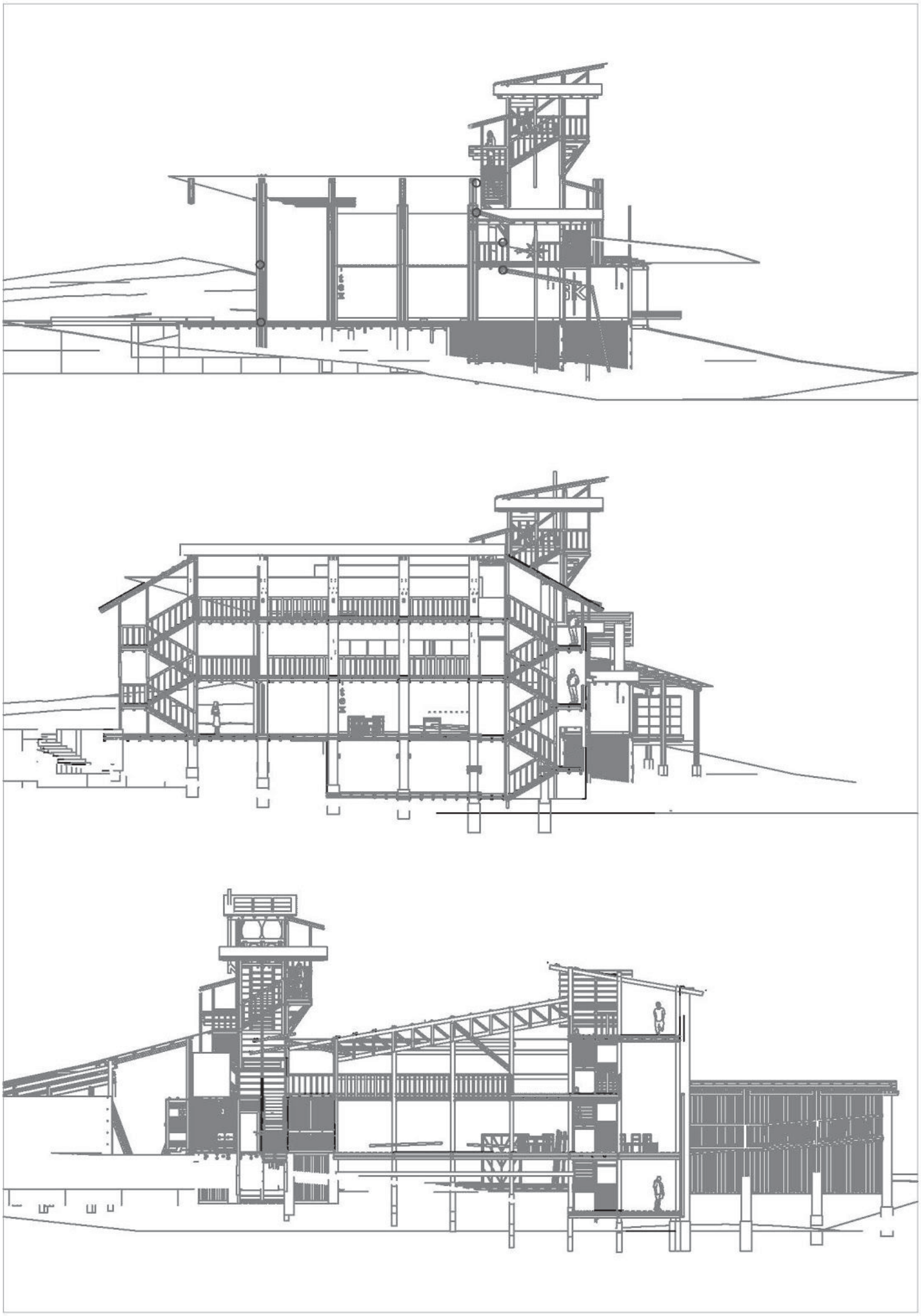


Fig 1.30. Sections nts

Fig 1.31, 32 are exterior views of the phase 1 of the development, which is intended to become an introduction / example to build with this alternative construction material in South Africa. As this development establishes and there is an abundance of construction materials being harvested, this 'living school' will be able to create a new treatment facility within reachable radious together with an installment of housing schemes that will aid its growth.

Fig 1.31. North Street View of Phase 1

Fig 1.32. West View of Phase 1

Fig 1.33 is an interior view of the open show room space in phase 2 where furnitures are concealed at the end of the day into the lockable containers, these are sold as demands are made and they contribute towards the holistic development of this scheme.

Fig 1.33. Process of Distribution / Entertainment Facility Development

1.10. Conclusion

In South Africa, the use of bamboo in construction has not been explored to its full potential compared to the rest of the world. Some of the durable construction bamboo species that have been brought to South Africa have adapted in the local conditions. This renewable resource should be given more attention and needs to be utilised for a variety of purposes, including construction. Bamboo could be the conduit to altering mindsets about perception of the built environment with the benefit of developing new skills and reducing the costs of construction.

This research has provided some examples of the uses and potential benefits of this plant using appropriate techniques. Historically, due to the lack of standardisation in the joining methods of bamboo, its use in building structures have been limited. The discovery of combining modern products, such as steel and concrete, and embedding them in the bamboo culm has proven to be durable for multi-storey buildings. With the advancement of technology, bamboo is able to transform into various products and could be used widely in the construction industry of South Africa, although its use in the construction industry may take a few generations to reach general use.

While theory and mass production may require a few decades to come together, the reality is that disadvantaged people need this resource today. Bamboo could be used in its raw state when the structure of the building is simple. Housing is a social issue in South Africa that could be addressed using bamboo, specifically, the rural settings where there may be limited resources that could be supplemented by bamboo. By having simple design detail visible and accessible using bamboo is aimed at providing an alternative method for rural communities. An integrated system of ‘living’ allows for the propagation of this plant while it is being harvested for use, thus spreading this resource together with the associated technology. The didactic nature of bamboo will assist in an even broader spread of its use beyond the initial construction. Moreover, this will increase the self-sufficiencies of the communities who use it, and improve the livelihood in many rural South Africans which could influence the country as a whole positively.

This paper has only touched upon the possibility of this plant, therefore there is a need for further research regarding the use of bamboo for construction in South Africa, and to develop practical solutions to make a meaningful contribution to our modern society.

LIST OF FIGURES

REFERENCES

Book

Hall, M. 2011. *Plants as persons - A Philosophical Botany*. Albany: SUNY Press.

Janssen, J,J,A. 1995. *Building with Bamboo: A Handbook*. Warwickshire. Intermediate Technology Publications.

Klostermaier, K. 2007. *A Survey of Hinduism: Third Edition*. 3rd ed. Albany: SUNY Press.

Journal

Hofmeyr, I. 2007. The Black Atlantic Meets the Indian Ocean: Forging New Paradigms of Transnationalism for the Global South – Literary and Cultural Perspectives. *Social Dynamics*, 33(2), 3-32.

World Wide Web

Dube Tradeport Corporation. 2017. *Company Profile*. Dube TradePort Special Economic Zone. [ONLINE]. Available from: http://dubetradeport.co.za/Pages/Company-Profile/Overview [Accessed: 28th Novemver 2017].

eThekwini Municipality. 2016. *Integrated Development Plan*. Durban: eThekwini Municipality, pp.69-72.

Koen, G. 2015. *The Bitter History of South African Sugar*. City Press. [ONLINE]. Available from: http://city-press.news24.com/Trending/The-bitter-story-of-South-African-sugar-20150802 [Accessed: 28th November. 2017].

Mount Moreland Inkonjane. 2013. The History of Mount Moreland. [ONLINE]. Available from:http://mountmoreland.com/History.html. [Accessed: 28th November 2017].

Mukherjil, A. 2011. *Durban Largest 'Indian' City Outside India*. The Times of India. [ONLINE]. Available from: https://timesofindia.indiatimes.com/city/mumbai/Durban-largest-Indian-city-outside-India/articleshow/9328227.cms [Accessed: 28th November 2017].

sahistory.org.za. 2017. *Ship list of Indian Indentured Labourers*. South African History. [ONLINE]. Available from: http://www.sahistory.org.za/article/ship-list-indian-indentured-labourers [Accessed: 28th November. 2017].

Tongaat Hulett. 2016. *Tongaat Hulett - About us - Introduction*. Tongaat.co.za. [ONLINE]. Available from: http://www.tongaat.co.za/au/introduction.asp [Accessed: 28th November 2017].

Vahed, G. Waetjen, T. 2013. Passengers of Ink: Decoding the Natural Indentured Records into the Digital Age. WISER. [ONLINE]. Available from: http://wiser.wits.ac.za/system/files/seminar/VahedWaetjen2013.pdf. [Accessed: 30th November. 2017].

Dissertation

Badassy, P. 2002. *TURBANS AND TOP HATS Indian Interpreters in the Colony of Natal, 1880-1910*. Honours. The University of Natal.

Moodley, P. 1981. *Indentured Indian Immigration to Natal, 1860- 1870 with special reference to the Hindu Caste System and its implications*. Honours. The University of Durban-Westville.

APPENDIX

October 10th 2017 Mock Jury Presentation (Process)