

The Role of Textiles in Sustainable South African Residential Architecture

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DECLARATION

I, Francois Werner De Flamingh, declare that the contents of this dissertation/thesis represent my own unaided work, and that the dissertation/thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

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ABSTRACT

Sustainable architecture prescribes the conscious consideration and active contemplation of ways of meeting the housing needs of humans while attempting simultaneously to prevent our consumption patterns from exceeding the resources at our disposal. Sustainability in the built environment is infinitely complex as the very nature of modern architecture is based upon the extraction and exploitation of finite natural resources to feed a linear system ultimately ending in the depletion of those resources and the destruction of the ecosystem from which they are excavated. When considering built environments, the most visible and measurable components of any sustainable design is its ecological and economic sustainability. Social sustainability, on the other hand is of an unquantifiable nature, making it a most contentious topic in design and development discourse.

This thesis uses a systems approach to sustainable architecture as a lens to focus on the practical applications of structural concepts made possible by the integration of textiles in the built environment and examines possibilities of adapting and incorporating vernacular and low-tech textile-based construction methods into contemporary sustainable architecture. More specifically, it explores the possibilities of using *architextiles*, or textiles in the building industry, as a vehicle for advancing sustainable development within the emerging economy of South Africa with its unambiguous diversity in all three bottom lines of sustainability; environment (ecology, resources, geography, built environment), society (community, culture, politics) and economy (employment, wealth, finance, industry, infrastructure, consumer behaviour). Although textiles are mere inanimate physical entities, the procedures involved in the extraction and processing of raw materials, manufacture and transportation of textiles or prefabricated units, construction/assembly methods as well as the socio-cultural acceptance of low-rise, low-cost residential buildings incorporating textiles are where the criteria for sustainability are addressed in this study.

Tensile membrane roofing and cladding, pneumatic fabric structures, earth-bag/ super adobe wall construction and the integration of waterproofing, insulation and reinforcement membranes in roof- and wall structures are some of the architectural components examined within the parameters of sustainable residential architecture. From the outset, low-tech processes involving the use of renewable natural resources, ecologically sensitive manufacturing methods and labour-intensive construction practices (eco-centric/ eco-social logic) are favoured as alternative to the current technologically advanced industrialised and mechanised processes where ecological sustainability is alluded to through predisposed corporate campaigns highlighting the amount of recyclable or recycled components contained in fossil fuel-based materials and products (eco-technical logic). The accumulated

data informed an assessment, study and development of an emergency shelter design initiated by a Brazilian architecture firm for possible deployment in South Africa.

The research subscribes neither to a pure positivist/modernist view, where the researcher is an objective and detached observer, nor to a pure relativist/post-modern view, where the researcher is empathetically and subjectively immersed in the research. Rather, a balanced and genuinely empathetic approach of the researcher determines the research path. The author follows a socio-technical research methodology involving both qualitative and supporting quantitative data in an extensive literature analysis, exemplars and interviews, and applies the collective information in the realisation of conceptual designs to demonstrate the practical application of authoritative theories and hypotheses on the topic of sustainable textile-based residential architecture.

KEYWORDS

- Advanced Textiles
- Architextiles
- Cape Town
- Earthbag Construction
- Eco-design
- Fabric Structures
- Pneumatic Structures
- Socially Responsible Design
- South Africa
- Sustainability
- Sustainable Architecture
- Tensile Membranes
- Textile Architecture
- Textile Structures

IN-TEXT CITATION CONVENTIONS

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GLOSSARY

Advanced Textiles	In the context of this research study, advanced textiles are technologically progressive fibrous membranes that inflict minimal negative impact on the natural environment and human health in both their manufacturing processes and applications.
Architextiles	Textiles specifically developed for integration in architecture. A term first used by <i>Architectural Design Magazine</i> in 2006.
Bedouins	Natives of the Arabian Peninsula who take their name from the Arabic word <i>bedu</i> , meaning <i>nomad</i> (Bahamon, 2004).
Bio-regionalism	A corollary concept that all life is established and maintained on a community basis and that all these distinctive bioregions or communities have mutually supporting life systems which are generally self-sustaining (Zeihner, 1996).
Composites	A term used where two or more materials, differing in form or composition, are combined to make a new material with enhanced performance characteristics (Braddock Clark & Mahony, 2005).
Cradle-to-cradle	This theory prescribes the conscious consideration of a product's life from initial manufacture to the end of its useability (cradle-to-grave) as well as the possibility for a second product life through repurposing or recycling.
Earth-sheltered Architecture	The design of buildings that are partially or totally below the ground, either as a result of digging into existing topography or filling over parts of the structure (Yeang, 2006:448).
Eaves	“The lower edge of the roof, extending beyond the line of the façade. Their purpose is to keep rainwater

off the façades and to provide the building with shade for heat control.” (Chueca, n.d: 130)

Fabrics

A Thin, flexible material made of any combination of cloth, fibre, or polymer, including films, sheets or foams.

Fibre

A fine, rodlike object in which the length is greater than 100 times the diameter.

Film

A polymers extruded as a sheet rather than a fibre. Not a true textile as it is not made of fibres, but because of a film’s similar physical and chemical properties to corresponding fibres; it is often included in studies of textiles.

Geogrids, Geomeshes and Geonets

Textile grids typically used for the reinforcement of vertical soil walls and steep rock or soil slopes. The usual method is an interlocking between the grid and the substance it is reinforcing. The mechanical interlock creates a flexible but sturdy platform, which can distribute loads evenly (Braddock Clark & Mahony, 2005).

Green Roof

Vegetation cover on roof surfaces. Type 1) Extensive green roofs (also known as ecoroofs or living roofs) consists of a thin soil layer with horizontally spreading, low-growing vegetation over the entire roof surface; adds minimal loads to structure. Type 2) Intensive green roofs (also known as traditional roof gardens) consists of a thick soil layer or planters with vegetation that requires intensive care and maintenance, such as trees or shrubs; ads substantial loads to building structure (Yeang, 2006).

Hybrid Materials

Combinations consisting of part textile (flexible), part non-textile (glass, carbon, metal and ceramic) offering high performance and reduced weight compared to the textiles or other materials they replace in different applications.

Hyperbolic Paraboloid	A simple canopy shape found in tensile structures generated when a rectangular or diamond-shaped membrane is tensioned between two low and two high points.
Passive Climate Control Systems	The use of various simple cooling or heating techniques to enable the indoor temperature of buildings to be modified through the use of ambient energy sources in the natural environment (Yeang, 2006:194).
Polyvinyl chloride (PVC)	A rigid thermoplastic polymer of vinyl chloride with good electrical properties and flame and chemical resistance that needs stabilizers to prevent discoloration from light or heat and plasticisers to give it various degrees of flexibility.
Sick Building Syndrome (SBS)	A pattern of health complaints related to poor indoor air quality, including nasal stuffiness, dry and irritated eyes, throat and skin, headache, fatigue and respiratory complaints, which typically resolve on leaving a building (Yeang, 2006:458).
Space structures / Space frames	“Space structures are three-dimensional assemblies of linear members in which the interconnections are such that a load at any point is distributed in all directions throughout the assembly. They can take the form of flat double-layer grid structures, or braced domes and vaults” (Wilkinson 1996:98)
Sustainable Architecture	The design of buildings that address sustainability in environmental, socio-cultural and economic terms.
Sustainable Development	“The management of resources that enables people living today to meet their needs without jeopardizing the earth’s future inhabitants to meet theirs” (Yeang, 2006:460).

Technical Textiles

Textile materials and products manufactured primarily for their technical and performance characteristics rather than aesthetic or decorative properties.

Textile

A general term for any product manufactured of fibres, filaments or yarns, characterised by flexibility and a high ratio of length to thickness. This includes non-woven, woven and knitted fabrics.

Vernacular Architecture

Architecture without architects or building construction by unknown builders. This indigenous approach to building construction is often seen as primitive by western cultures.

Yarn

Fibres twisted together in a continuous strand

CHAPTER 1:

What the Study is About

Introduction

This thesis looks at sustainable residential architecture, but more specifically at the incorporation and integration of textiles in the construction of homesteads intended for single family occupation. The general understanding of the theory of sustainable development prescribes an equilateral emphasis on the three components that make up the triple bottom line, namely socio-cultural, environmental and economic sustainability. However, addressing all three facets with equal prominence within the parameters of this specific research study would be nearly impossible. Conversely, attempts are made to address them with due emphasis given the context of the subject matter and each aspect's impact on the topic and direction of this particular body of work.

Although much progress has been made in the field of architectural textile development involving the latest technologies and industrialised production methods, it has become apparent during the course of this study that the most efficient and holistic approach to sustainable development in the South African built environment is instead one that focuses on labour intensive, job generating processes using the most basic of skill sets to erect structures that are environmentally friendly and within the financial scope of the largest possible portion of local population. In natural building practices, for example, earth-bag construction, a low-tech method of erecting walls using stacked fabric bags filled with soil, sand, gravel or rubble is a well-known and widely practiced building method that has proven to be a prime example of textile-based architecture that is, within current universal criteria, socially, environmentally and economically sustainable.

The study considers the advances made in sustainable building practices within South Africa, a developing country with a complex socio-political history and diverse spectrum of climatic conditions and socio-economic standings, and highlights the benefits of architectural structures incorporating textiles.

1.1 Motivation for Choosing this Topic

Besides being of personal interest to the author, sustainability has been one of the most talked about and arguably one of the most topically relevant concepts worldwide of the past two decades. Although local circumstances cannot be compared to that of first world economies, the gap between international developments in sustainable residential architecture and what is generally being implemented in the South African housing sector is substantial. Sustainable development needs to be addressed on all fronts, especially relating to the three most basic human needs for food, clothing and shelter. It is the belief of the author that both himself and others wanting to explore the responsible use of alternative building materials such as textiles can benefit from the research being conducted for this thesis and possibly contribute to making a developing country like South Africa a prime example of sustainability to the international community.

The personal motivation for choosing this topic stems from an interest as well as an academic and professional background in design, textiles, structures and sustainability. An undergraduate qualification in clothing design followed by further studies and a subsequent career in the South African film industry as designer, specialist fabricator and small business owner, combined with a more recent interest in eco-design and a desire to contribute to the well-being of others led to an exploration of career opportunities in sustainable development. This thesis is hoped to be a departure point for a long-term commitment to realise personal as well as professional goals. The topic is a deliberate amalgamation of the author's academic qualifications, past experience, current interests and future prospects.

1.2 The Research Problem in Context

The increasing cost, scarceness and destructive environmental impact of producing energy-intensive conventional building materials from non-renewable resources have made investigations into using innovative alternative materials and novel applications for existing materials in the built environment critical. The search for more sustainable ways of creating comfortable homes requires a fresh approach to structural design, construction practices and socio-cultural perceptions.

A very limited number of examples, particularly in the low-income sector, currently exist in South Africa of residential buildings integrating environmentally friendly construction practices, using renewable resources or promoting the concept of sustainable architecture in other ways. One of the country's most urgent humanitarian needs is low-cost housing, but because of the limited financial returns in low-cost housing developments, merchant enterprises frequently reserve innovative building materials and construction processes for public and commercial buildings. The conceptualisation and design of low-cost housing structures usually end up being the responsibility of property developers focussed on speedy delivery and short sighted profiteering instead of sustainability or longevity of the structure or the social needs and human dignity of its occupants. Design thinking and a systems approach, involving inclusive sustainable solutions is necessary to explore practical alternatives to the existing housing delivery system that is clearly ineffective. As will be elaborated upon later in the text, South Africa as an emerging economy is in a unique position for embracing alternative building practices in order to ensure development in the housing sector happens in a sustainable manner.

Building with textiles is by no means a novel approach in the construction of African or other vernacular structures and neither are the obvious benefits like economy of materials, simple construction methods and the numerous advantages associated with lightweight construction. Also, given the significant cost savings per square meter when compared with more common building materials, it is curious, to say the least, that in an emerging economy like South Africa, with its prodigious need for low-cost housing solutions, exists a limited amount of examples of textile-based or textile-assisted architecture, let alone of anything that could be considered sustainable.

While considered the fifth building element after stone, metal, timber and glass, the integration of textiles in especially residential architecture is a relatively uncommon concept worldwide. Textile structures are generally associated with temporary, vernacular or nomadic habitats. In contemporary architecture, textiles are almost exclusively developed for their use in large structures such as sport stadia and temporary exposition venues. The perceptions associated with textile structures have limited development in this area to specific structural forms in our contemporary built environment and have stimulated the conversion of a simple vernacular practice into a specialised field with limited investment and inadequate experimentation on the level of structural engineer, designer or architect. Extremely comfortable and efficient residential textile structures using locally obtainable materials have been refined over

centuries by nomadic and indigenous tribes of the Middle East, Africa and North America, yet so-called modern civilised architecture of both the West and East have for the most part opted to ignore such simple, efficient and sustainable answers to the need for housing in favour of profit-driven, energy intensive, industrialised architectural endeavours exploiting cheap labour and non-renewable natural resources. Conversely, the relatively few examples of textile architecture today clearly exhibit the benefits of using textiles in large structures, yet most residential configurations seem to steer clear of flexible membranes.

The majority of modern textile buildings fall under the category of lightweight structures, which implies a significant economy in material usage and an excellent coverage-to-weight ratio. This, along with other characteristics unique to textile structures, makes the study even more relevant in pursuit of innovative building materials and their contribution to sustainable construction practices. Textile membranes present a whole spectrum of possibilities for their use in residential architectural applications. However, the integration of architextiles in the South African built environment has largely been restricted to simple shade structures, temporary marquee tents for hosting events, covered vehicle parking bays and, more recently large textile claddings for sport stadia. This study aims to show how the conscious integration of specific textiles in South African residential architecture can advance environmental, economical and social sustainability.

1.2.1 Hypothesis and Basic Assumptions

- Applied in designs that specifically optimise on their features, certain commercially available textiles can offer unique benefits as creditable construction materials in sustainable residential architecture.
- In a developing economy such as South Africa, a low-tech, craft-based, people-centred approach to residential building design and construction should be considered a more sustainable alternative to eco-technical methodologies, where technologically advanced industrial material manufacturing processes and complex construction methods delineates sustainable architectural practice.
- If the potential and benefits of textile-based architecture are sufficiently illustrated, both architect and client will be enthused to consider the possibilities of commissioning such structures and in so doing endorse textiles as worthy component of residential architecture.

1.3 Research Questions

The main research question and its sub-questions address the following:

How can the integration of eco-friendly architextiles contribute to sustainable residential architecture in South Africa's low-income sector?

- How does the concept of sustainable architecture influence current approaches to textile-based building design and construction practices?
- Why are architextiles not widely diffused in contemporary South African architectural practice?
- How can sustainable architextiles, related construction processes and textile structures be assimilated into the current South African low-cost residential built environment?

1.4 Research Objectives

This research study aims to build on and contribute to the body of knowledge and the practical possibilities of using textiles in sustainable architectural design. It not only presents an overview of current examples of textile structures worldwide, but in addition proposes a specific design intervention within the South African low-income housing sector. With the limited literature available on the subject, this thesis also intends to provide guidelines for architects, engineers and designers interested in exploring this unique approach to structural design, while simultaneously addressing sustainability in the built environment. It proposes using textiles in a way that promotes sustainable development, not only in an environmentally responsible sense, but also for its social and economic significance. The study in sustainable development is conducted in South Africa, a developing country.

The main aims of this study are to:

- Explore how the principals of sustainable architecture apply to architextiles specifically.
- Evaluate the current use of architextiles according to the criteria for sustainable architecture in a South African context.

- Establish what the benefits are for incorporating certain textiles in residential building construction.
- Determine how the qualities of textiles influence the design development of membrane structures.
- Determine why textile-based architectural structures are not a familiar site in the current South African built environment.
- Ascertain which attributes of specific textile structures make it ideal for the multiplicity within South African climate, culture and developing economy.

The research aims to emphasize the advantages and promote the incorporation of textiles in permanent building design, but more specifically single-family low-cost homes that adhere to the principles of sustainable architecture. The researcher not only investigates what is currently accessible to architects and designers in the field of textile architecture, but also, based on the supporting knowledge gained on the subject, proposes building designs for application in South African residential architecture. Published literature on the technical considerations and requirements of, for example, tensile structures, pneumatic canopies and geo-membranes directs the research process, while authoritative opinions determine the aptness of the proposed design intervention.

1.5 Significance of the Research

This study selects and evaluates certain textiles used in the construction industry today according to the environmental impact of the extraction, processing, manufacture and transportation of these materials. Social influence enters the discussion when looking at the various construction practices as well as the possibilities for adapting current material manufacturing processes and further exploring the ones that are locally more viable and community-centred. Similar to the environmental impact evaluation, economic sustainability is assessed through the criteria of the cradle-to-cradle theory, taking the entire life cycle of the specified textile into consideration, from extraction of raw materials through to the operating and maintenance costs associated with the finished structure to replacement costs and possibilities of recycling or reusing the original artefact in the manufacture of a second-life product.

Not only is the social impact of alternative manufacturing processes considered, but also the economic implications noted and processes promoting job creation and

poverty alleviation naturally favoured. In South Africa, an emerging economy with an unemployment rate estimated at between 25 and 40 percent of the eligible population, the social and economic benefits of more manual labour-intensive and community-based material manufacturing and construction processes are closely intertwined and arguably more relevant than exploring the latest technologies as would most likely be the case in developed countries. This means that some of the conclusions and recommendations of this thesis will not necessarily be viewed as best practice in a universal sense, but relevant only to the particular circumstances currently experienced within South Africa as a developing country with its unique needs and possibilities.

1.6 Structure of the Thesis

Chapter 2: Sustainable Architecture: a South African Perspective examines selected authoritative definitions of and criteria for sustainable architecture in a universal sense followed by a look at the implications and unique considerations this concept imposes on a developing economy like South Africa. This section aims to position the study in the relevant context by providing a generalised view of the local conditions within which the focus lies.

Chapter 3: Architextiles commences by briefly looking at historical and vernacular uses of textiles in architecture and proceeds to examine technical properties of current architextiles as well as various ways in which textiles are incorporated into architectural structures or constitute the primary material some structures are made up of. This section's primary objective is to provide a summary of the various categories of textile-based architectural structures found today and what each structure's unique benefits, drawbacks and specific design requirements are. The description of each type of structure is accompanied by an example of an existing building to illustrate its physical manifestation in a particular geographical setting. The chapter pares down the broad field of textile-based architecture by relating it to the previous chapter and setting the scene for the true culmination of the two topics in the section about sustainable architextiles. It concludes by relating these global developments in textile architecture to the current South African built environment in general as well as the industry's move towards more sustainable construction practices.

It is worth noting that, although much of this study is dedicated to the technical characteristics of architextiles, the emphasis of the research is on the structural

development and social significance of textile-based buildings and related construction processes using locally obtainable textiles and not on the development of the textiles themselves. However, existing textiles not normally used for architectural applications or combinations and composites of different materials are in some cases investigated as possible alternatives to textiles developed specifically for this purpose. Chapters 2 and 3 should be seen as parallel studies and not following on or preceding one another. Both are descriptions of equally important contributors to the thesis, since the intended contribution of this research lies primarily in the novelty associated with the integration and symbiosis of the two concepts. Both chapters serve to delineate each other in order to moderate the wealth of knowledge available on each individual topic for the purposes of this study.

Chapter 4 delineates the conceptual and theoretical frameworks of this particular study. It discusses the theories of systems thinking in an architectural design context and architectural expression. It also elaborates on how, in our communities, architectural practice affects, and is affected by, all three bottom lines of sustainability.

Chapter 5 focuses on the research approach and methodology followed in this study. It illustrates which ontological assumptions and epistemological views determined the methodology and informed the research activities.

Chapter 6 commences by presenting research findings from the desktop study as well as opinions expressed in interviews and questionnaires relating to the topic of sustainable textile-based architecture in South Africa. It substantiates the literary data collected during the primary desktop study by weighing it up against responses of informants to the concepts and hypotheses conceived during the course of the research. Proposed 'solutions' to the perceived challenges identified in Chapter 1 are presented for critique by authoritative bodies. The author presents an account of an applied research study conducted in Brazil for an emergency shelter incorporating textiles that can be converted into a low-cost permanent house. This particular shelter design was initially developed to address the housing crisis faced by the population of Haiti after a devastating earthquake hit the region in January 2010, but has since been adapted for deployment elsewhere in the world as a shelter-to-house structure. The suitability of the shelter to address low-cost housing needs in South Africa will be affected by the proposed site's available resources, existing socio-cultural structure and perceived acceptance of the local community. The choices for specific design elements, material choices and particular construction methods are informed by the

data collected in the course of the study and evaluated according to how they relate to the existing conditions within the community for which it is proposed.

1.7 Summary

The integration of architextiles in South Africa's built environment holds significant benefits and forms part of a host of opportunities for development in this sector towards more sustainable practices. South Africa with its distinctive history, its diverse socio-cultural mix and current economic standing presents real-life prospects for the implementation of architectural structures using environmentally friendly materials and unique construction methods to meet the demand for more sustainable residential buildings. Textiles offer unconventional, yet proven effective, solutions to various challenges faced by segments of the South African population and, depending on the application, can address many needs that are currently not met by conventional construction practices.

CHAPTER 2: Sustainable Architecture: a South African Perspective

2.0 Introduction

Webster's 10th New Collegiate Dictionary defines the word *sustainable* as follows:

"Of, relating to, or being a method of harvesting or using a resource so that the resource is not depleted or permanently damaged." (Zeihner, 1996: 30)

This and similar definitions present sustainability from an essentially anthropocentric position concerned with how to maintain and possibly improve the quality of human life within the carrying capacity of supporting ecosystems (Williamson, Radford & Bennets, 2003: 3). Sustainability is one of the most significant concepts of the past two decades, influencing the design of global government policy, economics, energy resources, technology, manufacturing, community planning and architecture.

The concept of sustainability was first identified in the World Commission on Environment and Development (WCED) report *Our Common Future*, written by the former Prime Minister of Norway, Gro Harlem Brundtland and published in 1986 (Zeithner, 1996:30) Also known as the *Brundtland Report*, it states that:

Humanity has the ability to make development sustainable – to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs. Sustainability is not a fixed state of harmony, but rather a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are made consistent with future as well as present needs.

-WCED, 1990 (Williamson, Radford & Bennets, 2003: 1)

World-renowned architect Sim van der Ryn states in the foreword of the publication *Alternative Construction* (Elizabeth and Adams, 2005) that he believes humankind is on the brink of a fourth epoch. The first three great cultural epochs each had their own distinguishable forms of creating built environments and buildings.

In the first epoch of the pre-agricultural tribes of hunter-gatherers and primitive cultivators, the primary built environment was the village and the primary dwelling constructed of natural materials gathered from the immediate environment. Although no physical structures remained from this period, the mud houses of the Dogon-tribe of East Africa, the bamboo structures of the Malay-peninsula, and the adobe pueblos of

the Americas are current adaptations of indigenous tribal buildings from this era. Food surpluses, brought about by the birth of the second, or agricultural epoch, allowed larger permanent settlements and gave rise to the great empires of the Mediterranean basin, Central America and Asia. Tribal forms were replaced by hierarchical systems of organisation and control, while the need to predict time and space gave rise to first sciences and recordings of time, quantities and events. Sacred complex remains from this period include the great pyramids in Egypt, Mayan ruins and various temple structures in Asia.

The third epoch, or the epoch of the corporate state, has its roots in the philosophy of the Greeks: the society of equals. An intellectual, scientific, and artistic flowering in the fifteenth and sixteenth centuries in Europe produced the key philosophical elements for this epoch, while science began its long march toward domination and control over the natural world. The majority of buildings during this period follow an industrial model in which nature is disassembled into elements and reassembled in new chemical and structural configurations. Lumber from forests stripped of trees, mined and processed gypsum, new molecular substrates from petroleum reserves and the exploitation of water, coal and oil to meet energy demands define the ethic of this period.

Van der Ryn believes that the fourth epoch will be guided by ecological principles. History suggests that each new epoch incorporates and transcends the preceding one. "The new epoch will not reject science or technology but bring them into a context where phenomena are understood as parts of a systematic whole that includes the spirit of the whole," states Van der Ryn (Elizabeth and Adams, 2005: xiv). This ecological epoch will strive for a harmonious and mutually beneficial partnership between humankind and nature rather than a destruction of the living systems on which our lives depend. It is clear to this generation that nature will not merely survive, but thrive without man, but man cannot survive without nature.

The current South African building industry in general displays a particular, if sometimes restricted or distorted understanding of what is meant by sustainable development. Those who reflect on the broad outlines of the term and who are taking steps to render the buildings which they design or occupy more sustainable, are often motivated by the prospect of increased financial returns as a result of a company's improved public image or by the fact that it's a new and trendy concept that businesses and individuals are subscribing to in order to keep up with their peers. Moreover, because of the perceived financial implications of 'going green', most

sustainable development happens on the commercial front and not within the residential built environment.

Most South Africans not only associate sustainability with eco-friendliness, but often consider the two concepts to be one and the same and the terms to be interchangeable. It is thus often necessary to specify in conversation that by using the term sustainability, one is not merely referring to environmental sustainability, but social and economic sustainability as well. The concept calls for a balanced approach, where we are not elevating our own needs above those of nature, but neither should we endorse the reverse. Williamson, Radford and Bennets (2003) argue that the design of sustainable architecture must be grounded in an inclusive view of the scope of sustainability in each situation, without which attempts to use the available published advice may in many ways be counterproductive. Design decisions should be based on both an ethical position and a rational comprehension of the objectives, processes and systems involved.

2.1 Sustainable Construction Practice

It was William McDonough who brought the concept of sustainability to the forefront of the architectural profession with his publication of the revolutionary *Hanover Principles*. The office of William McDonough Architects was commissioned by the German government in 1992 to develop design principles for the Expo 2000 World's Fair to be hosted in Hanover, Germany, under the theme *Humanity, Nature, and Technology*.

Table 2.1 The Hanover principles (Zeihner, 1996: 47)

The Hanover Principles

1. **Insist on rights of humanity and nature to co-exist** in a healthy, supportive, diverse and sustainable condition.
2. **Recognise interdependence.** The elements of human design interact with and depend upon the natural world, with broad and diverse implications at every scale. Expand design considerations to recognise even distant effects.
3. **Respect relationships between spirit and matter.** Consider all aspects of human settlement including community, dwelling, industry and trade in terms of existing and evolving connections between spiritual and material consciousness.
4. **Accept responsibility for the consequences of design** decisions upon human well-being, the viability of natural systems, and their right to co-exist.
5. **Create safe objects of long-term value.** Do not burden future generations with requirements for maintenance or vigilant administration of potential danger due to the careless creation of products, processes, or standards.
6. **Eliminate the concept of waste.** Evaluate and optimise the full life-cycle of products and processes, to approach the state of natural systems, in which there is no waste.
7. **Rely on natural energy flows.** Human designs should, like the living world, derive their creative forces from perpetual solar income. Incorporate this energy efficiently and safely for responsible use.
8. **Understand the limitations of design.** No human creation lasts forever and design does not solve all problems. Those who create and plan should practice humility in the face of nature. Treat nature as a model and mentor, not an inconvenience to be evaded or controlled.
9. **Seek constant improvement by the sharing of knowledge.** Encourage direct and open communication between colleagues, patrons, manufacturers and users to link long term sustainable considerations with ethical responsibility, and re-establish the integral relationship between natural processes and human activity.

The Hanover principles should be seen as a living document committed to the transformation and growth in the understanding of our interdependence with nature, so that they may adapt as our knowledge of the world evolves.

Following the *Brundtland Report*, the *Hanover Principles*, along with *Agenda 21* (United Nations, 1992) and the *Framework Convention on Climate Change* (UNFCCC, 1992) presented at the World Summit in Rio de Janeiro in 1992, exist as some of the more topically relevant of a myriad of declarations, conventions and other plans of action for the consideration of sustainability in development worldwide. An unequivocal

commitment to this end within the discipline of architecture was the outcome of the Union of International Architects' *World Congress of Architects* in Chicago, 1993. But despite numerous conventions, principles and declarations, confusion and contradicting views still exist as to what, in practice, is meant by sustainable architecture. At best, these guidelines and checklists show a range of possibilities; at worst they risk providing a confusing or misleading indication of how to design a sustainable building. Because such guides are structured to be universally applicable they could, strictly speaking, be considered 'unecological', given that the concept of ecology has taught us to take account of complexity, interconnectedness and uniqueness (Williamson, Radford & Bennets, 2003: 13).

The label *ecologically sustainable design* (ESD) gets assigned as frequently to all-natural structures the likes of woven grass and thatch *bure* of the South Pacific Islands as it does to high-tech office buildings in the United States. Whereas the former is constructed entirely of biodegradable and renewable materials and appropriates the minimum of resources, the latter may require significantly less energy for heating, cooling and lighting than is typical for its class, making both valid manifestations of the values associated with sustainability.

Susan Maxman (1993), former president of the American Institute of Architects wrote that "sustainable architecture isn't a prescription. It's an attitude. It shouldn't really even have a label. It should just be *architecture*" (Williamson, Radford & Bennets, 2003: 7). Robert Berkebile, American Institute of Architects *Council on the Environment* founder and president, thinks that most of the attempts to label ecologically conscious design as 'green' or 'sustainable' are limiting. Citing Peter Ellyard, he says that 'sustainable' implies survival, when we should instead be focussed on thriving. Says Berkebile: "This labelling is symptomatic of our tendency to simplify, reduce, and label before understanding the complex systems we are modifying" (Zeihner, 1996: 31). Cape Town architect Keith Struthers (2011) also questions what the term sustainability implies. He advocates focussing on nurturing, rather than just sustaining. Especially in a capitalistic society, merely sustaining without aspiring to something better will not satisfy people's typical yearning for more.

In their book *Understanding sustainable architecture*, Williamson, Radford and Bennets (2003: 1) describe sustainable architecture as "a revised conceptualisation of architecture in response to contemporary concerns about the effects of human activity."

Not long ago a major part of the image of good architecture was a building that was 'suitable' for its environmental context – one that would adequately protect the inhabitants from the climate. More recently it is 'the environment' that has been seen as needing protection...In many ways the built environment, the very means by which we attempt to create secure conditions, is itself seen as becoming (or having become) a source of danger and threat

(Williamson, Radford & Bennets, 2003: 1).

Concepts like 'green', 'environment' and 'ecological' can be traced back to the 1970s, and are labels that embody the notion that the design, formation and continued development of the built environment should demonstrate a fundamental consciousness of its relationship with and impact upon the natural environment. An awareness of the effects of human activities on nature started to replace the primal and instinctive fear of what nature can do to us. Increasingly, perceived threats to human life have shifted from being external to self-manufactured risks, in other words risk situations which humans have never encountered and for which we have no traditional experience in dealing with. These manufactured risks result directly from the applications of technology in response to the circumstances of increasing populations and desired higher standards of living (Williamson, Radford & Bennets, 2003: 2). The majority of architects and designers, however, still seem to be under the impression that all glitches in the system can be resolved and streamlined through the continued and increased application of technology. What is often the case, though, is that a snowball-effect is created where the more technologies are developed and implemented to rectify the damaging effects of other innovations, the more destruction they seem to be perpetuating themselves.

When considering built environments, the most visible and measurable components of any sustainable design is its ecological and economic sustainability, although opinions vary as to which strategic measures will ensure this. Social sustainability, on the other hand is of an unquantifiable nature, making it a most contentious topic in design and development discourse. What is meant by social sustainability in construction practice is dependent on the region and the contemporary cultural, political and often socio-economic situations. Communities frequently need tailor-made solutions to meet their specific needs. Social solutions also depend on whether the need is for measures to maintain the status quo or for social upliftment and improvements to the current social structure. Poverty-stricken societies or communities under stress usually need selective interventions where not only a comprehensive understanding of the situation,

but a measure of sensitivity and empathy is critical in order to devise strategies that will eradicate social ills yet, simultaneously, preserve the cultural fibre that unite such communities.

2.2 Sustainable Building Materials

An overview of current international trends in building design reveals that architects increasingly take into account the environmental impact of the materials used in construction and also the energy efficiency and sustainability of the finished structure. Models for sustainable architecture require and encourage new technological developments in construction materials as well as their integration in building designs that optimise the advantageous qualities of these new materials.

The costs of raw material extraction and processes involved in the manufacturing of conventional building materials contribute a significant portion to high construction costs, resulting in a situation, especially within developing countries, where the construction and ownership of properly constructed homes remain the privilege of a select few. By sourcing local and/or renewable natural building materials that require little, if any preparatory processing for architectural applications, the material costs are reduced significantly, making decent homes built using so-called alternative building practices affordable and accessible to a much larger percentage of the total population.

Currently most environmentally conscious building design calls for products and systems with a higher price tag than conventional ones. Life cycle analysis (LCA) or life cycle costing (LCC) provides the underlying and long-term economic incentives that make ecological projects feasible. The U.S Departments of Health, Education and Welfare summarised life cycle analysis (LCA) as the systematic consideration of cost, time, and quality of a product. Life Cycle Costing (LCC) is fundamental in the design of environmentally conscious buildings, total quality management (TQM), and value engineering (VE) (Zeihner, 1996).

Besides the availability of certain building materials, the distance travelled to the construction site is an additional consideration. Choosing materials that are locally or regionally manufactured makes good sense. Local materials are usually more economically viable and climatically appropriate, thereby contributing to natural energy conservation and a reduced carbon footprint of the finished building. Supporting a local

or regional economy is equally important as a cultural contribution. The choice of material is further complicated when one considers the manner in which it is used within the building or combined with other materials after reaching the site. Portland cement, for example, contributes about 8% of the carbon dioxide to atmospheric global warming (Zeihner, 1996). According to Robert Berkebile aluminium is the most energy consumptive material used in the building trade today (Zeihner, 1996). Besides the tropical rainforests being stripped to unearth the bauxite, a vast amount of energy is needed to process it into aluminium. However, 17 percent of aluminium worldwide is recycled which is significantly greater than most other building materials. Architects have the prerogative to specify the use of recycled instead of virgin aluminium in their designs, which would mean that 95% of the energy consumption and 96% of the pollution in the bauxite conversion process is avoided (Zeihner, 1996: 9).

Structural elements of South African homes are predominantly of fired bricks, concrete, steel and wood. With the exception of certified responsibly forested wood, most conventional building materials either use non-renewable resources as core ingredient and/or the operations involved in processing the raw materials into building materials are energy and resource intensive and polluting with a high waste coefficient. Roof cladding of typical residential buildings in South Africa can be divided into 3 main categories namely metal, tile and thatch. Although the harvesting of the raw materials and processing involved in manufacturing these cladding products do not have the significant negative environmental impact of structures made of concrete or structural steel, the use of non-renewable iron-ore and zinc deposits, chemical treatments, galvanisation, energy-intensive smelting and firing processes make metal and fired tiles not the most environmentally friendly options as roofing materials.

2.3 Natural Building

A mysterious and intangible force powers what has become known popularly in North America as 'natural building'. This indescribable energy motivates growing legions of urban architects to reassess their sophisticated habits, to turn off the computer, unlace their shoes, and stuff their day timers with straw. The passion is essential, elementary, and basic as breath. It springs from subtle yearnings and a conscious desire to reconnect with nature

– Lynne Elizabeth and Cassandra Adams (2005: xvii)

Building with natural renewable materials makes sense. It made sense to our tribal ancestors more than 10 000 years ago and it makes sense today. Sourcing, excavating and working with earth, straw, hemp, and bamboo is harmless to the environment and humans, construction processes are instinctive, simple, non-industrialised and manual labour intensive. Besides not producing any harmful waste, structures are insulated, structurally sound, remarkably comfortable to inhabit and exceptionally cost efficient (Elizabeth & Adams, 2005). Natural building or bio-architecture is a philosophy related to the implementation of intuitive practices and methods adapted from the vernacular to serve as viable alternative to the mass produced, energy consuming building materials of today.

Finally, and most important, is the intangible quality of spirit we find in natural materials and systems. I believe people are drawn to natural materials because they stand in opposition to the industrial appetite for disassembling the organic, for destroying the soul and spirit inherent in living materials.

– Sim van der Ryn (Elizabeth and Adams, 2005: xiii)

2.4 Sustainability in the South African Residential Built Environment

The most important considerations in conventional South African home architecture appear to be construction and material costs, comfort and aesthetics. A very limited, but increasing amount of newly built local homes today have been approached from an environmentally conscious perspective. Improved awareness are starting to immerge of the impact the building has on the natural environment through the manufacture and transportation of building materials, construction methods and daily operations once completed. Sustainable architecture not only refers to the environmental impact of a building, but also considers its socio-cultural context and economical viability.

With the current housing deficiency experienced in most regions throughout South Africa, government's social housing schemes are under severe pressure to provide basic low-cost shelters to the lower income public that are quick to construct and cheap to service and maintain. This instigated massive *Reconstruction and Development Programme* (RDP) housing schemes consisting of poorly constructed, mass-produced dwellings. While the depletion of natural resources and irreversible ecological damage are already evident in some regions where the housing schemes had been constructed, the social effect of this short-sighted 'band-aid' solution to the housing crisis will most likely manifest itself in the form of increased communal discontent of residents.

Only a handful of local sustainable low-cost housing projects have been initiated in the last decade, indicating that not all developers of South African low-cost housing are unaware of the long term effects of these housing schemes. Initiatives like MMA's submission for the *Design Indaba 10x10* competition and the *Earthbag System* are discussed in Chapter 3 as good examples of how an ethical design approach can employ and improve on vernacular building methods like the age-old practice of sandbag construction.

Eco-friendly natural building practices like adobe brick, straw bale, earth bag, rammed earth and mud brick construction not only frequently use renewable material sources that are locally available and significantly more affordable than the more commonly used building materials, but community involvement in the low-impact processing of the raw materials as well as in the construction of the building itself means that sustainable development is being addressed on all fronts. The limited use or total exclusion of non-renewable raw materials and harmful refinement processes as well as the minimisation of transportation from manufacturing site to building site, make the use of these materials particularly environmentally responsible.

Economically the benefits of these low-tech processes are plentiful. Firstly, simple inexpensive extraction and processing of natural building materials denote that the embedded energy and life cycle costs of such materials start off as being significantly lower than traditional building materials. Secondly, the simplicity of most natural and alternative building methods means that a large sector of the local community is able to participate in the material processing and construction processes. As the occurrence of unemployment is most prevalent in communities in need of low cost housing, cooperative construction arrangements are more likely to be successful, meaning labour costs can be kept to a minimum. A social bartering system could also take the place of the usual labour-for-wage exchange. Even in communities where the cost of labour is not a hindering factor, the participation of homeowners, neighbours and other community members in the construction process is widely seen as having an overwhelmingly positive social impact. The involvement of the local community in the building process instead of external contracted companies means that not only does the construction of these houses help to create employment and skills development opportunities, but also a strong sense of community and dignity.

CHAPTER 3: Architextiles

3.0 Introduction

Textiles are considered the fifth building material after wood, stone, glass and metal. Although more commonly used for interior applications, textiles have an array of uses either in a primary or secondary role in building construction. Some benefits textiles offer in building design include a remarkable coverage-to-weight ratio in lightweight tensile configurations, varying degrees of translucency to allow natural light to enter the building, simple and cost-effective construction methods and unique design possibilities not always feasible in other materials.

Translucent fabric enclosures provide affordable answers to the design of delightful and useful architectural space. Fabric enclosures are more economical than glass enclosed structures; and they are more desirable for environmental reasons

- Horst Berger (2006: xi)

In the case of earth-bag construction, textiles even offer a cost-effective solution in thermal mass construction and a way of using locally available renewable resources like sand, clay, and rubble to construct permanent dwellings that offer superior comfort to its occupants. Tony Robbin says in the preface of Horst Berger's publication *Light Structures, Structures of Light* (1996: xi):

Membranes communicate between inside and outside, they are membranes in the biological sense: passing through or filtering out different elements from both sides. Membranes can be engineered to pass or reflect light, heat, sound, or moisture in whatever combination of directions one chooses

3.1 Textiles in Architecture: From Vernacular to Cutting Edge

3.1.1 Textile Architecture Timeline

Table 3.1 Abridged timeline on the development of architectural textile structures (Kuusisto, 2010)

~500 BC	Military tents: Persia, Greece and Rome.
70-82 AD	Velaria over the Colluseum - First retractable tensioned textile roof: Rome, Italy.
1300s	Open court tents: Iran
1520	Henry Tudor VII's conical tent banqueting house: Calais, France.
1655	Swiss guild sanitary tent: Basel, Switzerland.
1770-1780	Turkish-style garden tents: Palace of Versailles, Paris France.
1837	British colonialist emigrant tents: Australia.
1854	Portable army tents (Joseph Paxton): Crimean War.
1917	Patent for the first pneumatic building (Frederick William Lancaster)
1920s	Studies on tensegrity, geodesic and pneumatic forms (Buckminster Fuller)
1936-1937	Temporary pneumatic structures: World War II
	Portable canvass airplane hangars: World War II
	US Military <i>MUST</i> pneumatic temporary combat hospitals: USA.
1940s	US Air Force pneumatic radar antennae and building enclosures (Walter Bird)
1950s	Pneumatic storage facilities, shelters and greenhouses by Birdair (Walter Bird)
1954	<i>The Hanging Roof</i> , first publication on textile architecture (Frei Otto)
	Air-transportable Dacron-clad helicopter hangars (Buckminster Fuller)
1955	Kassel Garden Show shade sail music pavilion (Frei Otto): Kassel, Germany.
1957	<i>Tanzbrunnen</i> pavilion, Cologne Garden Show (Frei Otto): Cologne, Germany
1959	Boston Arts Centre vinyl-coated nylon pneumatic roof: Boston MA, USA.
1960s	Oasis No 7, cell for living (Haus de Rucker)
1962	Pneumatic dome over Manhattan, conceptual design (Buckminster Fuller)
1967	Tensile membrane German Pavilion, Montreal Expo (Frei Otto, Rolf Gutbrod)
	Geodesic US Pavilion, Montreal Expo (Buckminster Fuller): Montreal, Canada.
1968	Gridshell, Mannheim Garden Exhibition (Frei Otto): Mannheim, Germany.
1970	The Arctic City, pneumatic conceptual design (Frei Otto, Ewald Bubner)
	American Pavilion, Osaka Expo (Davis Brody Assoc.): Osaka, Japan.
1972	Munich Olympic stadia cable net & membrane roof (Frei Otto et al): Germany.
1975	Pontiac Silverdome Air-supported dome: Detroit MI, USA.
1984	Riyahd Stadium (Horst Berger): Saudi Arabia.
1986	Canada Place, Vancouver Expo (Eberhard Zeidler): Vancouver, Canada.
1990	Seregosa Arena (Schleich Bergermann Und Partner): Seregosa, Spain.
1992	Grimshaw membrane facade, Seville Expo: Seville, Spain.
2008-2010	Cladding of stadia for FIFA Soccer World Cup 2010: South Africa

3.1.2 Vernacular Textile Structures

Arguably the most elementary and most vital function of any architectural structure is its ability to shelter its inhabitants from climatic elements such as rain, wind and solar radiation. Textile structures have for centuries provided this protection for nomadic and indigenous tribes of the Americas, Asia and Africa. Even today Bedouins live in low profile rectangular tents, which are assembled, dismantled or adapted with the wet and dry seasons. The accurate construction of their basic dwellings, made up of wooden poles, cords, and large stones as foundations, ensures the structure can withstand strong desert winds. The covering is a fabric made of camel or goatskin, and the sides of the tent can be rolled up to let the breeze in or tightly sealed during rain or sandstorms (Bahamon, 2004). This ability to adapt a structure to particular climatic conditions makes the Bedouin tents one of the first known examples of not only the incorporation of a passive climate control system but also an early example of a basic convertible architectural structure.



Fig 3.1 Traditional Bedouin textile tent (Source: www.maryostler.com)

In his book *The magic of tents: transforming space*, Bahamon (2004) suggests that while textile architecture is still generally associated with the needs of nomadic cultures for temporary, mobile and lightweight structures, advances in construction techniques and the types of textiles and fibres used in recent decades have expanded the potential for application to projects in

contemporary architecture. He continues by describing the influences of vernacular architecture on today's technically advanced textile structures and architecture in general. Architects like Le Cobusier, Adolf Loos, Frank Lloyd Wright, Bruno Taut and Walter Gropius among others found inspiration and used clear reference from the traditional and vernacular architecture of India, Japan and Africa in their designs of government buildings to single-family homes (Bahamon, 2004: 8).

One of the most apparent features of tents or, for that matter, any example of vernacular architecture is the close relationship between their function and the socio-economic context of the area in which they are found. Whether buildings are constructed for temporary or extended use, their structure and construction materials are linked to the resources available nearby. This suggests that most examples of traditional and vernacular textile architecture, by necessity and physical restrictions on the builders, already applied some of the basic principles of sustainable architecture centuries before the concept was first documented. This is also true in a socio-cultural context. In the Taureg culture as well as the Gabra culture of northern Kenya, Somalia, and Ethiopia, the word tent (mina or mana) is associated with the concept of marriage (mini fuda) and the setting up of a new household. Cultural, social, and family customs are clearly reflected, not just in the distribution of space in the tents, but also in their interior and exterior decoration (Bahamon, 2004).

Tipis are the well known traditional dwellings of the Native Americans of North America. These conical structures, like most vernacular textile habitats, were conceived as a housing system that would meet the needs of a nomadic people. Quick to assemble and dismantle and easy to transport by having the entire dismantled structure horse drawn, buffalo hide and later cotton canvass Tipis allowed the Native Americans to follow migrating Buffalo herds across the continent.



Fig 3.2 Traditional buffalo hide Native American Tipi
(Source: www.firstpeople.us)

3.2.3 Pioneers and Design Champions in Textile Architecture

The names and projects of certain architects and designers continue to appear in the literature on textile architecture and sustainable building practices. Some of the more prominent names, however, are Walter Bird, David Geiger, Horst Berger and Frei Otto.

Membrane structures were first introduced into building engineering by Walter Bird as air-supported domes in the late 1940s. These were continuously developed between the 1960s and the 1980s. Through his invention of low-profile air-supported domes and Teflon-coated fibreglass fabrics, and his cable dome designs, the late David Geiger was among those who made some of the most significant contributions to the development of membrane structures. Horst Berger, former partner of Geiger, played an equally important role in the development of membrane tension structures. While Geiger mainly concentrated on air-supported structures, Berger worked on fabric tensile structures, and their introduction into a wide range of permanent architecture (Berger, 1996)

In the 1950s and 60s, when Modernism was predominant, many talented architects and engineers, among them Felix Candela, Eero Saarinen, Kenzo Tange, Frei Otto,

Paul Weidlinger, Anton Tedesko, Yoshikatsu Tsuboi, and Heinz Isler, followed the pioneers Torroja and Nervi (Berger, 1996).

3.2.3.1 Frei Otto

A true pioneer in textile architecture, Frei Otto is known for creating an extensive new language of hyperbolic paraboloids, joints, anchorings, fibres, and turnbuckles. In 1957 Otto founded *The Centre for the Development of Lightweight Construction* in Berlin, followed in 1964 by the more famous *Institute for Lightweight Structures* at Stuttgart University. His work in tensile structure design started as far back as 1955 with the realization of a simple music pavilion at the Federal Garden Exhibition at Kassel, Germany (Vandenberg, 1996) and continued throughout the 20th century, providing a solid base of remarkable achievements for future textile architects and designers.

The advances made in the design of tension-loaded structures were significantly influenced by Frei Otto's work in the development of cable-net and pre-stressed tensile membrane systems. From 1959 onwards he used miniature models to investigate the sort of shapes that could be used for tensile membrane structures. By stretching nets, soap bubbles and elastic membranes he generated an extensive range of exciting double curvature shapes which he applied to a series of live projects such as the German pavilion at the Montreal Expo in 1967 and the 1972 Munich Olympic roof structures (Wilkinson 1996).



Fig 3.3 1972 Munich Olympic Stadium (Source: www.checkonsite.com)



Fig 3.4 The German pavilion at the Montreal Expo in 1967 (Wilkinson 1996: 111)

3.2.3.2 Buckminster Fuller

The name Buckminster Fuller is synonymous with pioneering and perfecting the design of the geodesic dome and other futuristic developments. Other architects and designers have copied and adapted his revolutionary designs to come up with some of the world's most revered architectural marvels.

Bucky, as he is affectionately known, is still seen today by many as a utopian who dedicated the biggest part of his adult life to the betterment of humanity. Fuller did not limit himself to one field but worked as a 'comprehensive anticipatory design scientist' to solve global problems surrounding housing, shelter, transportation, education, energy, ecological destruction, and poverty. A visionary ahead of his time, Fuller developed structures using geodesic fractions in attempts to pare down and economise on materials and weight. He has been lauded by some as foretelling sustainable architecture decades before the term was coined. Jonathan Massey (in Chu & Trujillo, 2009: 121) states: "Fuller's commitment to geometry for a combination of structural, planning, and aesthetic reasons was based on its potential for effectiveness in rationalising production and consumption through the liberal mechanisms of democratic polity and a market economy."

Hsiao-Yun Chu (2008: iv) says in his introduction to *New Views on R.Buckminster Fuller*:

Actually, Fuller's major contribution to society as a whole may have been ideological, the artefacts serving only to illustrate a continuous discourse that unfolded across his lifetime.

The application of textiles to some of the structures Fuller developed, although not the main focus or essential to the conceptualisation of those structures, played an important role in the realisation of his futuristic concepts. In turn, the application of textiles to geodesic domes, for instance, influenced the perceptions and associations people had with textiles, seeing it in the novel role of exterior cladding material.

The *Buckminster Fuller Challenge*, launched in 2007, promotes a systems approach to design pioneered by Fuller which aims to address complex problems through comprehensive, anticipatory design thinking. Through the recognition of outstanding submissions, the challenge supports and draws attention to individuals and teams around the world whose innovative strategies have the potential to help solve humanity's most pressing problems in a holistic and sustainable manner (www.bustler.net, 2009)

3.2 Architextiles in Roof Applications

3.2.1 Introduction

Although the use of natural construction materials as well as design elements inspired by vernacular building practices have seen a revival under the *eco-friendly* and *green* architecture banners of late, a large contingent of recycled brick, adobe, straw-bale and responsibly forested wooden buildings have corrugated iron and fired ceramic tile roofs, reminiscent of a bygone environmentally insensitive era.

Some of the latest developments in textile technology, however, have increased the possibilities for permanent roof and even wall structure designs using advanced textiles, thereby offering a viable and possibly more sustainable alternative to traditional building materials. Structurally and aesthetically, flexible membranes offer an array of economical and unique

construction possibilities not easily achieved in metal, ceramic tile or thatch roofing configurations. The flexibility, weight-to-coverage ratio and translucency of fabrics have led to them being incorporated in many public buildings across the globe, helping to create structurally and visually advanced architecture and providing ground-breaking foundations for new sculptural building designs not previously feasible.

Roofs were created to meet man's need for protection against the elements. Each climate may require a different type of roof according to the level of protection required by the building and its occupants. A building's roof is the structural element that is subject to the greatest changes in temperature, and therefore the greatest amount of expansion and contraction. The type of roof selected for specific buildings depends fundamentally on the client brief, environmental considerations, the climatic conditions and the resources available. Roofs generally perform the functions of protection and insulation, and should, according to Chueca (n.d), meet the following requirements:

- **Acoustic insulation:** This includes insulation from aerial, impact and other ambient noise. This requirement is particularly relevant when looking at textile roofs.
- **Thermal insulation:** the incident heat affecting the building by direct radiation is an important factor in the thermal balance. As it is impossible to prepare materials that selectively reflect the thermal radiation in summer and absorb it in winter, a double-layered roof solution is usually required, in which the exterior layer takes advantage of the solar gain and the interior layer creates shade for cooling. In textile roofs, a layer of insulation material or trapped air between the exterior and interior layers can add significantly to the roof's thermal insulation.
- **Waterproofing:** As the pitch of the roof increases, so does the rate at which the water runs off it, reducing the amount of time it remains on the roof and the risk of penetration. Materials with a low water absorption coefficient and wide material widths are preferable as a reduced number of joints minimises the risks of infiltration.
- **Wind protection:** roofs resting on a continuous slab formed by joists and a sealed upper deck is more likely to be virtually windproof but at the same time is more exposed to solar radiation and moisture.

Sufficient tension should be present in a tensile membrane roof to be able to withstand strong winds.

- **Static and dynamic stability:** the roof must support its own weight as well as extra loads caused by maintenance, water, snow or hail, and the suction of the wind.
- **Fire safety:** the structure of the roof must offer fire stability to allow for the evacuation of the inhabitants. The resistance to fire of the roof must not be excessive as it is one of the escape routes for fumes and heat.
- **Durability** of the materials are vital for the longevity of any roof structure

3.2.2 Tensile Structures

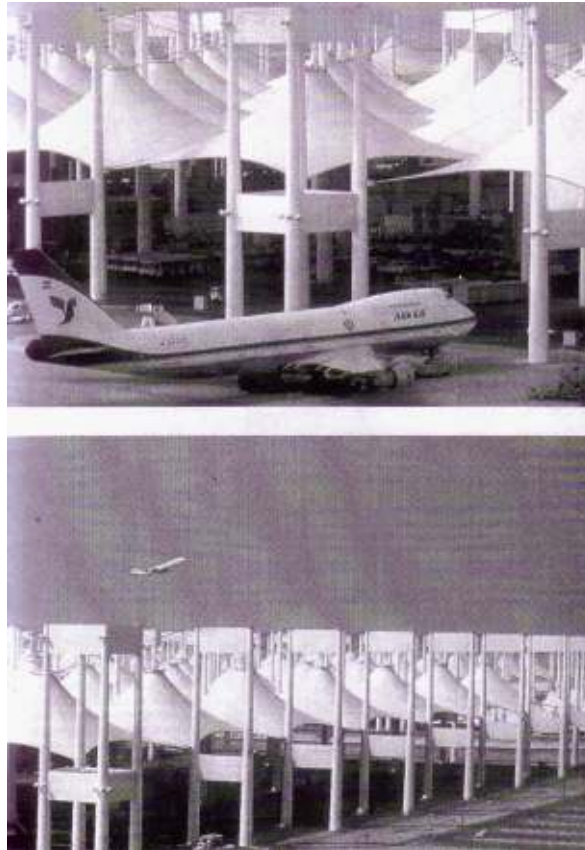
Being made of light and flexible materials such as woven, coated fabric, and high strength cables, they (tensile textiles) lack the gravity and rigidity which are the basis of structural strength in conventional building support systems. Instead, curvature and internal tension – similar to that which determines the pitch of a drum or holds the shape of a soap bubble – are the properties which make a tensile structure capable of resisting loads.

– Horst Berger (1996: 2)

Tensile fabric roofs are perhaps the most widely recognised of all types of textile architecture. Tension and complex curvature of the textile membrane are what give these roofs their distinctive organic sail-like shapes. Most often seen in the design of sport stadia and temporary shade canopies, they offer an exceptionally economic and aesthetically interesting way of covering a space while still allowing natural light to penetrate.

To keep a curved surface in tension while it carries upward suction from wind and downward loads from rain and snow requires a careful balance of curvatures in opposite directions. The curved surface needs to be stretched between support points above the surface, below it, and on all sides around its periphery. These geometrical requirements are common to all tensile surface structures and give them the shape by which they are instantly recognised. Curvature is a vital aspect of the structure. The shape of the structure cannot be arbitrary but derives from the structural function. Form not only follows function, but the two become inseparable (Berger, 1996: 2).

By allowing tension instead of compression to be the main force keeping a structure's shape, the size of tensile membrane structures are virtually limitless. The *Haj Terminal* roof at the airport in Jeddah, Saudi Arabia, for example, is the largest roof structure in the world while the roof over the Riyadh Stadium is large enough to fit the entire Houston Astrodome inside the circle of its support columns.



**Fig 3.5 - 3.6 Haj Terminal, Airport in Jeddah, Saudi Arabia
by Horst Berger (Source: Berger, 1996)**

The *Aura House* is located between two high rise buildings, a typical Japanese 'eels nest' site. The challenge was to bring light and air into the house without the possibility of installing windows. Concrete walls run down either side of the site so it was decided to stretch a translucent membrane between them as roof covering. In order to sustain tension in the fabric, a complex curve was created by incorporating a wave-profile in the two opposing walls which is identical but reversed. The opposing ridge lines of the walls cause the orientation of the cylindrical concrete beams bracing them to twist along the length of the building – despite appearances, a rational structural solution.

” The fabric skin filters sunlight by day, and glows by night: the building pulses, 'breathing' light with the 24-hour rhythm of the city” (Chueca, n.d: 100)

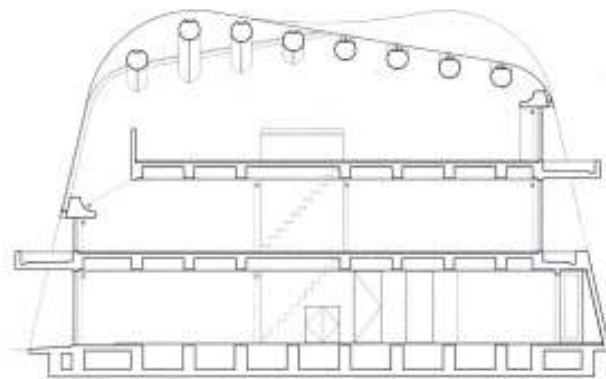
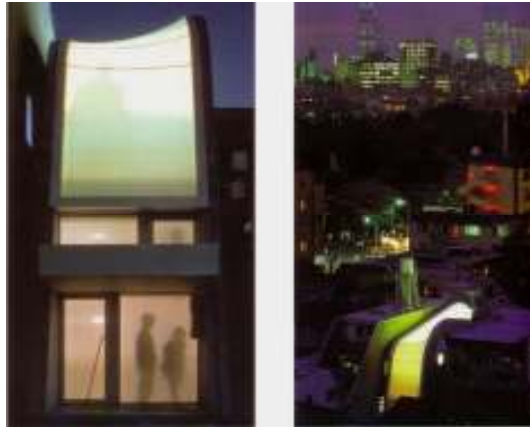


Fig 3.7 - 3.8 The Aura House, Japan (Source: Chueca, n.d)

3.2.3 Pneumatic Structures

The extent of textile applications in architectural roofing structures is usually perceived as limited to that of tensile membrane designs. Contrary to this common perception, numerous other applications have been developed and are part of the large palette available to leaders in structural design. Pneumatic textile configurations have for the most part been used as temporary structures, where a large coverage-to-weight ratio, quick assembly and dismantling, easy transportation and a novel aesthetic had been the main considerations. The development of synthetic fibres such as nylon and improved techniques for coating fabrics led to the appearance of the first pneumatic buildings during the Second World War.

The US Army's *MUST*-shelters use pneumatic systems for quick-deployable field hospitals and canteen facilities and due to logistical and weight restrictions in space exploration, NASA has developed several concepts for space stations and

extraterrestrial centres based on pneumatic principals (Kronenburg, 1995). There has been and currently are several examples globally of large column-free spaces like sport stadia and exposition pavilions using pneumatic roofs.

The American Pavilion at the Osaka Expo '70, designed by Davis Brody Associates, was a low-profile oval shaped membrane dome measuring 142m x 83m seated on a saucer-shaped bowl, partly dug into the ground and mounded around (Wilkinson 1996:114)



Fig 3.9 - 3.10 The American Pavilion at the Osaka Expo '70
(Source: Wilkinson 1996)

The *Pontiac Silverdome* in Michigan USA with a span of 228m is one of the largest air-supported cable-restrained fabric roof structures in the world. Covering 4 hectares, it houses an 80 000 seat covered football/ multi-purpose stadium used by the Detroit Lions and extensively for concerts. The structure by Geiger Berger Associates is domed by a single membrane translucent cable-restrained air-supported roof with a total structural weight less than 4.8 kg/m² (Wilkinson, 1996:114).

Although Pneumatic structures make economic sense in terms of material usage and significantly reduces the need for additional support as in ordinary compression-type structures, to keep a roof or entire building inflated permanently seems excessive and unwarranted, especially when looking at residential architecture.

3.2.4 Dome Structures

The occurrence of round, dome-shaped structures goes back about as far as the human need for man-made dwellings. Domes made of branches, mud, thatch, skins, leaves, stones or ice have been around for literally millions of years. Vernacular structures considered by the modern architecture fraternity as primitive, like wigwams, yurts and igloos show a profound understanding of some incredibly sophisticated and intricate engineering principles.

Dome structures serve as proof that convexly curved surfaces are stronger and more stable than flat planes, that most materials are stronger in tension than in compression, that prestressing members by fashioning them in curves adds integral strength, and that a hemisphere encloses the greatest amount of space with the least amount of material. A dome conserves thermal energy better than any other shape, because the least possible surface is exposed to exterior climatic elements. The shape also encourages natural air circulation and thereby facilitates the incorporation of passive ventilation systems (Prenis, 1973: 1).

In 1951 Buckminster Fuller patented the geodesic dome, a method for constructing a spherical surface by subdividing it into triangles. Geodesic domes are entirely made up of a network of interlocking triangles, the only inherently rigid structural configuration, making the geodesic dome the strongest, lightest, most efficient building system ever devised. A load applied at any point on the structure is spread over the adjacent members and shared among them, making it not only the ultimate structural configuration for otherwise weak or flimsy materials, but also the ideal shape for conceiving large, column-free interiors. More benefits of geodesic domes include its aptness to mass production because of the high frequency of identical parts, its quick and uncomplicated assembly because of its simplicity, and its transportability because of its light, flat, relatively small components (Prenis, 1973: 1).

Ethylene tetrafluoro ethylene (ETFE) has been used very effectively in a network of pneumatic cushions on a galvanised steel space-frame biomes (domes used to shelter

plant-life) at the *Eden Centre* in Cornwall, UK. Each dome structure, designed by Nicholas Grimshaw and Partners, consists of an icosahedral geodesic outer layer, with a combination of hexagons, pentagons and triangles as the inner layer of the three-dimensional space-frame. A small inflation system, powered by photovoltaic cells, is all that is required to maintain the necessary air pressure required by the ETFE cushions (Lyons, 2007: 283)



Fig 3.11 – 3.12 Eden Project by Nicholas Grimshaw and Partners
(Source: www.edenproject.com)

In some dome designs, mostly experimental, textiles like hemp, hessian or burlap canvass provide the necessary structural integrity by offering an interlocking base for the compression structure primarily consisting of earth or concrete plaster. The *Low-Tech Balloon System* by *TechnoCraft* uses a large inflatable airbag or bladder to give a building its distinctive shape, but only for the duration of the construction process. *TechnoCraft*, a Japanese Architecture Group entered it's *Low-Tech Balloon System* into Architecture for Humanity's 1999 Transitional Housing competition and got credited for designing " by far one of the most unusual transitional structures Architecture for Humanity has ever come across" (Architecture for Humanity 2006: 118). The design calls for hemp sacks, in this case animal feed bags, to be sewn together to form a dome-shaped structure. The textile structure can be prefabricated off-site or assembled by a local cottage industry in the vicinity. On site the 'hemp skins'

are connected via plastic ties and attached to the so-called “life elements” (doors, windows, and facilities for cooking, sanitation, and storage). Workers inflate specially made airbags inside the structure, tighten the plastic ties, and dampen the entire structure. They then apply mortar over the dome to create a thin concrete shell. The structure keeps its shape during the mortar application process thanks to the pressure from the airbags, making additional construction aids such as scaffolding or support beams unnecessary. Once the mortar has dried, teams cut out excess hemp from the openings, deflate and remove the reusable airbags, and plaster the interior, creating a waterproof, insulated shell. Individual units can also be combined to create larger living spaces.



**Fig 3.13 Low-Tech Balloon System by TechnoCraft
(Source: Architecture for Humanity, 2006)**

3.2.5 Convertible Roofs and Architectural Umbrellas

The integration of architectural umbrellas is an example of a novel approach to the art and science of constructing with textiles. Frei Otto led the way with his parasol designs for a garden show in the 1950s and also large convertible umbrellas for the Federal Garden Show in Cologne in 1970.

Probably the most well known example of architectural umbrellas is the installation of 12 giant square convertible umbrellas (1992) in the internal courtyards of the Prophet’s Mosque in Medina, Saudi Arabia (Rasch, 1995: 23). While the fabric structures produce shelter from the sun’s heat and UV-rays through its deployment during the

day, the closed umbrellas after sunset allow the floor and walls to radiate heat to the cold night sky. This passive air-conditioning system is further enhanced by the columns supporting the umbrellas acting as cold-air ducts or cooling towers by incorporating fine water jet nozzles.



Fig 3.14 – 3.15 The Prophet's Mosque in Medina, Saudi Arabia
(Source: www.bjsallahwalay.com)

3.2.6 Green Roofs and Earth Roofs

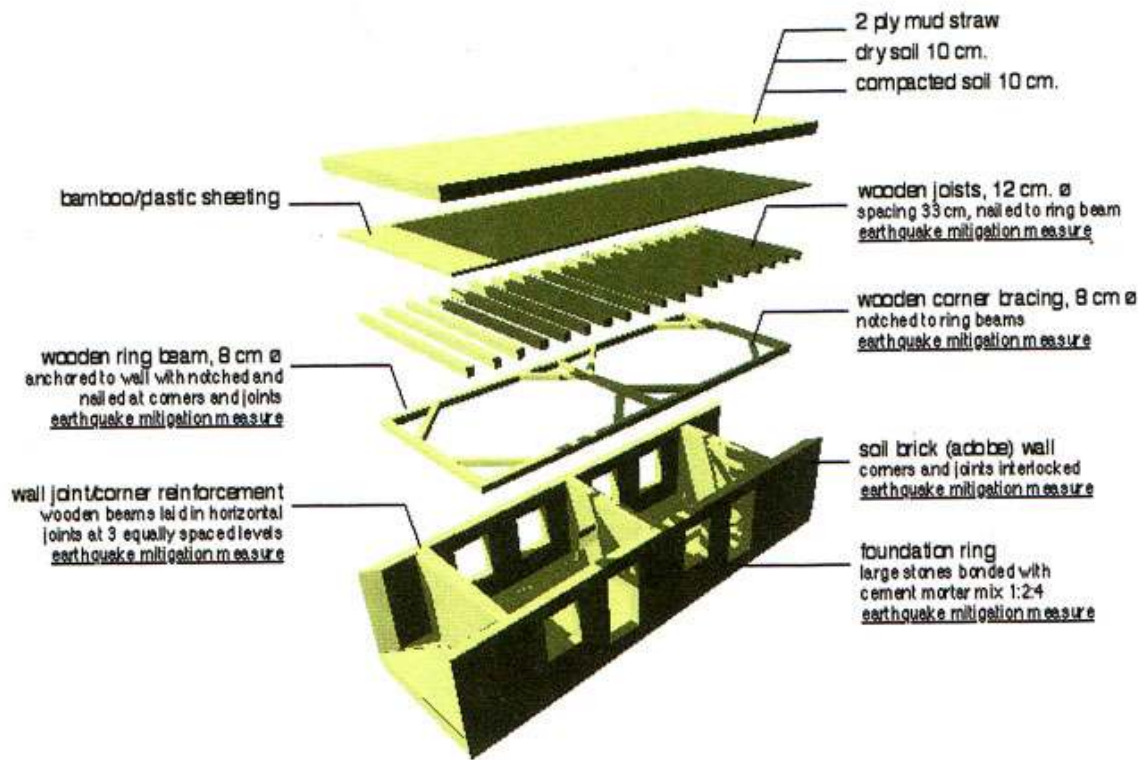
Extensive and intensive green roofs incorporate textiles in their composition mainly to form a waterproof layer to the primary weight-bearing structure of concrete, wood or bamboo. The membrane stops water from penetrating the roof and reaching the interior of the building. It generally consists of bituminous or synthetic prefabricated sheets that are overlapped and welded to give the roof continuous barrier against infiltration (Chueca, n.d: 60) The vegetation covering these roofs serves as ecological storm-water management systems by eliminating or delaying water run-off. It also reduces the temperature of the roof surface by absorbing solar heat (Yeang, 2006: 448). Earth is an excellent insulator and a green roof or earth roof generally does not

need additional insulation layers or even a ceiling structure to regulate the indoor temperature of the building it covers.

When a disastrous earthquake rocked Northern Afghanistan in 2002, *Shelter For Life* was called on to supply emergency shelter to some 30,000 people. Instead of providing winterised tents as they did previously, the organisation opted to build permanent housing for roughly the same cost as a tent (USD 610 per house). A total of 5000 adobe shelters in 76 villages were constructed with the help of local residents. Each adobe brick house incorporated a soil roof consisting of a 2 ply layer of mud and straw, a 10cm layer of dry soil and a 10cm layer of compacted soil on top of a sheet of bamboo and/or plastic supported by a series of wooden joists and a wooden ring beam. The construction of the roof forms part of seismic-mitigation features incorporated into the shelter's design to help prevent damage in future disasters (Architecture for Humanity, 2006: 133).



**3.16 Adobe Shelter by Shelter For Life, 2002
(Architecture for Humanity, 2006: 133)**



**Fig 3.17 Exploded View of Adobe Shelters by Shelter For Life, 2002
(Architecture for Humanity, 2006: 133)**

3.3 Architextiles in Wall Applications

3.3.0 Introduction

This section looks at all types of wall construction methods incorporating textiles. From earth-bag or sandbag construction, an alternative natural building method using fabric bags filled with soil for constructing familiar compression-type structures to the role of geotextiles in retaining soil stability in earth-sheltered architecture to lightweight fabric panels using tensile forces and curvature to provide sturdy facades to the primary load-bearing frameworks. It explores how textiles can replace or otherwise enhance traditional wall building materials used in conventional building design which segregates the structure into separate roof, wall and floor segments.

3.3.1 Earth-bag and Super-adobe Wall Construction

Sandbag construction falls under the category of alternative building practices or natural building methods in today's terms and uses woven fabric bags filled with soil and piled up on one another to form massive structures. The technique is seen as a category of earth architecture along with rammed earth construction, cob, adobe, mud brick and the likes. In this instance the strength and durability of the fabric bags are essential to the longevity of the structure itself. Possibly one of the simplest, most economical and also most environmentally friendly wall construction methods used today, it serves as a prime example of the role textiles play in addressing the triple bottom line in sustainable architecture.

The *California Institute of Earth Art and Architecture* or *Cal-Earth* is a non-profit foundation focussed on the development of earth and ceramic architecture technologies. Founded by architect Nader Kahlili, its scope spans technical innovations published by NASA for lunar construction to housing design and development for the world's homeless through projects instigated by the United Nations (www.calearth.org, 2011). Kahlili developed what he termed *Superadobe*, a construction method using long sand-filled synthetic textile tubes and barbed wire. Long or short sandbags are filled with on-site earth and arranged in layers or long coils (compression force) with strands of barbed wire placed between them to act as both mortar and reinforcement (tensile force). Stabilizers such as cement, lime, or asphalt emulsion are sometimes added (www.calearth.org, 2011). Research conducted by the foundation has shown that bags of both natural and synthetic material can be used, however natural woven jute bags are not used because of toxic chemical preservatives like formaldehyde. Instead, polyethylene, a degradable material with low ultra violet (UV) resistance has been preferred. The bags or long tubes serve primarily as temporary flexible forms. In a temporary structures, the bags are allowed to degrade and the building returns to earth within months of construction. For permanent structures, the synthetic bags are plastered over to provide an erosion resistant layer. Cal-Earth's sandbag structures, reinforced with barbed wire, have successfully passed tests for California's high seismic building codes and are considered resistant to earthquakes as well as fire, flood, and hurricanes. Their design and thermal mass create comfortable living spaces based on the time-tested, sustainable architecture of harsh environments like Kahlili's native Iran (www.calearth.org, 2011).



Fig 3.18 Cal-Earth Ecodome construction (Source: www.vestaldesign.com)



Fig 3.19 Superadobe structures by Cal-Earth (Source: www.roomu.net)

3.3.2 Earth-sheltered construction

Earth-sheltered architecture is the design of buildings that are partially or totally below the ground, using the consistency in temperature of deep earth in a location to improve energy efficiency while decreasing maintenance and environmental impact of the building. In some cases, geotextiles like geogrids, geomeshes and geonets provide reinforcement of soil roofs, walls and steep rock or soil slopes. The mechanical

interlock between the grid and the substance it is reinforcing creates a flexible but stiff platform, which assists in distributing loads evenly (Braddock Clarke & Mahony, 2005).



Fig 3.20 Geotextiles & geomeshes
(Source: Braddock Clarke & Mahony, 2005).

3.3.3 Textile Cladding and Panelling

The use of textiles for cladding and panelling of permanent structures is usually limited to particular sections where an economical solution for protection against the elements is of more significance than acoustic- or thermal insulation. The Services Tower in Ipswich by Michael Hopkins Architects demonstrates the use of fabric as an alternative cladding material to a steel panel or masonry construction. The fabric is stretched over a 2m square steel frame and pushed out with a stainless steel ring structure to create a curved tension-loaded shape. The panels, which are fitted to the inside of a tubular steel structure, form a translucent envelope to a stair and lift tower which was added onto the face of an existing car parking building. In this example, fabric provides an economical, weather-tight enclosure where the control of temperature was not a priority (Wilkinson 1996: 111)

The simplicity of extruded forms has been adopted for a wide range of architectural applications worldwide and has been used by many designers to meet specific requirements. A particularly innovative interpretation was completed by Alsop, Lyall and Stroner for the *Cardiff Bay Visitors' Centre*. Here the architects, working with structural engineers Atelier One, have used a complete oval cylindrical section for the

long vaulted structure, constructed of plywood panels bolted onto mild steel ribs. A fabric membrane provides the watertight skin around the plywood, out of which shapes are cut in an unusual pattern to admit light. The whole structure is raised off the ground on a steel undercarriage and the simple clean form of the building makes a dramatic appearance in the Cardiff Bay Dockland setting (Chueca, n.d: 62)



Fig 3.21 Cardiff Bay Visitors Centre (Source: Chueca, n.d)

Another example of textile cladding or cloaking of a structure is MMW Architects' *Fhiltex-X* moveable home design. The structure consists of two 20 foot x 40 foot steel shipping containers bisecting each other at a 90 degree angle to form a cross profile that rests on a simple four-pillar support structure. It was designed to be totally self-sufficient, incorporating solar panels for electricity generation as well as tanks for drinking- and waste water storage. Its hinged staircase, external insulation cloaking and minimal substructure all fit inside the containers when transported to be erected in a different location.

The waterproof, multi-layered cloaking textile provides the necessary insulation to make the shipping containers habitable (Echavarria, n.d: 143).

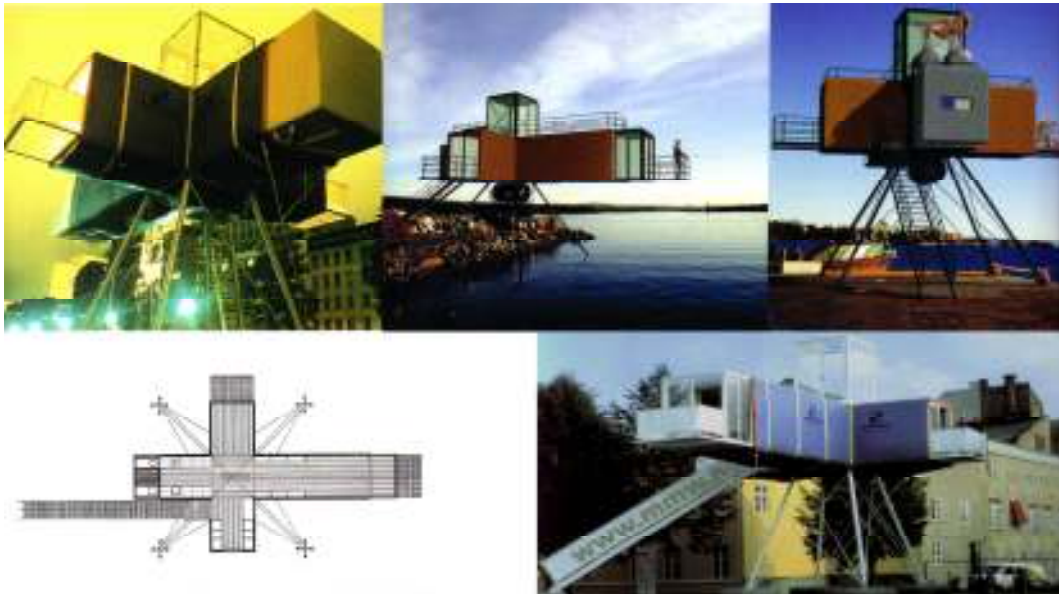


Fig 3.22 Fhiltex-X by MMW Architects (Echavarria, n.d: 141).

3.3.4 Textile-reinforced Cement

The principle of reinforcing cement using metal rods, grids and fibrous additives is known worldwide and has proven to add significant strength to cement and concrete components in various applications within construction. By incorporating woven cloth into the composition of cement-based construction components saves between 80 and 90% on the amount of cement needed (Van Lengen, 2008). At *TIBA*, a centre for bio-architecture and ecological building techniques in the coastal jungle of Brazil, founder architect Johan van Lengen developed a technique for reinforcing cement panels and arches with repurposed woven plastic fruit packaging bags. The open-weave plastic mesh is soaked in cement slush and sandwiched in the casting process between two 6mm layers of cement, creating different cement panel profiles that can be used for cladding panels, structures like reservoirs, concrete shell vaulted panels for roofs or slabs, or door and window lintels. Because of the vaulted profile of concrete shell panels, a panel (3cm thick on the sides and 1cm thick along the centre axis) of up to 4 m long and 50cm wide are used in the construction of elevated floor slabs and green roofs. (Van Lengen, 2011) The images below show the application of textile-reinforced panels at TIBA.



Fig 3.23 Textile-reinforced vaulted concrete shell panels at TIBA, Brazil
 (Photos: F.De Flamingh)



Fig 3.24 Dry Toilet being assembled from textile-reinforced cement panels
 (Photo: F. De Flamingh)

3.4 Unique Features and Benefits of Architextiles

Introduction

One integrated structure... does all the things which in conventional buildings requires the combination of many additive elements, demanding the expert attention of numerous specialists for their design... This integrated approach to building design is largely foreign to the segregation and specialization which pervades the design and construction process today, a result of the technological and scientific advances of the industrial age. It resembles much more the ways of the pre-industrial architect

-Horst Berger (1996: 3)

The main attributes of architextiles that set them apart from conventional building materials typically relate to their light weight, high strength, flexibility, translucency and ease with which forms can be achieved through the application of minimum energy and simple processes. Structures made of textiles or incorporating textiles display unique features, liberating forms from the rigidity and limitations imposed by the use of unyielding substances. Stretch, tension, inflate, collapse or unfold elements of or entire housing structures, textiles inspire elegant organic shapes hardly conceivable in other materials. Perhaps the most unique feature of textile-based structures is that a different set of rules seem to apply to structures of this sort. Mamoru Kawaguchi, in his foreword of *Light Structures – Structures of Light* (Berger, 1996: xiii) states:

Their structural components - poles, cables, struts, roof, wall surfaces and all connecting joints – are visible both from outside and inside, in a composition necessitated by their function: namely the transmission of forces. This is in direct contrast to ‘ordinary’ structures, where structural components are usually hidden behind finishing elements, and whose textures and forms are considered more comfortable to the human eye and tactile senses. Although light structures may be painted, galvanised, or plated, the structure itself, being clearly visible, becomes the architecture of both form and space.

3.4.1 Lightweight structures

Textiles as building material can in a lot of ways be seen as the modern day solution in man’s pursuit of ever lighter structures. Massive masonry arches and domes, weighing several tons per square meter, were for a long time the only means of achieving large spans. The advent of iron and steel during the 19th century enabled engineers to reduce the weight of roof structures to a few hundred kilograms per square meter. (Berger, 1996). A similar lightness in concrete, using thin shell construction became possible in the 1920s, whereafter further development in structural engineering accelerated the inclination towards even lighter structures, such as space frames, cable structures, and finally, fabric membranes (Berger, 1996).

Even compared to today’s convention of brick and mortar, frame structures clad with lightweight textile panels allow structures to perform all the functions of regular buildings while simultaneously exhibiting superiority in economy of structural support materials, adaptability of the structure and maintenance. Lightweight structures are

easier, more economical and more energy efficient to assemble, maintain and dismantle at the end of the product life.

3.4.2 Material-to-coverage Ratio

A major objective in the development of especially large-volume buildings has been achieving greater spans with less material. Also, because of the current global economic recession and massive housing backlogs in the developing world, new construction methods and newly developed materials offering economy in material usage while maintaining adequate spatial coverage are overall favoured for those obvious reasons. Currently, computer-aided stress analysis makes it possible to pare down the size of structural members to the absolute minimum.

Continuous development in and the refinement of tensile fabric structures and pneumatics have enriched the vocabulary for lightweight structures. Wilkinson (1996) asserts that the most suitable structural systems are more likely to be of a tensile or pneumatic type with fabric covering for cost effectiveness rather than a space grid structure.

...With the continuing threat of economic recession, the soaring cost of energy and the accelerating depletion of our natural resources, the essence of Buckminster Fuller's Dymaxion concept for achieving 'more for less' seems ever more relevant, and the future of lightweight structures ever more promising

- Wilkinson (1996: 98)

Textile membranes offer an extremely lightweight form of enclosure and their low self-weight makes long spans achievable with the minimum amount of structure. The usual shortcomings on thermal and acoustic performance can to some extent be remedied by the use of double-skin construction (Wilkinson 1996). The possibility of incorporating insulation into the cavity of double-skinned membranes and to control solar gain by the use of reflective surfaces was proposed by Dr Laing at the First *International Colloquium on Pneumatic Structures* in Stuttgart 1967 (Wilkinson 1996:113).

3.4.3 Construction Cost & Time

Compared to other building practices, textile structures offer the unique opportunity of prefabricating units off-site where centralised production lines are set up and

resources like 3-phase electricity are at hand. This reduces on-site construction time considerably and means that preliminary construction is not ceased when bad weather or unforeseen complications slow down the construction process on site. Even if units are not assembled off-site, construction time is considerably less than building with concrete, wood or glass. Significant cost savings are possible due to time savings on the construction process' equipment hire and labour as while a smaller labour force is required to assemble lightweight units than with conventional construction practices.

Frei Otto's team, for instance, took approximately 20 000 hours to complete the design of the German pavilion at the Montreal Expo 1967 but only three and a half weeks to erect it. The spans of about 45m were not ground-breaking but a new and effective system for providing lightweight large volume enclosures had been clearly demonstrated (Wilkinson 1996: 110).

3.4.4 Material Transportation/processing

Because textiles are thin, flexible and lightweight, packing and shipping are usually exceedingly simple and affordable compared to most other building materials. Prefabricated units can also be manufactured off-site and transported with relative ease to be assembled at the building site. Although specialised software is needed for the design of fabric canopies, converting textiles into custom made membranes takes relatively few processes with varying degrees of complexity and involves limited light industrial machinery from sewing machines to hot-air welding units.

5.4.5 Textile Architecture in Extreme Environments

With the low weight-to-coverage ratio of fabric membranes, it has been proven that it is technically possible to enclose extremely large spaces, even entire cities. A study was conducted by an international design team led by Frei Otto and Ewald Bubner with Ove Arup and Partners and Kenzo Tenge to investigate the possibility of constructing an entire city in the Arctic and covering it with a transparent inflated skin of 3 square km. The primary objective was to create an artificially controlled climate corresponding to European conditions for up to 45 000 inhabitants in areas where the natural climate is extreme and inhospitable. The team proposed a cable-net of high-strength polyester fibres with cables of 270mm diameter at 10m intervals spanning 2km with a height of 240m. Anchoring would be by means of a ring foundation (Wilkinson 1996:114).

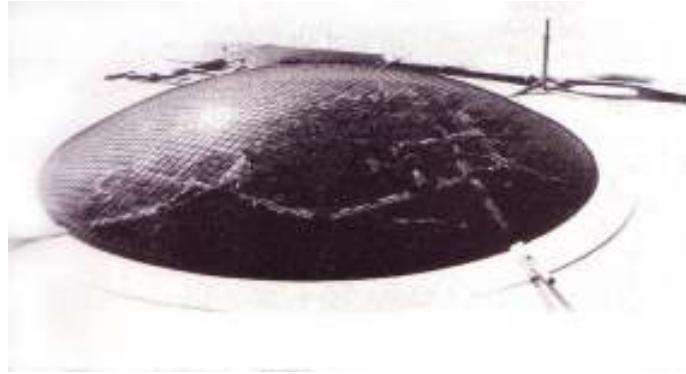


Fig 3.25 Arctic City Concept by Frei Otto et al (Wilkinson 1996:114)

3.4.6 Unique Architextile Structures

3.4.6.1 Geodesic structures / Space frames

Although not always covered in textiles, space grids and frame structures optimise on two of their unique features, light weight and achieving large column-free spans, by using fabric membranes as cladding material. Especially in temporary configurations textile cladding makes sense for ease of assembly, transportation and reuse of the same material on different sites. Buckminster Fuller's geodesic structures, which through their ease of prefabrication, have contributed much to the popular use of lightweight domes.

The geodesic dome uses the icosahedral division of a spherical surface into 20 equilateral triangles, each of which are subdivided into six triangles by drawing medians and bisecting the sides of each triangle. This complex geometry called 'energetic and synergetic geometry' by Buckminster Fuller has made it possible to construct domes of virtually any size out of prefabricated linear units (Wilkinson 1996: 103)



Fig 3.26 Dome house by Buckminster Fuller
 (Source: richardjafferty.files.wordpress.com)

Fig 3.27 Geodesic dome by Geodomehome (Source: www.geodomehome.com)

Fig 3.28 Dome space by Zendome (Source: www.inhabitat.com)

3.4.6.2 Air-supported Structures

As mentioned earlier in this study, pneumatic structures offer a whole spectrum of possibilities within the category of textile architecture. More frequently used in transient architecture, permanent and semi-permanent structures like stadium roofs and enclosed sports- and exhibition facilities demonstrate the benefits of this lightweight, economical way of enclosing large spaces. Air-supported structures are flexible, space-enclosing membranes which are tensioned by the difference in air pressure between the enclosed space and atmosphere. They are usually characterised by double curvature shapes, although there are hybrid-forms which use tension cable support and restraint (Wilkinson 1996: 98)



Fig 3.29 - 3.32 Innovative pneumatic structures by *Inflate*, UK
 (source: www.core77.com)

3.4.6.3 Floating Houses and Cities

Although mostly conceptual design fantasies at present, the idea of floating habitats has been explored by designers since the 1950s. With the reality of global warming threatening to decrease the little inhabitable landmasses left on earth, these mocked concepts of yesteryear have become viable and arguably essential concepts of today. Pneumatic textile structures and shells of glass matting- resin composites play an important role in most floating habitat concepts, especially in smaller floating houses.

A Flying saucer-shaped floating shelter called *Les Anthenea* was conceived by Jean Michel Ducanelle as half house, half submarine and allows its inhabitants to enjoy marine and coastal environments without damaging these fragile ecologies (Echavarria, n.d: 92). The modular units are constructed of composite polyester-fibreglass and are assembled on land after which the unit can be towed out to sea or transported by helicopter to the final marine or land-based site. The circular floatation ring of roto-moulded polyurethane (PU) serves as a platform or terrace for deck chairs, diving or boat landing and also provides a protective crash-barrier around the main housing unit. The unit can also be converted into a catamaran by adding an optional frame and with floating water skis.



Fig 3.33 *Les Anthenea* by Jean Michel Ducanelle (Echavarria, n.d: 92)

The *Hydrahouse* by Jennifer Siegal is a modular structure responding to issues of global warming, water desalination and recycling. It consists of structural stalks that provide the internal structure as well as means of generating renewable electricity (via photovoltaic solar panels with kinetic solar tracking), water collection & filtration (via an expandable fabric rain water collector), water desalination and waste water treatment (via water filtration rings). The outer pneumatic skin is of neoprene, a synthetic rubber sheet more commonly used in the manufacture of wetsuits. Each Hydrahouse comes with a separate pneumatic floating garden attached to the main unit via a flexible 'umbilical cord', which also supplies the garden with desalinated water. (Echavarria, n.d)

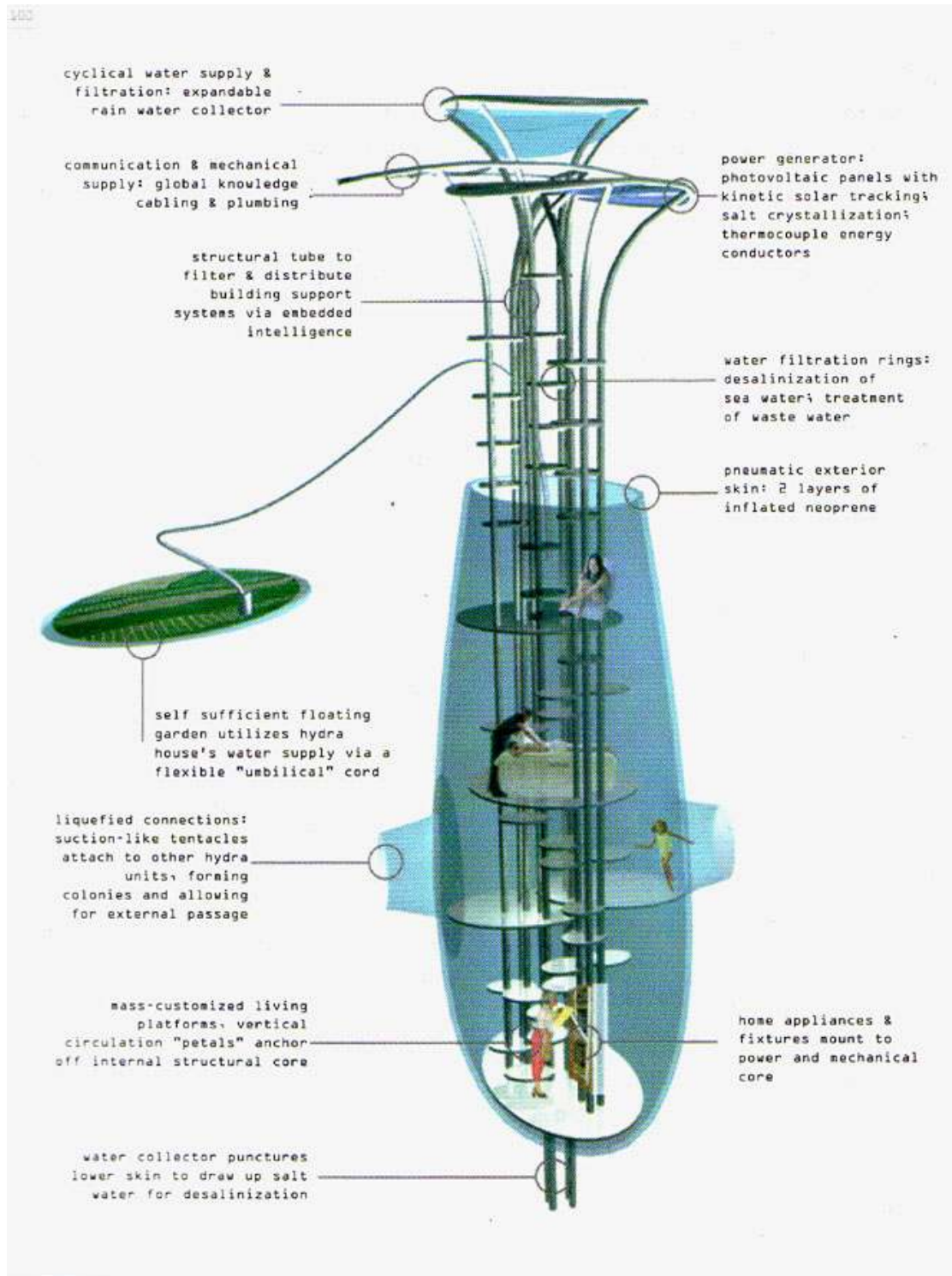


Fig 3.34 Hydrahouse by Jennifer Siegal (Source: Echavarria, n.d)

3.4.6.4 Convertible Structures

Architectural umbrellas, retractable canopies, collapsible permanent or temporary textile edifices and even pneumatic assemblies are unique textile architectural structures that offer distinctive dimensions and dynamism to otherwise static

configurations. Buildings can be transformed to adapt to changing thermal, lighting and climatic conditions or space needs of the occupant. The relatively light weight of most convertible structures also make the transformation a task that one person can perform with the help of mechanical devices, but often without the need for electric or hydraulic aids.

The *Markies* by Eduard Bohtlink, for instance, was conceived as a mobile holiday home, although it resembles a caravan in many ways and meets all legal road transport requirements. It differs from ordinary caravans in that, once it reaches its destination, its floor space can be increased three-fold in a matter of seconds by folding down both side walls. The resulting area can then be partially or completely covered by concertina-like awnings, creating a dwelling divided into three zones: the middle section houses the kitchen, bathroom and dining area, the one side with a transparent awning cover serves as a living area or open terrace, weather permitting, and the other side is a dividable bedroom covered by an opaque awning. (Echavarria, n.d: 89)

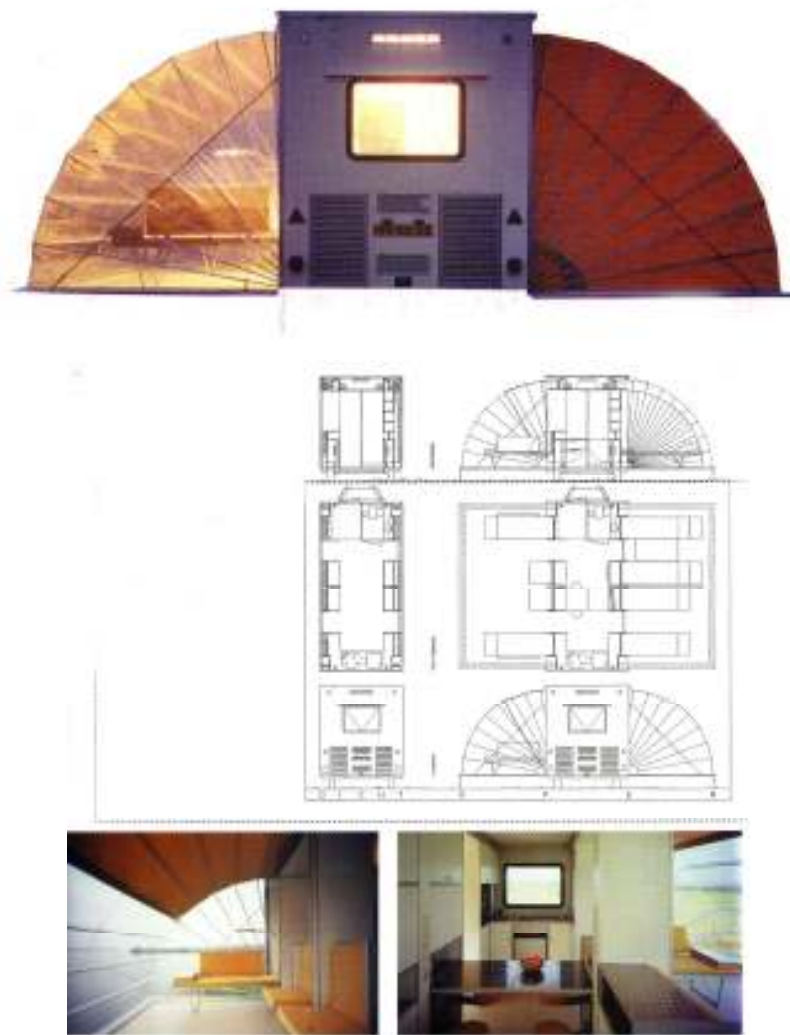


Fig 3.35 The *Markies* by Eduard Bohtlink (Echavarria, n.d: 89)

3.4.6.5 Mobile and Temporary Architectural Structures

Mobile architecture is an intelligent way of inhabiting an environment in a given time and place, being able to react and interact with ongoing social and cultural changes. Complex cities, uncertain territories, unidentified boundaries, changing structures... All of these multifaceted contemporary phenomena and processes require a more flexible and open architecture (Echavarria, n.d: 10).

The integration of textiles into mobile architecture structures makes sense since most textiles meet the demands of mobile structures perfectly. Light weight, flexibility, adaptability and flat-pack features of textile structures enable them to be readily transportable, easy to assemble, disassemble and transport from site to site.

Easy to move, flexible single-space structures made from lightweight, resistant materials: construction technology thus merges with that of transportation...In motion, the concept of permanence is in repetition; in the recreation of the same spatial order in each new location (Echavarria, n.d: 17).

In areas where natural or human-instigated disasters have struck, a very urgent need usually exists for temporary housing to accommodate the victim population while a more permanent solution is being conceived.

Architecture for Humanity, a non-profit organisation based in San Francisco California, regularly launches international design competitions to a global network of designers, engineers and architects for the design of temporary shelters for implementation in such areas. They also organise the realisation of the most suited designs through volunteers and aid organisations in the affected area. Often the most successful designs incorporate a combination of economical shipping of materials or locally sourced materials, quick and simple assembly or construction and suitable protection of the inhabitants from ongoing climatic phenomena.

Designs incorporating textiles are naturally well suited for these types of structures because of their weight-to-coverage ratio, prefabrication and flat-pack shipping possibilities and overall simple construction methods.

A good example of temporary housing solutions incorporating architextiles in South Africa are the UN tent villages constructed shortly after a spate of violent xenophobic attacks in some townships across the country in 2007. Such large settlements

consisting of white UN tents have become synonymous with refugee camps around the world and demonstrate the tried and tested use of fabrics in temporary architecture.

For *Architecture for Humanity's* 1999 Transitional Housing Competition for refugees returning from Kosovo, architects Mike Lawless of LA Architects and Mark Whitby of Whitby Bird Engineers employed, like many other designers, gabions, which are walls built by filling large wire mesh baskets with broken stone. What made the *Rubble House* unique was that all the materials arrive on the site packed flat. A team assembles the wire gabions with rods for structural integrity, then forms walls with the gabions and fills them with rubble from the war-torn area. A nylon-reinforced aluminium foil membrane forms the lightweight, semi-rigid roof which is both waterproof and insulated. The Foil membrane is 'quilted' so that the air trapped inside pockets aids towards the roof's rigidity as well as increased insulation. Velcro connects the roof's edges while the rest of the system snaps together without the need for any tools. In 2000 a full-scale prototype was constructed by 10 people in less than 6 hours as part of an exhibition at the Spacex Gallery in Essex, England (Architecture For Humanity, 2006).

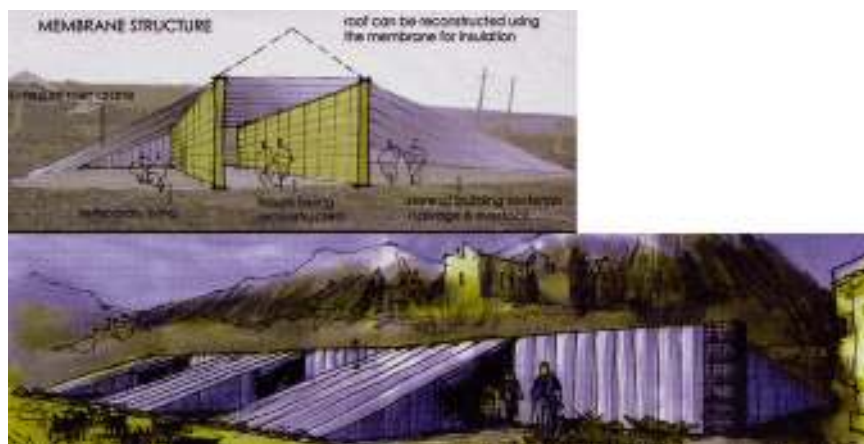


Fig 3.36 – 3.37 Rubble House by Mike Lawless and Mark Whitby
(Source: Architecture For Humanity, 2006)

Temporary textile structures are also used for hosting events and exhibitions where the rapid assembly and dismantling of a large covered space is desired and no permanent alterations can be made to the site. Besides ordinary small tents used for outdoor excursions and camping, cultural festivals, concerts, weddings, expositions all use textile structures because of the cost efficiency, quick construction and pleasing aesthetic.

The *Momi* tent is a demountable building, designed by Future Systems with Ove Arup & Partners which forms the hospitality space for the Museum of Moving Image on the South Bank of the Thames in London. The PTFE fabric membrane structure with slim tubes and rod supports can be erected and dismantled in two days by six people. It is supported on pairs of inclined GRP ribs that stabilize the structure through attachment to a steel floor edge beam. When in use, the ribs are braced in position with stainless steel struts and overlapping tension cables (Wilkinson, 1996: 63).

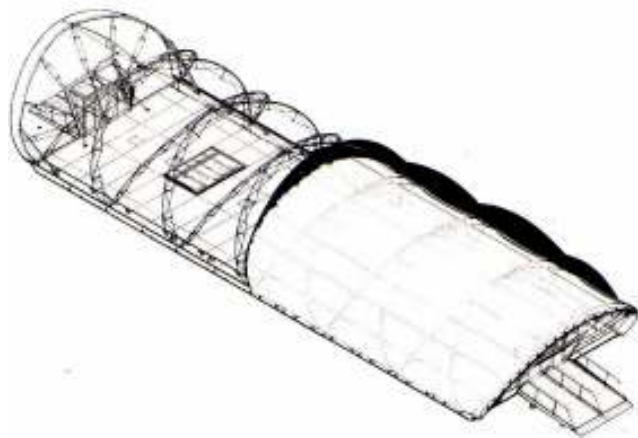


Fig.3.38 – 3.39 The Momi Tent (Wilkinson 1996:63)

3.5 Textile Choices

3.5.1 Fibres and Textile Manufacturing Processes

Most architextiles used since the first half of the twentieth century for tensile canopies and cladding applications are either of natural or man-made origin, but predominantly conventional man-made fabrics incorporating polymers or plastics are used.

Natural fibers used in technical textiles are commonly wool and cotton, and in smaller volumes, silk, flax, hemp, jute and ramie to name but a few (Kuusisto 2010: 68). After the development of *Nylon* (polyamide/ PA) which became commercially available in 1939, came *polyester* (polyethylene terephthalate/ PET) in 1951. The development of so-called high-performance fibres started in the middle of the 20th century and include organic fibres such as para-aramids like *Kevlar* (polyphenylene terephthalamide/ PPTA), meta-aramids and high performance polyethylene like *Teflon* (polytetrafluoroethylene/ PTFE), together with inorganic or mineral fibres such as carbon, glass and ceramics (Kuusisto 2010: 68).

Most commonly used today are Polyvinylchloride (PVC)-coated polyester and the more costly PTFE-coated glass fibre textiles (Kuusisto 2010: 69). Fabric bags used for earth-bag construction are mostly made of woven polypropylene strips. These synthetic polymers originate from processing by-products of petroleum production and create toxic pollution and waste. Weaving is the most frequently used technique to produce architextiles because of the superior strength and structural stability of woven textiles. Generally, woven fabrics are produced using 2 sets of yarn, one for the warp and another for the weft interlaced orthogonally, although tri-axial (3 sets of yarn interlaced at 60 degree angles) and tetra-axial (4 sets of yarn interlaced at 45 degree angles) weaving are also used (Kuusisto 2010: 70). Most tensile membranes as well as fabric bags used for earth-bag construction are woven.

Knitting is not often used for the manufacturing of architectural textiles, although it has several advantages in terms of versatility, economy of material usage and rapid production. Knitted textiles are often chosen where drapability, flexibility, malleability or an economical option is required. Unlike structures of woven textiles, which are constraint by the fabric widths, knitted structures can be designed to meet exact end-use requirements. The yarn is also under less stress than in woven textiles, making it more suitable when working with delicate fibers such as aramid, carbon and glass (Kuusisto 2010: 71). Knitted fabrics consist of a series of interlaced loops, making it both more flexible but also more difficult to ensure water impermeability.

Non-woven fabrics are sheets of fibres, continuous filaments or chopped yarns formed into a web structure and bonded together chemically, mechanically or thermally. Unlike weaving and knitting, there is no need to convert fibres into yarn and the process is both simpler and more economical than either weaving or knitting. In the web formation stage, the fabric's tensile strength mainly depends on the relative orientation of individual fibres, while the degree of bonding between fibres affect the fabric's density, porosity, flexibility, softness and strength. Non-woven fabrics are often used in geo-construction as geotextiles where drainage, filtration and reinforcement are required. Needle-punched non-wovens are also used in green roof construction as filtration and waterproofing membranes (Kuusisto, 2010: 72).

Coating is a direct application of a polymer spreading on a fabric substrate that effectively covers the gaps between threads in order to make the fabric waterproof and/or windproof. Most textiles used in outdoor applications are coated. Coating materials include, amongst others, polyvinylchloride (PVC), polyvinylidenechloride (PVCD), polytetrafluoroethylene (PTFE), polychloroprene (neoprene), chlorosulphonated polyethylene (Hypalon), polyurethanes (PU), silicone rubbers, natural rubbers and synthetic rubbers. Lamination gives similar results to coating, though it has a shorter production time, lower production costs and gives a more regular finish. The process uses solvents or water-based films, granules, jellies, powders or webs to attach pre-formed polymer sheets to fabrics. The substrate fabric gives the finished composite its physical properties, whereas the lamination or coating determines its chemical properties, though many of the properties of the finished fabric result from the combination of the polymer and fabric layers. (Kuusisto, 2010: 74)

3.5.2 Conventional Architextiles

Most architectural textiles are coated or laminated fabrics with a closed or open textile matrix base, although meshes, sheets or films and uncoated fabrics like polyester, cotton, metal and fluoropolymers are also common (Kuusisto 2010).

Cotton and polyester fabrics are rendered weather resistant by impregnation with special additives and used in small to medium structures (Moritz, 2000: 3).

The most widely used architectural textiles today are Polyvinylchloride (PVC) coated polyester and Polytetrafluoroethylene (PTFE) coated fibreglass, while silicone (Si) coated fibreglass is becoming increasingly popular. Coated fluoropolymer fabrics like PTFE, ETFE, PVDF as well as PVC coated glass fibres and aramid fabrics are also

frequently used. Ethylene tetrafluoro ethylene copolymer (ETFE) foils and sheeting are regularly replacing coated fabrics at present (Moritz, 2000: 3).

3.5.2.1 PVC-coated Polyester

PVC-coated polyester is one of the most widely used textiles in architecture. It has good tensile and tear strength and high elasticity because of added plasticisers to the PVC coating. Considered one of the more economical architextiles, it has a lifespan of 15 to 20 years and is often used for structures with long spans and temporary structures. PVC is a rigid polymer that needs added plasticizers to give it flexibility and stabilisers to avoid discolouration or deterioration from UV radiation. PVC-coated polyester is generally easier to handle during manufacturing of architectural products and cheaper in initial cost than PTFE-coated glass fibre, but it is also less durable, requires more frequent cleaning and stretches more under stress (Vandenberg, 1996: 27).

3.5.2.2 PTFE-coated Fibreglass

PTFE or *Teflon* is one of many terrestrial 'spin-offs' from the NASA space programme and is most widely known as the non-stick coating on kitchen utensils and pots. The same "non-stick" quality of Teflon makes it the ideal addition to fabric structures to create self-cleaning tensile membranes (Wilkinson, 1996: 50) Coating glass fibre fabric with PTFE has resolved the problems associated with having a separate weatherproof fabric and structural cable net. The material provides a durable weatherproof membrane which can be highly pre-stressed, is relatively lightweight and translucent (Wilkinson 1996: 110).

Although more pricey than PVC-coated polyester, it is often chosen as an alternative because of its superior stability, reduced deformation under tension, lower maintenance costs and greater life expectancy of 30 to 40 years. Unlike PVC-coated polyester, however, it has a low elasticity and flexes poorly, making it unsuitable for use in convertible structures.

3.5.2.3 Silicone-coated Polyester/ Glass Fibre

Because of the negative impact the production of PVC has on the environment and people handling the material, along with the amount of plasticisers and stabilisers necessary to allow PVC to subsist as a creditable architectural textile coating, an alternative in the form of a silicone coating for applications on both polyester and glass

fibres has been developed. Silicone is made of Silica, a derivative of ordinary sand, making it significantly more cost effective and more environmentally friendly to use as a coating than both PVC and PTFE.

3.5.2.4 *ETFE Foil*

Strictly speaking, plastic foils like ETFE are not considered textiles, but so often are ETFE foils replacing coated textiles nowadays that the material deserves to be included in studies of flexible membranes. ETFE has excellent mechanical properties and high fire resistance. It is also one of the more affordable options and has a lifespan of 25 to 35 years (Kuusisto 2010). The material is often employed in pneumatic structures, greenhouses and indoor swimming pool areas. Its maximum span is less than that of coated fabrics and it is therefore not used in large span load bearing structures (Moritz, 2000: 3). Translucent ETFE foil is often used for low-pressure pneumatic metal-framed building envelope cushions like the *Eden Project* in Cornwall, UK by Nicholas Grimshaw and Partners. The fluoro-copolymer has the advantages over glass that when used to form two- to five-layer air cushion systems, it offers higher thermal insulation with greater transmittance of UV light, which is advantageous when housing plants. ETFE is strong, shatterproof, half the cost and only one hundredth the weight of the glass equivalent, meaning a significant saving on the required structural supporting system. ETFE cushions can withstand maintenance loads, be easily repaired and is recyclable. (Lyons, 2007: 283).

3.5.3 Textile Properties

3.5.3.1 *Fabric Quality and Assembly*

Most manufacturers carry out tests on the textiles they develop to ensure all the requirements are met for their end-use applications. Datasheets should accompany any technical textile, stating physical, chemical and mechanical properties as well as recommended methods of joining panels e.g. by sewing, welding or using adhesives. All processes the textile needs to undergo in order to arrive at the desired finished structure, should be carefully considered. Besides the properties of the fabric itself, joining methods, supplementary reinforcements, transportation, construction practices and cost all influence the choice of membrane (Kuusisto, 2010).

3.5.3.2 Tensile Strength and Tear Resistance

The required strength of a textile depends on the span between supports of the structure in which it will be used as well as loads imposed on the structure like wind, snow, rain and people during maintenance. Besides the relative strength of the textile itself, patterning, pre-stressing, fabric widths, methods of joining panels and the strength of joints also influence the choice of fabric and structural form. Tensile strength is calculated and expressed in Newton per 5 cm (N/5cm) with figures usually varying between 0.2 and 10 kN/5cm (Pudentz, 2004: 48).

3.5.3.3 Resistance to Buckling and Mechanical Wear

The processes of material manufacturing, transport, construction and maintenance of fabric structures demands that architextiles display a certain degree of resistance to buckling. Textiles used in kinetic and convertible structures in particular should have good resistance to buckling and mechanical wear. Here, PVC-coated polyester display superior resistance compared to PTFE-coated glass fibre, which are considered unsuitable for kinetic membrane construction (Pudentz, 2004: 64).

3.5.3.4 Chemical Resistance

Commonly used fabrics like PVC-coated polyester and PTFE-coated fibreglass have good to very good resistance to chemicals.

3.5.3.5 Weight

Fabric structures usually fall under the category of lightweight structures (structures weighing less than 100kg/m²), with fabric weights typically ranging between 0.2kg/m² to 1.5kg/m² (Kuusisto, 2010: 74). Some massive construction techniques, however, like earth bag construction, incorporate textiles as the containment device for compression-type earth walls.

3.5.3.6 Durability

The chemical and mechanical wear, UV light and weather resistance of a fabric affects its life expectancy. PVC-coated polyester in general maintains its technical properties for 15 to 25 years. Its durability is directly related to its degree of translucency; at 15%

transmission, 15 years life expectancy is reasonable, whereas at greater levels of translucency, the expected serviceable lifetime is considerably reduced (Lyons, 2007: 283). Because of its superior flexibility, PVC-coated polyester is the preferred material for convertible structures involving movement in the membrane as well as for temporary structures which may be folded for transport or storage. PTFE-coated fibreglass textiles and ETFE foils often last for more than 25 years (Pudentz, 2004: 65). Damage to tensile structures through excessive strain, accident or vandalism can usually be repaired with ease on site.

3.5.3.7 Weather, Radiation and Temperature

The degradation of plastic textiles is most frequently attributed to the breakdown of the long molecular chains or, in the case of PVC, the loss of plasticisers due to effects of heat, ultraviolet light and/or ozone (Lyons, 2007: 277). Fabrics designed for exterior use are typically resistant to weather phenomena like wind and rain as well as UV radiation. It is generally recommended that fabric structures should not be assembled in temperatures under 5C. Also, PVC-coated polyester is not able to perform in sub-zero temperatures, making PTFE-coated glass-fibre textiles the fabric of choice in such climates (Pudentz, 2004: 64). It should be noted that polypropylene, used in the manufacture of earth-bags, is not UV resistant and walls built of polypropylene bags should not be left unplastered for extended periods.

3.5.3.8 Translucency

Amounts of light reflection, absorption and transmission often affect the choice of architextiles as this is one of the many benefits of building with textiles. Illumination of the enclosed space through transmission of natural sunlight is an energy saving measure often employed in eco-friendly buildings. The degree of translucency also has an effect on the thermal properties of the interior.

3.5.3.9 Colour & Prints

Although textiles like PVC-coated polyester and ETFE foils can be printed on, most architectural textile structures are of uniform colour. The colour of a fabric influences its light reflection and transmission as well as its thermal properties because of solar radiation absorption. Most common are white fabric roofs because of the colour's excellent heat reflective and light transmission qualities (Kuusisto 2010). The enclosed

space has a naturally illuminated quality during the day and the white surface can reflect interior lighting bounced off it at night. Transmitted light levels through ETFE cushions can be made adjustable by incorporating partially printed internal layers within the cushions, which can be moved closer or further from one another by changing the air pressure inside the cushion, thereby adjusting its shadowing effect (Lyons, 2007: 283).

3.5.3.10 *Acoustic and Thermal Properties*

Most single layer fabrics have weak acoustic and thermal insulation properties. Additional fabric and perforated foil layers increase acoustic absorption. Thermal insulation can be enhanced by creating air-cavities in a multi-layered fabric structure (Kuusisto, 2010).

3.5.3.11 *Fire Safety*

Textiles generally have a low fire load capacity, which is widely seen as a positive attribute. Fire retardant finishes coatings can be applied to textiles to increase its resistance, but especially roof structures should burn away rapidly once ignited to provide an escape route for flames and smoke and to not keep occupants trapped within a burning solid enclosure. Architextiles are usually certified by their manufacturers according to international standards that measure materials according to its resistance to ignition as well as smoke production and droplet formation once ignited. PTFE-coated glass-fibre emits toxic combustion products in a fire, while PVC coated polyester gives off hydrogen chloride fumes when ignited. With a fire-rating of Class 0, PTFE-coated glass-fibre membranes are less fire-resistant than the Class 1 rated PVC-coated polyester (Lyons, 2007: 283).

3.5.3.12 *Cleaning and Maintenance*

Resistance to soiling assists in alleviating cleaning and routine maintenance of a textile structure. Coatings of PTFE and PVDF (a topcoat for PVC) and ETFE Foils provide good resistance to soiling. A recent development by *Birdair* uses an additional coating of titaniumdioxide (TiO₂) on top of PTFE-coated glass fibre fabrics to form a top layer that cleans itself by breaking down organic materials through an oxidation reaction. Rain washes the remnants away (Birdair, 2010: nd).

Other maintenance depends on the extent of damage to the fabric itself or joints as well as the method in which the textile panels had been joined initially. Minor tears in the fabric can be patched, hand-sewn, glued or welded, but major repairs can only be performed once the structure has been dismantled.

3.5.3.13 *Cost*

Fabrics are generally seen as one of the most economic building materials available, although costs of the necessary support structures, attachment devices and need for specialist services in the construction process adds significantly to the total amount, though not enough to make textile structures an unattractive option from an economical point of view. Economy of material use while achieving great coverage make textile structures a good buy overall per square meter compared to metal, brick, wood or glass. PVC-coated polyester is notably cheaper to produce than PTFE-coated fibreglass, although the higher life expectancy and lower maintenance costs make the latter a more attractive purchase in terms of lifecycle costs (LCC).

The properties of the most commonly used architextiles are compared in the table on the following page. Technical specifications were provided by the manufacturers for their specific product as listed under 'brands'. The technical specifications of similar products of other manufacturers may differ from the products listed.

**Table 3.2 Comparative table of conventional architectural textile properties
(Kuusisto, 2010:79)**

	PVC Coated Polyester	PTFE Coated Fibreglass	Silicone Coated Fibreglass	ETFE Foil	Polypropylene (Earthbags)
Brand Names	-Naizil SportCover Tp1 -Naizil BigCover Tp2 -Ferrari Stamisol FT381	-B 18039	-Interglass A Tex 3000TRL -Interglass A Tex 5000TRL	-Novofol Novoflon ET 6235Z	-Earthbag System (South Africa)
Physical Characteristics	<u>Width:</u> 1780-3000mm <u>Weight:</u> 720-1050g/m2 <u>Tensile Strength:</u> 3000 – 4000 N/5cm <u>Life Expectancy:</u> 15 – 25 Years	<u>Weight:</u> +-800 g/m2 <u>Tensile Strength:</u> 4000-4200 N/5cm <u>Life Expectancy:</u> 30 – 40 Years	<u>Width:</u> 2000-3000mm <u>Weight:</u> 595 <u>Tensile Strength:</u> 3000 – 3500 N/5cm	<u>Width:</u> <1550mm <u>Tensile Strength:</u> 42 – 50 Mpa	<u>Width:</u> 1500-3000mm <u>Std Bag/Tube Widths:</u> 350-550mm
Typical Applications	-Tensile structures -Facades -Temporary structures -Kinetic structures	-Tensile structures -Facades	-Tensile structures -Facades -Adhesive Tapes	-Roofing structures - Pneumatic structures -Kinetic structures -Solar collectors	Woven bags used in Earthbag construction
Manufacturing Process	-Chemical, Extrusion -Woven Polyester -PVC Coating Relatively inexpensive to manufacture.	-Processed Mineral -Woven Glass fibres -PTFE Coating Expensive to manufacture.	-Mineral/Chemical -Woven Glass fibres -Silicone Coating Relatively inexpensive to manufacture.	-Chemical -Sheet extrusion Inexpensive to manufacture.	-Chemical, Extrusion -Woven Polypropylene Inexpensive to manufacture. Can use repurposed bags
Textile Joining methods	-Stitching -Hot-air welding -Adhesive joining	-Stitching -Hot-air welding -Adhesive joining	-Stitching -Hot-air welding -Adhesive joining	-Adhesive joining	-Stitching -Bags secured by barbed wire
Environmental Impact	Uses fossil fuels & harmful additives in manufacturing. VOC Emissions during manufacture. Partially Recyclable	Uses fossil fuels & harmful additives in manufacturing. Partially Recyclable	Uses fossil fuels in manufacturing. Partially Recyclable	Uses fossil fuels in manufacturing. Fully Recyclable	Uses fossil fuels in manufacturing. Used feed & grain bags can be repurposed for construction.
Climatic Protection	-Water & Wind resistant -UV Resistant -Temp: -30 to +70 C	-Water & Wind resistant -UV Resistant	-Water & Wind resistant -UV Resistant -Temp: -50 to +200 C	-Water & Wind resistant -UV Resistant	-Water & Wind resistant -Not UV Resistant
Insulating Properties	Poor acoustic insulation provided by single layer application. Fair thermal insulation.	Poor acoustic insulation provided by single layer application. Fair thermal insulation.	Poor acoustic insulation provided by single layer application. Fair thermal insulation.	Fair acoustic insulation. Fair thermal insulation.	Poor Insulation from textile bags, but excellent acoustic and thermal insulation because of soil filling.
Resistance to Deterioration	Good chemical & mechanical wear resistance	Good chemical resistance	Good chemical & mechanical wear resistance	Good chemical & mechanical wear resistance	-Good chemical resistance

3.6 Sustainable Architextiles and Textile Structures

3.6.0 Introduction

The integration of environmentally friendly fabrics and advanced textiles in residential architecture has only recently begun to receive recognition as one of a variety of ways of contributing to the concept of sustainable development. Compared to most other building materials, textiles use minimal amounts of natural and non-renewable resources in their production. Conversely, all synthetic polymers use fossil fuels in their production and the manufacturing process of PVC creates toxic fumes that are harmful to nature and a human carcinogen. Because of their light weight and ultra thin profile, transport and packing of textiles are optimal.

In *Techno Textiles 2*, Braddock Clarke and Mahony (2005:162) state that environmental concerns are increasingly determining the direction of future architecture. The energy crises, an awareness of green issues and sick-building syndrome have combined to focus architects' attention on design solutions that are more compatible with our environment. This means using more renewable resources than fossil fuels in the entire construction process and concentrating on a more dynamic use of the building itself. The authors validate their claims by referring to the statistic that currently half our consumption of energy is accounted for by buildings (Braddock Clarke & Mahony, 2005: 161). The advent of cheap energy and mechanical air conditioning has diminished our ability to use building form and mass effectively. In accordance with this general shift to more environmentally friendly design, the use of advanced textiles in architecture has been driven by some of the most creative minds in architecture, engineering and textile development, resulting in a fundamental shift in the appearance of temporary, and increasingly, permanent buildings. What we are seeing today is the use of fabric in just about every conceivable aspect of building and structural design.

In terms of fibres, an environmentally sustainable fibre is one that ideally involves completely renewable chemicals in its production and non-fossil-fuel-derived energy in the production processes (Blackburn, 2005: xx). In *Biodegradable and Sustainable fibres* (Blackburn, 2005: xx), Vink (2003) sets out a number of characteristics that the ideal sustainable material should possess.

- Such a material should: be available at a competitive or lower price;
- have a minimal environmental footprint for all processes involved, including those up- and downstream;
- provide an equivalent function to the product it replaces and perform as well or better than that product;
- be manufactured from renewable resources;
- use only ingredients that are safe to both humans and the environment;
- not have any negative impact on food supply or water.

3.6.1 Environmentally Friendly Architextiles

3.6.1.1 *The Oeko-Tex Certification Network*

The Oeko-Tex Standard 100 was introduced in 1992 with the aim of offering consumers the maximum possible confidence in terms of health and safety when buying textile products, as well as reminding companies in the textile chain around the world of the need to deal responsibly with problem substances. Oeko-Tex Standard 100 has since become the world's leading eco label for textiles with more than 4,200 companies worldwide subscribing to it. Products carrying this label have been tested and certified by internationally renowned textile institutes using the same set of test procedures and specifications to ensure worldwide uniformity (www.oeko-tex.com).

3.6.1.2 *Eco-friendly Alternatives to Polyvinylchloride (PVC)*

Although currently being used extensively in textile architecture, the production of polyvinyl chloride (PVC) is banned in many parts of Europe due to environmental releases during manufacturing. The vinyl chloride monomer is also a known human carcinogen and PVC is hazardous when burned. An on-line guide to environmentally friendly alternatives to PVC was developed by Greenpeace (Yeang, 2006: 455), which is summarised in the list below (See Full Table in Appendix).

Table 3.3 Extracts from the Greenpeace PVC Alternatives Database (Greenpeace International,nd)

MANUFACTURER	PRODUCT	DESCRIPTION	APPLICATION	ADVANTAGES
White Cross Rubber Products Limited (Lancaster, UK)	Butylite 1000EP roofing system	1.0mm thick single-ply synthetic rubber EPDM membrane, laminated geotextile backing.	- Flat, pitched or shaped roofs. Loose-laid, partial/ fully adhered or mechanically fixed.	-High resistance to UV light, ozone, heat and microbial attack. -Pre-fabrication and on-site welding.
Triton Chemical Manufacturing Co. Ltd. (London, UK)	System Platon cavity drain membranes	Studded, highly impermeable HDPE moisture barrier.	-Waterproofing interior and exterior walls and floors. - Drainage tray for green roofs.	Meets ISO 9002 requirements.
Carlisle UK Ltd (Abingdon, Oxon UK)	Sureseal EPDM rubber/lining membrane	Flexible EP rubber and polypropylene roofing membrane.	Installed fully adhered, mechanically fastened, loose-laid or in a protected membrane system.	Thermoplastic polyolefin membrane with the performance of rubber and the heat weldability and aesthetics of plastic.
Syntech - Synseal Linings Ltd (Derby, UK)	<i>Superseal</i> EPDM roofing membrane	Rubber and EPDM membrane with/ without fleece backing.	-Sheets can be prefabricated or welded on site. -Applied bonded or un-bonded.	
I.C.B. Ltd (Altwitra) (Bournemouth, UK)	<i>Evalastic</i> membrane	Polymeric EPDM/PP single-ply roofing and waterproofing membranes. EVALASTIC - un-backed EVALASTIC V - bonded polyester fleece backing.	-EVALASTIC V: Mechanically fastened or fully adhered roof constructions. -EVALASTIC: Loose-laid and ballasted systems incl green roofs.	-Free from halogens, bitumen, chlorine and plasticisers. -Laps joined by hot air welding. -Excellent long-term performance.
Firestone Building Products (Carmel, IN USA)	<i>Ultraply TPO</i> roofing membrane	Thermoplastic polyolefin combining polypropylene and ethylene propylene rubber	Roofing membrane	-Contains no plasticisers, chlorine or other halogens. -Environmentally-friendly. -Hot-air welded seams
Flag SpA Ltd (Flag, UK)	<i>Flagon EP</i> membrane	Length: 25 metres Width: 2.1 metres.	-Ballasted roofing /green roofs. -Mechanically fixed, fully adhered.	
Seabrook Wallcoverings (Memphis, TN USA)	Grass cloth, paper, hemp, burlap		Commercial and Residential.	
Clyde Canvas Fabric Structures (North Somerset, UK)	Cyclan tensile membrane	Silicone & PTFE Coated Glass fibre tensile fabric.	-High translucency eg. solar roofs. -Jointing by cementing process, sewing or welding.	-Acceptable strength -Great flexibility.
Timber Intent Ltd (Bristol, UK)	Tensile membranes	Waterproofed cotton canvass, Teflon-coated fibreglass, hemp, flax and recycled textiles.	Timber and fabric tensile structures eg. architectural and exhibition canopies.	
Hirshfields Inc (Minneapolis, IL USA)	Textile and grass cloth weaves		Commercial and residential	
Stevens Roofing Systems (Holyoke, MA USA)	Thermoplastic polyolefin roofing membranes	Thermoplastic polyolefin (TPO)-based roofing membranes	Commercial, industrial and institutional applications.	-Contains no chlorine or plasticisers. -Hot-air welded seams -Meets EPA Energy Star Roof Products requirements

3.6.1.3 Biodegradable Fibres and Textiles

Strictly speaking, it is impossible for synthetic polymers to be considered sustainable since they are made from non-renewable resources. Generally they are also non-degradable. The prolific use of synthetic fibres has contributed significantly to oil consumption worldwide. “ At the current rate of consumption, estimated to be 100,000 times that of its natural generation rate, oil-stocks are only expected to last another 50 to 60 year” (Blackburn, 2005: xv). A material is considered to be *biodegradable* if it is able to be broken down into simpler elements or components by naturally occurring decomposers, put simply anything that can be ingested by an organism without causing the organism harm. It usually also refers to materials that are non-toxic and are degradable within a relatively short period even on a human time scale (Blackburn, 2005: xvi).

Blackburn (2005: xvi) breaks biodegradable polymers down into three main categories:

- *Natural polysaccharides and biopolymers* – e.g. cellulose, alginates, wool, silk, chitin and soya bean protein
- *Synthetic polymers*, particularly aliphatic polyesters – e.g. poly(lactic acid) and poly(E-caprolactone)
- *Polyesters produced by micro-organisms* – e.g. poly(hydroxyalkanoate)

Depending on the fibre, their degradation may occur by biotic or abiotic processes. Biotic processes involve biochemical reactions that are typically mediated by micro-organisms such as bacteria and fungi. Abiotic processes include chemical oxidation and hydrolysis, and photo-degradation (Fedorak, 2005: 1). Although biodegradable polymers and their fibres are attractive options when environmental sustainability is the primary concern, currently they are overall significantly more expensive than their traditional polymer equals. A cost comparison done by Blackburn (2005) shows this price difference clearly.

Table 3.4 Cost comparison of traditional and biodegradable polymers
(Blackburn, 2005: xvii)

	Material	Average Cost (US\$/kg)
Traditional polymers	Polypropylene	0.73
	High density poly ethylene	0.82
	Poly ethylene terephthalate	1.15
Biodegradable polymers	Poly lactic acid	3.30-6.60
	Poly hydroxyalkanoate	8.80-13.90

3.6.1.4 Natural Fibres and Textiles in Architecture

Natural materials made from renewable resources such as agro-cellulose fibres are becoming increasingly popular for applications other than apparel and household textiles. Agro-fibres used in the production of non-wovens, technical textiles and composites offer a new environment-friendly angle in technical applications (Netravali, 2005). Netravali (2005) states that the botanical classification of natural fibres relates to the part of the plant where cellulose, the most abundant of naturally occurring organic compounds, is found, namely:

- Bast- or Stem Fibres: Flax, Hemp, Jute , Ramie, Kenaf, Abaca
- Seed Fibres: Cotton, Kapok, Ochroma, Milkweed, Akund floss
- Leaf Fibres: Sisal, Palms, Yukka, Pineapple, Manilla hemp
- Fruit Fibres: Coconut, Coir

Table 3.5 Structural and mechanical properties of some natural fibres and estimated cost (Shishoo, 2007: 111)

Fibre	Density (g/cm ³)	Breaking Extension (%)	Moisture Absorption (%)	Tensile Strength (N/Text)	Tensile Strength (Mpa)	Elongation (%)	Price per kg, raw (US\$)
Ramie	1.56	3.7	6	0.59	870	1.2	1.5 – 2.5
Hemp	1.48	2.2	8	0.47	690	1.6	0.6 – 1.8
Jute	1.44	1.8	12	0.31	400 - 800	1.5	0.35
Flax	1.54	3.0	7	0.54	780	2.4	0.5 – 1.5
Coir	1.24	1.8	10	0.31	140	15.0	0.25 – 0.5
Bamboo	0.8	1.3	-	-	221 - 661	-	-
Cotton	1.5	7.0-8.0	8 - 25	-	287 - 597	-	1.5 – 2.2
Pineapple	-	1.6	11.8	-	413 - 1627	-	-
Sisal	1.5	3.9 – 7.0	11.0	-	511 - 635	-	0.6 – 0.7
E-glass	2.55	3.0	-	-	2400	-	1.3

Flax, sisal and hemp are most suitable for technical applications. Flax fibres are already being used in reinforcing applications of polymeric matrices and paper, applications in the automotive industry, textile fabrics and as a substitute for glass fibres and asbestos. Because flax is more crystalline than cotton in addition to having a relatively high modulus, tensile strength and heat resistance, it is particularly suitable for technical textile applications. The successful, commercially-viable production of flax fibres should meet the requirements of textile products and replace synthetic- and glass fibres in many technical textile applications (Miraftab & Horrocks 2007: 117).

When looking at a replacement for glass fibres in certain applications, sisal-, jute-, flax- and coconut fibres are of significance because of their low cost, approximately a quarter of the price of glass fibre. However, coconut and jute fibres have low fibre strength, making only flax and sisal worthy substitutes. A comparison between some mechanical properties of sisal, flax and E-glass shows a relative difference in tensile strength, but otherwise discrepancies are negligible (Miraftab & Horrocks 2007: 112).

Table 3.6 Mechanical properties of sisal and flax compared to glass fibres (Miraftab & Horrocks 2007: 113)

Property	Dimension	Sisal	Flax	E-glass
Tensile Strength	Mpa	610	900	2300
Modulus of Elasticity	Gpa	28	50	73
Elongation	%	2.2	1.8	3.2
Density	g/cm ³	1.3	1.5	2.6
Specific Strength	Mpa/r	470	600	880
Specific Stiffness	Mpa/r	22	33	28

Factors that favour the use of certain natural fibres in technical textiles are price and environmental considerations, however problems such as inconsistent quality, continuity and supply along with high moisture sensitivity needs to be solved in order for these fibres to be worthy substitutes for synthetic and glass fibres in technical textiles.

3.6.1.3 Green Plastics

Green Plastics, bioplastics or biopolymers are predominantly biodegradable polymers made mostly or entirely from natural renewable resources like corn and soy using biotechnological processes. Bioplastics, like conventional plastics, are composed of a polymer combined with plasticizers and additives and processed using extrusion or thermosetting. How eco-friendly a particular bioplastic is, is usually determined by how environmentally friendly the manufacturing process is with regards to pollution and waste creation, the amount of renewable resources used in its composition, and the biodegradability of the product at the end of its life.

Lyocell, or *Tencel*, is a solvent-spun cellulosic fibre, made by mixing wood pulp and amine oxide (NMMO) as a solution in water and passed through a continuous dissolving unit to yield a clear viscose solution which is then extruded, precipitated, washed and dried before the fibre is ready for processing. The process uses only environmentally friendly materials and the recycling of the solvent is an integral part of the process, meaning that waste is both minimal and non-hazardous (Miraftab & Horrocks 2007: 113). Lyocell has a higher than average molecular weight, orientation and crystallinity compared to most other man-made cellulose, resulting in a high tensile strength, even when wet, high resilience and modulus.

Poly (lactic acid) fibre (PLA) is an aliphatic cornstarch-based polyester where the monomer is lactic acid, which can be produced by a bacterial fermentation process. Copolymerisation can lead to materials with a wide range of properties from glassy to rubber-like. The tensile strength of these copolymers varies from 0.6 to 48 MPa and elongation ranges are between 1 and 400%. PLA fibres are being commercially produced by many fibre companies, mainly because of its suitability as raw material in materials for applications such as active wear, technical textiles, nonwovens and home furnishings (Miraftab & Horrocks 2007: 116). Some important consumer-relevant attributes of PLA fibre are:

- Low moisture absorption & high wicking
- Low flammability
- High resistance to UV
- Low refraction index
- Low specific gravity
- High elastic recovery
- High stain resistance

As is evident in the table below, the physical properties of the PLA filament are comparable to that of PET and PA6 synthetic polymers.

Table 3.7 Comparison between the physical properties of PLLA, PET and PA6 (Miraftab & Horrocks 2007: 116).

Properties	PLLA	PET	PA6
Tensile Strength (Gpa)	0.40 – 0.55	0.44 – 0.61	0.36 – 0.5
Elongation (%)	20 - 35	20 – 35	20 - 35
Modulus (Gpa)	6.0 - 7.0	10.0 – 13.0	2.7 – 3.6
Density (g/cm ³)	1.27	1.40	1.15
Crystallinity (%)	83.5	78.6	42.0
Melting Index (Deg.C)	175	256	222
Crystallising temp (Deg.C)	103	170	140
Shrinkage in Boiling Water (%)	8-15	8-15	8-15
Moisture Regain (%)	0.6	0.4	4.0-5.0

Bio-composites can be defined as any combination of renewable resource-based fibre structures held together by a renewable resource-based matrix. The objective is to combine two or more materials in such a way that the synergism between the two components results in a new material with much better properties than the individual components (Miraftab & Horrocks 2007: 113). Once a fibre web has been produced, it can be directly used as geotextile, filter or sorbent, or it can be further processed into a structural or non-structural composite, moulded product, packing material, or combined with other resources. The most commonly used agro-based fibres in bio-composites are flax, jute, sisal, straw and wood, while the most interesting developments in terms of matrices are those related to thermoplastic biopolymers. Of these, cellulose acetate, cellulose propionate (CAP) and cellulose butyrate (CAB) are where the most noteworthy development is currently taking place. The main disadvantage biopolymeric thermoplastic matrices have compared to the more commonly used commodity polymers such as polyethylene (PE), polypropylene (PP) and polyvinyl chloride (PVC), are the degradation of lingo-cellulose at elevated temperatures. Although the advantages of developing true bio-polymers have been demonstrated, to date commercial applications in the form of technical textiles are few.

3.6.2 Textiles in Passive Climate Control

An excellent example of the use of textile architecture for climate control is the structure used for Expo '92 in Seville, Spain. The event was staged between April and October, the most popular time for visitors, but soaring temperatures brought the climate well above comfort levels. Conscious of environmental concerns, the organizers decided to try and improve the climatic conditions, making use of passive or natural methods. Architects Lippsmeier and Henninnormier used a mixture of tensile shade structures, water, concentrated vegetation and devices to promote air movement. The 30 cooling towers consisted of 5-meter high masts with tensile coverings made from white polyester / polyvinylchloride (PVC) fabric. The environmental control system of the towers was inspired by ancient Middle Eastern wind towers, which circulated cool air by wind and natural air movement brought about by temperature differences in pockets of air. The evaporative cooling of the air inside allowed large-scale treatment of the air in the avenue. This finely regulated system provided a comfortable outdoor environment as well as some groundbreaking research in the field of outdoor climate control using passive energy systems (Braddock Clarke & Mahony, 2005: 161-162). The climatic shielding capabilities that textiles can offer have also been employed more recently by architects such as Samyn And Partners in, to name but two examples in 1999, their designs of a metro station in Brussels, Belgium and a research laboratory in Venafro, Italy (Bahamon, 2004: 18-29). These examples of cutting edge building design use tensile PVC-coated fabric roof structures because of its ability to provide a lightweight, translucent barrier against most weather phenomena.

3.6.3 Textiles in Renewable Energy Generation

By incorporating certain design features, fabric membrane roof structures can have the ability to contribute to the collection and utilization of environmentally friendly renewable energy sources such as solar radiation and wind power. Small-scale portable power generators like the *Powerflex 20* by *ICP Solar* use a fabric base with integrated flexible solar panels for charging cellular phones or GPS-devices of hikers and cyclists. Companies developing this technology are continuing exploring energy generating potential on a much larger scale. Entire textile roofs can incorporate solar power generating abilities through flexible solar panels, eliminating the need for complex installation, wiring and maintenance issues usually associated with rigid roof-

mounted solar panels. Photovoltaic (PV) cells, converting solar radiation into electric energy, are integrated into flexible plastic films or can even be printed onto textiles. This enables the production of three-dimensional energy-generating fabrics that can be used in canopies or building envelopes. Conductive fibres or an integrated conductive layer is necessary to carry electrical current from the PV-cells to devices or storage batteries.

PowerMod by *FTLsolar* are flexible fabric panels with integrated PV cells, each generating 1200Watts. The total Electrical Efficiency is 75%, meaning that on a day with typically 5 Hours of sunlight, it can generate 4.5kWh ($1200 \times 5h \times 0.75 = 4.5kWh$).

The *Powershade* was developed by *FTL Design Engineering Studio* with two grants from the US Department of Defence to provide shade for vehicles, humanitarian aid workers or troops, while simultaneously generating one kilowatt of electricity that can be used to charge cellular phones, laptops or other electronic field equipment. Thin-film technology allowed for this design to be a mobile power source that is easy to transport, quiet and eco-friendly. The 6.7 x 6m structure folds flat to a dimension of only 71 x 183cm for transportation (Architecture for Humanity, 2006: 290)



Fig 3.40 Powershade by *FTL Design Engineering Studio*
(Source: *Architecture for Humanity*, 2006)

Wind power is another energy source that has been utilized for centuries through the employment of textile structures from windmills to sailboats. The potential for harnessing the wind's power in architectural structures is limited only by a designer's imagination and it requires relatively little technical knowledge to take advantage of this free and renewable energy source. Mini windmill designs known as *wind spinners*,

made by arranging twisted ribbons around a central axis and fastening the outer edges to a circular wire frame, are a common site in gardens across South Africa, and exists as a miniaturised prototype for a potential alternative to expensive carbon fibre or metal wind generator blade configurations. The concept of the wind spinner has already been taken a step further in a design for wind turbine blades adapted from that of power kites, as can be seen in the figures below.



Fig 3.41 Wind spinner (Source: www.ssww.com)



Fig 3.42 Textile wind turbine blades
(Source: www.kitesoar.com)

Even some basic bio-digesters, which produce methane gas from human and animal effluent, use textiles in the manufacture of their gas collectors. A large bladder-like bag that inflates when gas is produced creates the necessary pressure to deliver the gas, through flexible piping, to buildings in the nearby vicinity for cooking purposes.

3.6.4 Textiles in Rainwater Collection

Besides harnessing nature's energy sources, textile roof structures also have the potential to salvage one of nature's indispensable life-sustaining resources, namely water. With the increasing need for fresh drinking water around the globe and certainly in a lot of arid and semi-arid areas in South Africa, the design of traditional roof structures, intended to draw rain away from buildings via diagonal trusses' gravitational flow, gutters and drainage systems, should be re-evaluated in their overall efficiency and also their contribution to the desecration of this essential resource. Besides the installation of rainwater tanks at downpipes in ordinary gutter systems, which is currently the most popular way of incorporating a rainwater collection system in

existing buildings, a complete reverse-approach to the shape and structural design of roofs could see the roofs of the future collecting rainwater instead of allowing it to dissipate by literally turning the traditional pitched roof profile on its head. The University of Melbourne, for example, has done just that. The institution's North Court is enclosed by a textile shade structure covering about 750 square feet. It is attached to the surrounding buildings near the roof on 3 sides and is secured by two poles on the open end that faces the campus. The fabric is pulled toward a point on the ground and because of the funnel-like shape, rainwater is collected by the tent structure and accumulates in a circular pit which is dug into the ground and accentuated by a rain-activated perimeter lighting system (Bahamon, 2004: 38). Although in this instance the collected rainwater is not used for human consumption, the design of the structure itself serves to illustrate how simply inverting the triangular profile of a traditional pitched roof could increase its expediency form merely providing protection against the elements to also aiding in the collection of a rarity in many regions around the world, fresh drinking water.



Fig 3.43 University of Melbourne North Court (source: www.unimelb.edu.au)

3.6.5 Second Life Architextiles

The recycling or repurposing of a textile product can, to a certain degree, change its status from being viewed as non-sustainable to sustainable. As an example, PVC coated polyester billboards are already seeing a second life as handbags and wallets.

Small-scale canopies and building envelopes are also being made from repurposed PVC coated banners and billboards.

Polypropylene feed and grain bags already see a second life in earth-bag construction, but can be reused many more times when an earth-bag structure is demolished and/or rebuilt in a different location. With earth-bags, the main consideration to ensure a long product life is minimal exposure to Ultraviolet (UV) radiation as this deteriorates the chemical makeup of polypropylene. While ETFE Foils are completely Recyclable, PVC-coated polyester fabrics may be partially recycled. Most long-life PTFE-coated glass fibre fabrics are issued with a buy-back guarantee and their recycling properties are continuously being developed (Pudentz, 2004: 54).

In 2009, the first fully recyclable architextile was launched by *Taio Kogyo*. The fabric, *Kenafine*, is made of the bast fibre of the kenaf plant. The plant has an exceptionally high carbon dioxide absorption rates. At the end of its life as a membrane, the fibers can be recycled and used in the production of paper products (Textile World, 2009: n.d). Similar to traditional fabric membrane roofing products, Kenafine functions as a highly durable, moisture resistant material that features a high degree of translucency. As a sustainable building product, Kenafine meets a variety of United States Green Building Council (USGBC) ® as well as Leadership in Energy and Environmental Design (LEED) ® credit requirements. The kenaf plant contains no halogens that could produce fluorine and chlorine upon landfill disposal. The plant grows well in a variety of climates and is farmed principally throughout China, India, Africa, Australia and North America (www.birdair.com)

Although the fact that a product can be reused reduces its carbon footprint, producing the primary product is still, in most cases, causing the depletion of non-renewable resources and pollution. Furthermore, the motivation for reusing items that caused environmental damage during its initial manufacture and first life use should be carefully approached as the demand for second life products should not become the driving force behind increased production of the primary product.

3.6.6 Textile Structures for Sustainable Communities

In order to be considered sustainable, a chosen textile should ideally display attributes that could be maintained or repurposed by future generations at infinitum, although very few materials or processes in any industry can claim this. An acute awareness

and conscious effort to this effect usually suffices, although concerted efforts to attain complete sustainability should always be the objective. Economic sustainability is a relative concept concerned with a community's general affluence and average household financial situation at a certain point in time as well as what is predicted or planned with relative certainty for the future.

Textiles and the construction of textile structures should not only be affordable to the majority of residents in a specific community, but in some cases, manufacturing and construction processes that can take place within the community itself, creating employment and skills development opportunities for the unemployed, should be favoured, especially in developing economies where unemployment is usually relatively high. Environmental sustainability is perhaps the easiest component to measure. Processes, products and transportation to the building site should have a minimal negative impact on the natural environment or living beings occupying the structure once it has been erected. Renewable resources should always be chosen instead of fossil fuels and other raw materials in limited supply.

Arguably the most pertinent aspect when looking at sustainability in a communal sense is social sustainability. Culturally and aesthetically, structures of textile or other materials should not offend, segregate or alienate any section of, or entire communities. A community should be able to identify with and be proud of their built environment. Wherever possible, textile manufacturing and construction methods should aim to unite communities. Manual labour, although not always seen as being optimally efficient, should replace industrial and mechanical processes in order to create job opportunities and social upliftment through neighbourliness. Building, maintaining and improving residential structures should provide members of the community with a sense of dignity and self-respect for it to be considered socially sustainable.

3.6.7 Design for Sustainable Behaviour

Designing the most efficient structure or most sustainable building using the most environmentally friendly materials possible within the scope of a particular site becomes a pointless exercise if the structure is not being utilised in a sustainable manner. Users of an architectural structure should, in some way, be encouraged to inhabit and operate a building in such a way that it reflects the concerted efforts invested in its embodiment.

3.7 South African Architextile Structures

3.7.0 Introduction

Most soft canopies in the world are currently either made of polyester with a polyvinylchloride (PVC) coating or glass fibre with a coating of polytetrafluorethylene (PTFE). Both of these fabrics have been integrated in a limited number of examples of South African architecture, indicating that the rarity of permanent structures incorporating textiles in the country is not necessarily due to materials being inaccessible or unavailable locally.

3.7.1 Historical and Vernacular Textile Structures

Traditionally, most vernacular structures of the indigenous peoples of South Africa are made from mud, grass, dung, wattle and, less frequently, animal hides.

Although perhaps not considered fabric in the strictest sense, a number of woven reed mats overlap each other on a framework of bent branches to form modest traditional huts, called a 'Matjieshuis', of the indigenous Nama people of the Northern Cape or Namakwaland. This economic and environmentally friendly way of building is still being employed today although the reed coverings are often replaced with more modern materials such as sacking cloth or burlap (The Tourism Blueprint, 2010: 16)



Fig 3.44 Traditional *Matjieshuis* (Source: The Tourism Blueprint, 2010)

The Afrikaner people who explored the land between the current cities of Cape Town and Polokwane in the late 19th century, known as the *Voortrekkers* used cotton

canvass canopies to cover their ox-wagons, which were used both as means of transport as well as mobile housing. The wagons, similar to animal drawn vehicles of the their European and North American contemporaries, employed a length of cotton canvass stretched over a convertible cane or wooden framework to cover the seats, bedding and other goods transported in the wagon.



Fig 3.45 Traditional Voortrekker ox-wagon with textile canopy (Source: www.afrikaans.be)

5.7.2 Modern Textile Structures

A prime example of the design possibilities and advantages of textile architecture on the local front is the roof structure of the new Nelson Mandela Bay Sport Stadium, constructed for the 2010 FIFA Soccer World Cup (Design Magazine, 2009: 51-55). The Roof structure consists of a combination of aluminium cladding and tensile membrane panels of a glass-fibre fabric coated with polytetrafluorethylene (PTFE) over a steel superstructure.

Another current example of PTFE-coated glass fibre fabric being incorporated in a South African building is in the cladding of the reconstructed Green Point stadium in Cape Town. The entire façade of the stadium is covered in the fabric, providing an economical translucent and weatherproof architectural cladding system that allows the Stadium to “glow” during evening events.



Fig 3.46 The Greenpoint Stadium, Cape Town (Source: www.inhabitat.com)

Fig 3.47 Detail of stadium textile cladding (Source: www.dezeen.com)

Fig 3.48 Space frame roof structure showing tensile membrane cladding (Source: www.paragon.co.za)

3.7.3 Sustainable architextiles in South Africa

3.7.3.0 Introduction

The largest part of the current South African textile industry consists of fabrics developed for the manufacture of clothing and home interiors. Architextiles fall under the category technical textiles within the larger clothing and textile sector of South Africa. It currently represents an especially small niche of a division identified by government as one of eight key industrial sectors with the greatest growth potential

and marketability (Foure & Mlauli: 2007: 101). Meanwhile, the development of technical textiles from renewable resources, like agro-cellulose fibres are receiving increasing international interest, particularly in the development of agro-fibre based products like absorbents, geotextiles, filters, packaging and bio- composites for the automotive and building sectors.

3.7.3.1 Eco-textile development in South Africa

With great diversity in climatic conditions, Southern Africa offers enormous scope for the cultivation of natural fibres for textile production. The government supported *Centre for Scientific and Industrial Research* (CSIR) has a specialist *Centre for Fibres, Textiles and Clothing* (Foure & Mlauli: 2007:102). In addition to technical support to the textile industry at large, one of the key activities of the centre is the development of small scale and commercial ventures in the growing, conversion and production of new textile products using natural fibres such as hemp, sisal and flax. The locally grown cactus-like plant, *S. Ethiopia*, for instance, has particularly strong fibres in its leaves which are successfully converted to non-woven geotechnical fabrics.

Between 2000 and 2003, the eco-friendly growing of cotton was the main focus area of the *Danish Cleaner Textile Production Project*. The project covered feasibility studies, integrated pest management training (IPM) and the development of training aids which can be used easily even by illiterate small scale farmers. To continue the work initiated by the Cleaner Textile Production Project, an extension was granted in the funding by the Department of Trade and Industry (DTI) together with the Danish government between 2003 and 2005 to establish the *Clothing and Textile Environmental Linkage Centre* (Foure & Mlauli: 2007: 99). In short, the objectives of the centre include:

- Establishment and maintenance of a comprehensive repository of environmental information relating to the textile pipeline
- Raising awareness of environmental issues in decision makers throughout the textile and clothing pipeline
- Increasing knowledge of environmental issues in textile product development
- Identifying and communicating market opportunities for textile products produced in an environmentally responsible manner

There are several regional initiatives in the textile sector within the *New Partnership for Africa's Development* (NEPAD) countries. This includes initiatives like *The Sustainable Trade and Innovation Centre*, which promotes trade and market access in sustainable goods and services between developed and developing countries and is supported in the sub-Saharan region by South Africa.

Certification owing to compliance with international standards as required by initiatives like the *EU Flower*, *Oekotex label* and *ISO 14001* has been undertaken by a very limited amount of South African textile manufacturers, mostly due to the fact that such certification is only required by those manufacturers operating within or exporting to European and American markets. Faure and Mluli (2007: 103) believe that the increased flexibility, open-mindedness and commitment to improvement by the South African government, business and civil society will continue the process of reducing the environmental footprint of the textile industry.

3.7.3.2 Sustainable textile-based construction endeavours in South Africa

There are only a handful of examples of the incorporation of textiles in construction projects in both the eco-design or sustainable development sectors in the current South African built environment. Especially the development of small-scale structures incorporating textiles in an effort to save on material costs, labour costs or building materials obtained from increasingly scarce non-renewable resources, are rare in the country, despite the housing deficiency currently experienced by a large portion of the population.

Two projects in the Cape Town region that serve more as prototypical experiments than solutions rolled out on a large scale are the *10x10* low cost housing structures in Mitchell's Plain by Luyanda Mpalwa of MMA Architects and the *EarthBag Building* project. Both these initiatives use woven polypropylene textile bags in two different advanced derivatives of traditional sandbag construction practices to create structurally sound massive buildings.

Luyanda Mpalwa's winning entry for the *2007 Design Indaba 10x10* housing competition shows a contemporary version of earth-bag construction as an experiment toward the delivery of low-cost housing in South Africa. The competition brief stipulated that designs entered had to fall within government subsidies at the time, which was R50 000 for a 40m² house.

Mpalwa's firm, *MMA Architects* felt that the main considerations for a cost-effective solution were to reduce the cost of the building materials, reduce the building time, and consider involvement of the community in the building process. The design submitted by *MMA Architects* incorporated the *Eco Beam* system, developed by *Eco-Build Technologies* in Cape Town, which uses a timber structural frame with metal inlays to provide tensile strength and earth-bags as infill for the walls of the building. Architect Keith Struthers (2011) commented in an interview that although insulation is much better when building with sandbags than with clay or cement brick, installing door and window frames and attaching anything to the walls are tricky. Therefore, using the eco-beam system makes sense since the incorporation of a timber frame resolves those issues. The earth-bags incorporated in the system provide excellent thermal mass qualities for passive thermal control, making the buildings thermally sound and comfortable to live in. The excellent sound insulation provided by the earth-bags also helped to provide a measure of privacy in close-quarter living. The most important benefit of using the *Eco Beam* system, however, is that the simple construction process creates job opportunities and skills development for the local community and favours unskilled labour, including women. The construction method is predominantly manual, with little or no need for electricity in both the production of the *Eco Beams* or the construction process on site (Pieterse, 2010: 162).

We (MMA Architects) believe that it does not yet provide a solution to the acute design and delivery problems associated with the public housing programme, but the experience of undertaking this experiment has given us a much better understanding of what it will require to achieve more effective and sustainable public housing

– Luyanda Mpahlwa (Pieterse, 2010: 162)

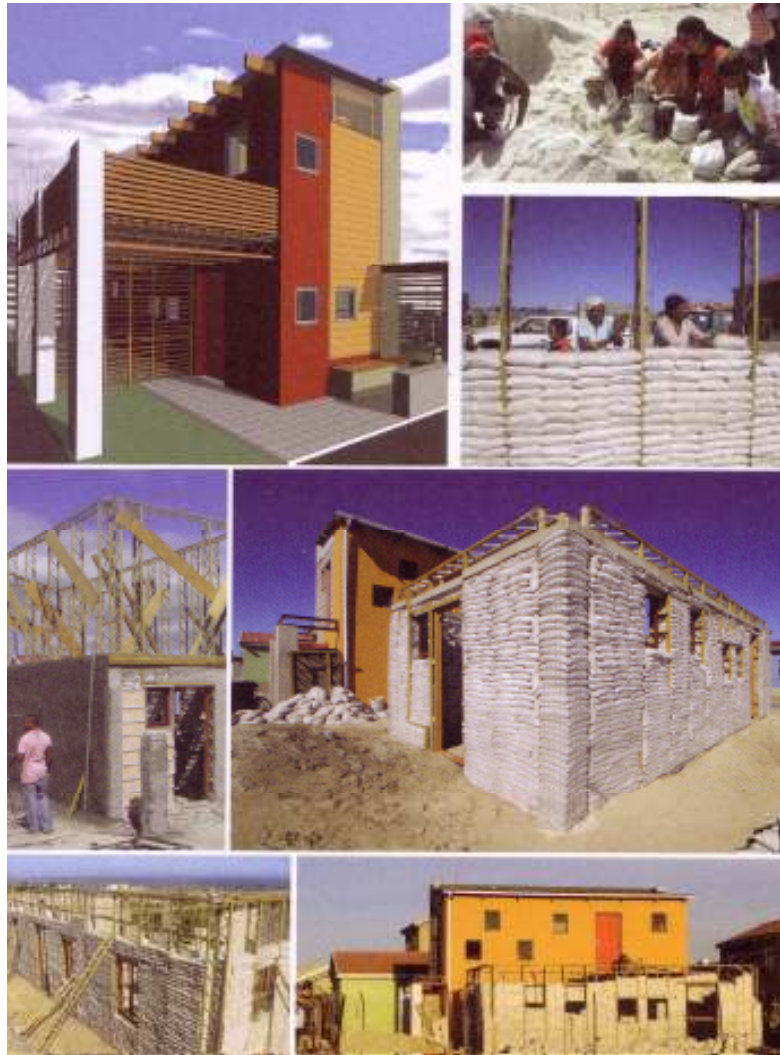


Fig 3.49 Design Indaba 10 x 10 winning design by Luyanda Mpahlwa for MMA Architects (Source: Peterse,2010)

The *EarthBag Building System* is a patented South African design by *Eternally Solar* using specially developed woven polypropylene bags which are manufactured in Cape Town (Eternally Solar, n.d). The simple addition of sewn channels to the manufacturing process of fabric bags improves technically on the traditional method of sandbag construction. By stitching longitudinal channels in the woven bags, the construction of walls become much more akin to building with clay bricks in that there are no additional supporting elements required as in the case of traditional sandbag building. By filling only the 2 outer channels of the 3 sewn channels with soil, each individual bag forms a flattened H-profile as opposed to the traditional sandbag's flattened O-profile, making the occurrence of slippage between bags during the construction process less likely. It also forms a cavity where the unfilled centre channel is located for filling with loose soil or gravel between bags and thereby creating a

unique slotting system. This system has been tested locally and internationally and examples of buildings that used this construction method can be seen at locations in and around South Africa and neighbouring countries.

The system was developed as part of a study conducted in the department of structural engineering at the Cape Peninsula University of Technology (CPUT) in 2008. It was tested using the Agreement Board set of specification and easily exceeded the specified standards. A simple cost comparison reveals the claimed savings one can incur when employing the EarthBag Building System (+-R400/m²) as an alternative to concrete block wall (+-R500/m²) or cavity brick wall construction (+-R700/m²) (Eternally Solar, n.d). Following is a cost estimate for a 36m² structure using the Earthbag Building System. It excludes design fees, plan approval, plumbing & electrical connections, site clearance and internal walls or partitions.

Table 3.8 Construction Cost Estimate for a 36 m² EarthBag Structure (Eternally Solar, n.d)

Division	Unit	Estimated Cost
Foundations	Materials	R2400.00
	Labour (@ R100pp/h)	R600.00
Walls	Materials (Earthbags, Mortar for Lintels, Plaster, Sundries)	R17000.00
	Labour (@ R100pp/h)	R8000.00
Floor and Screed	Materials (Earthbags, DPC, Sand)	R2000.00
	Labour (@ R100pp/h)	R1000.00
Roof	Materials	R10000.00
	Labour (@ R100pp/h)	R2000.00
Doors and Windows	Materials	R3000.00
Total		R45 000.00

Significant economy in the transportation of materials is claimed by *Eternally Solar*, stating that sufficient Earthbags to build the walls of two hundred 40sqm houses can be transported in one standard 12m shipping container (Eternally Solar, n.d)



Fig 350 – 3.54 School building in Burundi using the Earthbag Building System (Source: www.earthbagbuild.com)

CHAPTER 4:

Conceptual and Theoretical Frameworks

4.0 Introduction

This chapter presents the conceptual and theoretical frameworks underpinning this study. The literature review of publications on the concepts of sustainable architecture and architextiles in chapters 2 and 3 respectively provides insight into the theory and concepts, which inform the study. Whereas a systems approach to sustainable architecture serves as the principle analytical lens for this study, it must be emphasised that other theories and/or concepts should also be seen as relevant to the research approach and having had an influence on the outcome. The concept of architectural expression involves looking at the design of buildings from the perspective of architect or designer and how, through the use of symbolism, architectural structures can be not only sustainable in the context of environment, economy and society, but also serve as icons of sustainability by their very existence.

Sustainable architecture as a generic concept as well as related fields are universally known and understood, however the framework should be adapted and customised to suit the specific requirements and restrictions of the region it is implemented in. This particular study, focussing on South Africa, brings with it its own set of parameters, requirements and a unique approach for addressing the issue of sustainability in residential architecture. By applying the theories and concepts described below, this study aims to direct the research process to best capture these unique characteristics of approaches to sustainable development in the architecture of an emerging economy in Africa.

4.1 A Systems Approach to Sustainable Architecture

4.1.0 Introduction

The way modern man generally approaches complex situations is to attempt to break them down into smaller, more comprehensible, more manageable units. Indeed, one credo of modern living is *reductionism*, the belief that if we break up a problem into smaller units and come to understand these smaller units, we can reassemble and understand the larger structure (Williamson, Radford & Bennets, 2003). While this method certainly has its strengths, many critics have pointed out the limitations of this

hard scientific approach, most notably for it not factoring in human bias. The way we reduce a situation into more manageable parts is inevitably influenced by our circumstances, values and ethics, as well as the implicit boundaries between our knowledge and our ignorance.

Systems theory, although inherently reductionist, deals with the relationship between parts in an attempt to understand this relationship, rather than the act of simply reducing a situation into parts, as is implied by the term reductionism. It is a widely accepted way of looking at the world that provides a conceptual framework for structuring sustainability assessments (Williamson, Radford & Bennets, 2003). Ludwig von Bertalanffy (1971), considered to be the founder of general systems theory, defines a system as a set of elements standing in interrelation among themselves and the environment (Williamson, Radford & Bennets, 2003: 82).

The way a system is delimited and described depends more on the observer's viewpoint than how the system came into being. At the most basic level, systems may be classified as closed or open. A closed system is one where the components making up the system only interact with one another and are not influenced by any external processes, whereas an open system interacts and is influenced with other processes and systems external to itself. Buildings are inherently open systems, which, according to Katz and Kahn (1966), are characterised by the following:

- The import of energy or information from the environment
- The transformation of that energy into a form characteristic of the system
- The release or export of products into the environment
- The re-energising of the system from sources in the environment

Sustainability of the environment in which an open system exists depends on two rules:

- *Input rule*: Inputs to the system must be limited to within the capabilities of the greater system for it to be able to continue supplying the same inputs without degradation
- *Output rule*: Emissions from the system must be confined to within the limits of the greater system to continue to assimilate them without degradation
(Williamson, Radford & Bennets, 2003: 84).

A common aim of sustainable architecture is to progressively close up these open systems in an attempt to create structures that reduce their dependency on their environment by using fewer resources, feeding back into it, and/or reducing emissions into this environment in an effort to regulate the input and output scope of the greater system.

The systems approach referred to in the context of this study involves elements of both theory and practice of *system design for sustainability* (SDS) as well as the approach described above, known as *systems theory*. SDS theory denotes the conceptualisation and design of systems consisting of products and services that will be jointly capable of satisfying specific needs and desires of the customer and related innovative stakeholder interactions, while simultaneously leading towards eco-efficiency, as well as social equity and cohesion (Vezzoli, 2007). The general framework of sustainable design as a concept has evolved and enlarged its scope from *life cycle design* or *eco-design* of products, to *design for eco-efficient systems* or *product-service-systems (PSS)*, to *design for social equity and cohesion* (Vezolli, 2007). The rationale for using both SDS and systems theory is to look at all the elements making up the system in which a designed product or service functions, how the product or service effects the dynamics of the system, and the sustainability the system as either an open or closed unit.

When considering the concept of sustainability as a system, three interdependent subsystems, otherwise known as the triple bottom line (environment, economy and society), make up an arrangement that is often pictured as a three-legged stool; fail in sustaining one subsystem and the entire structure topples over. Although the triple bottom line satisfies general development sustainability assessments, considering the sustainability of physical buildings necessitates the inclusion of two more subsystems, namely the building itself and its users. While being interconnected and often interdependent, each subsystem has its own needs ascribed to it which, in turn, determines its inputs and outputs. Connections between subsystems imply that a change in one subsystem often instigates a chain-reaction affecting other subsystems as well as the greater system.

4.1.1 The Environment

Although seen as an indisputable aspect of architectural sustainability, what is implied by environmental impact within the discipline of architecture often needs to be

elucidated. That said, in its most elementary form, the environmental impact of a building can be divided into two categories:

- *Emissions*- Releasing substances into the environment, and
- *Extractions* – Removing substances from the environment

4.1.1.1 Emissions

Emissions into the environment as a result of human activities associated with buildings, consists of either chemical or physical agents. These agents may affect humans, fauna and/or flora, or contribute to the degradation of the earth's ecosystem. According to Williamson, Radford and Bennets (2003), the most pertinent of concerns include:

- *The greenhouse effect* – gasses blocking the earth's radiation of infra-red rays alters its heat balance and causes volatile climatic changes.
- *Depletion of the ozone layer* – the ozone layer, earth's stratospheric ultraviolet (UV) radiation absorber, is damaged by chemical substances, causing excessive UV radiation which is dangerous to both plant and animal life.
- *Smog* – caused by nitrogen oxides and carbohydrates in summer, and sulphur dioxide (SO₂) and small particulate matter (SPM) in winter, smog can cause respiratory problems and serious economic damage to crops.
- *Toxins* – many substances released into the environment by the construction process and operation of buildings are poisonous to humans, animals, plants and their supporting ecosystems. Sick building syndrome(SBS) related to poor indoor air quality (IAQ) as well as an awareness of volatile organic compounds (VOCs) are all associated with toxic emissions from buildings.
- *Waste disposal* – besides having expanded beyond the carrying capacity of many disposal facilities worldwide, the inappropriate dumping of solid waste causes pollution of the air, soil and water.
- *Radioactivity* – the possibility of accidents at nuclear power plants plus problems related to radioactive waste storage is seen by many as potentially the most hazardous threat caused by and faced by humans.

4.1.1.2 Extractions

Concerns over the depletion of some natural resources in the discourse relating to human activity have necessitated a distinction between renewable and non-renewable resources (Williamson, Radford & Bennets, 2003).

- *Non-renewable resources* – Finite sources like Fossil fuels and uranium used in energy generation for the transportation, assembly and production of building materials and components (embodied energy), as well as in the operation of finished structures, have both practical and economical limits to their excavation. Metals are mostly recyclable, but each cycle requires more energy to process, and repeated recycling ultimately leads to a lower quality material.
- *Renewable resources* – While thought to be inexhaustible, the production potential of renewable resources such as wood and agro-fibrous products is in fact limited by its reliance on other resources like fresh water and fertile soil, both of which face an uncertain future. Although solar and wind energy are virtually in unlimited supply, most devices used to capture and utilise this energy currently contain elements made from non-renewable sources. Also, the production of these devices only recently became justifiable when the energy used in their manufacture no longer exceeded the energy expected to be generated by the device during its lifetime.

4.1.2 Social and Cultural Sustainability

Cultural diversity is mankind's way of creating differentiation within a variety of circumstances experienced worldwide. The preservation of cultural diversity remains an integral part of sustainability in architecture because of it enhancing a society's ability to adapt to and innovate within its surroundings. Culture as tradition is a transmittance of societal knowledge between generations that is itself adaptive to changing circumstances (Williamson, Radford & Bennets, 2003). Changes in economic and environmental circumstances affect the sustainability of societies and cultures. In relating sustainable architecture to culture and society, one cannot merely follow a pattern of the regional vernacular and should assume some degree of flexibility, as socio-cultural circumstances are constantly evolving. Different building types house different 'cultures', which can be geographic or non-geographic entities,

and should be addressing the needs of that specific group in order to sustain it (Williamson, Radford & Bennets, 2003).

4.1.3 Economic Sustainability

Capitalist societies with market-based economies are undeniably dependent on patterns of capital accumulation. Thus, for architectural projects to be economically sustainable in such societies, it must show a profit of some kind. While this logic is generally agreed upon, it is noticeably absent in most discourse concerning sustainable building design (Williamson, Radford & Bennets, 2003).

The principle of capital accumulation fuels a societal system built on taxation, employment endorsement and capital investment. This system, some say, is based on materialistic values and greed, and the cause of most environmental and social problems. Smith et al (1998) in Williamson, Radford & Bennets (2003: 92) states:

The root cause of the mess lies in an overwhelming emphasis on consumption and the route to human happiness and economic growth as the means of achieving it...Economic growth in the conventional sense is the problem...its pursuit damages the environment, leads to social injustice, and is detrimental to real economic development.

Economists tend to favour one of two points of view when referring to economic sustainability. The neo-classical approach sees sustainable economic growth as resulting from competitive markets, deregulation, privatisation and global economic integration. The other stance supports the notion of abandoning economic growth as measure of a society's success, and instead favours equity, reducing poverty, encouraging resource conservation, ecological limits, and regulation as the way to sustainability (Williamson, Radford & Bennets, 2003: 92).

4.1.4 The Occupants

Concerning the occupants or end-users of a building, architectural sustainability addresses their well-being, health and safety. Besides these measurable components, this subsystem also addresses levels of satisfaction of users within the building as well as the notion of comfort, which generally relates to design considerations addressing the intangible *human-factor* of a building (Williamson, Radford & Bennets, 2003). Specifically developed performance-based building codes are often used as indicators

to measure the satiation of those human needs deemed necessary to constitute a sustainable building.

4.1.5 The Building

This subsystem is concerned with performance, serviceability, durability and longevity related to the service life of a building and its components. Designers of sustainable buildings need to consider maintenance and life expectancy of specified materials and components in a considered attempt at addressing current, as well as future, requirements. According to Williamson, Radford & Bennets (2003), the life cycle of a building can generally be broken down into four separate stages:

- *Production* – this includes initiation of the project, design, manufacture of materials and components, and their assembly
- *Use* – the operation and maintenance of a building
- *Renovation/ Rehabilitation/Recycling* – strategies to determine what happens at the end of a building's first life/purpose
- *Demolition* – processes relating to the paths materials and components follow once a building is destroyed

All four stages should be considered in the design process, as decisions made and strategies employed during this initial phase will have repercussions.

4.1.5.1 The Production of Buildings

This stage includes the design and construction processes as well as the excavation, processing and transportation of materials. Environmental sustainability is determined by an assessment of the impact the construction process and finished structure will have on the site, the impact of materials processing, and the impact of individual elements and products directly related to the construction of the building (Williamson, Radford & Bennets, 2003). The process of selecting the most appropriate materials and construction methods are usually problematic, as the judgement on the relative importance of environmental factors is subjective and without any universal guidelines or widely accepted models.

4.1.5.2 Using and Maintaining Buildings

The very existence of a building creates an impact on its surrounds, but more measurable effects are related to the energy and resources, like electricity, gas and water, imported to it when in operation as well as waste products, such as solid waste and effluent, exported from it. Although the operational sustainability of a building can, to a large extent, be determined by calculating its rate of consumption of imported resources and disposal of exported waste, measures to reduce these must be implemented with consideration for the ramifications it has on social and economic systems most likely built to accommodate a much larger consumption and waste-generating pattern (Williamson, Radford & Bennets, 2003). Reducing water consumption, for example, can lead to increased water charges from a supplier that bases its rates on large volume/ small profit principles. Similarly, reusing grey-water reduces flow-rates of a sewerage system, having the knock-on effect of an increase in solid waste and accompanying micro-organisms stuck in the system, which in turn has negative effects on human, animal and plant health (Williamson, Radford & Bennets, 2003).

4.1.5.3 Demolition and Recycling of Buildings and Materials

The irony of using terms like 'housing development' stems from the popular notion that land is elevated to a higher purpose when converted from agricultural or natural terrain to a space for accommodating buildings. This usually coincides with a disregard for the possibility of ever reusing the building site for something else in future, let alone the building itself or materials it consists of. Even in cases where reclaimed land is to be used for another purpose, soil contamination often renders the area unfit for farming or recreation (Williamson, Radford & Bennets, 2003).

Most modern societies have an ingrained culture of consumerism, relying on the concepts of waste and replacement to keep the system (including business and global economies) going. Sustainability within such systems means materials should be recyclable and ultimately biodegradable so as to create a shift in consumerist thinking. Unlike most processed materials, traditional materials are much more akin to the processes of natural and biological degradation at the end of a product's life. David Lea (1994) is quoted in *Understanding Sustainable Architecture* (Williamson, Radford & Bennets, 2003: 97) as stating:

Materials that grow on or lie close to the living surface of the planet, as close as possible to the building site – earth, lime, stone, plants – are the most pleasant to see and touch, and we need not burn much coal, oil or nuclear fuel when we convert them for use and carry them to the site. The roof and wall will not poison us, and when the building comes to the end of its life it will crumble into earth to support the life of future generations.

4.1.6 System Innovation

Vezolli (2007) argues that a serious approach to sustainability requires radical innovation in consumption and production patterns, that system discontinuity is essential. He continues by stating that, given the scale and nature of this change, it is imperative to see the transition towards sustainability and sustainable ways of living as a wide-reaching social learning process. According to him, most authorities on design research agree that radical change in sustainable consumption will most likely evolve from an approach where the scope of innovation is widened beyond the product.

Systems made up, not only of products and services, but also the environmental social, cultural and economic components affecting and being affected by these products and services need to be scrutinised and evaluated for its pertinence, significance and longevity. The need for a system or conventional way of operating within that system needs to be assessed, analysed and either adapted, improved or entirely eliminated to ensure it's compatibility to the changing environment in which it functions (Vezolli, 2007).

4.2 Architectural Expression of the Image of Sustainable Design

4.2.0 Introduction

One of the most important tasks of architecture, according to the author of *The Ethical Function of Architecture*, Karsten Harris (1997), is helping to articulate a common ethos, to interpret a way of life for our period. He is concerned with the actual and rhetorical function of buildings, the associated roles of aesthetics, and misunderstanding of the language of architecture by those not comprehending the secondary or symbolic meaning of structures (Williamson, Radford & Bennets, 2003). The invention and recognition of accepted symbols for concepts like sustainability form a significant part of the tasks of architecture.

Sunshades, cooling towers, solar panels and earthen walls have become synonymous with eco-friendly or sustainable architecture and have become exploited design elements used for the purposes of providing buildings with the desired aesthetic, image and character. In this way, the modernist approach of ‘form follows function’ becomes, as was often criticised in modernist design, a means of justifying the invention of a function to suit the desired aesthetic. The incorporation of these *symbols* of sustainability in a design becomes more important in the discourse of architecture than a regard for the attempts at actual sustainability. Symbolisation, however, is a profound human need and is indispensable in the perpetuation of culture. In many ways, the perception of sustainability through symbolic reference renders the building truly sustainable by it being a symbol itself, a thought- and question-provoking catalyst for awareness.

Three contrasting images of sustainable architecture are presented by Williamson, Radford and Bennets in *Understanding Sustainable Architecture* (2003: 1), namely the *natural image*, the *cultural image* and the *technical image* (see Table 4.1). These should not be seen as images used to deceive the end-user, however, but perceptions and approaches to design from the architect’s perspective. The three images are seen by some as mutually exclusive corners of a triangle, but in actual fact, often overlap and is combined in the conceptualisation and execution of building design.

**Table 4.1 Three images of architectural sustainability
(Williamson, Radford & Bennets, 2003: 25)**

Image	Dominant concerns	Dominant Horizon	Symbolism / Aesthetics	Approach
Natural	Environmental place, ecosystems, health, balance	Local	‘Touching the earth lightly’, forms echoing nature	Study local natural systems, emphasise sensitivity and humility in relation to nature.
Cultural	Cultural place, <i>genius loci</i> , difference, cultural sustainability	Local	Highly contextual with forms, materials and construction methods echoing the local vernacular	Study local culture and building, emphasise local involvement and local expertise
Technical	Technologies, global environmental impacts, cost benefit analysis, risk management	Global	Leading edge contemporary international systems	Study science, economics and technology, emphasise trans-national expertise

4.2.1 The Natural Image

In the natural image, the key to architectural sustainability is to work with, not against, nature: to understand, sensitively exploit and simultaneously avoid damaging natural systems

(Williamson, Radford & Bennets, 2003: 27).

Ian McHarg's book *Design with Nature* (1969) is described as a code for recognising sun paths, breezes, shade trees, and rock formations as natural features that can be 'worked with' in creating a dwelling for people. Acknowledging and preserving trees, animal tracks and habitats, and natural drainage systems as features is pertinent in the design process. The archetypal visual image is the remote and isolated self-sufficient building dominated by its surrounding landscape. Devices allowing the structure to be independent of imported services and exported waste, like rainwater collection, reed beds for sewerage and wind- or solar electricity generation, has the potential to permit this form of structure to keep its environmental footprint within the footprint of the site. Guy and Farmer (2001: 142), in their discourse of architecture, identify three different paths of logic linked to the natural image, namely:

- *Eco-centric logic* – a belief that 'nature knows best', that human activity should be a non-damaging part of the continuous ecological cycle.
- *Eco-medical logic* – a discourse focussing on healthy people in 'healthy' buildings, drinking 'pure' water and breathing 'clean' air.
- *Eco-aesthetic logic* – a move away from the clearly artificial towards an immersion in the subtleties, folds, movement and restraint of nature. The building expresses humility in the face of nature and never dominates its natural surroundings. Soft, organic, sensuous curves created through the use of unprocessed natural materials and finished in earth tones define this style

The natural image stipulates both physical- and spiritual comfort through the minimal disruption of natural ecological systems by human activity. Like its occupants, the building lives in harmony with its natural surrounding (Williamson, Radford & Bennets, 2003).

4.2.2 The Cultural image

The cultural image portrays a distinct *genius loci* in which architecture forms part of an authentic and localised cultural system. It reflects the anthropological belief that 'the

local culture knows best' and preservation of the link between culture and place is key in the conceptualisation of buildings. Sustainability of place determines and directs the sustainability of buildings. The image embraces the unique way local people interact with their buildings and how that differs from interactions towards and between other cultures and other buildings. Since local vernacular building methods are seen as having authentically emerged as a response to, and as a part of, local culture, it becomes the model for new building forms, colours and materials. New building symbolises the continuing vitality of the local culture, and is expected to rework, rather than reproduce the vernacular, to be identifiably contemporary while eminently respectful of the past (Williamson, Radford & Bennets, 2003). The cultural image brings with it the acceptance that sustaining culture may mean limiting the incorporation of what is *new* by including what is culturally and socially *appropriate*. Guy and Farmer (2001: 146) identify two paths of logic that overlaps with the cultural image:

- *Eco-cultural logic* – where local ecology and climate form part of the sense of place and help to define the culture and vernacular.
- *Eco-social logic* – it suggests the formation of architectural structures that embody the notion of a democratic community embracing social and ecological values and where full participation and freedom within that community is the norm.

In the idealised cultural image, the community is assumed to be healthy, democratic and self-sufficient with a clear sense of identity and belonging (Williamson, Radford & Bennets, 2003). Buildings, like the community, interact with one another in an atmosphere where identity and distinction are equally important.

4.2.3 The Technical Image

The technical image of sustainability sees technical innovation as the solution for social, economic and environmental problems. In this image sustainability is a matter of developing technical devices that neutralise or make attributes out of challenges opposing, and/or brought about by, development (Williamson, Radford & Bennets, 2003). Success is determined by levels of expertise and it is believed that for every problem or side-effect there is, or should be, a set technical solution that will counteract it. Hard scientific facts are favoured in this image, especially quantifiable environmental and economic data. Efficiency of a system can be measured in terms of reduced energy consumption, reduced embodied energy in materials, interior temperature regulation and lighting levels as well as reduced initial and operating

costs. Technical proficiency defines this image in glass, steel and precision cladding panels in aluminium, its use justified by its longevity and recyclability (Williamson, Radford & Bennets, 2003). Other devices include double-skin external walls and roofs, filtering and responsive glass, sun-tracking sunshades, photovoltaic cells, geothermal systems, and intelligent lighting, heating and cooling. The archetype of the technical image is the high-tech corporate office or apartment block in a densely populated vibrant city, where efficient people are housed in efficient buildings. People and buildings are both in control of their environment and both respond to challenges through innovation. Guy and Farmer (2001: 142) state that the *eco-technic* logic, along with the concept of *ecological modernisation* at policy-making level, sums up the rationalisation within this image. Serious environmental-, social- and economic side-effects of development are seen as just more problems in the path of modernisation that can be overcome and managed by international treaties, local regulation and global innovation (Williamson, Radford & Bennets, 2003: 32).

4.3 Summary

A systems approach to sustainable architecture, a deliberate amalgamation of systems theory and system design for sustainability (SDS), serves as the principle analytical lens for this study. Systems theory is used to simplify into manageable units the intricate complexity of different approaches and theories relating to sustainable architecture, while SDS helps to elaborate on and better understand the various components that are identified. At the most basic level, systems may be classified as either closed, where the components only interact with one another, or open, where the system interacts and is influenced with other processes and systems external to itself. Buildings as well as environmental sustainability are inherently open systems, indicating that in order to obtain a comprehensive understanding of these systems, external factors impacting on them and as well as interactions within each system should be considered.

The concept of architectural expression involves looking at the design of buildings from the perspective of architect or designer and how, through the use of symbolism, architectural structures can serve as icons of sustainability. Symbolisation is indispensable in the perpetuation of culture and often serves as tool to direct the mindset and behaviour of communities or to advance a particular paradigm. Three contrasting images of sustainable architecture, namely the natural image, the cultural image and the technical image inform the perceptions and approaches to design from

the architect's perspective. The three images often overlap and are combined in the conceptualisation and execution of sustainable building design. More than purely functional, what a building represents or symbolises often has a much greater impact on the sustainability of the community which it houses than its own physical environmental footprint.

CHAPTER 5: Research Methodology

5.0 Introduction

This chapter discusses the basis of the chosen epistemological bearing and describes the research methodology employed in achieving the objectives outlined in Chapter 1 of this thesis. The chapter provides a description of the sources of data, methods used to collect the data, as well as analytical processes used to evaluate the information gathered during the various stages of the study.

5.1 Contextualising Research Perspectives

5.1.0 Ontological Assumptions

A realist ontological assumption assumes “that social reality can be understood from an *external* point of view (the *realist* position that abstract objects have an objective existence: reality is of an objective nature, out there)” (Maree & van der Westhuizen, 2007:31). Alternatively, reality can be understood “merely through words and names created in the mind and within levels of individual consciousness (the *nominalist* or “in name only” position) (*ibid*).

The realist stance of this study, as elaborated upon in Table 5.1, denotes a concrete perception of actuality and endeavours to understand the parameters of the sociological circumstance to get a reality-based picture of the challenge for which it is attempting to find practical and applicable solutions.

The concept of sustainable architecture is a well-known, widely practiced theory. Various individual interpretations of this concept, however, make the prospect of a universally shared understanding of what is considered best practice an unattainable ideal. The author chooses to adopt an anthropocentric approach, advocating a holistic

equilibrium and symbiosis between humankind and nature. This interpretation and application of the theory within the context of residential architecture and its impact on construction material and design options guide the direction of this thesis.

5.1.1 Epistemological Views

Epistemology is the division of philosophy that investigates the origin and nature of knowledge, otherwise known as the study of the foundations upon which human knowledge stands (Spencer, 1998). This thesis, set in a socio-technical paradigm, predominantly adopts a qualitative stance, while technical quantitative data is used to support and justify decisions and conclusions pertaining to sociological fundamentals while simultaneously lending scientific quantifiable credibility to the research. Numeric data is used in this study to calculate and systematically compare the technical attributes of structural forms and materials used in socio-economically- and environmentally-sensitive architecture practices. Often, however, the reasoning behind certain resolutions are based on observations of sociological dynamics or unquantifiable human bias.

Because of the author's cultural heritage and western Euro-centric education, some trademarks of this inheritance should be acknowledged as having an influence on the general perspectives and approach to the compilation of this body of literature. It should be noted, however, that one's heritage, although intrinsic to some extent, merely provides a base from which to evaluate other approaches to thinking and being. According to Williamson, Radford & Bennets (2003: 7), in societies of European descent or influence, three predominant trademarks, namely dualism, reductionism and positivism, pervade modern living.

Dualism expresses a distinction between body and mind, between matter and spirit, and between reason and emotion. Body/matter/reason represents the extended or corporal world in which all phenomena can be completely determined by mechanistic principles, whereas mind/spirit/emotion is totally severed from sense experiences and is described by Bauman (1995: 260) as the "unruly voice of conscience that may prompt one to help the sufferer".

Cartesian dualism sets humans apart from nature, but also an individual self apart from 'the other', or everything outside the self.

Reductionism perceives all entities as being made up of simpler or more basic units. From this derives a method of acquiring knowledge by breaking down a problem into simpler units in a process of atomisation. After studying and attempting to understand these simple units, we reassemble them in a 'logical' fashion in order to shape our understanding of the problem as a whole (Williamson, Radford & Bennets, 2003: 7).

Positivist notions, according to Spencer (1998), drives the prevailing Anglo-Saxon academic conventions. Positivist positions are quite varied in themselves, but generally the positivist position is that knowledge deals with the things out there for which we can gain positive evidence. "It (positivism) is inherently objectifying, separating the knower from the known. It focuses on objects, whether they be astro-physical or sub atomic entities, or social systems and historical events, rather than our perception and knowledge processes" (Spencer, 1998: 2).

In contrast to the positivist position, the interpretivist epistemological view assumes that "the meaning of human action is inherent in that action, and that the task of the inquirer is to unearth that meaning" (Schwandt, 2001:134). In addition, the study adopts a functionalist stance, aiming to solve irregularities in what has been investigated and interpreted by proposing solutions or amendments to address necessary changes to the current product, service or system. The research subscribes neither to a pure positivist/modernist view, where the researcher is an objective and detached observer, nor to a pure relativist/post-modern view, where the researcher is empathetically and subjectively immersed in the research. Scientific numerical data lies within the positivist realm, whereas social interactions and human responses to design interventions direct the outcome of the study to a relativist sphere.

It is therefore believed that by allowing both positivist and relativist perspectives to influence the direction of the study means that a balanced understanding of real-life situations is able to better deliver authentic concrete proposals. This study follows an applied research direction, as apposed to a pure or basic research route. Pure or basic research involves the formulation and testing of hypotheses and theories not necessarily linked to actual applications (Fielding & Lee, 1998), whereas applied research is typically a problem-based focus on real-life social challenges. Although physical design intervention is in this study substituted with conceptual or theoretical intercession, the proposals are based on acute observations of actual real-life circumstances and designed to be employable within the designated locale.

**Table 5.1 Delineation of paradigmatic assumptions and perspectives
(Maree & van der Westhuizen, 2007:33-34)**

Ontological dimensions	Epistemological dimensions; paradigm/perspective	Nature of relationship between researcher and what is being studied
Realist stance: external reality is stable; general laws govern universe	Positivist (modern)	Researcher is an objective, detached observer
Nominalist stance: informants' internal and subjective experiences are important	Interpretivist (post-modern)	Researcher is empathetically and (inter-) subjectively immersed in the research
Reality is constructed by persons; researchers need to analyse the informants' discourses	Constructivist (post-modern)	Researcher is suspicious of object of study; political undertones can be identified; constructs own version of events

5.1.2 Methodological Considerations

This study primarily uses a desk review of available literature to develop an understanding of the complexity of factors influencing the topic. It uses observation and interpreted literature on a series of exemplars to narrow down and focus appropriate applications that could be realistically achieved within the limitations of the selected locality as well as the parameters of the study. The rationalisation for choosing to focus more on some materials, processes and practices than others are substantiated by referencing authoritative theoretical and epistemological stances on sustainable development and its relevance to textile-based architecture.

5.2 Experimental Design and Sampling Method

Bailey (1987:214) identifies two approaches to social research concerned with establishing relationships between variables: *correlational analysis* and *experimentation*. The fundamental difference between the two approaches is that in correlational studies researchers “typically have very little control over the research environment. [...] In such a case the researcher’s control is limited almost entirely to statistical data manipulation”. In contrast, the experimentation researcher “is present on the scene when the data are collected and exercises considerable control over the

experimental environment. This control over the research process allows the experimenter to attempt to establish causation rather than mere correlation, and thus the establishment of causation is the goal of the experimenter” (*ibid*).

Bailey (1987) further distinguishes between ‘pure’ experimentation and quasi-experimentation – the latter utilise ‘partial’ experiments lacking one or more of the characteristics of pure experiments (*ibid*). The steps taken in a typical experimental process include the following (Bailey, 1987:221):

- Select subjects;
- Select experimental environment;
- Pre-test;
- Administer experimental stimulus (test factor); and
- Post-test.

Of the various forms described, this study followed a ‘one-group pre-test post-test design’ approach. Such a design has all the steps listed above but has no control group (Bailey, 1987). The choice of this variant of experimentation was due to tight time constraints within the timetable of the architecture firm for which the design development was intended (a one month timeframe). The task of the researcher and the research unit was to analyse and develop the existing design conceptualised by the architecture firm. Fellow researchers present at and contributing to the research project in various capacities (as informants or research assistants) played the role of observers and repertoires to reduce the possibility of bias as well as to enhance the validity of the findings from the study.

5.3 Role of the Researcher

The Researcher assumes a non-participant passive observer status during stages within the study that requires only recording or documentation of observations and informant responses. However, the researcher took on the role of active facilitator/participant observer in the case of the focus group discussions. Even though aimed at addressing real-life challenges, the proposed design interventions are kept at a conceptual level, making active participation, facilitation and intercession unnecessary within the scope of this particular study. The administration of questionnaires was carried through electronic correspondence with informants and thus required minimal involvement of the researcher.

5.4 Research Activities

This research primarily employs qualitative methodological approaches related to social sciences, but uses quantitative data collected to justify, validate and support social strategies which could otherwise be seen as subjective. A literature review of archival data and numerous publications on relevant global strategies and practices informs the research of universal trends and applications within the area of study. A theoretical analysis is carried out to determine the special requirements applicable to South Africa as an emerging economy, South Africa as an African state and the specific constituents influencing the particular site conditions within the communities in the Cape Town region earmarked for the theoretical construction of the proposed conceptual designs. International examples of textile-based architecture guide the direction of the study through the analysis of recent developments in the relevant field and relating it to conditions present within the selected locale.

5.4.1 Database Methods

This process involved collecting relevant data from literary sources such as books, journals, internet-based resources as well as other information available on the selected cases such as photos, drawings and technical specifications. Expert opinions were drawn on to validate the collected data.

5.4.2 Personal Interviews

Unstructured, informal interviews were conducted with a limited number of key informants. Responses were open-ended and based on informants' experience in the field of study. The opinions and responses of experts were used to bridge the gap between theories and literature relating to the topic and the proposed applied design intervention. The views of key informants also served to validate or disprove the researcher's assumptions and hypothesis.

5.4.3 Questionnaires

The questionnaires used to obtain the views and opinions of experts consisted predominantly of open-ended questions, which were used to gather qualitative information with respect to the study. Structured and semi-structured questionnaires were administered to design practitioners, which included professional architects and design/architecture educators.

5.5 Workshops

Workshop discussions were held with regards to a particular project included in this study during a strategic phase of the research in collaboration with professional designers, an architect and participating academia. The author ran a participatory workshop that served to stimulate the debate on different perspectives on a particular emergency shelter project, the product development phase of which the author was personally involved with (see Appendix D for a summary of issues arising at the workshop). The researcher was in the privileged position to run this workshop during an international academic exchange, which meant that this particular case study benefited from a wider range of expertise than that which was accessible to the researcher in South Africa.

5.6 Data Collection Methods

Voice recording during interviews and workshop/ brainstorming sessions as well as electronic data from questionnaires were used as the main tools to accurately log the responses and opinions of key informants. These recordings were transcribed, analysed and segments introduced into the writing where it would supplement, enhance or validate the relevant topical literature or research findings (M'Rithaa, 2009).

5.7 Data Evaluation Methods

The data analysis was conducted side-by-side with data collection, data interpretation and narrative report writing. Foster (1996:59) notes that observation offers advantages over interviews and questionnaires in that it allows for recording of human behaviour directly “without having to rely on the retrospective and anticipatory” responses of informants. However, Bailey (1987:31) cautions against the danger of “reactivity”,

describing reactive research as “one whose application causes a reaction on the part of the persons being studied in such a way that the data are affected”.

The data analysis was primarily based on the principles of *reduction* and *interpretation*, meaning voluminous amounts of data was reduced to certain patterns, categories and themes and then interpreted through the implementation of a form of schematic representation (Sapsford et al., 1996)

During data analysis, information was organised categorically and chronologically, reviewed repeatedly, continually compared with new findings and, if necessary, updated accordingly.

5.6.1 Verification of Technical Specifications

No specific brand, product or company were singled out in the collection or documentation of the technical specifications of specific materials or processes. The numerical data of various products and systems were obtained, compared and added to the written narrative as universal averages, causing the choices between the multitude of textiles and construction techniques to be less dependent on specific data and more on the universal characteristics and suitability of types of materials or processes.

5.6.2 Exemplars

Numerous exemplars were extracted from the literature reviewed for this study. In each instance the available literature as well as other relevant data (photos, illustrations, technical specifications) were collected, interpreted and summarised to be included in the written body as a concise description and an appropriate example of the type of structure or material it is meant to represent. None of the individual examples can rightfully be considered case studies as they are not analysed in excessive detail, yet they serve as existing universal archetypes of the range of materials and systems described in the research. This approach was specifically implemented to facilitate the reader in obtaining an overview, rather than a specific perception, of this particular area of study.

5.7 Ethical Considerations

The select number of interviews conducted for this study meant that ethical concerns could be anticipated, considered and checked with relative ease. The key actors involved in this study were the respondents/interviewees, referred to as informants, and the interviewer/researcher.

5.7.1 Ethical Issues Relating to the Informants

The following measures were taken to ensure that the study is ethical (M'Rithaa, 2010):

- The informants were not compelled into participating in the study.
- Any informant who chose to withdraw from the study and revoke the information she/he supplied to the investigator was granted their wish without prejudice.
- Information on personal details by informants was optional and treated with due confidentiality.
- The informants were not deceived but were told the truth about the intent of the study.
- Informants were not seduced into the research or persuaded to participate in the study through any form of incentive.
- After analysing data and finishing the report, the informants were provided with the findings in order to resolve any misconceptions which might have occurred during the data collection process.

5.7.1 Ethical Issues Relating to the Researcher

The following issues were taken into account by the researcher when dealing with the research:

- The researcher attempted to ensure that the data collection procedure and interpretation was not biased or the outcomes influenced or altered by any third party.
- Appropriate methodology was used when collecting the information for this study.

- There was no information obtained from an informant unbeknownst to them or in any adverse manner.
- No information provided by an informant was published without the knowledge and consent of that informant.
- The researcher endeavoured to uphold accepted and expected code of ethic principles in relation to human dignity and a universal understanding of justice.

5.8 Summary

The research is inevitably influenced and directed by the ontological and epistemological views of the author. Displaying characteristics of both interpretivist and functionalist standings implies that the aim of this study is first and foremost to understand and subsequently to resolve irregularities or needs within a specific system. By the researcher assuming a predominantly objective role, it is believed that the findings and resulting recommendations of this study will serve as an unbiased and grounded reality-based guide for significant future design interventions. The next chapter will elaborate on the specific implications of the findings from this study.

CHAPTER 6:

Data Analysis and Discussion of Findings

6.0 Introduction

A rich diversity socially, culturally, economically and environmentally is evident within South Africa. The most urgent need for housing exists within the low- to no income social housing sector and as has been illustrated by this study, textile-based configurations offer various proven solutions for low-cost structures that can be built using low-tech processes and manual labour construction methods.

To illustrate the positive impact building with textiles can have on low-income communities within South Africa, a shelter-to-house concept developed in Brazil is proposed as possible solution to the current and continuous social housing crisis experienced in many parts of South Africa. This conceptual shelter design was originally intended to provide temporary shelter that can be gradually for addressing the specific needs of these communities are directed by the shared converted into permanent housing structures for victims of natural disasters, but is in this study adapted to address the unique requirements of those in need of permanent residential housing structures within informal settlements. The adapted design proposed conditions within South African informal settlements, although an underlying flexibility gives the design a certain measure of adaptability for implementation in similar settings within emerging economies worldwide.

6.1 Roles of the Principal Actors

6.1.0 Introduction

Professional architects known for being leaders in sustainable architecture in South Africa were either interviewed or asked to complete a short questionnaire containing open-ended questions to capture their views on the role of textiles in sustainable architecture. Etienne Bruwer, Gita Goven and Keith Struthers responded and provided the researcher with authoritative perspectives on the topic. Gerhard Bosman of the Unit for Earth Architecture at the University of the Free State provided an academic perspective on the assimilation of sustainable architecture practices and level of exploration of materials like textiles currently happening in architectural courses in South Africa.

In Brazil, the views of architects Rebeca Paciornik Kuperstein and Johan van Lengen shaped the assessment of the *Bossa Nova Instant Housing Project* and its subsequent proposal in this study as a medium for addressing the current South African housing crisis through textile-based architecture in a way that reflects on the principles of sustainability. Kuperstein is the founder of *Sersustentavel*, the firm that developed the Bossa Nova Instant Housing Project and Van Lengen is the author of the international bestseller *The Barefoot Architect* (2009), widely considered the bible of natural and sustainable architectural practice.

6.1.1 Thematic Analysis: Architects' Perspective

When asked which aspects of sustainability they consider to be most neglected presently in South African residential architecture and how these relate to textile-based architecture, the architects' responses were:

- *'Sustainability' is about connective tissue between social economic and environmental considerations, and thus holistic. If atomised, and defined by material considerations to the exclusion of moral-aesthetic and contextual considerations, it devolves to 'just the next materialist myth'. Serving primarily the profit motive, as it does, policy-makers, regulatory agencies and vested interests (Government, CSIR, NPO'S, NHBRC, GBCSA, SABS etc) have adopted select aspects of 'sustainability' suited to this purpose . Aided and abetted by funding with EU 'guilt money' (the carbon trade and trade-off system), which is a front for the creation of a new 'green' market, the upshot is that strategies specifically associated with sustainable practices in cold climates and highly industrialized first world economies ('energy-saving', 'recycling' etc) have been adopted – essentially, job creation for Northern Hemisphere citizens as the emissaries of products not invented or manufactured here. This has been done to the express exclusion of those aspects that could have been be more suitable here (key words: low density, value addition materials, low-dependency, labour-intensivity, job-creating poverty-alleviation, skills developing, vernacular etc – all 'less profitable' , please note), which have been marginalized by intent and law.*
This is all held in place by a market created, controlled and thus dictated to by policy-makers, regulatory agencies and vested interests (the consumer who is dependent on/buys from them/borrows money/aspires to prestiged brands)
Ergo sum, the 'sustainability industry' is driven by a 'techno-solutioneering'/'industrial' mindset – which by design have economic imperatives as its sole driver; it measures all in kilojoules and carbons, not aesthetic/human or other qualitative 'betterment' considerations (Bruwer, 2011).

- *Simple climate sensitive design and the use of landscape to shade and shelter the buildings (Goven, 2011).*

With regards to the reason(s) why, in their opinion, textiles in architecture has not found wider acceptance within South African residential architecture, Bruwer (ibid) and Goven stated:

- *The savannah is a place of grass, so thatch or grass matting is the suitable vernacular here. Even the Mediterranean climate of extremes as we have in the Cape has traditionally seen the use of textiles for kinetic architectural use and temporary seasonal shelter, as it is lightweight (windmills, sails, tented stoep summer tarps) , but not really as winter, i e 'permanent', enclosure.*

Until sail ships and ox wagons arrived here, cotton and hemp weaving occurred north of the equator in Africa. Architectural weaving and textiles are thus somewhat 'volksvreemd' to both white settlers(coming from the cold) and abantu indigent peoples – it is associated with temporality and transience , and even the Khoi San of used skins, matted weavings for shelter I think came later. The temporality of textiles has to do with associations - the monsoon zone (leaf and Bamboo) tropics (leaf and stem culture – macouti, sisal and palm), nomadic cultures(tents) in all areas cold and hot .

In modern times, it remains unsupported by agencies and operatives (govt SABS NHBRC And business etc) which have advocated and reinforced an extremely narrow 'chemically defined' mineral-based/ synthetic/ Eurocentric approach, which favours wet trades and steel over all else, and is upheld through fear-mongering and regulation(the fear of combustibility, short lifespan, performance 'inferiority' etc is punted to keep fibres like hemp and sisal and so on, out of the industry controlled by cement and steel fabricators) This in turn has defined and delineated our building culture and construction.

Essentially, "Turning Mud into Concrete/add Victorian corrugated iron, voila."

There is also even greater across-the-board rejection of architecture that does not hail the machine aesthetic because it 'fits' neither aspirational profile nor economic motive of either the old-haves, new-haves or have-nots. Consequently, – environments that are natural/ healthy/ handmade/ vernacular/ low-tech/ labour-based are considered inferior an are aggressively being phased out in favour of instant industrial 'flat-pack-solution' (the Deputy President said last week, "poor children in rural are "STILL GOING TO SCHOOL IN MUD BUILDINGS" – which will probably be replaced with steel sheds and temporary classrooms ,given the urgency to eradicate a past perceived as inferior/ African/ unWestern/ un-American/ pre-industrial (Bruwer, 2011).

- *I would choose it mainly for external areas because of the beautiful light and shade qualities. It can be expensive and tricky in windy climates if not well designed as a pure tensile structure (Goven, 2011).*
- Keith Struthers (2011) is of the opinion that alternative building practices like sandbag construction is not more widely diffused in South Africa because of the limited returns for contractors when compared to regular building methods. Another reason, he says, is that sandbag construction for instance, is perceived as a temporary solution, not a technique used to construct permanent dwellings. Convincing a client to pay millions or Rands off over 20 years on a house made from a material that he is unsure about, is a massive challenge. Convincing a conventional client to think in an unconventional way is almost impossible, according to Struthers (ibid). He is of the opinion that a lot of people's resistance to the use of textiles is that it is seen as requiring more maintenance than more common building materials. Taking into account the maintenance and overall life expectancy of a chosen material is critical in rating its sustainability.

6.1.2 Thematic Analysis: Architecture Educator's Perspective

A Questionnaire was completed by Mr Gerhard Bosman (2011), head of the *Unit for Earth Architecture* at the University of the Freestate (UFS) following a brief introduction and informal discussion with him.

According to him, his department/unit does not have a specific policy that informs design for sustainability or sustainable architecture. The incorporation of textiles in architecture also does not form part of the architecture department's standard curriculum. The only theme related to textiles referred to in the standard curriculum is the use of natural fibres for insulation. Bosman believes that there are definite merits in teaching and promoting all aspects of sustainable architecture, including the use of alternative materials such as eco-textiles, in his department and in architecture courses countrywide. He believes that lecturing staff teaching building science subjects would be in the best position to champion sustainable architecture and/or textile-based architecture in the institution. The only obstacle Bosman (ibid) anticipates in adopting sustainable architecture as a strategy in his department is the acquisition of a physical workshop space in the department building to accommodate experimentation

by staff and students. In his opinion the best way to promote textile-based architecture to future architects, engineers and designers is by encouraging experimentation with regards to unconventional materials and construction methods.

Implications for Principal Actors

6.2.0 Implications for Architects

When asked to name specific examples, in their own work or that of others, where the incorporation of textiles in permanent exterior architecture contributed to a residential building's sustainability (ecologically, economically or socially), Bruwer and Goven stated:

- *-Geotextiles in roofing applications as water filter interlayer/cementitious binding layer and sheet former. – own office and house.*
-Extensive use of shade netting /partially waterproofed shade netting or imbedded 'Ferrari' types upvc cloth - nationally and internationally, used as canopies and rain screen.
-Gernot Minke uses cloths of different kinds throughout his work
-Chris Alexander built housing South America using burlap in domes, tiles
-Frei Otto's tented structures inspired using living tissue of creeper plants to create cross-laminated lattices- offices Munchen. The Alexander work is great, close to what this study seems to be searching for. The Otto work contains a picture of the future – beyond 'dead' materials, but transformed, not naturalistic. (Bruwer, 2011)
- *-Hartleyvale Stadium, Liesbeeck Parkway, Observatory Cape Town- Textile roof,*
-Sustainable: It is light weight and therefore reduces the structure required,
has great aesthetic quality and provides shade and light. It is however very technically challenging to design, install and maintain.
Sossusvlei- Karos hotel- tented camp- Ditto above.
A very wide range of projects that ARUP international have designed and executed (Goven, 2011).

When asked how, in their opinion, the incorporation of textiles can be mainstreamed in residential architecture, responses were:

- *Without incentivisation and extensive further development at probably huge investigation, R&D costs, and a 5-10 year foreign-funded marketing drive before*

significant returns, it probably will not be possible. I can and do use fireproofed cloths like hessian, but not prefabbed, which causes waste, is anti-labour and being componentised, tends to destroy design freedom (Bruwer, 2011).

- *Not* (Goven, 2011).

6.1 Implications for End-users

Designing and constructing residential buildings, Keith Struthers (2011) says, poses some unique challenges, since a house is often the largest private purchase an individual or family will ever make. Commissioning a building, the client wants to make sure that it is a good investment, something they would be able to sell one day for more than what they had paid for it. The choice of building material and method is directed more by the client's perception than actual statistics. If a particular building method is perceived by the client as appreciating less over time than the standard, the client will more often than not opt for the latter.

Struthers (ibid) says that people in the low-income bracket want a miniature version of whatever those with money have. Therefore, before a concept for low-cost housing using unusual building methods will be accepted by people needing financial assistance, the principle should first be popular with people in the medium to upper income bracket. According to him, recipients of low-cost housing do not want to live in structures that remind them of their poor or oppressed past or alienate them by the provision of something different to what the rest of the population has. A trade-off needs to happen between what the architect proposes as the most effective solution and what the end-user would accept. Government bureaucracy is another massive challenge to architects and designers looking for solutions that will optimally benefit the end user and not necessarily the arguably corrupt system of housing delivery that is currently the norm. Although numerous technically effective solutions to low-cost housing exist, the challenge of linking problem and solution in this instance is rendered far more complicated by associated social, administrative and governmental issues. Struthers (ibid) says that the only way of circumventing this challenge is by proving to authorities the efficacy of the technical solution through private initiatives serving as prototypes for government housing schemes.

6.3 Case Study: The Bossa Nova Instant Housing Project

6.3.0 Introduction

In a response to the devastation caused by the massive earthquake that ravaged Haiti in January 2010, *SerSustentavel*, an architecture firm based in Curitiba, Brazil developed a bamboo-framed shelter with textile wall cladding and a roof made from recycled plastic roofing sheets as part of their *Bossa Nova Instant Housing Project*. The main aim of this initiative, lead by Brazilian architect Rebeca Paciornik Kuperstein, is to develop a versatile shelter which can be erected on site in less than 4 hours, providing a comfortable, water and wind resistant habitat that, if need be, can last for more than 15 years in it's assembled state. The idea, however, is for the translucent textile walls to provide initial shelter against the elements, and that the shelter occupants themselves will be able to gradually replace the triangular textile cladding sections with bamboo-and-mortar or wattle-and-daub panels within the existing bamboo frame structure, thereby steadily converting a temporary shelter into a permanent low-cost home without having to dismantle and/or rebuild the entire structure.

The initial design and prototype has been well received by authorities and aid organisations alike, both because of its ease of assembly and because it is a relatively inexpensive solution to humanitarian crisis situations of this kind. Besides these features, it is also developed with optimal sustainability in mind. Materials are selected for their low environmental impact and low energy consumption during manufacture and the physical housing structure forms part of a more encompassing plan for social sustainability in the form of community rebuilding/revitalisation initiatives. Research is continuing on material alternatives that are even more eco-friendly and/or that can be more economically produced in or shipped to the disaster-affected areas.

Although the shelter structure was primarily developed to address the housing crisis in Haiti, the various design elements are continuously scrutinised, developed and refined for the structure to become universally adaptable to serve as solution to other disaster-hit areas throughout the world. Furthermore, the ability to transform from temporary shelter to permanent housing structure makes it an ideal solution to address the critical need for low-income housing that exists in developing countries like Brazil and South Africa. The developers of this product have expressed interest in constructing full-scale working prototype structures in Brazil as well as South Africa in an attempt to test its feasibility in those areas as well as to propose an alternative to current government

housing schemes. Unlike the fired brick and mortar structures currently built by large construction firms as part of massive federal contracts, with the *Bossa Nova Instant Housing Project*, communities in need can actually do most of the assembly and construction themselves, regardless of age, gender or conventional construction skills.

6.3.1 Outcomes from First Meeting with Client

A meeting was held with the client, *SerSustentavel* on 30/03/2011 where the Bossa Nova Project was discussed with specific focus on the current system and product, challenges encountered and the role and deliverables of the research conducted by the author and researchers at the *Nucleo do Design e Sustentabilidade* (NDS) at the Federal University of Parana (UFPR) in Curitiba, Brazil. A comprehensive and categorised transcript of this meeting highlights the history, current design strategies and shortcomings of the *Bossa Nova Instant House* (See Appendix D).

During this meeting five key requirements emerged as assessment tool for the evaluation of current elements and the development of alternatives.

- **DIY:** It has to be easy and quick to assemble and not require special skills or tools. Consider the composition of the kit, ways of transporting, size, weight etc.
- **Must Provide Resistance** against rain, wind and fire. Must meet UN standards / other temporary shelter standards
- **Optimal Material Use:** Design must employ materials economically while still maintaining structural integrity and optimal efficiency
- **Aesthetics & Perceptions:** Must feel/look like a house, not a tent. Structure must not only *be* sturdy, but also *look* sturdy. Occupants must feel safe/protected. It is crucial to consider the perceptions and human dignity of occupants.
- **Ventilation & Insulation:** The Bossa Nova shelter was developed specifically for tropical or sub-tropical areas. Shelters must provide a certain comfort-level in all seasons.

6.3.2 Outcomes of Internal Brainstorming Session

Besides discussing findings from the research that had been completed up until 13/04/2011 and comparing it to the notes from the first workshop, suggestions were also heard and discussed on various types of connectors for bamboo structures as well as potential textiles manufactured locally to be used in floors, walls and roof of the shelter structure. The last item on the agenda was an idea generation session based on the principles of the 635 technique (Rohrbach, 1969: 73). This session focused specifically on generating as many ideas as possible for types of connectors that can be employed in the construction of the shelter.

6.3.3 Research Findings and Recommendations

6.3.3.0 Introduction

The recommendations formulated after a one month study are aimed at proposing realistic and viable design developments to render the current shelter design easier to manufacture, transport and assemble in post-disaster scenarios. Recommendations are included for future advances when time and available funding allows for further research and development by contracted professionals.

6.3.3.1 The Bossa Nova System

When looking at the Bossa Nova system, the shelter structure as product forms only a small, yet undoubtedly significant component of it. The proposed system is divided into 3 different phases, namely manufacturing of kits, assembly of the emergency shelter, and conversion of the emergency shelter into a low-income house.

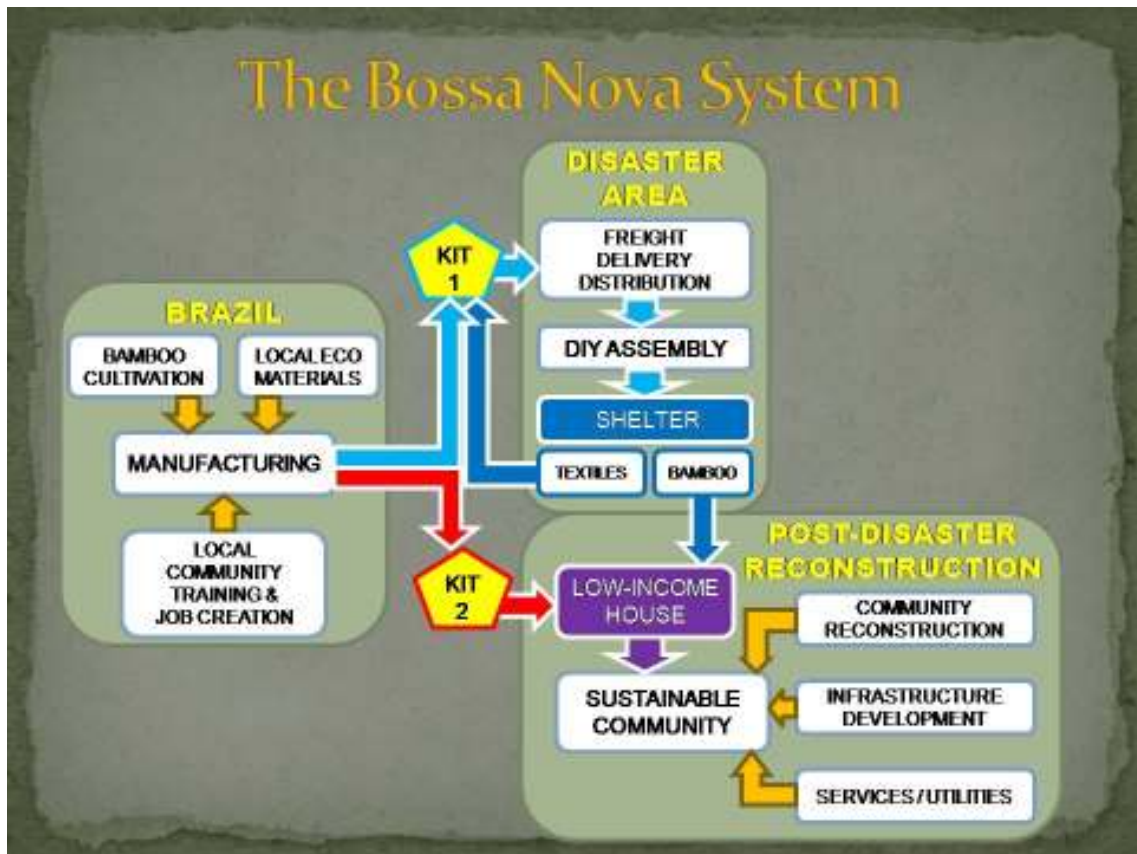


Fig 6.1 The Bossa Nova system (Author's own construct)

Manufacturing of Kits (Brazil)

Community projects fabricating and assembling the Bossa Nova housing kits will be putting together two different kits: one to meet the need for immediate deployment of emergency shelters in post-disaster areas (Kit 1) and another for meeting the longer term need for low-cost housing structures (Kit 2) in the reconstruction of the cities destroyed by the natural disaster. Manufacturing of both kits will happen in Brazil, using locally sourced materials, which includes the cultivation and harvesting of locally produced bamboo for the structural frame. Initially, manufacturing of components for both kits will be undertaken by *Guarda Viva*, a social upliftment project located in a low-income community in Sao Jose dos Pinhais, Parana. Members will be receiving training on how to manufacture the various parts of the shelter and assemble the kits to be ready for shipping to the disaster areas.

This phase addresses the principles of design for sustainability within Brazil, firstly by using environmentally friendly materials, secondly by obtaining all materials from local producers, and thirdly by structuring its manufacturing process to address poverty alleviation, stimulate job creation and incorporate skills development initiatives.

Assembly of Emergency Shelters (Disaster-struck Area)

Kit 1, consisting of a bamboo frame, connectors and pre-fabricated textile panels for cladding the roof, walls and floor, will be shipped as a do-it-yourself solution for victims of natural disasters in need of immediate shelter. The kits will be shipped from Brazil to the disaster area using standard shipping containers. After arriving at the post-disaster area, aid workers will collect the shipment of kits and transport it (via available local transport) to the various distribution areas. Aid workers familiar with the product will demonstrate the assembly process by convening victims in a specific area and constructing one temporary shelter. Thereafter they will be distributing the kits to the heads of affected families for them to assemble their own shelters in an area designated by the local authority.

The assembly process is extremely simple and have been specifically developed to be constructed using intuitive construction practices as well as to eliminate the need for instruction manuals or any hand- or power tools. Users will be able to construct the shelter even if they are not literate, skilled in construction or familiar with the shelter design. The assembled shelter is designed to last for a period of up to three years, although ideally, communities will start converting their temporary shelters into permanent houses within less than a year. For the temporary emergency shelter to be converted into a permanent, low-income house, residents would use a combination of Kit 2, which would be shipped from the manufacturing facility in Brazil, and locally sourced materials such as soil and tree branches. Once the textile cladding panels on the roof, walls and floor have been replaced, all of these panels can be reintroduced into kits destined for relief efforts in other disaster areas.

Design for sustainability is in this phase put into practice by the minimising of transportation cost and energy in keeping kits as compact and light as possible, by using materials that would have zero negative impact on the site, by reusing all textile panels continuously until the end of the product life, and by preserving the bamboo structure in the conversion from temporary shelter to permanent house, thereby optimising material use. This final attribute not only means structural materials are being used optimally, it also means families will not be displaced a second time as they would not need to move from the initial shelter structure. The transition is gradual and does not necessitate the demolition of one structure or the construction of another.

In the case of Bossa Nova, the conversion process simply entails replacing temporary cladding panels with permanent filling materials in a standard bamboo frame.

Conversion into Low-income House (Post-disaster Reconstruction Area)

The temporary shelter structure (Kit 1) is designed to be converted into a permanent low-cost house structure by combining components in Kit 2 and local materials that become more regularly available as the disaster area starts recuperating. The bamboo frame from Kit 1 remains the structural framework of the house, although additional triangular panels can be added at this stage to increase the size of the structure and/or divide the structure into separate rooms. Multiple complete pentagon-shaped frames can also be joined together in order to create larger dwellings. Kit 2 will be put together in Brazil according to the specific demands of the post-disaster area, but the minimum it will contain will be enough tiles or sheets to replace the textile roof with a permanent roof as well as elements for converting the floor into a waterproof, permanent floor and elements like door and window systems. The textile wall panels can be gradually replaced by reinforced earthen walls made by the vernacular wattle-and-daub technique or even textile-reinforced concrete panels (Van Lengen, 2011).

Other additions that can be included in Kit 2 are safety stoves, solar lighting units, solar water heaters, kitchen kits, bathroom kits, solar ovens, wardrobe units, room dividers, DIY furniture kits and unit expansion kits. Before the conversion can begin, it must be ensured that the unit is situated on a site suitable for its integration in the larger housing scheme being planned for and reconstructed in the area. Infrastructure, the provision of services to the house and the planned reconstruction and rehabilitation of the community influence the positioning of individual housing units and limit them to allocated sites, which is likely different to sites previously allocated for the erection of emergency shelters.

The light weight of the Bossa Nova shelter structure makes it relatively easy to partially disassemble and reassemble in a matter of hours on a nearby site before the conversion commences. As with the previous phases, ecological sustainability is being implemented in this phase in the form of energy efficient manufacturing of materials, optimally efficient use of materials, and using materials with little to no negative environmental impact on the site, either during use or at the end of the product life.

Economic sustainability is addressed by the very nature of the design specifications of the shelter being focussed on reducing material use to the absolute essentials only. It can be further optimised if as many locally produced materials and products are used as is possible under the circumstances.

6.3.4 Architect's Perspective on the Bossa Nova Project

Johan van Lengen (2011) was interviewed to obtain his views on the concept of the Bossa Nova Instant Housing Project as well as approaches to shelter and low-cost house design and implementation in a more generic sense.

Looking at the Bossa Nova shelter design, he wanted to know how the present design can be expanded or customised to meet the needs of specific families i.e. how one would go about adding bedrooms, a bathroom, a second storey etc. When told that this shelter will be proposed as a low-cost housing structure in South Africa, Van Lengen (ibid) suggested not only looking at this structure as a house, but also exploring other functions for the same structure like utilising it as a workshop, small factory or shop. He agreed that structures should not only be looked at in terms of individual products, but that the system should at all times be considered in the development process. The fact that the current construction/assembly process of the Bossa Nova Shelter is structured specifically to create job and skills development opportunities are instrumental in rebuilding or improving communities and should be preserved. He suggests teaching people to use their indigenous knowledge and intuition as basis for community reconstruction initiatives like this. He concurs that an effective strategy is to start with a simple structure that can be assembled by people with various levels of skill and literacy and they will customise the design to their level of competence and their personal preferences. Abandon the misconception that we (architects/designers) know what's best for the end user, that we can come up with an effective solution without in-depth knowledge of their 'real' needs. Rather work with the people, 'teach' them in a participatory process and guide them in a way that allows them to come up with their own solutions. In his experience, Van Lengen (ibid) says that across the world, governments are not open to the idea of creating sustainable communities. In areas of great need for low-cost housing, typical government strategy is to outsource the tender to local contractors who follow the same top-down approach and who build structures "for the people, not by the people". He suggested relinquishing the usual control aid organisations and governments across the world want to maintain in projects like this and giving the community as much control and

responsibility over the process of construction as possible. He has enormous trust and faith in people's ability and inventiveness to come up with solutions to their own problems. It is essential for architects to engage with the community they are developing ideas for, to get an understanding of the actual situation and the requirements that need to be met. Van Lengen (ibid) teaches intuitive architecture practices at his institute *TIBA* , but does not recommend only teaching local people what their ancestors knew, but to combine what has been proven to work in various cultures and communities internationally and taking into account changing circumstances that influence and alter what is considered best practice in a particular context. He warned that not only should designers refrain from assuming they know what communities need, one also needs to be aware that what communities in need of housing "want" and "need" often differ quite substantially. He concluded by saying that architects and designers should allow in their designs room for the user's own individual creativity to. "Putting them on the third floor, you know, you kill them...If one is creative, he's dead...while if you give him a system and you come back after five years you will see that he has improved your system" (Van Lengen, 2011)

6.3.5 Implementation of Bossa Nova in South Africa

6.3.5.0 Introduction

The implementation of this project in South African informal settlements is proposed as a means of providing instant low-cost housing units to communities consisting of those who are entirely homeless or live in sub-standard housing in the form of informal shacks. Often conditions caused by natural weather phenomena or damage by human-induced activities cause massive losses of housing structures in this area. Damage caused by heavy rain, strong winds and fires instigated by knocked over paraffin stoves or lamps are the most common causes of the loss of existing structures. Instantaneously thousands of inhabitants can become destitute and in need of immediate shelter. Thus, not only does a great need for permanent well-constructed low-cost housing units exist in these communities, but instant shelter units are also frequently needed to house victims of adversity. Because of a particularly high unemployment rate in these communities, labour is widely available to construct the houses. Also, because of the very nature of the Bossa Nova shelter, unskilled workers and even the end-users themselves are able to assemble the basic structure in less than four hours. Depending on the chosen fill material, the remainder of the






construction process is also simple, using materials that are both locally available, cost-effective and environmentally friendly.

6.3.4.1 Climate






South Africa has a moderate climate ranging from humid sub-tropical conditions on the east coast to semi-arid on the west coast and Karoo regions (www.climate-zone.com). Winds in some parts of the country can be strong up to gale force, though no hurricanes or tropical cyclones occur in this part of the world. Temperatures rarely go below freezing in most parts of the country and in extreme conditions have gone up to 50C, although temperatures ranging between 6C and 28C are normal for most of the country (www.climate-zone.com). In the recorded history of the country the only phenomena that could be classified as natural disasters in the region are droughts and floods. Light snowfalls rarely occur in isolated parts of the country. The tables below display average monthly climate indicators in 5 regions of South Africa based on 8 years of historical weather readings

Table 6.1 Average monthly indicators in 5 Regions of South Africa
(www.climate-zone.com, 2004).






PRETORIA 25 73 S, 28 18 E, 4337 feet (1322 meters) above sea level.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
 Avg. Temperature	22	22	21	17	14	11	11	15	18	20	21	21
 Avg. Max Temperature	29	29	28	25	22	21	20	23	27	28	28	28
 Avg. Min Temperature	17	17	16	12	7	3	3	7	11	14	15	16
 Avg. Rain Days	6	6	4	3	1	0	0	0	2	4	7	4
 Avg. Snow Days	0	0	0	0	0	0	0	0	0	0	0	0






CAPETOWN 33 98 S, 18 60 E, 137 feet (42 meters) above sea level.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
 Avg. Temperature	20	20	19	16	14	12	11	12	13	16	17	20
 Avg. Max Temperature	27	28	26	25	21	19	18	19	20	23	24	26
 Avg. Min Temperature	15	15	13	11	9	7	6	7	8	10	12	15
 Avg. Rain Days	3	2	3	4	7	9	9	9	7	6	5	4
 Avg. Snow Days	0	0	0	0	0	0	0	0	0	0	0	0






DURBAN VIRGINIA 29 76 S, 31 5 E, 45 feet (14 meters) above sea level.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
 Avg. Temperature	25	25	25	22	19	19	18	20	20	21	23	24
 Avg. Max Temperature	27	27	27	25	22	23	22	22	22	23	25	26
 Avg. Min Temperature	22	22	22	19	16	16	15	16	17	18	21	21
 Avg. Rain Days	0	0	0	0	0	0	0	0	0	0	0	0
 Avg. Snow Days	0	0	0	0	0	0	0	0	0	0	0	0

PORT ELIZABETH 33 98 S, 25 60 E, 196 feet (60 meters) above sea level.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
 Avg. Temperature	20	21	19	17	15	13	12	13	15	16	17	19
 Avg. Max Temperature	26	26	25	23	22	22	21	21	21	22	23	25
 Avg. Min Temperature	16	17	15	12	10	7	6	8	10	12	13	15
 Avg. Rain Days	7	7	8	7	5	4	6	6	7	9	8	7
 Avg. Snow Days	0	0	0	0	0	0	0	0	0	0	0	0

BLOEMFONTEIN 29 10 S, 26 30 E, 4422 feet (1348 meters) above sea level.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
 Avg. Temperature	21	21	18	14	10	7	6	10	14	17	19	21
 Avg. Max Temperature	30	30	28	24	21	18	17	21	25	27	28	30
 Avg. Min Temperature	13	13	11	6	1	-2	-3	0	3	8	10	12
 Avg. Rain Days	6	4	5	3	2	0	1	0	1	3	5	4
 Avg. Snow Days	0	0	0	0	0	0	0	0	0	0	0	0

6.3.4.2 Environment / Ecology

Prevailing climatic conditions in the immediate vicinity of the sites were considered, but seen in the context of this study as less relevant than other environmental factors such as building density, availability of or access to building materials and geological conditions. The rapid unstructured expansion of most informal settlements without the infrastructure of regulated residential developments means that the natural ecology

has been impacted upon by human activities without there being any sort of system in place to deal with the waste or pollution generated by the community. Effects on the construction of houses in these areas include limited access to or a complete absence of electricity and/or running water, contaminated soil and water as well as rubble-filled, irregular sized, unlevel plots. The natural ecosystem of such settlements are generally so severely impacted upon that it hardly has any influence on new man made housing developments or vice versa. Informal settlements, like Kayalitsha outside Cape Town, are not only situated in areas with high natural water tables, but most of these areas also lack vital infrastructure elements such as stormwater drainage systems. This means that most of the area gets flooded on a regular basis, more frequently during the rainy winter months. The structures that constitute the largest part of the informal settlement lack proper foundations and stormwater drainage systems, meaning that shack floors are usually flooded entirely during medium to heavy rain spells.

6.3.4.3 Economy

Informal settlements throughout South Africa are generally characterised by high unemployment rates and high levels of dependence on social grants and government financial assistance. Families have little or no expendable income for acquiring any building materials or contracting and generally rely on financial and commodity-based aid from government or non-profit organisations. Currently housing structures in particular are either owner-built of scavenged discarded building materials or government funded and built *Reconstruction and Development Programme* (RDP) houses. Factors like skills development and unemployment influenced the type of construction recommended for the proposed house design's assembly.

6.3.4.4 Society, Culture and Community

The social and cultural elements that impact on the aptness of the proposed design include cultural diversity, cultural symbolism, identity, traditions and customs, sustainable community building, health and wellbeing of inhabitants as well as the daily routines of residents. Although Brazil and South Africa are both emerging economies with similar circumstances regarding the need for low-cost housing in poorer communities, cultural differences inevitably influence the general acceptance of house designs, whether it is paid for by the end user, government or aid organisations. Incorporating an allowance for customisation by the end user gives the proposed house design greater flexibility to be incorporated into a wide range of communities with diverse cultures.

6.3.4.5 Material Choices

Bamboo naturally occurs in the sub-tropical Kwazulu Natal region of South Africa. This means that to start fabrication of the kits immediately, bamboo struts would need to be harvested and distributed from the east of the country to other provinces or otherwise replaced in the assembly of kits by an alternative structural material such as wattle or eucalyptus, which are not indigenous to South Africa, although much more accessible in most regions and currently more affordable. The long-term plan with the Bossa Nova project is to start community-run bamboo cultivation initiatives. Initiating a bamboo crop within the community has many benefits, including creating employment, helping to purify grey or sewerage water, and converting airborne carbon dioxide into oxygen. However, it generally takes a minimum of 3 years for a newly established crop to yield its first harvest of mature bamboo suitable for construction.

Textiles recommended for implementation in the initial shelter phase should be existing technical textiles currently produced by local manufacturers that do not contain hazardous PVC. The textiles will be selected with optimal eco-friendliness, cost-efficiency and suitability for its purpose as moisture-, sun- and wind barrier cladding material with sufficient insulating properties for the various South African climates (See 3.7.3 Sustainable architextiles in South Africa). As mentioned before, the South African textile manufacturing industry focuses mainly on the supply of textiles for clothing and home interior sectors. Technical textiles produced in the country suitable for architectural applications are rare and those considered environmentally and user friendly even more scarce. As with the shelter's bamboo frame, to meet the immediate need for housing, locally produced PVC-coated polyester canvass and imported environmentally friendly technical textiles would need to be weighed up against one another in terms of cost, overall environmental footprint, life expectancy and maintenance. However, new textile production initiatives should be established to produce environmentally friendly technical textiles suitable for a variety of architecture applications. Natural fibres most suitable for technical applications are flax, sisal and hemp (See 3.6.1.4 *Natural Fibres and Textiles in Architecture*) Similar to bamboo, these crops can be grown and processed locally by small-scale community initiatives. Green Plastics, although involving more sophisticated processing, can also be produced locally as a viable alternative to PVC-coated canvass. Green Plastics, bioplastics or biopolymers are predominantly biodegradable polymers made mostly or entirely from natural renewable resources like corn and soy using biotechnological processes (See 3.6.1.3 *Green Plastics*).

According to Keith Struthers (2011), 80% of a building's carbon footprint has to do with the product life of the building. The choice of building materials and construction process, although significant, does not constitute the largest part of the building's carbon footprint. If a fabric wall does not provide sufficient insulation, the negative environmental impact of attempting to make up for that shortcoming through other means far outweighs the positive attributes of the textile being more economical and more environmentally friendly to manufacture, transport and construct a building with.

For the conversion into low-cost house structure, it is recommended that the textile-reinforced cement technique described in Chapter 3 (3.3.4 *Textile-reinforced cement*), using repurposed plastic mesh fabric obtained from used 'orange-bags' is imbedded into thin-shell cement and sand panels. This technique was developed by architect Johan van Lengen and uses around 10% of the cement required to form a similar panel that's not reinforced. A more eco-friendly alternative to cement is *Hempcrete*, a substance with similar properties consisting of hemp fibres. Although this substance is significantly more expensive than ordinary cement, it is hoped that with increased use internationally, the price will come down to within a more competitive range.

Another recommended fill-in material is sand-bags or super-adobe developed by Nader Kahlili of Cal-Earth (See 3.3.1 *Earthbag and Superadobe Wall Construction*). The existing frame provides the structure for this simple vernacular technique of filling repurposed polypropylene or jute feedbags with sand, soil, gravel or rubble available on-site and stacking the filled bags on top of one another. Most inhabitants, even women, children and the elderly can participate in the construction process using this simple building method. Walls display the insulating properties of the earth filling and provide inhabitants with a weather- and moisture-proof shield.

6.3.5 Design Development of Shelter

6.3.5.1 *Current Shelter Design*

The current Bossa Nova shelter design employs a pentagon-shaped bamboo frame, a concrete floor, translucent polyvinyl chloride (PVC) and opaque polyethylene (PE) film wall cladding as well as roof sheets made from a recycled plastic composite (Recycled Tetrapak packaging / toothpaste tubes) . Areas with room for improvement were identified and formed the main focus of the research conducted. Although an overview of the system and social angle of the Bossa Nova initiative were constantly considered

and acknowledged throughout the research, mainly the instant emergency shelter (Kit 1) was focussed on and practical, easily employable solutions sought (See Appendix E).



Fig 6.2 Bossa Nova Shelter Exterior
(Source: www.sersustentavel.com.br)

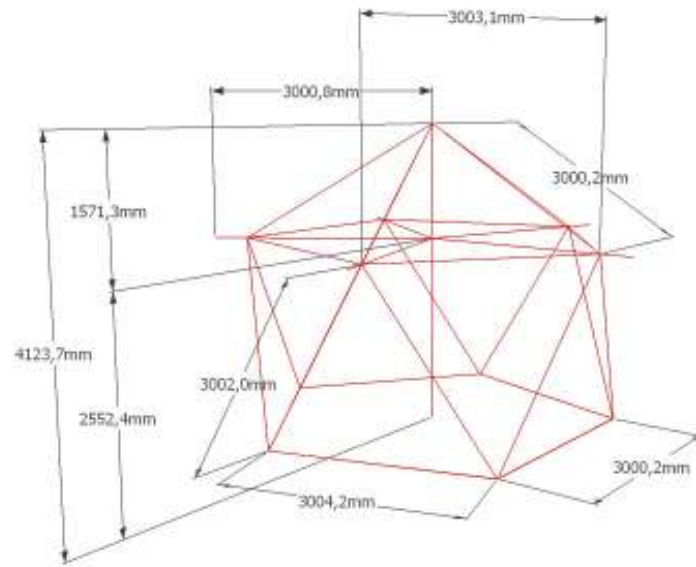


Fig 6.3 Bossa Nova Shelter bamboo frame and roof
(Source: www.sersustentavel.com.br)

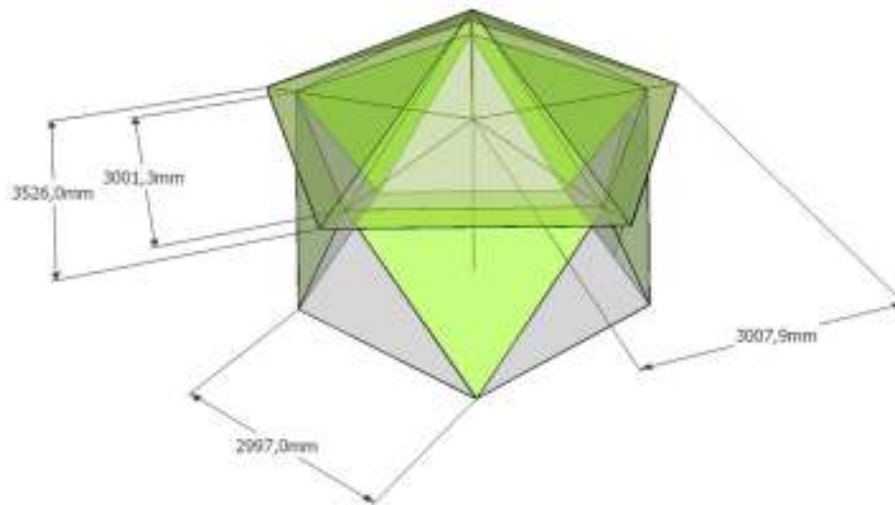


Fig 6.4 Bossa Nova Shelter interior (Source: www.sersustentavel.com.br)

6.3.5.2 Proposed Design



**Fig 6.5 Three-dimensional line-drawing showing measurements
(Illustration by Benedikt Schmitz)**



**Fig 6.6 Measurements of 15m² Shelter
(Illustration by Benedikt Schmitz)**

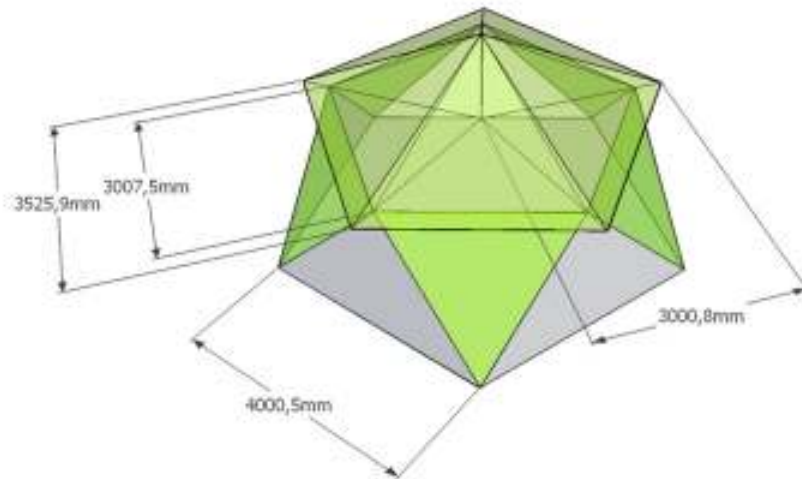


Fig 6.7 Measurements of 35m² Shelter
 (Illustration by Benedikt Schmitz)

The new design's equal strut lengths forming a series of equilateral triangles and the new connector design allow the floor coverage of the Bossa Nova shelter to be adjustable, varying between 15m² to 35 m². This flexibility is possible without altering any of the structural components, but by simply amending the position of the anchoring points. The table below shows approximate measurements of two variations of the shelter with different floor size. Using uniform strut lengths of 3 m, the distance between the anchoring points can range between 3m and 4.5m.

Table 6.2 Table showing variations in adjustable shelter design (Author's own construct)

	New Design 15 m ²	New Design 35 m ²
Amount of struts	25	25
Diameter struts	4-8 cm	4-8 cm
Length struts	3 m	3 m
Distance between anchoring points	3 m	4.5 m
Square meter Floor [m ²]	Ca. 15	Ca. 35
Square meter Textile [m ²]	Ca. 60	60 to 70
Height ceiling	2.55 m	2.23 m
Height Rooftop	4.12 m	4.80 m

The following figures show a 1:10 scale model constructed for the purpose of illustrating the improvements as recommended by the research report compiled (See Appendix E).



Fig 6.8 New Bossa Nova Shelter exterior – 1:10 Scale model
(Photo: F.De Flamingh)



Fig 6.9 New Bossa Nova Shelter cut-out view – 1:10 Scale model
(Photo: F.De Flamingh)



**Fig 6.10 New Bossa Nova Shelter interior – 1:10 Scale model
(Photo: F.De Flamingh)**

6.4 Summary

This chapter focussed on the analysis of data generated from multiple sites and at various phases of this thesis. Analysis of various operations, actions, and activities shed light on the complex and multi-sectoral imperatives in promoting a novel concept like sustainable architecture through the incorporation of textiles in an emerging economy. A summary of the research carried out in Brazil by the author in collaboration with a design research group on the *Bossa Nova Instant Housing Project* culminates the collective data in a real-life case study that serves to illustrate the practical application of textile-based structures in a similar developing world context. It is believed that this study sufficiently illustrates the possibilities that exist within the South African building sector to adopt and embrace sustainable construction practices using unconventional materials like textiles in an effort to not only meet one of the most basic needs of humankind, but to help build thriving sustainable communities.

Chapter 7:

Conclusions and Recommendations

7.0 Introduction

This final chapter reviews the research objectives and presents pertinent conclusions from this exploratory study. Further, the chapter attempts a justification of the study in terms of its contribution to knowledge in a number of inter-related fields. A concerted effort was made to provide in this study a comprehensive overview of textile-based architecture as well as a reflection on how the incorporation of textiles into South African residential architecture can possibly promote the principles of *design for sustainability*. As with most single studies, it can not claim to adequately address all questions arising from the research process. Consequently, limitations of the study and implications for further research are presented for due consideration.

7.1 Revisiting Aims of the Research

The overall objective of this study was to explore the feasibility of using textiles in sustainable architectural design within the context of residential architecture in an industrially developing context. To achieve this, it addressed the specific objectives by doing the following:

- *Presenting an overview of current examples of textile-based structures worldwide and relating it to the practice and principles of sustainable architecture;*
- *Narrowing down the wide range of possibilities to those most applicable to residential structures in developing economies like South Africa;*
- *Obtaining the authoritative views of professionals in the field of sustainable architecture so as to determine factors limiting greater acceptance a wider adoption of textile-based architectural structures in the current South African built environment; and*
- *Proposing the incorporation of textiles into affordable, low-cost structures in South Africa in a way that promotes sustainable development.*

The specific conclusions linked to the abovementioned research objectives are elaborated in the following section.

7.2 General Conclusions and Proposed Strategies

Concerning the integration of textiles in South African residential architecture, this study found that the use of these textiles is predominantly limited to commercial buildings. Subsequently, textiles have not been assimilated into the residential market on the scale proportionate to the development of new improved technical textiles and related materials.

Textiles are mostly employed in both small outdoor canopies and as cladding material to some of the sports stadiums recently revamped or newly constructed for the *2010 FIFA World Cup™*. Notwithstanding, the value of textiles as cost-effective and generally environmentally-friendly building materials is currently not fully appreciated within the South African context. Further, the potential of textiles is not fully exploited by the South African construction sector. This study found that lightweight structures incorporating textiles are commonly associated with temporary or novel commercial architecture rather than with more permanent residential building applications. To convince authorities and/or consumers that textile-based architecture is a viable way of addressing the current housing shortage in South Africa in a sustainable manner – this is undoubtedly a complex task that does not only involve proving the technical efficacy of such structures, but also engendering greater social acceptance. Social perceptions of the temporality and aberration of textile structures more often determine a community's acceptance or rejection than quantifiable attributes. This thesis argues that the reluctance of South African end-users to embrace unorthodox concepts poses the most significant barrier to overcome in trying to link the need for low-cost structures to the inherent advantages that such solutions present.

An array of construction methods involving the incorporation of textiles are presented in this study as viable solutions to the challenges facing the South African housing sector, particularly within the low-cost housing sub-sector. Many of the low-tech, vernacular-inspired designs and methods are particularly germane to the conditions in South Africa and it is believed that the patent affordability of these structures should suffice as evidence to motivate for both private clients and government agencies to seriously consider textile-based structures as an alternative to brick and mortar box dwellings.

Findings from this study also inform the need for a comprehensive analysis of the principles of sustainability to be integrated into core architecture studies.

Experimentation and exploration of new concepts in building design is imperative and should be encouraged in schools of architecture, design, and engineering so as to expose and orientate students in these disciplines towards more sustainable and eco-friendly building praxis. It is anticipated that the greater the number of architects who are willing to explore [progressive yet] unorthodox building materials and methods to create more sustainable homes, the more likely the public will be to accept these ideas as the way forward – new ideas turn to cutting-edge trends which in turn influence emerging consumer trends.

7.3 Contributions to Knowledge

The main objective of this study was to evolve and propose strategies for the incorporation of building techniques incorporating environmentally friendly textiles in sustainable residential architecture projects within the context of an emerging economy. The proposed strategies are sufficiently adjustable and context-responsive to allow for application in similar developing world settings. The thesis serves as a substantiated endorsement for the increased implementation of textile architecture in a South African context, particularly in the critical low-income and social housing sectors.

This thesis clearly demonstrates that from a technical point of view, the integration of textiles in various elements within single-family homes is not only possible, but advantageous in a South African context when considering overall life cycle cost (LCC), environmental impact, structural simplicity, and sheltering efficiency. It is anticipated that through physically demonstrating appropriate techniques and processes as described in this study, low-income end-users will become aware of techniques for constructing certain textile-based structures. These textile structures decrease the dependence on external aid by individuals with limited economic/financial means by allowing them to become increasingly self-sufficient in the construction of their own homes. In turn, it is hoped that this increased awareness will lead to demonstrable levels of acceptance of textile-based structures as creditable popular forms of architecture.

The research offers a database of international best-practice exemplars of textile-based architecture for reference and benchmarking purposes by design practitioners. It provides a rich repository of relevant information on material options and techniques developed worldwide with emphasis on the most appropriate methods applicable within the context of an emerging economy.

7.4 Limitations of Research

From a purely quantitative point of view, the limited number of informants, mostly professional architects, means that the opinions informing the study should be seen as individual perspectives rather than a generalised view of the industry. Due to time, logistical and other resource constraints, limited time was available for engaging with the informants – in some instances personal interviews had to be substituted for electronic questionnaires to increase response rates. Notwithstanding such limitations, the findings reveal rich multi-dimensional aspects that offer a reasonable degree of transferability in related matters with respect to the research intent and focus (Dolan & Hall, 2001).

7.5 Implications for Further Research

This study focuses on sustainable building practices through the integration of textiles in products and systems. Admittedly, the focus was predominantly on addressing the physical sheltering needs of a particular sector of the South African population. Further research would need to interrogate the social perceptions of the end-user and the impact the assimilation of these structures could have on poor communities, be it in a rural or urban setting. A process of user participation would provide rich qualitative data to continue the exploration of sustainable building practices and materials within an emerging economy context. The social and cultural implications associated with owner-built housing structures such as the Bossa Nova instant house (discussed herein) offer readily adoptable and adaptable solutions for rapid deployment in either post-disaster areas or low-income communities. Such settings would further provide a basis for testing and validating the outcomes and recommendations presented by this study.

The interaction between the various key actors and stakeholders within low-cost social housing schemes and related models of housing procurement in a developmental state such as South Africa although falling outside the focus of this study should be interrogated further. The technical solutions to the challenges faced by financially constrained communities presented in this study provide a basis from which the policies, politics and social interactions which informs their implementation could be studied. By proposing owner-built housing structures as a solution to the social housing crisis in South Africa, this thesis contributes towards a potentially rich study of

challenging prevailing welfarist models that are clearly unsustainable. As M'Rithaa (2009:57) argues, "the welfare case in South Africa is ultimately unsustainable – it offers only short-term financial relief and is attracting ever more people, thereby perpetuating dependency and promoting an entitlement syndrome amongst the general populace". This outcome is particularly disenfranchising to those in the lower income sector of the economy as it fails to enlist their participation in the design and construction of their houses.

7.6 Summary

The use of textiles in modern architecture is a relatively new concept in industrially developing or majority world contexts. Through the documentation of international exemplars this study clearly demonstrates the technical benefits of incorporating this uncommon building material in more sustainable building practices. The study also reveals certain challenges related to social stigma and negative perceptions associated with the use of textiles in residential buildings that would need to be addressed. Despite this, the general impression is that textile-based architecture is considered worthy of further interrogation, investigation and application, and that with minor alterations, similar strategies could be applied in related contexts elsewhere on the African continent and beyond. The findings also inform the context-responsive strategies that should be dispersed to a wider audience via interactive, collaborative, inclusive and participatory processes which M'Rithaa (2009:217) emphasises as a means to "maintaining diversity through a battery of strategies, as opposed to amalgamating the diverse proposals into a unified or standardised approach that ignores or negates *in situ* realities."

The findings in this study suggest that new concepts in sustainable architecture should be presented in a non-prescriptive manner that respects and embraces socio-cultural and philosophical diversity. Products, services and systems should not only be technically efficient, but also adaptive and universally accessible to allow end-users a degree of customisation and for the notion of 'ownership through participation' in the homemaking process.

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Appendices

Appendix A: Table of PVC Alternatives (Greenpeace International, n.d)

PRODUCT	DESCRIPTION	APPLICATION	ADVANTAGES	MANUFACTURER'S DETAILS
Butylite 1000EP roofing system	1.0mm thick single-ply synthetic rubber EPDM membrane with laminated geotextile backing. Suitable for flat, pitched or shaped roofs.	-Loose-laid, partial/fully adhered or mechanically fixed. - New build or refurbishment with 'Green Design' option.	-Highly resistant to UV light, ozone chemical, heat and microbial attack. -Pre-fabrication and on-site welding.	White Cross Rubber Products Limited Lancaster, UK Tel: +44 (0)1524 585200 Fax: +44 (0)1524 585201 info@wcrp.co.uk http://www.wcrp.co.uk
System Platon Cavity drain membranes	A studded highly impermeable plastic moisture barrier made from HDPE.	-Waterproofing interior and exterior walls and floors in new build and refurbishment. - Used as a drainage and storage tray for flat roof gardens.	-Meets ISO 9002 requirements.	Triton Chemical Manufacturing Co. Ltd. London, UK Tel: +44 0208 3103 929 Fax: +44 0208 3120 349 info@triton-chemicals.com http://www.triton-chemicals.com
EPDM and TPO membrane	EPDM and TPO membrane (both PVC free)			Versico, Inc. Akron, Ohio USA Tel: +1 800 992 7663 http://www.versico.com
Sureseal EPDM rubber/lining membrane	A flexible EP rubber and polypropylene blend roofing membrane to take the place of PVC plastic.s	Can be installed fully adhered, mechanically fastened, loose-laid or in a protected membrane system.	A thermoplastic Polyolefin membrane with the performance of rubber and the heat weldability and aesthetics of plastic.	Carlisle UK Ltd Abingdon, Oxon UK Tel: +44 1235 848000 Fax: +44 1235 848 727 enquiries@carlisleroofting.co.uk http://www.carlisle-syntec.com
Superseal EPDM Roofing Membrane	A rubber and EPDM membrane developed specifically to replace single ply PVC roofing membrane. Available with or without fleece backing.	Sheets can be prefabricated or welded on site. Applications include bonded and un-bonded.		Syntech - Synseal Linings Ltd Derby, UK Tel: +44 (0)1332 200001 Fax: : +44 (0)1332 200900 enquiries@syntech-synseal.co.uk http://www.syntech-synseal.co.uk
Evalastic membrane	Polymeric single-ply roofing and waterproofing membranes based on EPDM/PP. EVALASTIC is un-backed EVALASTIC V has a bonded polyester fleece backing.	-EVALASTIC V: Mechanically fastened or fully adhered roof constructions -EVALASTIC: Loose-laid and ballasted systems including roof gardens	-Free from halogens, bitumen, chlorine and plasticisers. -Side and end laps are homogenously joined by simple, environmentally friendly hot air welding. -Excellent long-term performance.	I.C.B. Ltd (Alwitra) Bournemouth, UK Tel: +44 1202 579 208 Fax: +44 1202 581 748 tech@alwitra.co.uk http://www.alwitra.co.uk

<i>Ultraply TPO</i> roofing membrane	A proprietary thermoplastic polyolefin combining polypropylene and ethylene propylene rubber		-Contains no plasticisers, chlorine, or other halogens. -A white environmentally-friendly roofing membrane. -Hot-air welded seams are VOC compliant.	Firestone Building Products Carmel, IN USA Tel: 1-317-575700 Fax: 1-317-575-7100 http://www.firestonebpco.com
<i>Flagon EP</i> membrane	Manufactured by a unique twin head extruder. Length: 25 metres Width: 2.1 metres.	-For use in ballasted roofing and roof gardens. -Mechanically fixed, fully adhered.		Flag SpA Flag UK Ltd Surrey, UK Tel: +44 1428 604 500 Fax: 44 1428 606 8981 www.flag-spa.com
Grass cloth, paper, hemp, burlap		Commercial and Residential.		Seabrook Wallcoverings Memphis, TN USA Tel: +1 901 320 3500 Fax: +1 901 320 3673 http://www.seabrookwallcoverings.com
Cyclan Tensile Membrane	Silicone & PTFE Coated Glass fibre tensile fabric.	-Developed for use where high translucency is desirable such as solar roofs. -Jointing either by a cementing process, sewing or welding.	Acceptable strength while providing great flexibility.	Clyde Canvas Fabric Structures North Somerset, UK Tel: +44 (0) 1275 810400 Fax: +44 (0) 1275 810500 sales@clydecanvas.com www.clydecanvas.com
Tensile Membranes	A variety of waterproofed cotton canvass, Teflon-coated fibreglass, hemp, flax and recycled textiles.	Timber and fabric tensile structures for use as architectural and exhibition tents and canopies.		Timber Intent Ltd Bristol, UK Tel: +44 117 939 6948 Fax: +44 117 939 6948 Email: timberintent@csi.com Web: http://www.timberintent.co.uk
Textile and grass cloth weaves		Commercial and residential		Hirshfields Inc Minneapolis, IL USA Tel: + 1 612 377 3910 Fax: + 1 612 377 2734 mrh@hirshfields.com http://www.hirshfields.com
Thermoplastic Polyolefin roofing membranes	Thermoplastic polyolefin (TPO)-based roofing membranes	Commercial, industrial and institutional applications.	-Environmentally friendly TPO thermoplastic contains no chlorine or plasticisers. -Hot-air welded seams -White reflective, energy-saving membrane meets EPA Energy Star Roof Products requirements -Does not contribute to urban heat islands-effect	Stevens Roofing Systems Holyoke, MA USA Tel: +1 (0) 413 533 8100 Fax: +1 (0)413 552 1070 info@stvroof.com jps europe@aol.com http://www.stevensroofing.com

Appendix B: Questionnaire for Professional Architects/Designers

Greetings. My name is Francois De Flamingh. I am a Masters student at the Department of Industrial Design, CPUT, presently conducting a survey on the role of textiles in sustainable architecture. Subsequently, I wish to gain an insight into your views on the subject in your personal and professional capacity. Kindly answer the following questions as candidly as possible. Your responses are appreciated and will be cited in my dissertation unless you explicitly object.

Questions for 'The role of Textiles in Sustainable South African Residential Architecture' research

Contact Details

Name:																																							
Organisation & Position:																																							
Phone No.																					Mobile																		
Facsimile No.																					Email																		

1. Are you aware of specific examples, in your own work or that of others, where the incorporation of textiles in permanent exterior architecture contributed to a residential building's sustainability (ecologically, economically or socially)? If so, please give details of project/s and your opinion thereof.

2. Briefly comment on the reason(s) why, in your opinion, textiles in architecture has not found wider acceptance within South African residential architecture.

3. What aspects of sustainability do you consider to be most neglected presently in South African residential architecture and how does this relate to textile-based architecture?

4. How, in your opinion, can the incorporation of textiles be mainstreamed in your specific discipline?

5. Please feel free to make any further comments you believe to be relevant to this topic.

Authorisation to publish responses

I hereby request your authorisation to publish your responses in my dissertation,
subject to the conditions mentioned above:

Signed:

Date:

Thank you for your valued time and input

Official use only	Interviewer's Name: FANCOIS DE FLAMINGH				Signature	
Date			Start Time		End Time	
Scrutinised	Yes	1	No	2	by (name)	Signature
Questionnaire Serial Number						

Appendix C: Questionnaire for Institutional Architect

Greetings. My name is Francois De Flamingh. I am a Masters student at the Department of Industrial Design, CPUT, presently conducting a survey on the role of textiles in sustainable architecture. Subsequently, I wish to gain an insight into your views on the subject in your personal and professional capacity. Kindly answer the following questions as candidly as possible. Your responses are appreciated and will be cited in my dissertation unless you explicitly object.

Questions for 'The role of Textiles in Sustainable South African Residential Architecture' research

Name:											Institution:																					
											Department																					
											:																					
Phone No.											-											Mobile										
Facsimile No.											-											Email										

1. Does your department/unit have a specific policy that informs design for sustainability or sustainable architecture? Kindly elaborate.

2. Does the incorporation of textiles in architecture/ textile-based architecture form part of your department's/ unit's standard curriculum? Kindly elaborate.

3. What do you believe are the merits in teaching and promoting all aspects of sustainable architecture including the use of alternative materials such as eco-textiles in your department's curriculum?

4. Who (individuals and/or departments/units), in your opinion, would best champion sustainable architecture and/or textile-based architecture in your institution?

5. What obstacles do you perceive/anticipate in adopting sustainable architecture as a strategy in your department?

6. What would you say is the best way to promote textile-based architecture in your course to future architects, engineers and designers?

--

7. Please write down any further comments you might have on this topic.

--

Authorisation to publish responses

I hereby request your authorisation to publish your responses in my dissertation, subject to the conditions mentioned above:

Signed:

Date:

Thank you for your valued time and input

Official use only	Interviewer's Name:				Signature		
	FANCOIS DE FLAMINGH						
Date				Start Time		End Time	
Scrutinised	Yes	1	No	2	by (name)	Signature	
Questionnaire Serial Number							

Appendix D: Minutes from Meeting held on 30/03/2011

Welcome

Francois de Flamingh (FD) welcomed all to the meeting and thanked them for their time and contributions to it. He showed the participants the main discussion points

Present at the meeting were (in order of introducing themselves) :

- **Carolina Daros (CD)**- Brazil – Graphic Design, MSc Candidate (UFPR) assisting Francois De Flamingh on this project
 - **Ivana Marques (IM)**- Brazil – Product Design, MSc Candidate (UFPR) assisting Francois De Flamingh on this project
 - **Joao Victor(JV)**- Brazil – Researcher at NDS, experience in working with Bamboo
 - **Francois De Flamingh (FD)**- South Africa – MTech Design Candidate (CPUT), at NDS/UFPR as part of an academic exchange, tasked with coordinating the product research development on behalf of NDS/UFPR/CPUT
 - **Claudia Zacar (CZ)**- Brazil – Product Designer, Lecturer at UTFPR
 - **Prof Dr Aguinaldo Dos Santos (AD)**- Brazil – Head of NDS, Professor at UFPR
 - **Jairo Da Costa Jr (JD)**- Brazil – Graphic Design, MSc Service DesignCandidate (UFPR)
 - **Benedict Schmitz (BS)**- Germany – Wood Engineering, MSc Product Development & Solutions, started working with NDS in 2009 on Low-income housing design & development projects
 - **Allessandra Enriconi (AE)**- Brazil – Product Designer, Researcher at NDS, Experience in Textiles
 - **Rebeca Paciornik Kuperstein (RK)**- Brazil – Architect, Technical Director of SerSustentavel, the founder and developer of the **Bossa Nova Instant Housing Project (BNP)**
 - **Bernadette Brandao (BB)**- Brazil – Designer, UIA Eco Design Consultants & Projects
-
- FD mentioned that the process of research and development carried out by himself and NDS will be recorded and analysed for the purpose of using BNP as case study in his MTech Thesis as well as for writing an article with IV and CD (co-authors) for submission to an accredited international scientific journal.
 - BB Apologised for arriving late because of other commitments

Briefing

- RK Thanked AD and FD for the opportunity of having the input of so many professionals and this project

History/ Timeline of the Bossa Nova Instant Housing Project (BNP)

- RK has been an architect for approximately 20 years. After experiencing conventional architecture for a number of years, she started looking for more sustainable ways of operating in her profession.
- RK went to a conference/meeting organized by FIEP: Business as an Agent of World Benefit (BAWB) - www.bawbglobalforum.org – This event changed the way RK wanted to work. 19 Groups took part in the event, one of which, studying sustainability, RK became a member of and remained a member for approximately 3 years. BB is also a member of this group. RK said that most of what she knows/ have learned about sustainability came about through working with this group.
- The use of bamboo in architectural structures was one of the topics discussed in this group, although RK has personally been studying bamboo for the past 5-6 years. She admitted that this research was not done in a formal academic way.
- RK has been giving talks on bamboo, it's production chain and its social, economic and environmental benefits to a range of different audiences in an attempt to create awareness and familiarity with and wider acceptance of this material as well as its value in terms of the concept of sustainability
- At one of her talks, RK met Richard Brigass (RB), a French businessman, who expressed an interest in initiating a bamboo production project in Martinique.
- In January 2010, when the earthquake occurred in Haiti, RB asked RK to design an emergency shelter structure, using a bamboo frame. RK had already designed a structure for an organic fair, which she used to base her design for the emergency shelter design on.
- RK took the newly developed shelter design in the form of a Marquette to the *5th World Urban Forum in Rio de Janeiro 2010* (<http://www.unhabitat.org/categories.asp?catid=584>) to show and get feedback from any interested parties. Representatives from the UN expressed a lot of interest and asked to take pictures of the model, which surprised RK.
- Present at the *World Urban Forum* was the Brazilian Minister of Foreign Affairs. He encouraged RK to investigate the possibilities for the deployment of the BNP in Haiti and provided government funding for the reconnaissance trip.

- RK visited Haiti in May 2010 to investigate the feasibility of implementing the BNP there. She was taken around by a local architect friend and found a 14 Ha bamboo plantation approximately 10 years old, growing in the rural North of the country. RK also spoke to the chief local architect in charge of the construction of brick houses, who requested the construction of 2000 BNP shelters in Haiti. Unfortunately, at the time, there were no resources available to fund and initiate this project.
- After returning to Brazil, RK started investigating the need for shelter/housing in Brazil. She found that approximately 7 million Brazilians were homeless in 2010; Some affected by natural disasters, like mud slides in the states of Rio and Parana, and others living in sub-standard housing because of their economic circumstances. According to RK, the UN claims that 1 Billion people globally are homeless currently.
- After the mudslides and loss of 6500 homes in the state of Parana in March 2011, the Civil Defense of Parana requested 10 BNP shelters for their staff to use as temporary accommodation for the duration of the relief efforts in Morettes and Antonina in Parana.
- AD mentioned that, in a meeting with NDS, the director of *COHAPAR* (State of Parana Low-income Housing Agency) said that currently, due to a lack of ready-developed solutions such as BNP, leased shipping containers are being utilized for this purpose, but that this is not a viable solution because of cost and logistical issues. To this RK responded by stating that they (SerSustentavel) met with COHAPAR and the organisation seemed interested in BNP, but that they had reservations(perceived as prejudice/ preconceived notions) about the use of bamboo in housing structures despite all the benefits explained to them. The perception of bamboo being a poor man's construction material exists worldwide, according to RK.
- *COHABI* (Curitiba) have requested the construction of one BNP Shelter, which RK hopes will help demonstrate to COHAPAR the viability of BNP as solution for the housing crisis in the disaster-affected areas of Parana.
- Currently the BNP is focused on providing solutions for Parana (local/regional), Brazil (national) and countries near Brazil (International).

The BNP Shelter as Concept and Product

- The most unique characteristic of the BNP Shelter is that it is designed to be initially assembled as a shelter, but at a later stage converted into a permanent house without the need for inhabitants to be moved. In fact, the conversion will be done by the inhabitants themselves. This concept is a world first. The conventional way is for emergency shelters, in the form of tents, to serve as temporary housing to the affected population until the local government or NGOs have constructed more permanent dwellings for the people to be transferred into. This method has serious social

consequences as temporary social structures and communities formed during the temporary phase of this housing plan are dissolved when people are moved to their permanent houses given to them by government or NGOs. This process adds more distress to an already volatile situation.

- RK mentioned that in some cases, like the native Indian population of Brazil, government housing in the form of standard brick houses are rejected by the community, defeating the purpose of providing housing to these communities. Because of a lack of understanding for the needs of these communities, the intended beneficiaries cannot relate to these structures and subsequently choose to rather live outside the houses than inside.

Research / Development Objectives

The contribution of NDS / UFPR / CPUT to the project

- RK stated that the reason for approaching NDS was that she realized the limitations of an architect's approach to a product design challenge such as this. The development of this project, in her opinion, needs the expert input of designers and academia in design. Also, special government funding is available to companies working in collaboration with academic institutions in product development projects, which RK intends to apply for in June 2011.
- AD reminded all that NDS is, at this stage, committing to work on this project for one month only (April 2011), contributing the expertise of NDS in product design and development.

Group discussion on project objectives

- AD stated that although the BNP can be constructed and used as low-income housing for the homeless and in areas of poverty, the focus of this particular phase of the project is the development of a temporary shelter (3months – 1 year use) in disaster-affected areas, something that can be economically shipped as a compact DIY-kit and is easy and quick to assemble. It's important to make sure that the different materials are produced and/or easily maintained locally.
- AD suggested to the group to break the challenge down into 5 key characteristics/ concepts that the BNP should contain. The group came up with the following concepts:
 1. **DIY:** It has to be easy and quick to assemble and not require special skills or tools. AD suggested considering the composition of the kit, ways of transporting, size, weight etc.
 2. **Must provide resistance** against rain, wind and fire – BS & RK recommended to check into UN standards / other temporary shelter standards

3. **Optimal material use.** Design must employ materials economically while still maintaining structural integrity and optimal efficiency.
 - Group discussion ensued on the need to pre-treat the bamboo before shipping it and that sourcing bamboo from the site vicinity might not be a possibility because of this. BB and JV agreed that bamboo should be treated in the location where they are harvested before shipping to ensure longevity of the structure.
 - *Phyllostachys* is the most common bamboo species in Brazil and what has been used so far in the development of BNP. Bamboo must be specified and certified (environmental impact certification) by the appropriate bodies. Various bamboo species must be investigated to find a species that is widely available, affordable and has sufficient structural strength for the construction of BNP.
4. **Aesthetics & Homely feel.** Must feel/look like a house, not a tent. Structure must not only *be* sturdy, but also *look* sturdy. Occupants must feel safe/ protected. Perceptions of occupants are crucial.
5. **Ventilation & Insulation.** RK said that BNP was developed specifically for tropical & sub-tropical areas. FD mentioned that if the shelters is to be used for a year on average, shelters must provide a certain comfort-level in all seasons.
 - RK requested that academic material of international experts on bamboo be gathered by NDS as part of its research on BNP as SerSustentavel has limited access to academic publishings. She particularly asked about works by Ruiz.
 - Group discussion on the concept of an assembly manual and alternatives to manuals in providing instructions on the assembly process. AD suggested printing instructions on the textile panels, or making the assembly simple enough to allow for an intuitive assembly process. The example of commercial tents was mentioned as model for intuitive assembly of a similar structure.

Current Product

- FD asked RK to explain to the group, in her opinion and experience, what is working and what isn't with the current BNP product. Which materials, structural or cladding, should be kept and for which ones should alternatives be searched?
- RK said the following materials/ aspects should remain:
 1. Bamboo (Structural strength/Grows fast/CO2 Converter/Wide availability)

2. Recycled Roofing Sheets (Waterproof/ Good insulation/Easy to work with/ Low or no maintenance)
 3. Translucent Canvass Panels (Creates comfort through natural lighting)
 4. 30 Deg. (minimum) Roof Pitch (Optimal Wind resistance) – This may call for joining bamboo pieces to meet required spans.
- RK mentioned the following shortcomings regarding the current product:

Structure Concept & Design

- The shelter is too light. It needs additional methods of securing it to the ground.

Material Choice

- Metal parts can/should be replaced with more eco-friendly, non-corrosive alternative materials.
- Bamboo is currently the most expensive component of the BNP shelter, second is the transportation of the roof sheets. BB recommended investigating ways of streamlining/ economizing the bamboo production chain.

Assembly Process

- Roof and roof tiles were difficult to put up, because of the height of the ridge. With the current structure, to fasten the bolts on the centre connector at a height of 3.5m requires the use of a ladder, which is not ideal.
- A big challenge, according to RK, is to indicate to the assemblers where exactly to mark out the five points on the ground where the triangular frameworks should be affixed for the shelter floor to form the required pentagram shape.

Discussion: Improving On Current Product

Structure/ Bamboo Framework

- AD suggested using textile earth bags at strategic points to weigh down and secure the shelter
- AD mentioned that, to overcome the common perception that bamboo is a poor man's construction material, ways of adding value to the material should be investigated eg. branding

Dimensions & Specifications

- Current measurements should be looked at for possibly minimizing material use/ minimal space requirements ratio.

Current shelter:

- 30 sqm
- 10 000 People in 1500 Shelters = Average 6 -7 People/Shelter
- AD suggested looking at optimal usage of floor space by looking at separating communal spaces (kitchen, showers, toilets) from shelters, reducing the function of the shelter to a space for sleeping only.
- The measurements of all structural elements should not need to be precise and should accommodate a range of mistakes/discrepancies as the fabrication of most parts will be done manually and not mechanically.

Features & Accessories

- AD mentioned the possibility of including Solar powered LED lighting for nocturnal illumination. RK concurred and named existing examples already investigated. Requirements: Supply 8 Hours of light on a single charge, affordable, portable.
- Look at commercially available safety stoves for use inside the shelter. Alternatively, AD suggested solar ovens.
- Having a way of dividing the interior space should be investigated – To create privacy and incorporate a changing area.
- AD suggested the addition of a (fabric?) storage space in the roof cavity.
- FD asked about possibly incorporating a wooden door as alternative to the tent opening of the current structure in order to give the shelter a more house-like appearance and feel, but RK said this would only be a consideration during the second phase of the shelter (conversion into a low-income house).
- Suggestions for additions during the second phase (conversion from shelter to house) include a solar oven, trombe wall, simple solar water heater, rain collector.

Cladding

- AD suggested looking at ways of incorporating features in the triangular textile wall panels (wardrobe/solar oven/black board for teaching/fireproof panel as cooking wall)
- RK said panels should include bottom extensions/rain flaps to direct rain water away from the structure
- RK, AD and AE discussed fastening the wall cladding panels on the outside of the bamboo frame, covering it, as apposed to the current arrangement of

panels as filling material and the bamboo frame exposed to the elements. Also, it was suggested that the panels be joined together (sewn) instead of the current method of fastening individual panels with cable ties.

- FD suggested incorporating 'skylight' roof panels, possibly replacing one roof panel with a translucent textile/PET panel.
- AD suggested looking at using repurposed textile bags, primarily used in freighting to offload supplies in ports worldwide, as possible cladding material.
- AD also mentioned textile producers in Brazil having problems with the disposal of large amounts of waste created during textile production. The possibility of producing textile products from this waste, which could be used in the BNP shelter, should be investigated. He cautioned, however, about the stigma attached to living in a house/shelter made from rubbish.
- AD suggested looking at possibilities of impregnating fabric panels with a substance like citronella, to release pleasant smells, but also as an insect repellent.

Connectors

- AD suggested looking at recycled polypropylene / aluminium as alternative to the steel connectors currently employed.
- FD stated that, because the entire structure is made up of triangles, connectors do not need to be rigid, that even connectors cut from repurposed rubber tires would suffice.
- Bamboo limbs need to be filled at both ends to strengthen it against side compression when the connector bolts are tightened. The current method is filling the ends with wood and clamping it with metal strapping. Alternatives should be investigated.

Floor

- RK suggested looking at splicing and flattening bamboo combs to use as flooring material (Cheap/ Easy to Assemble/Creates Water-resistant Barrier) Employing a suspended floor is preferable, but not essential.
- AD suggested including a drainage moat on the floor periphery to prevent flooding of the shelter during rain spells.
- RK enquired about the *EcoPaver* by *Soliforte*, a paving product made from recycled concrete and developed by NDS, as possible flooring solution.
- AD suggested creating polymer frames (similar to pavers) that could be filled with concrete, rubble or soil to form a floor. This is a lighter, easier-to-transport alternative to the *EcoPaver*. He suggested that the stacked polymer 'pavers' can even form the packaging for the shelter kit during shipping.

Manufacture, Transport & On-Site Assembly

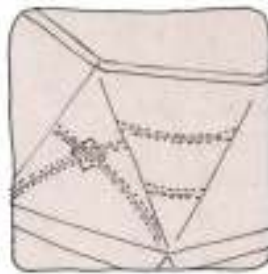
- FD mentioned that materials that might be available on-site should be considered as alternatives to materials needing to be shipped, e.g. tires, rubble from collapsed buildings etc.
- FD said the structure should be adaptable to enable it to address the unique requirements in a variety of locations created by various types of disasters in different parts of the world (material availability/shipping costs etc)
- AD and BS said that assembling the structure without the use of tools should remain, but once assembled, disassembling the connections should be child-proof
- AD suggested using the polymer paver flooring assembly concept mentioned above as possible measuring/layout tool for the 5 points of the pentagram floor-shape to be easily determinable.
- RK informed about the *Guarda Viva* social project, located in a low-income community in Sao Jose dos Pinhais, where members will be receiving training on how to manufacture the various parts of the shelter and assemble the kits to be ready for shipping to the disaster areas.

Appendix E: Research Report Extract – Bossa Nova Instant House

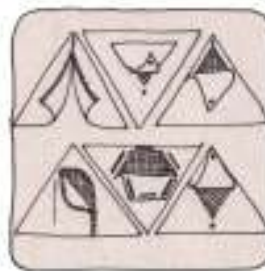
Recommendations for Kit 1: Instant Emergency Shelter

Structure & Cladding

- Include bottom extensions/rain flaps to direct rain water away from the structure
- Textile wall panels should be joined together (sewn) or cut in one piece instead of the current method of fastening individual triangular panels with cable ties
- Bamboo/recycled plastic 'ribs' can be inserted into sewn pockets of the wall and roof panels to create tension. The arches formed by the ribs decrease the amount of areas on the structure with insufficient tension against strong winds.

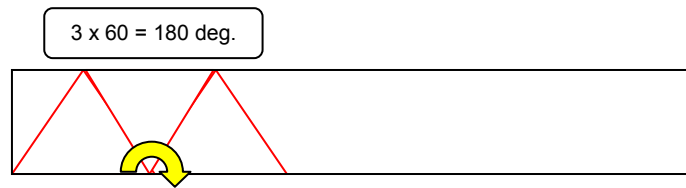


- Several door and window openings should be looked at in terms of functionality and economy in the fabrication process. It is often necessary, especially in tropical and sub-tropical areas, to create an insect barrier. In the new Bossa Nova shelter design, this comes in the form of fine mesh inserts in window and door openings.



- The fact that equilateral triangles are recommended to make up the entire structure has many benefits:
 - i. *All bamboo strut lengths are of equal length* – simplifies component fabrication, assembly process and maintenance/replacement of struts significantly
 - ii. *Wall-cladding can consist of a single rectangular piece of fabric or film* cut from a roll. If equilateral triangles are used for making up the walls, a straight-

edged roll of fabric/plastic film can simply be cut to the required length (Circumference of the pentagon) and wrapped around the entire structure as a one-piece wall panel



iii. *The structure becomes modular-* extensions, alterations and modifications to the basic structure simply entails adding more triangles of a similar size.

Dimensions & Specifications

- The measurements of the current shelter were re-evaluated to economise on material use and facilitate transportation as well as to simplify the assembly process for the end-user. The current shelter measures 30 m². The intent was to place 10 000 People in 1500 Shelters, averaging 6 to 7 People per shelter. Because of the structural changes proposed for the improved design, shorter bamboo struts of uniform length and flexible connectors denote that there is adjustability within the total floor surface of the structure. Floor dimensions vary between 15m² and 34m² depending on the angle at which 5 wall triangular panels are in relation to the ground.
- According to the *Sphere* shelter and settlement standard for covered living space (UN-Habitat, 2008), a minimum space of 3.5 m² is required per person living in a shelter. Accordingly the new shelter design of 15m² will be suitable to house 4 adults or 2 adults and 3 children.

Materials

- The current specified steel connectors should be replaced with more eco-friendly, non-corroding alternative materials. Depending on the chosen connector design and the requirements associated with that design, materials can include recycled/recyclable plastics, aluminium, rubber or even certain technical textiles or textile-based composites like textile-reinforced hoses.
- New bamboo cultivation initiatives should be established in Brazil in which SerSustentavel is a primary stakeholder to enable bamboo supplies to be more readily available and affordable. Currently the use of bamboo as structural

component makes the cost of the shelter significantly higher than if alternative materials were used.

- A textile roof should be employed in the shelter-phase of the structure instead of the rigid roof currently specified. This will decrease the size and weight of Kit1 significantly, meaning easier and more economic transportation. It also makes the roof easier and faster to assemble on site. A translucent textile roof provides natural lighting inside the shelter and can be easily maintained and repaired with the inclusion of a patch-kit.
- Materials available on-site and/or in close proximity of the disaster-struck area should be considered as alternatives to materials and components needing to be shipped from Brazil. The fabrication of most components are simple enough that setting up a local low-tech manufacturing facility closer to the site, using locally/regionally available materials and local labour makes sense from an environmental-, economic-, social- and logistic point of view.
- The following tables contain suggestions for cladding materials from local suppliers:

ROOF											
Product	Company	Composition	Weather Resistance	Cost	Tensile strength	Durability (life expectancy)	Translucency	Insulation	Fire Safety	Observation	Site / Telephone
Lona Forte	Plásticos do Paraná	Plastic woven bag lined with high and low density polyethylene	Impervious and immune to the action of bacteria and fungi that cause mildew and rot	R\$3,80/m ² + 5% de IPI	High tensile strength	3 years (medium durability)	No translucency	Good insulation	Non-flammable		http://www.plasticospr.com.br Tel.: 55 41 3075-8000
Tiles	Onduline	Recycled plant fibres	Good weather resistance	not available	Not applicable	15 year warranty (high durability)	No translucency	Not available	Not available		http://www.onduline.com.br Tel.: 0800 0 245 260
Lining	Bambu Carbono Zero	Bamboo	Do not exhibit cracks when exposed to sunlight or very dry environments.	Thickness 3cm - R\$144,00/m ² 4cm - R\$138,00/m ²	Not applicable	Requires maintenance every six months with waxes and oils (low durability)	No translucency	No insulation	High inflammability	Secured with nails, screws or pneumatic gun pinadora	http://www.bambu carbonozero.com.br Tel.: +55 11 6095-3308
Divfoil	Divsystem	Polyethylene film	Impermeable barrier against moisture	30 m ² Roll- R\$ 91,58	Not applicable	Not available	No translucency	Good thermal insulation	Not available		http://www.divsystem.com.br/prod_divfoil.swf

Product	Company	Composition	Weather Resistance	Cost	Tensile strength	Durability (life expectancy)	Translucency	Insulation	Fire Safety	Observation	Site / Telephone
BMD Canvas	BMD	Polyester + PVC High density polyethylene coated with low density polyethylene	Good weather resistance (waterproof) Protection from weather such as rain, hail, frost and winds	R\$ 8,637 / m (screen) R\$ 8,50 / m (canvas)	High tensile strength	High durability	30-75% stading (according to need)	Allows passage of sound according to need	Not available		http://www.bmdtexteis.com.br/ Tel.: + 55 71 2104-6312
Viti Forte 230	Plásticos do Paraná			R\$ 8,00 / m	High tensile strength	3 years (medium durability)	Approx. 80% translucency (according to need)	Not available	Not available	light and malleable fibers surrounded by a high strength resin, which prevents the penetration of water and dust	http://www.plasticospr.com.br/ Tel.:55 41 3075-8000
Aqua Block Impermeable Textile	Textile stores	28% Cotton 72% Polyester	Good weather resistance (waterproof)	R\$ 28,00 / m	Good tensile strength	Medium durability	No translucency	Not available	Not available		http://www.mimasa.com.br (11) 32292197
Aramid Fabric-TA-4 (Tecido de Aramida-TA-4)	ASALIT Produtos Industriais or Fibretex	100% Aramid fiber	Low weather resistance	R\$ 200,00 / m	Tensile strength warp: 50 Kg / cm Weft: Failure load: 30 kgf / cm, resistance to abrasion and Great cutting	Depends on use	Will depend on the thickness	Without such a purpose	Non-flammable		http://www.asalit.com.br/ Tel.:+55 31 3495-6065
silica fabric (Tecido de Silica)	ASALIT Produtos Industriais	Made from wires with high silica content	Low weather resistance	R\$ 300,00 / m	Tensile strength warp: 59 Kg / cm Weft tensile strength: 35 kgf / c	Depends on use	Will depend on the thickness	Without such a purpose	Non-flammable		http://www.asalit.com.br/ Tel.:+55 31 3495-6065
Ceramic Fiber Cloth (Tecido Fibr Cerâmica)	ASALIT Produtos Industriais	Composite wires with high ceramic-fiber content	Low weather resistance	R\$ 250,00 / m	Tensile strength warp: 18 Kg / cm Weft tensile strength: 8 kgf / c	Depends on use	Will depend on the thickness	Without such a purpose	Non-flammable		http://www.asalit.com.br/ Tel.:+55 31 3495-6065
OSB (Oriented Strand Board)	Masisa	Strips of pine reforestation + resins	Weatherproof and greater resistance to warping (good show) Do not exhibit cracks when exposed to sunlight or very dry environments	Sheet (2,44 x 1,22 m x 18 mm): R\$ 56,22.	Not applicable	Not available	No translucency	Excellent thermal and acoustic insulation	Not available	FSC certified	http://www.masisa.com.br
Bamboo Trellis	Bambu Carbono Zero	Bamboo		R\$ 70,00 / m2	Not applicable	Outdoors: 7 years Indoors: 30 years (medium and high durability)	No translucency	No insulation	High inflammability		www.bambucarbonzero.com.br

FLOOR											
Product	Company	Composition	Weather Resistance	Cost	Tensile strength	Durability (life expectancy)	Translucency	Insulation	Fire Safety	Observation	Site / Telephone
Plastic wood	Wisewood	Mixed Post-consumer Plastic (PEAD, FEBD, PP, PS) and Natural Fibers	Weather Resistant (Salt Spray, Sun, Rain)	Deck: R\$ 105,00/m ² . Batten: R\$ 52,50/m ² .	not applicable	50 years (high durability)	Not applicable	Not applicable	Not available	Weight near 800kg/m ³	http://www.wisewood.com.br/ Tel.: + 55 (11) 4394-3813
Bidem TC (Cetaxite)	Bidm Merchem	100% Polypropylene	High chemical and mechanical resistance	Approximately R\$ 5,00/m	high tensile strength	Extremely high durability (lasts hundreds of years)	Not applicable	Not applicable	Not available	Is certified ISO 9001	http://www.bidm.com.br/ Tel.: +55 (12) 3946-6801
Tatami	Futon Brasil	Rice straw	Interior Applications Only, Poor Weather Resistance	80cmx60cmx5mm: R\$ 310,00 1,30cmx30cmx3mm: R\$ 442,00 2m60cmx6: R\$ 478,00	not applicable	High durability (several years if not exposed to direct contact with water)	Not applicable	Not applicable	Not available	Also available for sizes customization up to 2mx90cm	http://www.futonbrasil.com.br Tel.: 35 11 3081-7072
Traditional Tatami	Original Tatami Yamamura	Compressed Rice Straw	Interior Applications Only, Poor Weather Resistance	Double mat: R\$300 Single mat: R\$230 Imported mat: R\$220 approximately R\$180/m ²	not applicable	High durability (several years if not exposed to direct contact with water)	Not applicable	Not applicable	Not available	Approximately 20kg in a piece of 180x90 and 5,5cm of thickness	http://www.yamamuraonline.com.br/ Tel.: +55 (13) 3821-4478
Marmoleum and Ardeum	Primatefaria	Lined Oil, Wood Flour, Natural Resin, Limestone, Jute and Natural Pigments	Interior Applications Only, Poor Weather Resistance	Approximately R\$ 140,00/m	Not applicable	High durability (not recommended to wet environments)	Not applicable	Not applicable	Non-flammable		http://www.primatefaria.com.br Phone: +55 (11) 4114-0162
Recycled Rubber Flooring	Hajah	Recycled Rubber from Pharmaceutical Waste Products (Pacifiers, Eye Droppers etc)	Good Resistance	40cm x 40cm x 10mm: R\$ 165,00/m ² 1,25m x 80cm x 10mm: R\$ 165,00/m ² 40cm x 40cm x 20mm: R\$ 188,00/m ² 1,25m x 80cm x 20mm: R\$ 188,00/m ² 1,25m x 80cm x 30mm: R\$ 220,00/m ²	No variation (not applicable)	3 year warranty for fabrication and 1 year for installation (medium durability)	Not applicable	Not applicable	Low flammability		http://www.hajah.com.br Phone: +55 (11) 4053-5477
Carpet of Corn Starch (Carpete de Amido de Milho)	Interface	Up to 58% Recycled Carpet Fibres, Corn Starch	Good Resistance	Available in sheets of 50x65cm, R\$ 88 to R\$ 104/m ²	Not applicable	Medium durability (odors: 7 years indoors; 30 years medium and high durability)	Not applicable	Not applicable	Not available		Phone: +55 (11) 3371-0900
Bamboo Decking	Bamboo Carbon Zero	100% Bamboo	Good Resistance	Giant bamboo: R\$ 170,00/m ² . Bamboo Planks: R\$ 319,00/m ²	Not applicable		No translucency	Not applicable	High inflammability		www.bambucarbonzero.com.br

SUGGESTIONS BY SUZANA BARRETO						
Product	Composition	Fire Safety	Weather Resistance	Tensile strength	Durability (life expectancy)	Translucency
WALL						
frame with strips of bamboo with the technique of basketry	bamboo	depends on the treatment of the material	good weather resistance depending on treatment	not applicable	depends on the treatment of the material	entry of light depends on the type of mesh made in the process of basketry
whole bamboo culms joined through 'figure of eight' moorings	depends on the treatment of the material	depends on the treatment of the material	good weather resistance depending treatment	not applicable	depends on the treatment of the material	low light
retrace textile pressed plates	retrace the textile industry of Londrina	not available	good weather resistance depending treatment	depends on the selection of the retrace	depends on knowledge of chemicals involved	depends on the selection of the retrace
ROOF						
Plates of coconut fiber	Coconut fiber	Flammable	Good weather resistance depending treatment	Not applicable	High durability	Not translucent
FLOOR						
Bamboo floor	Bamboo	Low flammability with proper treatment	Good weather resistance depending on treatment	Not applicable	25 years (high durability)	Not applicable
OTHER OPTIONS						
Natural fiber fabrics	<p>AMC Têxtil Ltda (Jaraguá do Sul, SC)</p> <p>Barcellos & Cia Ltda (Americana, SP)</p> <p>Caiman Indústria e Comércio de Malhas Ltda (Schroeder, SC)</p> <p>Camelon Tinturaria e Estamparia Ltda (Guarulhos, SP)</p> <p>Carmotex Fios e Tecidos Ltda (São Paulo, SP)</p> <p>Celenza Têxtil Ltda (Vinhedo, SP)</p> <p>Cia de Fiação e Tecidos Cedro Cachoeira (Sete Lagoas, MG)</p> <p>Cia Fiação e Tecidos Cedro e Cachoeira Ltda (Belo Horizonte, MG)</p> <p>Cia Tecidos Santanense (Montes Claros, MG)</p> <p>Cia Tecidos Santanense (Belo Horizonte, MG)</p> <p>Cia Tecidos Santanense (Pará de Minas, MG)</p> <p>Cia Têxtil de Castanhal (Castanhal, PA)</p> <p>CIC Cia Industrial Cataguases (Cataguases, MG)</p> <p>Cotermias Cia de Tecidos Norte de Minas (Belo Horizonte, MG)</p> <p>Cotermias S/A (Macaíba, RN)</p>	Cotton, hemp, bamboo, jute, banana, sisal, coconut	Dependence of the chemical treatment			
Biopolymers		Soybean, corn, sugar cane, cellulose, chitin, chitosan, whey, etc				

Connectors & Anchoring

The following connectors have been selected and developed to serve as alternative to the steel connector plates currently employed in the bamboo frame assembly of the shelter.



Pipe/Hose Connector 1 (Wall) – Use textile-reinforced rubber hose (Repurposed fire fighting hose), PVC or metal water pipe or rubber tubing. The bamboo is inserted in the tube and secured with hose clamps. A single bolt connects two tube sections to the bamboo strut from the roof, which is reinforced by a metal / plastic ring.



Pipe/Hose Connector 2 (Floor) – Similar materials as above. The two bamboo struts coming together is secured to the floor by rawl bolt being cast in concrete, the mould of which is a standard plastic bucket included in the emergency shelter kit.



V-Connector (Wall) – This connector is cast in recycled plastic or aluminium and works on the same principle as the Pipe/Hose Connector above. A single bolt or pin secures the bamboo struts inside the connector and a bolt secures two V-Connectors to the roof strut to form a 5-point joint.



Sandwich Connector (Roof/Wall) – This is an adaptation of the connector currently used. It's made of recycled plastic/aluminium / scrap metal and sandwiches 5 bamboo struts between the two identical parts of the connector by tightening the single bolt running through the centre of both. Pins running through strut-ends secure the struts to the connector.



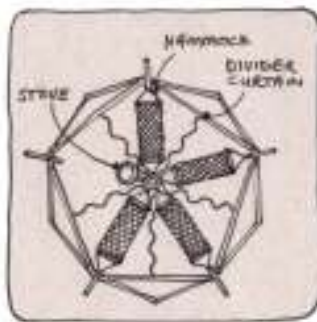
Ring Connector (Roof/Wall/Floor) – This is the simplest and recommended connector. It uses a ring of recycled plastic / aluminium / scrap metal with a tapered side profile. Bamboo struts have pins / bolts inserted close to knots. A hook/eye bolt hooks around the pin in the strut and through the ring, securing the strut to the ring when the wing nut on the inside of the ring is tightened.

is fastened.

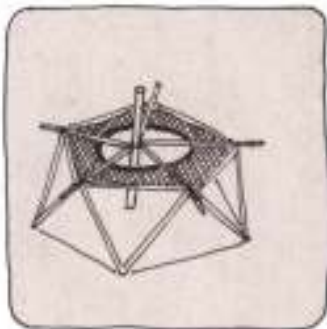
Shelter Interiors



Cooking Area – The central post in the new shelter design could serve as a chimney to channel smoke from wood/fuel stoves to the exterior as well as attachment point for 4 to 5 hammocks. By positioning the cooking area close to the centre post minimises the risk of accidental fire at the edges of the shelter.



Sleeping Area - Four hammocks can be attached on four of the five corners of the pentagon-shaped ring beam and to the centre upright post. Between hammocks, textile curtains serve as room dividers to divide the shelter into 4 private sleeping quarters. The fifth segment is used as a cooking area and houses the stove. During the day, hammocks are detached from the centre post and hung folded against the outer walls, forming 'bags' for stowing away bedding in the day. Room divider curtains can also be drawn back to the outer walls so the entire shelter becomes a communal area during the day.



Storage Area - A mesh net resting on top of bamboo rafter struts and attached to periphery struts serves as a 'net shelf' for storing belongings of the inhabitants of the shelter.

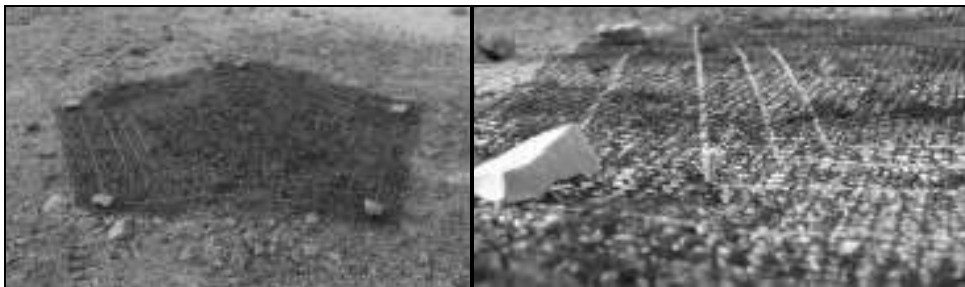
Manufacture, Transport & On-Site Assembly

As mentioned above, fabrication of parts constituting the two kits will be administered in Brazil by social community projects. SerSustentavel would oversee the training, operations and logistics of the manufacture, compilation and distribution of orders for the product. The shelter design is such that fabrication of the different components is kept as simple as possible using low-tech methods and the most basic of tools.

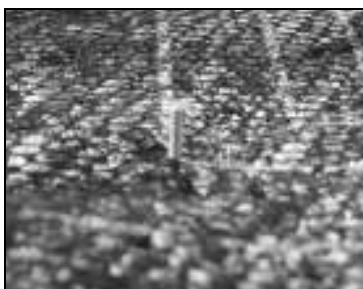
Kit 1 will be compiled at the fabrication facility and packaged in cylinder-shaped textile carrier bags that measure 3m in length (length of bamboo struts) and approximately 35 to 40cm in diameter (depending on bamboo strut diameters). Kit bags will then be packed in standard 6 or 12m shipping containers ready to be shipped to the designated area. From the port at the designation, kits will be unloaded onto local means of surface or air transport for distribution to specific areas in the affected region. One kit per community will be unpacked and assembled by aid workers as demonstration model to the communities, after which kits will be distributed to families to be assembled themselves on allocated sites. Certain members of the community will be trained to act as construction managers. They will advise and assist families in the construction of their shelters and will also function as intermediaries between aid workers administering the distribution of kits and the affected community.

The sequence of assembly of Kit 1 is as follows:

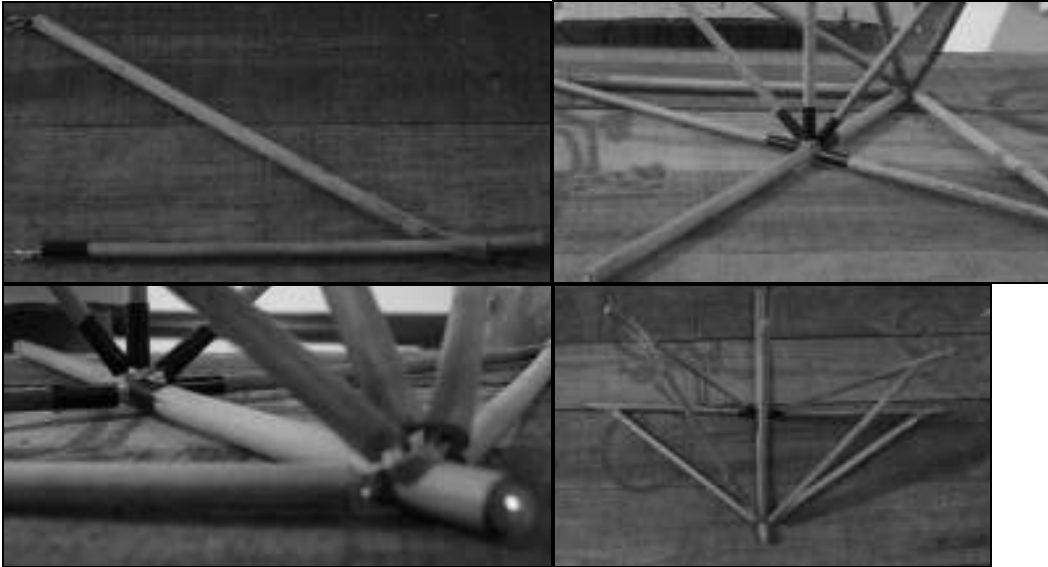
1. Select a level site and remove as many stones and other debris from the site
2. Unroll the textile floor panel on the cleared site – this acts as template for the placement of 5 anchoring points



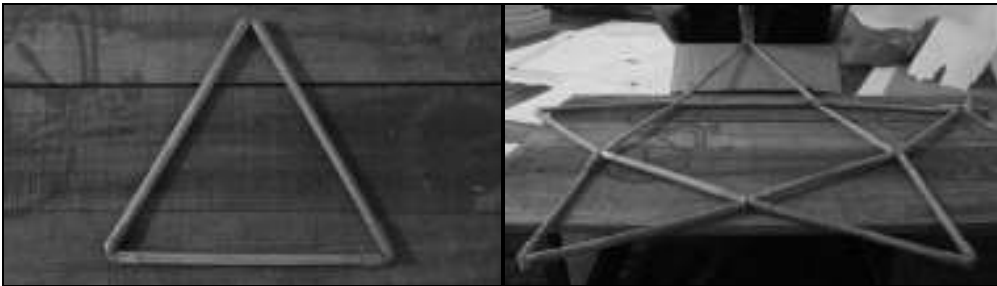
3. Prepare the 5 anchoring points



4. Assemble the roof trusses by attaching 5 diagonal struts to the top of the middle pole as well as 5 horizontal struts to the mid-section of the middle pole and also each diagonal strut to a corresponding horizontal strut



5. Assemble 5 equilateral triangles that will form 5 of the 10 wall frames.



6. Attach the 5 wall triangles to the 5 roof trusses and lay the entire structure flat on the floor panel.



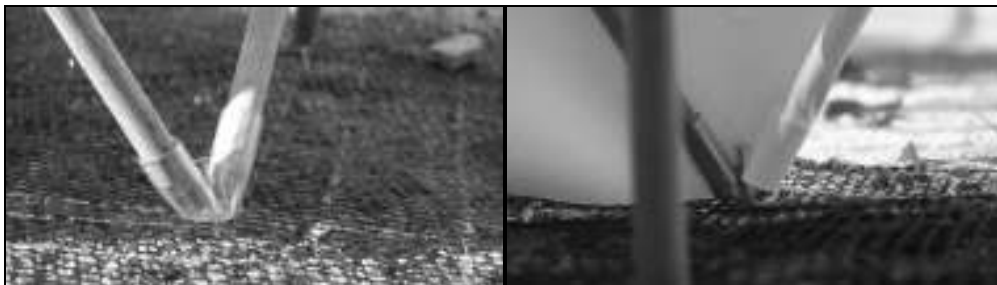
7. Attach the textile roof panel to the roof trusses and ensure that there is sufficient tension in the roof when assembled.



8. Insert the bottom section of the middle pole while simultaneously lifting the entire frame at the 5 corners.



9. Line up the bottom corners of the 5 wall triangles to meet the 5 anchoring points and secure these points.

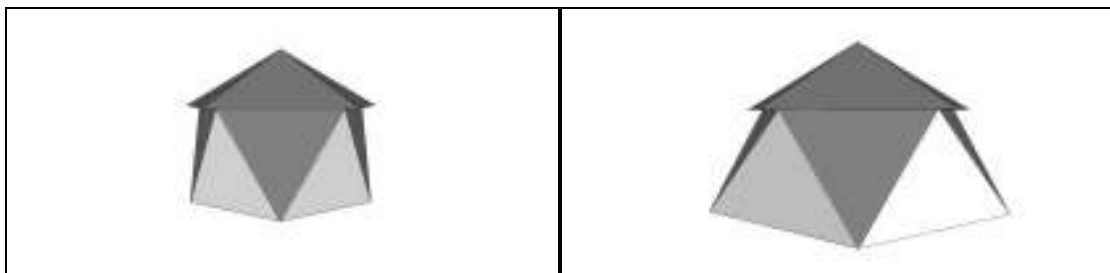


10. Unroll the textile wall covering and attach it at various points along the periphery of the bamboo wall framework.



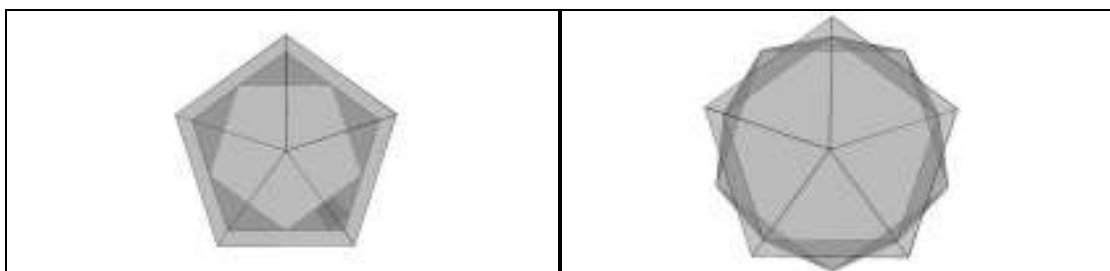
New Bossa Nova Shelter Design

The new Bossa Nova Shelter is constructed using only equilateral triangles. This means that every strut in the framework of the new design has the same length. For creating the walls, groups of three struts are joined to form triangles, which are the main construction elements. Five of these triangles pointing downwards are connected to the base anchoring points. The other five wall triangles pointing upwards are formed by the spaces between 2 anchoring points on the floor and where 2 downward-pointing wall triangles meet. The new design's equal strut lengths forming a series of equilateral triangles and the new connector design allow the floor coverage of the Bossa Nova shelter to be adjustable, varying between 15m² to 35 m². This flexibility is possible without altering any of the structural components, but by simply amending the position of the anchoring points as illustrated by the figures below:



In the image on the left the anchoring points are placed close together. The distances between the anchoring points in the image on the right are greater, creating a slanted wall and increased floor coverage. This simple change in the geometry of the structure is the secret of the new Bossa Nova design.

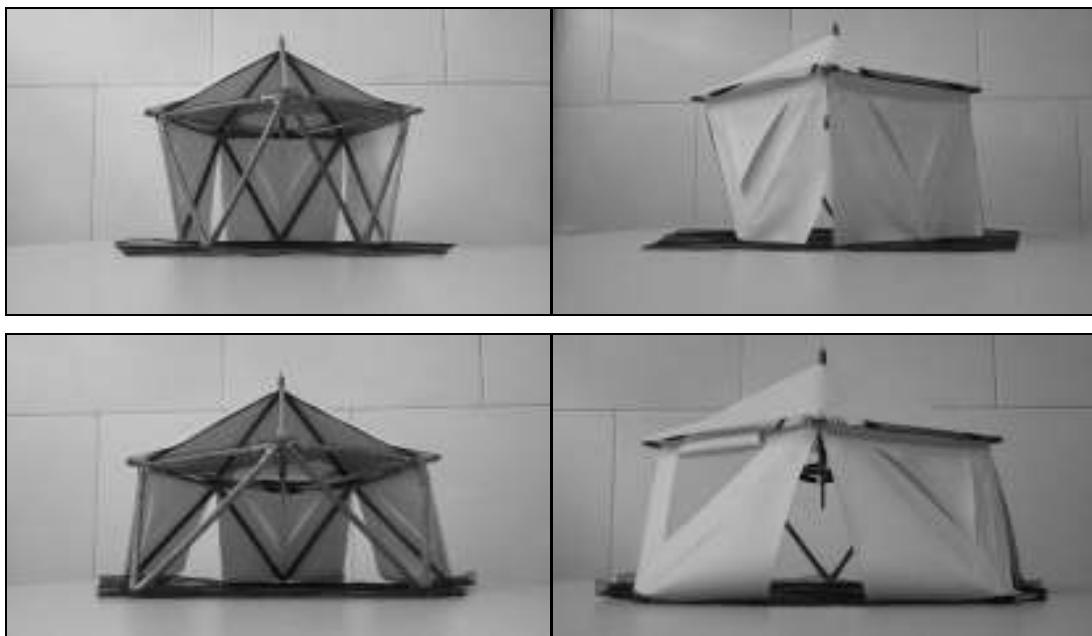
The following two pictures demonstrate the variation in floor size in a top view. By simply altering the anchoring points, the left side shelter is approximately half the size of one on the right.



The table below shows approximate measurements of two variations of shelters with different floor size. Using uniform strut lengths of 3 m, the distance between the anchoring points can range between 3m and 4.5m.

Size Table	New Design	
	15 m ²	35 m ²
Amount of struts	25	25
Diameter struts	4-8 cm	4-8 cm
Length struts	3 m	3 m
Distance between Anchoring points	3 m	4.5 m
Square meter Floor [m ²]	Ca. 15	Ca. 35
Square meter Textile [m ²]	Ca. 60	60 to 70
Height ceiling	2.55 m	2.23 m
Height Rooftop	4.12 m	4.80 m

The four images below demonstrate the 15 m² variation (images 1 and 2) as well as the 35 m² variation (images 3 and 4) using the new 1:15 scale mock-up. The mock-up serves as functional model to demonstrate the main features of the full scale Bossa Nova shelter. For this reason one side of the mock-up is not covered so that the inside structure of the mock-up is visible.



Conclusion

The research conducted on the *Bossa Nova Instant Housing Project* was part of a preliminary study and can not be considered comprehensive or conclusive. Because of

limited resources, particularly time and funding, the recommendations of this report serve as 'quick fixes' to minor challenges experienced by the client. Much more comprehensive research is necessary to be able to fully study, develop and test the system, product and sustainability of the Bossa Nova Instant Housing Project. It is hoped that the research conducted will assist the client to accumulate interest and financial support for the project to allow for further research and development to be conducted.