EXPLORING THE ROLE OF DIGITAL TECHNOLOGY IN ENHANCING AN ENVIRONMENTALLY RESPONSIVE ARCHITECTURE:

Toward a fog water harvesting and visitors centre on Signal Hill

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Lady Anne's voyage was a long one. After passing Madeira and the Canary Islands, and reaching the low latitudes of the Cape of Good Hope, her ship, the Guardian, was blown into the icepacks of the southern Atlantic. Eventually, there came a change of wind and the 'joyful news' that land had been sighted. Alas, the sea mists and fogs were still so thick as 'not to permit us to enjoy its appearance till we were exactly placed in the Bay opposite to Cape Town... Then, as if by one consent the Lion's Rump whisked off the vapours with his tail; the Lion's Head untied, and dropped, the necklace of clouds which surrounded its erect throat, and Table Mountain over which a white damask table cloth had been spread half way down showed its broad face and smiled'.

- *Tristram Hunt, Ten Cities that Made an Empire, 2014*

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I………………………………………………………. declare that,

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DECLARATION

I declare that this dissertation is my own unaided work. All citations, references and borrowed ideas have been duly acknowledged. This document is submitted in partial fulfilment of the requirements for the degree of Masters in Architecture at the faculty of Social Studies and the Built Environment, University of Kwa-Zulu Natal, Durban, South Africa. None of the work has been previously submitted for any degree or examination at any other University.

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- **Natasha,** your continued support, unconditional love and belief in me, spurred me on especially in the really difficult times.
- My friends who helped me during these trying times and supported me throughout, you guys are true friends.

DEDICATION

This dissertation is dedicated to my parents and my gran. For everything you have sacrificed to help me fulfil my aspirations, I am truly thankful. An Mama und Oma, ohne euch beide hätte ich es niemahls geschafft. Ihr wart stehts immer bereit mir zu helfen und dafür kann ich mich nicht genug bedanken.

Thank you

ABSTRACT

The development and progression of architecture throughout the ages has been for the most part as a result of the influence of new technologies. Today, more environmentally responsible and innovative buildings are being constructed thanks to research and developments in technology. As the information age transforms into the digital age, the trend for digital integration into every-day life is becoming the norm. Concurrently, the promotion of sustainable living in our society has been facilitated by digital technology. While digital technology and sustainable living might seem like completely different fields, they are more interconnected than we may believe. This dissertation explores how digital technology can enhance an environmentally responsive architecture. The thesis provides principles for developing a connection between digital technology and environmental architecture in order to facilitate a sustainable approach toward sourcing water.

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1.0 INTRODUCTION

1.1.1 Background:

Buildings account for a substantial proportion of gross energy consumption in the industrialised world through services such as air conditioning, heating, lighting and ventilation (Hawkes et al., 2002). Third world economies such as China who are embracing industrialised economies are becoming recklessly extravagant in their energy demands, becoming major sources of environmental pollution.

Throughout history, the impact of architecture on the environment has steadily increased, contributing to a high percentage of carbon dioxide emissions, raising air temperatures significantly, as well as using a large amount of water (EPA, 2009). Furthermore, the use of land is increasing at a dramatic rate which greatly harms the various natural ecosystems, and at the turn of the 20th century its negative impact began to be scrutinized by environmentalists. Architects are responding to this by designing buildings which consider the environment as well as address their energy efficiency in order to reduce our dependence on natural resources. This led to many architects (Frank Lloyd Wright was arguably the first) adopting passive technologies such as sun shading, the use of natural materials and building orientation, which would consciously provide a standard of comfort to the inhabitants without relying on foreign sources of energy.

The science and technology behind renewable sources of energy has been growing at an astounding pace, but has until recently been received with much hesitation by design professionals in the field of environmental design. The environmental movement has been hesitant in adopting digital technology, citing it as the primary cause for climate change and the negative impacts on the natural environment (Maffey et al.,2015). This is due to the negative connotations associated with man-made technologies and the anthropogenic impacts they have had on the environment, such as loss of biodiversity, deforestation and pollution. This research considers how architecture can be influenced by digital technology in order to be more environmentally friendly. It seeks to explore if digital technology has the potential to help address the environmental crisis and whether it will be the great epoch to a new architectural style. Many avant-garde architects have realised the potential in digital technology in various different ways, from fabrication, to documentation, construction as well as energy performance and aesthetics. This study will ultimately seek to determine the role of digital technology and how it can positively contribute to the relationship between architecture and the environment.

Digital technologies impact on architecture is mostly experienced in the abstract form-making of various contemporary buildings which have become trademarked by a handful of "Master" architects, namely Frank Gehry, Zaha Hadid Architects, Norman Foster and Jan Kaplicky of Future Systems, to name a few. The reliance on computational architecture to generate the forms is a radical departure from traditional architecture design. These methods have often received criticism due to the insensitivity of the designs which often seem to be indifferent to the environmental context in which they have been sited, as well as the recurring typology in which it is used (museums, opera and theatre houses). Critics of the movement argue that the style is purely aesthetic, however the superiority of the architectures ability to adapt to a multitude of complexities has largely been overlooked. It is important to note that the methods and theory are very much geared towards the correlation between systems, including environmentalism. Whilst this type of architecture for many seems to take on more of a sculptural purpose, it is possible to use the various digital methods in an environmental context to improve effectiveness.

1.1.1.1 Contributions of digital technology to the environment

Historically, major technological innovations have had far-reaching environmental impacts, some bad and others good (Sui and Rejeski, 2002). The pressure to conserve and protect the natural environment has however transformed the way in which technology is being used. The introduction of digital and "green" technologies is already helping many sectors of environmental movements such as nature conservation (Arts et al., 2015). Termed 'digital conservation'(fig.1), this method relies on data and data integration in order to monitor, evaluate, and implement effective strategies towards the conservation project. What makes it so effective is the ability to use high-tech, mass-produced sensors for cheaper, faster and more accurate data capture (Arts et al., 2015).

Figure 1: The five key dimensions of digital conservation. Source, Arts et al., 2015

Sustainable energy is one of three most important global problems along with healthcare and water scarcity (Vergragt, 2006). Reductions in toxic vehicle emissions of 70-80% since 1977 were made possible by innovations in electronics, and energy-related greenhouse gas emissions are being slowed down thanks to innovations in fuel cell technology and the use of natural energy sources, such as the sun and wind (Austin and Macauley, 2001).

Digital technology has also impacted water scarcity by allowing innovations of sourcing and purifying potable water. One of the most technological advances is in desalination, which essentially removes the dissolved salt and impurities from ocean waters (Llamas and Gunn, 2008). One of the methods for desalination involves a process called reverse osmosis, which became possible due to advancements in chemical engineering and membrane technology (Service, 2006). The benefits of reverse osmosis compared to multi-staged flash distillation (using heat to evaporate water) is the reduced amount of energy required for the process.

The downside to this technology is the negative impact that desalination can have on the environment, such as air and noise pollution and high concentrated discharges of brine and other chemicals to name a few (Mutatz, 1991). Desalination is currently being heavily researched in order to find ways to minimize negative environmental impacts.

Other innovations in water harvesting around the world include the use of rain-water harvesting technologies. Geographical Information Systems (GIS) provide the ability to identify the best potential sites for rainwater harvesting, and include maps of rainfall, slope, soil texture, drainage, soil depth and land cover (Mbilinyi, 2007). In the North Western Himalayan Region, Jammu, water scarcity is being combated with the help of GIS and remote sensing to find out where the moisture deficits and surpluses are. Thanks to these technologies, suitable sites for rainwater harvesting were identified (Jasrotia et al., 2009).

In Cape Town, the reliance on surface bodies of water which are replenished by rainfall resulted in a water crisis, due to longevity of the drought. The water shortage in the Western Cape has influenced commercial, private and public sectors and driven the need to explore alternate water sources. Some suggested methods for sourcing water have been desalination plants and boring for groundwater, both of which have many negative environmental implications. Fog water harvesting has proven itself successful as an alternative source of potable water in many arid regions of the world, including Namibia in the south western part of Africa, and the Atacama Desert in Chile. The research will attempt to drive awareness on sustainable water sources which go beyond traditional methods of collecting water through the influences of digital technologies.

1.1.1.2 The relationship between digital technology and environmental design

Digital technology has the potential to assess the complex nature of the architectural design process holistically. While the typical design process is linear and sequential, to achieve maximum efficiency the optimization of the system as a whole - by addressing building form, envelope, orientation, glazing area and a host of interaction and control issues involving the building's electrical and mechanical systems - is required (Metz et al., 2007). The possibility for near perfect optimization for all of these is reliant on modern technologies and systems which are integrated into the design, throughout the entire design and building process. Thus, with the aid of digital technology and the advancements of materials, the possibility for the improvement of environmental design can be researched.

1.1.2 Motivation:

Innovations in digital technology have resulted in many design tools becoming digitalized. These methods rely on the strength of computational software to accurately translate data into real world parameters which can be translated by people into a design which achieves the most optimal environmental response. Architectures capacity to respond to environmental factors has traditionally been static, passive and fixed. As humans we require a stable core temperature to survive and as such the shelters we create need to maintain a stable environment (Meagher, 2014).

This environment is generally operated by human interaction such as the opening and closing of windows, vents, operating louvres and blinds and air-conditioning. Technology's influences are already being felt through building automation; sensors which respond and adjust to external factors such as temperature, humidity and light intensity. Adopting these technologies into environmental architecture to address the issues of water security may have the ability to drive awareness and to change the perceptions that water shortages are a chronic problem by going beyond traditional means of sourcing water.

1.2 DEFINITION OF THE PROBLEM, AIMS AND OBECTIVES

1.2.1 Problem statement

The impact of digital technology in society is experienced in almost all facets of living. With the encouragement to live sustainably, many of these technologies are being utilized in architecture in ways which minimize energy usage. Despite this, the transition into an environmental architecture has been slow and the potential of digital technology to inform an environmentally responsive architecture needs to be explored.

1.2.2 Definition of the problem:

The Western Cape, and Cape Town specifically, have been most affected by water shortages, prompting researchers across many fields to look for alternate solutions of sourcing water. The use of fog to capture water has been used effectively in semi-arid and arid regions which are water scarce and which meet the climatic requirements for regular fog. Although effective, the systems used are basic and not adaptable. With the recent advancements in technology and digital design, research into implementing future proof and "smart" design principles in the outdated technology to improve efficiency of collecting water can be explored. Furthermore, the impact that this technology might have on the architecture and the changes it might bring to spatial arrangements as well as the aesthetics must be explored.

1.2.3 Aims and Objectives:

The aim of the study is to facilitate a paradigm shift that considers digital technology as a strong proponent for environmental architecture and sustainable design. This in turn aims to drive a shift in paradigm which considers water scarcity as a chronic challenge by looking beyond conventional water supplies as a backdrop to address local water scarcity.

The objectives of this study are:

1. To explore how digital technology and computational design can inform environmentally responsive architecture
2. To explore the evolution of architecture within current technology.
3. To contextualise digital technologies and environmentally responsive architectures in the South African context

1.3 SETTING OUT THE SCOPE

1.3.1 Delimitation of research problem:

The focus of this dissertation is on the impact and influences of digital technology on environmental architecture, specifically in the South African context. The issues of water conservation, alternate water sources and sustainability will be addressed through the corresponding architectural lens. The impact that this might have socially will therefore not be covered. The systematic complexities of Parametricism are intricate and varied, and can be applied to small scale design as well as large urban schemes and as such the focus therefore will be solely on the environmental aspect. Digital technology may be applied to architecture through a broad spectrum of ways. For this dissertations purpose, the focus will be solely on sustainable and environmental impacts which it may or may not affect.

1.3.2 Definition of terms

GCM

- A Global Climate Model which mathematically represents the major components of the climate system, including, atmosphere, ocean, land surface and sea ice, and their corresponding interactions.

CAD

- Computer Aided Design is used to create, analyse, optimize and modify designs using a computer system. CAD helps to effectively increase efficiency, productivity and quality.

Blobism

- A sub-style of parametricism. An architectural movement where buildings take on bulging, organic-amoeba shaped forms.

Foldism

- A sub-style of parametricism. An architectural movement where buildings seem to take on the form of folded fabrics.

NURBS

- Non-uniform rational basis splines are mathematical representations of 2 and 3-dimensional objects. NURBS are used in computational design for generating surfaces and curves.

Splines

- A mathematical function which is used for smoothing or interpolation.

Digital scripting

- a list of commands written by a person that are executed by a certain scripting engine or program.

Environmental architecture

- Concerns itself with minimizing the negative impacts of built form to the surrounding environment through efficiency and moderation in the use of energy, materials, and the ecosystem at large.

GIS

- Acronym for Geographic Information System, a computer system holding multiple layers of geographical and spatial data.

High-Tech

- Using the most advanced and developed methods or equipment.

Low-Tech

- Simple technology, often absent from anything mechanical. Traditional, pre-industrial revolution.

Parametric Design

- Parameters of a particular design that are declared rather than its shape.

Parametricism

- An avant-garde design theory termed by Patrik Schumacher of Zaha Hadid Architects.

Tectonism

- A sub-category of parametricism and the newest development of the theory tectonism aligns itself with materiality within the movement.

Digital Morphogenesis

- computationally based processes of form origination and transformations.

Digital Technology

- the branch of scientific or engineering knowledge that deals with the creation and practical use of digital or computerized devices, methods and systems.

Responsive facades

- Building envelopes or facades which have the ability to respond to their environment by either physical transformation or the altering of material properties to reflect surrounding environmental conditions.

Kinetic facades

- The physical movement of the building envelope or façade, motions or transformation in space which don't compromise the overall structural integrity.

Digital Design tools

- *Grasshopper*

Grasshopper is a plug-in for Rhinoceros 3d, meaning it operates within Rhinoceros 3d. It is a visual programming language and allows programming to become more intuitive by providing a visual representation of various algorithms.

- *Rhinoceros 3d*

3D graphic, computational design software which focuses on the mathematical precision of NURBS to generate complex curved and freeform surfaces.

1.3.3 Stating the Assumptions

It is assumed that digital technology can play an important role and have a positive contribution to sustainable design through an architectural implementation. If successfully implemented, it can potentially respond to a variety of environmental concerns. The assumptions are that digital technology can help to address the problem of water scarcity in Cape Town by enhancing and updating existing technologies to be more effective. Furthermore, it is assumed that this will help to create awareness in finding and embracing alternate sources of energy and water.

1.3.4 Key Questions:

Primary question:

1. How can digital technology and computational design inform an environmentally responsive architecture?

Sub-questions:

2. What water harvesting technologies have been implemented to inform an environmentally responsive architecture?
3. What technologies in a South African context are relevant in order to facilitate an architectural response to the water crisis in Cape Town?

1.4 CONCEPTS AND THEORIES

1.4.1 Introduction

The digital approach to architecture and environmentalism concerns itself with improving various sustainable systems using technological means. This may happen during the design stage and in the final built form or even in both. In many cases, these influences appear in the form of automated systems which allow the building to adapt to various environmental, economic and social conditions.

Digital technology also translates into the use of cutting edge materials and various ways of constructing a built form. Finally, technology is increasingly being integrated into our daily lives in the form of personal computers, cell phones and cars, and is rapidly being introduced into buildings in ways to control things such as ventilation, light and interior temperature.

Theorizing this technological approach to built form is perhaps best understood by looking at environmentally responsive architecture and adaptive architecture, which as the name suggests, allows buildings to adapt to a multitude of conditions. Another important theory to look at is parametricism, which currently may be associated with neo-futurism.

Parametricism, as an architectural style is immediately recognizable due to the abstract, free-form shaped architecture. What separates this style from “regular” modern architecture, is the use of various digital design and form-finding tools which allow the generation of such complex forms. These design tools have the fundamentals required to respond to environmental challenges by being able to simulate conditions. Furthermore, interactive systems and non-static building components can be animated and their behaviours visualized virtually.

1.4.2 Environmentally Responsive Architecture

Environmental architecture is in essence an ecological and aesthetic response to the buildings surroundings, in a harmonious way. Its relationship with architecture has been considered at its earliest with Vitruvius, (fig 2), (Fieldson, 2004).

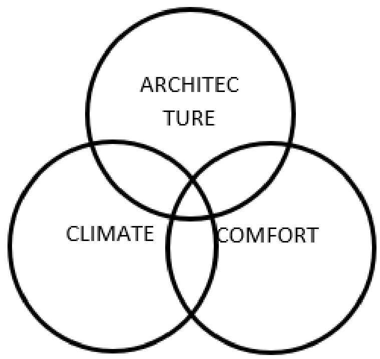


Figure 2:Vitruvius fundamentals to building. Source: Authors own edited from Fieldson, 2004

These three requirements, (fig.2) considered the fundamentals to building, were evident in many vernacular building types which allowed the survival of communities in harsh environments (Fieldson, 2004). Vernacular buildings were made from locally sourced materials and responded to the various seasons, which made them environmentally responsive. Over the years, the influence of fashion and aesthetic resulted in a removal of these values, as "exotic" materials sourced internationally (at a great cost) became popular. A resurgence in vernacular ideologies of making buildings however, has resulted in environmental architecture stemming from anti-industrial revivalists on the one side, and passive design theorists looking for a new model on the other.

Industrialization and increasing energy demands have taken the brunt of environmentalist criticism, but it is widely accepted that the influence of technological advancements led to the improvements of architecture (Fieldson, 2004). The introduction of electricity and internal lighting for example was a considerable factor in how architecture advanced and firmly stamped its intention on ridding the inadequacies of vernacular design (Fieldson, 2004). Olgyay (1963), provided his interpretation of the relationship between architecture and the environment, as seen in figure 3.

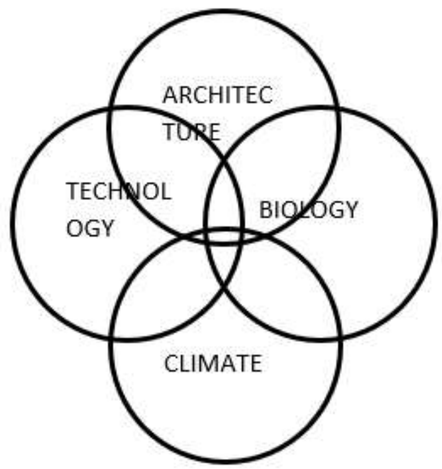


Figure 3: Olgyay's interpretation of the fundamentals to building. Source: Authors own, edited from Fieldson, 2004

This interpretation (fig.3) requires technology to be present in order to create an optimal environment in the built structure. The progression of technology, especially digitally, has the potential for addressing environmentalist concerns in an innovative way.

With technology and industrialization, modernism imprinted itself on everything during the 20th century. It moved away from ornamentalism, embraced simplicity and minimalism and placed an emphasis on structure and materialism. This resulted in rectangular, rigid buildings, cream or white in colour (generally) with static, disorientating layouts. During this period when architecture was largely a proponent of the ecological and economic crisis associated with industrialization, environmental and "green" or "sustainable architecture" was only being practiced by a handful of prominent architects.

The effects of modernisms uncertainties, which was marked by a few styles including Postmodernism, Deconstructivism and Minimalism, are still felt today and should be closed to allow for a new movement which is able to better deal with various complexities. Environmental architecture is in essence an ecological and aesthetic response to its surroundings in a harmonious way. Environmental design encompasses sustainable practices and promotes design strategies which rely on the function of the building as a selective filter for the conditions that determine human comfort (Hawkes et al., 2002).

In the past, humankinds need for defence against nature's elements resulted in architecture which was removed from the environment and damaging to nature itself. In an effort to preserve nature, environmental architecture seeks to impart a more responsible and responsive relationship with the natural environment. In order to reduce negative environmental impacts, Rayner Banham (1969), proposes the idea of 'selective design'. This theory proposes that the environmental process of a building should selectively be organized through form and construction, the intention being to dissolve dependence on mechanical systems of environmental control (Hawkes et al., 2002).

1.4.2.1 Selective vs. exclusive design

With the introduction of power-operated systems for environmental control came significant energy consumption, and a new phase of architecture began. During this time, it was believed that technology provided a solution to most problems. The most effective approach for mechanical systems comes in the fine-tuning stages of an environmentally capable building structure, which adheres to selective environmental principles (Hawkes et al., 2002).

The general characteristics of exclusive vs selective mode buildings are shown in table 1 below.

To determine the relationship between the internal and external environment, the distinction between "exclusive" and "selective" modes to control the environment need to be identified (Bay and Ong, 2006).

Exclusive design (table 1) deals with minimizing the impact of the natural exterior climate, on the interior of a building. Mechanical and electrical systems as well as an enclosed building envelope result in a building which is almost entirely artificial.

Selective design (table 1) is an answer to the separation between exclusive design and nature, and introduces the notion to achieve holistic interior conditions by working with the natural environment.

Table 1: Table demonstrating the differences between exclusive and selective design. Source: Author edited from Olgyay, 1963

EXCLUSIVE MODE	**SELECTIVE MODE**
ENVIRONMENT IS AUTOMATICALLY CONTROLLED AND PREDOMINANTLY ARTIFICIAL	Environment is controlled by a combination of automatic and manual means and a mixture of natural and artificial elements
SHAPE IS COMPACT AND AIMS TO MINIMIZE EXTERNAL AND INTERNAL ENVIRONMENT INTERACTION	Shape is dispersed and aims to maximize the collection of ambient energy
ORIENTATION IS UNIMPORTANT	Orientation is a crucial consideration
FIXED WINDOWS AND RESTRICTED IN SIZE	Windows vary in size and depend on room size, orientation and function. Solar controls are incorporated.
ENERGY COMES PRIMARILY FROM GENERATED SOURCES AND IS USED CONSTANTLY	Energy is primarily ambient supplemented by generated sources when essential. Usage varies seasonally

Olgyay (1963) further then invented the ‘Bioclimatic Chart’, an analytical system which can determine the relationship between climate and comfort for any conditions. Then, a taxonomy of environmentally friendly building forms can initiate an appropriate design. Whilst this might be an effective solution, it does not take into consideration unique environmental situations, and rather than be adaptive, simply remains a reactive solution. By inputting environmental parameters digitally into software, greater customization of form is achieved, unique to the site and its conditions. The building relies on its form, but also responsive automation in order to provide the maximum comfort at all times, whilst keeping energy input low.

1.4.3 Adaptive Architecture

If adaptive architecture were to be defined, a line would have to be drawn between what is adaptable and what is adaptive. Buildings are all adaptable, being able to be altered manually through human intervention (fig 7, 8), whilst adaptive architecture is specifically designed to function automatically as a built-in system within the building to adapt to either the external and internal environments (fig 5.), or the objects and inhabitants within.

Figure 4: Flood house adapts to its immediate environment, rising and falling with the tides of the Thames estuary.
Source: Brotherton Lock, 2016

Figure 5: The new headquarters of the Institute of Environmental Science and Technology and the Institut Català de Paleontologia (ICTA-ICP) in Barcelona is wrapped in a responsive, bioclimatic skin which reduces water consumption up to 90% and energy consumption levels by 62% Source: Inhabitat, 2015.

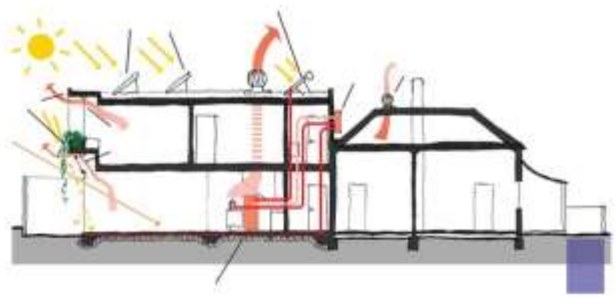


Figure 6: Adaptive design strategies such as automated louvres for ventilation and solar control, as well as adjustable solar panels. Source: Architecture AU 2011

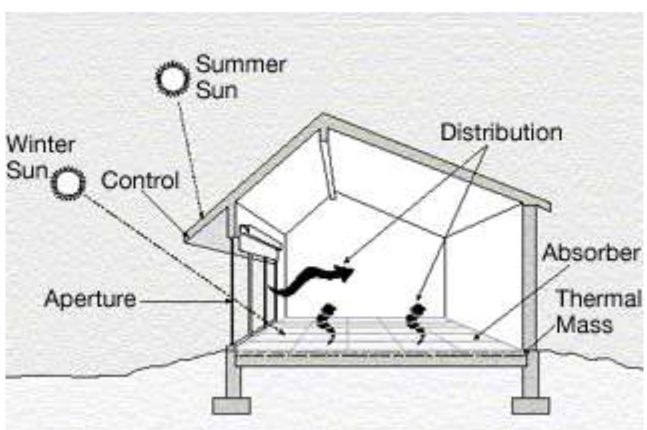


Figure 7: passive design strategies are static in nature and cannot adapt to large variety of environmental conditions. Source: http://www.eere.energy.gov, 2018

Adaptive Architecture is primarily concerned with buildings which are specifically designed to adapt to a changing environment, which is steadily becoming the main concern as sustainable design evolves. According to Frazer (1995), architecture should be a “living, evolving thing.” And Le Corbusier (1923) famously called architecture “machines for living in.” The connection between architecture and living things is very static as buildings are just a rigid, permanent space for human habitation. Adaptive architecture then suggests that the architecture itself may be the managing system of the spaces and interactions within the built form.

The adaptation process can be through automation or by human intervention and often relies on digital technology to function, which is the primary driver of the research (Schnadelbach, 2010). The concept of adaptation has become important to architects who realise that flexibility of a building, whether it be in the buildings envelope or even in interior spaces, can ensure a positive response to events (climate change) which may unfold in an unpredictable way.

Adaptive architecture has a broad range of implementation in architecture as well as other disciplines and is thus difficult to categorize as one specific field. According to Schnadelbach (2010), its range extends from eco-buildings, to art installations, media facades and artificial intelligence. Ultimately, buildings which adopt strategies that allow them to be flexible or dynamic, that is, the ability to change spatial form and function as well as the ability for the buildings envelope to change, take preference over buildings which exists as static objects (Schnadelbach, 2010). The process of having a variety of disciplines on board to create innovative designs to address an adaptive architecture is a great advantage, however may cause perceptions of extreme complexity and disjointedness.

The key driver in environmental adaptiveness lies in the motivation to live more sustainably. Striving to live sustainably has manifested itself in our society to the extent where adaptive elements are used to control interior comfort levels as well as energy expenditures (Schnadelbach, 2010). This may be done in a variety of ways including adaptive surfaces of buildings (adaptive facades externally and digital image projection on internal surfaces), adaptive components and modules (such as re-usable components and adaptive internal partitions), spatial features (transformation of orientation, form and location) and technical systems (sensors, actuators and system software).

Some adaptive elements of internal environments are things such as lighting which can have a profound effect on occupants' mood and wellbeing. (Christoffersen, 2011). Furthermore, airflow and air quality may be optimized according to various environmental parameters such as high C02 levels, and the temperature can be controlled either through full automation or through user assisted automation. There are many strategies for adaptive architecture, such as re-use, mobility etc, the focus for this research is however geared towards automation. How much of the building is automated is dependent on the buildings context. Automation is based on a pre-programmed system designed to respond to a certain time frame of events and can then be introduced to respond to a variety of stimuli. The effects that it has on a building are either visible as an external component such as a façade or envelope, or internally as adjustable spaces.

Adaptive architecture translates to flexibility in a building and is really governed by the buildings context. As discussed, there are various situations in which different adaptive methods can be implemented into the built form. In the case of sustainable and environmental architecture, the adaptations would exist to improve the sustainability of the building by replacing expensive mechanical systems such as air-conditioning with systems which rely on various passive design strategies to ensure thermal regulation, lighting and air quality conditions. The initial cost as well as the running and maintenance cost of adaptive systems are much lower, due to less energy requirements, and can produce much better results.

The impact that this might have on the architecture can range from being very subtle, relying on sensors to control the internal environment, to becoming the primary design strategy which affects the buildings external aesthetics and internal spaces. It is clear, however, that adaptive architecture is an important theory in understanding the implications that digital technology may have on sustainability and environmental architecture.

1.4.4 Parametricism

Coined in 2008 by Patrik Schumacher, Parametricism describes a contemporary, avant-garde style of architecture which is projected as a successor to post-modern architecture. According to Schumacher (2008), the defining characteristics of this style are the parametrically malleable elements across the architectural product (fig.8). The design parameters are all variables, digitally designed and fabricated, which allow the designs to adapt to various complex requirements. Instead of relying on traditional and classic geometries such as rectangles, circles, spheres, cubes and pyramids, Parametricism relies on splines, NURBS, and subdivisions.

Figure 8: Nordpark cable railway, Innsbruck, Austria, Zaha Hadid Architects. Source: www.austinsails.com, 2016

Of the five agendas intended to further the parametric paradigms, parametric responsiveness, which deals with kinetic adaptation, can be most related to environmental design. According to Schumacher (2009, p.17), *'urban and architectural environments possess an inbuilt kinetic capacity that allows those environments to reconfigure and adapt in response to prevalent occupation patterns.'* In essence, the architecture seeks to establish a complex spatial order, using digital scripting to differentiate and correlate all subsystems and elements of a design. This allows all elements of the architecture to be interconnected and to function as an eco-system. Parametricism in its infancy stages concerned itself with various sub-styles such as ‘blobism’ (fig. 10) and ‘foldism’ (fig 9).

Figure 9: The Heydar Aliev Centre by Zaha Hadid Architects illustrates the concept of foldism. Source: Hufton Crow/Zaha Hadid Architects, 2013

Foldism as a style concerned itself with the architecture being one continuous flowing element rather than many joined together, whilst blobism formed architecture that had an organic, blob, or amoeba-shaped form. These sub-styles resulted in architecture of continuous curves made only possible by the use of steel frames clad with polypropylene or fiberglass sheets and were mostly white in colour. This is most problematic in terms of contextualizing place, and thus a new sub-style emerged called Tectonism.

The epoch to a new style of architecture is how Patrik Schumacher (2008) envisions parametricism. The theory describes this new style to consist of malleable elements which are not constrained to classic geometric shapes such as squares, rectangles, etc. It makes use of computational software to manipulate form into any shape imaginable and thus exploring new and alternative ways of interlinking various spaces and functions.

Parametricism can be seen as elitist; only a handful of architects have been able to utilize this style in real buildings. This may be due to the immense cost of engineering and constructing such complex forms, and the multitude of challenges which come with it, not to mention a very open and forward-thinking client. The trade-off is an architecture with a spatial freedom and expression and sculptural qualities not experienced in traditional, non-computational architecture. It is difficult to justify the worth of such an architecture, and thus the focus of parametricism in this research proposal falls onto the digital tools used to design it.

Parametricism makes use of various software such as Grasshopper, Rhinoceros 3d, and even Autodesk Maya (an animation software) to visualize complex shapes and forms. Its real strength lies in the ability for optimization and simulation and architects with the know-how for coding are also able to write specific scripts to solve very specific project related challenges.

Figure 10: The Kunsthaus in Graz, Austria, designed by Archigram founders Peter Cook and Colin Fournier is a blobism landmark. Source: citylab.com, 2017

1.4.4.1 Parametricism in environmental architecture

Whilst Schumacher (2010, p.1) suggests that *"style is virtually the only category through which architecture is observed and recognised. A named style needs to be put forward in order to stake its claim to act in the name of architecture"*, parametrics may actually be a style where aesthetics is a result of environmental, sustainable architecture and not the other way around with predetermined styles of fashion (Schumacher, 2009). Whilst styles in the past created aesthetics by utilizing theory which could be informed by various trends or ideologies, parametrics is entirely pragmatic.

The software used are programmed to search for solutions based on constraints or a set of given parameters. If for example the parameters related to environmental design such as prevailing winds, pressure zones, orientation, natural light, comfort and massing, the software will search for the ideal solution based on the set of constraints, forming iterations of the ideal shapes. The difference between this method of design and traditional, linear design methods, is that the parametric systems function as a spreadsheet, where the values are interdependent of one another. This means that by changing one value, the entire project is modified automatically whilst maintaining pre-determined parameters between areas, functions or elements. This is a very effective way to manage efficiency in projects both small and large and is a method being adopted by many architects.

1.4.4.2 Tectonism

Much like traditional Tectonics, the emphasis is placed on materiality, and materiality of the context. Tectonism concerns itself with material performance and aesthetics (within the dogmas of Parametricism), and seeks to revolutionize traditional methods of utilizing traditional materials through the use of advanced fabrication techniques (fig.12). Essentially, tectonism allows much greater expressive variety. According to Patrik Schumacher (2007, p.113)*, "tectonic articulation is understood as the architectural selection and utilization of technically motivated, engineered forms and details for the sake of a legible articulation that* *aims at an information-rich, communicative spatial morphology, for the sake of visual or tactile communication”*.

Figure 11:ICD/ITKE Stuttgart Research pavilion 2013-2014 represents tectonic articulation through its woven form. Source: designboom, 2013

1.4.5 Parametricism as an informant for adaptive architecture

Parametricism forms the basis for adaptive architecture and computation by generating design solutions through the use of digital design tools such as parametrics, simulation, optimization and generative design. Parametricism also describes a type of art in which the power of computational processing is used to generate complex shape and form development relying on various different design methods (Kolaveric, 2000). The impact that this might have on environmental architecture is rather significant. With the help of computational processing power, the collection of various data such as weather patterns can be synthesized and projected to develop an architectural language which we use to respond to the environment. Furthermore, the use of prediction software has the ability to accurately predict conditions which the designer can account for in the early stages of design.

1.4.5 Conclusion

From an environmental perspective, adaptation plays a crucial role in its preservation, and is important to enhance and protect the natural environment. In order to survive in our ever-changing conditions, mutations need to happen. For the built environment to co-exist with the natural environment, the most important form of adaptation is structural. Parametricism and adaptive architecture are theories which challenge the traditional methods of construction which are rigid and can be adapted, but are not by nature adaptive. These theories further seek to create buildings which will encourage the user to adapt its behaviour. Additionally, in order to improve old systems and to respond to new challenges, new design and construction methods and tools are required. Parametricism and Adaptive Architecture are at the forefront of harnessing cutting-edge technology which has the ability to address the ever-changing, complex nature of our environments.

The following chapter will discuss the research methods and research materials which were used to gather the relevant information. Additionally, it gives a brief explanation why specific methods and materials were used.

1.5 RESEARCH METHODS AND MATERIALS

1.5.1 Research Methods

The approach towards this research is primarily qualitative in nature, making use of primary and secondary data.

The primary qualitative method involved the use of semi-structured interviews with leading authorities and workers in the field of computational design as well as structural and Mechatronic engineers, and environmental architects. Each field sought to collect semi-structured interviews from one and two workers/experts of each field respectively, in total 3 respondents, in order to evaluate similarities and differences. This small sample size ensured that all information gathered could be thoroughly explored. Observational data was also collected from the particular site in its climatic context.

The secondary research method involved the use of literature, particularly relying on relevant and up-to-date material published in books, journals and on the internet. Dissertations as well as precedent studies were used as examples to justify research and were of relevance to the research and the context.

Key information on Fog harvesting in the Western Cape was provided in literature by Jana Olivier, (2002, p.349-359) from the University of South Africa.

Respondents from Zipcord Industries and Modena Design Centres deemed critical for the research were identified. There was one respondent from Zipcord Industries specialising in building automation, and two from Modena Design Centres in Cape Town, one of who specialises in software engineering and applications, and the other respondent in environmental and sustainable design and software.

Key ideas and questions relevant to each particular respondent was provided in order to promote a discussion. The interviews were voice recorded and key elements highlighted for further analysis.

1.5.2 Research Materials

The literature which was analysed gave insight into Adaptive architecture and Digital design methods for enhanced environmental performance. Key ideas and or concepts formed part of the discussion within the semi-structured interviews.

This research was done in order to determine if the relationship between digital design and environmental architecture, specifically with regards to fog water collecting, can produce effective and efficient solutions to the current drought and future water resources in Cape Town.

A case study in Cape Town was done to gain a better understanding of its climatic conditions. The case study looked at the relationship of the topography of Cape Town and the climate, as well as the context of Signal Hill, as it was identified as a suitable site for the research.

Concurrently, literature research was conducted, through the use of published books, journals and online sources. New findings or ideas were presented to the supervisor.

Every effort was made to ensure that the topic of discussion was approached in an unbiased and critical manner. Every effort to ensure academic rigour throughout the research process was made. The research presented was done in an ethical manner and all sources are referenced.

CHAPTER 2.0

2.1 INTRODUCTION

Architectures path towards the digital really first began in the early 1990's when electronic technology began to influence and change almost every aspect of daily life (Carpo, 2013). Whilst electronics were revolutionizing society, architecture, despite having high expectations of being at the forefront of change, was not following suit. This is still true in the AEC industry today and occurs as a result of the uncertainties of being 'first-adopters' of new technologies (Becerik-Gerber, 2011). Furthermore, the lack of training to use new technologies also plays a significant barrier in adopting new methods of design, especially when time-management is crucial for design professionals whose need get things done outweighs learning a new way of doing it. During this time, many Architects assumed that the influence of electronics would transpire to traditional mortar and brick buildings being replaced by designs in virtual reality; codes existing in cyberspace - a radical alternative to the physical existence of a building. The change however, would ultimately develop more slowly. The introduction of digital tools for fabrication and design would not radically change the architecture itself, but would change how physical buildings were made (Carpo, 2013).

To understand how the relationship between environmental architecture and computational architecture is evolving, this chapter will focus on the digital influences of computer software on the design and fabrication of physical buildings. In turn, the various implications this might have on sustainable and environmental architecture will be explored. This will help to understand the relationship between digital technology and environmental architecture.

The various components will be briefly explored in the following sub-chapters:

I. Splines and the roots of computational design
II. Environmentally responsive architecture
III. Digital technology in architecture
IV. Adaptive and Kinetic Facades

V. Fog-water harvesting

VI. Merging Fog-water harvesting and the built environment

2.2 THE ROOTS OF COMPUTATIONAL DESIGN

In order to understand how digital technology became more widespread in architecture and design, it is important to know what specifically was so ground-breaking that it ended up changing the course of the AEC industry. Curves have for many centuries existed in architecture, as is evident in Roman arches, where they were structurally quite important. In ancient Greece, they were used aesthetically, for example, the entasis made columns appear to be bulging under their load (Townsend, 2015). Computers and CAD had already existed for some time, and it was really the introduction of the spline curve which led to digital and computational design as we know it today.

The term spline originally referred to the flexible bows of wood which made up the cross sections of boat hulls. Today, splines can be defined by various definitions, the most basic being a flexible, computational curve (Steenstrup et al., 2016). However, in building design, the spline takes on a geometric definition, where it is most often used in NURBS modelling. NURBS stands for Non-Uniform Rational B-Splines which are mathematical representations of 3-D geometry. This allows any shape from a simple 2-D shape, line or curve to the most complex free-form or surface of a 3-D model to be accurately described (Townsend, 2015). This means that any shape created from NURBS can be manufactured. This is applicable in multiple disciplines, from various engineering components to furniture design and ultimately, architecture.

New technical development of spline modelers in the early 1990's in the form of software were made possible by cheap processing power. This allowed designers to directly manipulate spline curves using control points directly on a screen. This resulted in the development of two lasting design consequences: continuous splines, and parametric functions which would determine whether lines or surfaces are created (Carpo, 2013). This allowed designers the freedom to visually express their ideas without being limited by their design tools.

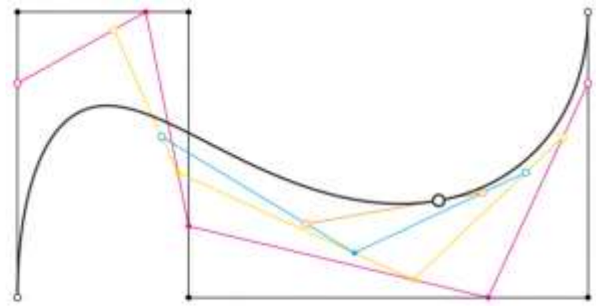


Figure 12: Casteljau's method creates points (black) at proportional distances. Then new points are created to connect these points (pink) and this process is repeated until one final point remains. Source: Sto Editors, 2016

As splines progressed, each geometrical representation expanding on previous ones, greater inclusivity was created. NURBS and subdivision surfacing are allowing the designer to create objects without the traditional constraints of blending different surfaces from various fixed construction geometries (Townsend, 2014). The implications of this? Splines are bringing mankind ever closer to complete mastery of form.

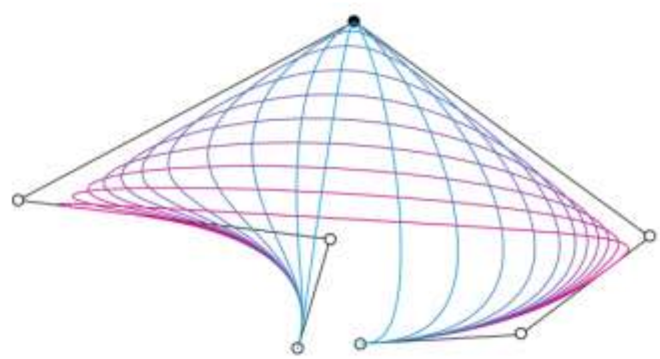


Figure 13: The control points of NURB's can be manipulated individually. Source: Sto Editors, 2016

With mastery of form, the challenges for architects now not only present themselves as needing to master certain software knowledge to create free forms, but rather in how to feasibly bring these forms to life. Architecture and engineering have made advances in this regard by using computation to rationalize irregular forms into discrete components for fabrication and assembly (Townsend, 2014).

2.2.1 Digital design theory

Carpo (2014) argues that the anti-mechanistic ideologies from digital designs earlier times often drew on psychologistic and 'ethereal' notions of cyberspace and immersive environments. Today, the uniqueness and magic of craft have furthered a more spiritual approach to digital tectonics. The emergence theories of the early 2000's were inspired by less spiritual, but more technological ideologies, which still form part of contemporary digital design, particularly in performative design experimentation.

2.2.2 The influence of 3-D Printing

The introduction of 3-D printing in 2013 allowed craft and industry to merge, and complexity in modelling to be realized. Complex surfaces and new materials are able to be created with almost no limits. Many advantages of 3-D printing include being able to discard of moulds, and the elimination of waste materials as experienced in milling, where a shape is cut and the material around it discarded. The true strength of 3-D printing however lies in its ability for custom design, where for example, optimized structural nodes for certain parts of a building can be created.

When thinking about computational architecture and 3-D printing from an environmental perspective, the possibilities for the creation of a building which serves the environment are very conceivable. Kengo Kuma, Japanese architect and professor at the Graduate School of Architecture at the University of Tokyo is one such architect who relies on digital design to produce architectures which serve the environment. He recently produced a spiralling, air-purifying sculpture able to absorb the emissions of up to 90 000 cars produced each year.

Figure 14: “Breath/ng” by Kengo Kuma is a sculpture made from a fabric that filters air. Source: Luke Hayes, 2018

The sculpture aptly named “Breath/ng” is made from a new cutting-edge material which contains a nano-molecule activated core which has the ability to separate and absorb toxic molecules by using the natural flow of air (Novozhilova, 2018). Made from hand folded panels, the entire structure is suspended from carbon rods and fixed in place by 46 unique, 3-D printed joints.

2.3 DIGITAL TECHNOLOGY IN ARCHITECTURE

Since its inception, digital technology has played a major role in Architecture. The connection between architectural design and other disciplines is either direct, for example, a BIM collaboration with a structural engineer, or indirect, as a platform for the translation of data. The combination of this is where the power of technology becomes apparent.

The first part of this chapter will briefly provide a background on the predominant tools used to bridge the connection between technology and design. The second part will focus on the influence which these technologies have on the architectural and design process. The intention is to provide a technical knowledge foundation to understand the many ways in which digital technology may be used as a tool for environmental and architectural design.

2.3.1 The computer

At the core of digital technology lies the computer which through development has provided the ability to process vast amounts of information. The reciprocal effect of this has been an exponential increase in access to information which in turn has demanded an increase in processing ability. The computer has evolved from being a programmable, general-purpose, computation machine, to a machine which can augment the ability of man to deal with complexity (Loveridge, 2012).

In the design professions, computers are more frequently being used to develop new methods of design, through digital scripting and software design, and to manage complexity. In this regard, the power of computers to respond to problems has reached new heights. Processing power in the computers of today has increased one-trillion-fold in the last 50 years. To provide some perspective, Floating Operations Per Second (FLOPS), which measures the performance of a computer, increased from 10 thousand FLOPS in 1956 to over 1 -Quadrillion FLOPS in 2017 for super computers. Commercially available hardware, like Video game consoles, Personal Computers and smartphones manage over 100 Billion FLOPS (Routley, 2017). The processing power of two Nintendo Consoles is the same processing power which powered the Apollo 11 spaceflight. This type of processing power has the ability to solve incredibly complex equations in very little time. The implications this has on Architecture is difficult to assess, especially when we are still at the beginning of the revolution. Climate modelling (GCM) however - the simulation of the interactions between the atmosphere, land surfaces, oceans and ice - can help to project future climates and help architecture respond as efficiently as possible to the environment - but requires an unimaginable amount of processing power.

Advanced software, which acts as a “translator” for mathematical representation of problems, enables the contextualization of output for the user. Devices carrying various types of data can be “plugged in” to the computer’s hardware enabling it to respond to that specific input. What this means essentially, is the ability to solve a magnitude of complex problems given that the required data can be collected. These complex numerical results can then be translated to be understood at a human scale. Furthermore, these tools allow for the modelling of geometrical information under the mathematical rules of geometry.

2.3.1.1 Digital Control

The ability of the computer to exert control is manifested mechanically where precision and timing is required and this ability to control machines makes the computer an invaluable tool. Digital control has extended to almost all common devices such as cell phones and computers and is largely used for physical construction, e.g. robots in automobile manufacturing, robotics and printing. The translation of this to complex modelling can now happen as the computer is able to simulate conditions (Loveridge, 2012). If, for example, a model is encoded with parametric variables, various conditions and contexts can be predicted.

In architectural and environmental design where climatic conditions can be unpredictable, the software is not only able to predict performance more accurately, but also determine the conditions which provide the optimal performance and in turn, the designer is able to provide an optimized solution.

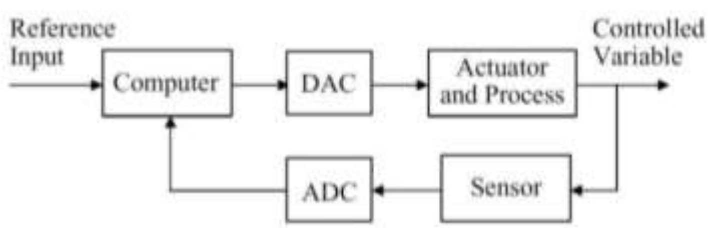


Figure 15: Structure of a digital control system for mechanical machines. Source: Rind, 2016

2.3.1.2 Digital simulation

The precision of simulation systems has dramatically improved over the last decade (Loveridge, 2012). Everyday workstations have the ability to manage basic to intermediate simulation and evaluation, whilst more complex simulations can be accessed via online cloud-based services. Software analysis can provide feedback for design decisions or form finding (fig. 16), but in the case of environmental requirements evaluation data may also be used. The quality of the parameters directly influences the quality of the results, which means the utmost quality needs to be maintained. According to Loveridge (2012), the criteria for evaluation and simulation can be divided into four main objectives:

1. Design optimization
2. Structural, energy, environmental or any other objective performance optimization
3. Safety issues and occupancy performance, and
4. Manufacturing and construction optimization

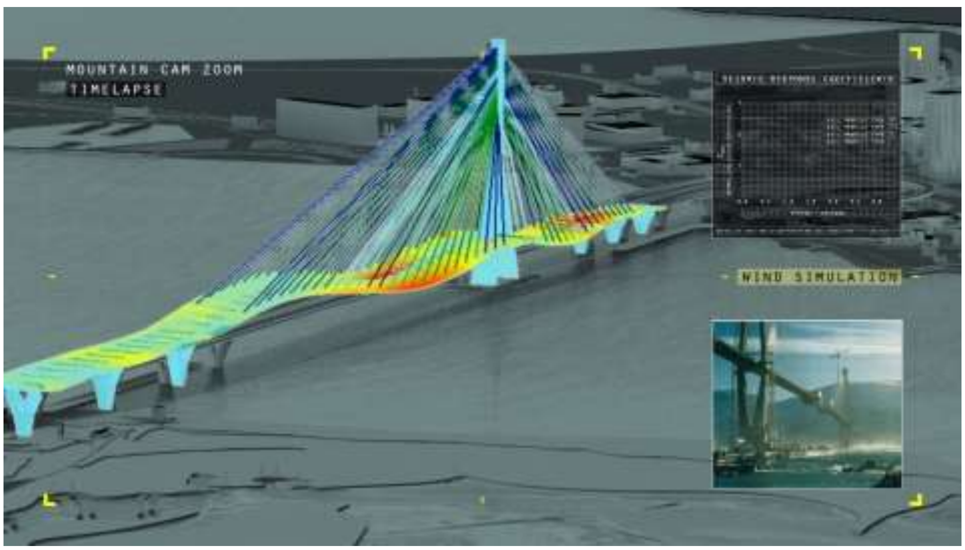


Figure 16: Simulating wind movement over a bridge. Danjiang Bridge, Zaha Hadid Architects. Source: Lynch, 2015

There are various digital evaluation tools such as Grasshopper, Arduino, Rhinoceros 3d, Dynamo and Autodesk's Ecotect, which encompasses environmental simulation and evaluation.

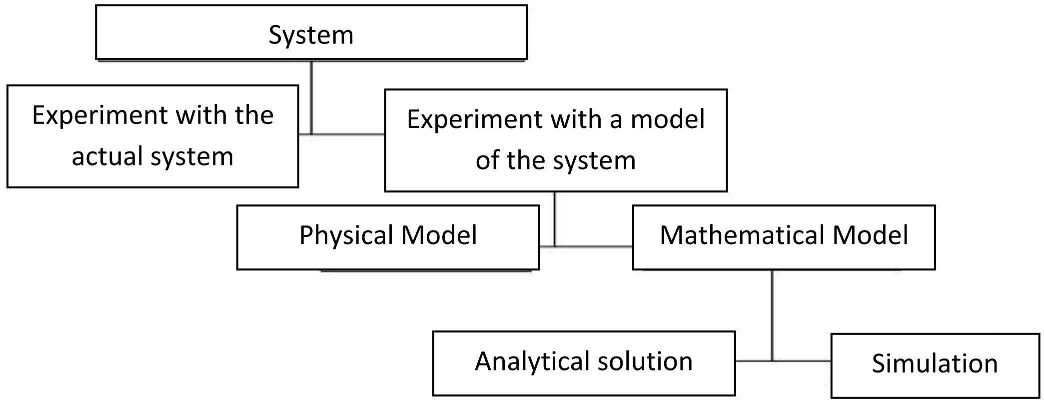


Figure 17: example of how a system may be structured. Source: El-Dabaa,2016

Figure 17 provides a diagram of an approach to an architectural or mechanical system whereby the system can be replicated as a virtual model where it is tested in a variety of ways, evaluated and optimized, and ultimately implemented in the final product.

2.3.1.3 Digital output

In order for the design process to be implemented, instructions need to be provided. These typically appear as plans, sections, elevations and 3D visual representations. CAD software keeps evolving, allowing various other representations such as exploded axonometric, detail views, rendered sections and various other forms of representation. With the introduction of VR (virtual reality) and AR (augmented reality) it is becoming more possible for 3-dimensional digital models to replace traditional 2-D documents.

2.4 DIGITAL FABRICATION AND ITS INFLUENCE ON THE ENVIRONMENT

2.4.1 Introduction

The potential of expanding the limitations of environmental architecture lies in innovative technology such as digital fabrication. Being able to directly fabricate elements from design information is helping many production and design disciplines to transform (Augusti-Juan, Habert, 2017). A study performed by Augusti-Juan and Habert (2017) on environmental design guidelines for digital fabrication indicated that sustainability of architectural projects was dependent on the production of the building materials and the impact of digital fabrication was very similar to the manufacturing process of the materials. The study also showed that environmental impact could be lessened by incorporating additional functions into structural elements using digital fabrication. Furthermore, the study showed that the use of high amounts of highly industrialized materials can be reduced using digital fabrication.

2.4.2 Fabrication methods

The increasing use of manipulating digital geometry has allowed more complex geometry to be formed relatively easily, however, traditional fabrication methods have been optimized for Cartesian and Euclidean geometries and struggle to deal with the complex forms inherent with emerging designs. With the introduction of Computer Numerically Control (CNC) Machines, complex as well as simple geometry can be created, as the machine is controlled by digital control system, which determines the precision, movement and speed of the modulated step motors. The digital control system is directly encoded in the CAD package which issues the instructions, which means the machines do not need to be set up manually.

There are two types of fabrication methods (Loveridge, 2012):

- Additive
- Subtractive

The additive method includes tools such as 3D printing, which creates 3D objects directly from CAD software. Complex forms can be created by creating sections of the model and printing each section layer on top of the other sequentially. There are various materials and methods which are used, based on the requirements of the design.

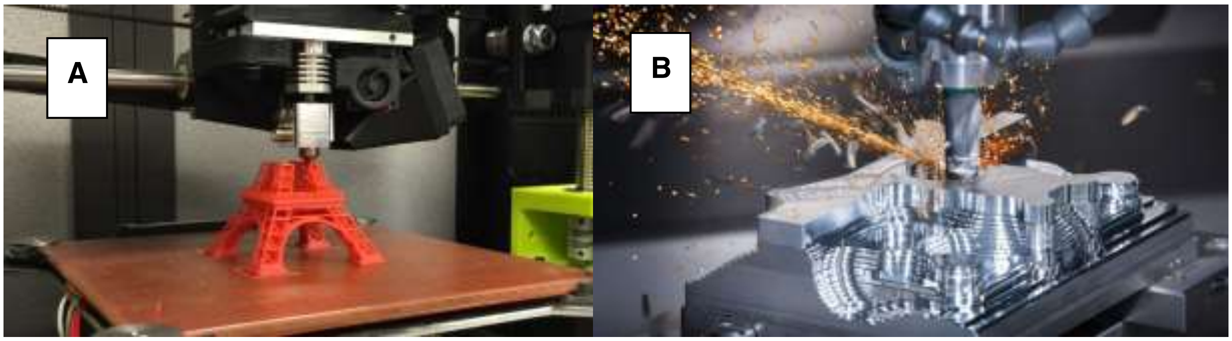


Figure 18: (A) 3D-printer, (B), CNC milling machine. Source: YouTube, 2018

The subtractive method includes the use of milling and CNC machines, which remove material from a block, until the final form is realized, the contemporary equivalent of a marble sculptor chiselling the marble down to the desired form. Other forms of subtractive fabrication include laser cutting 2D shapes and lathing.

The potential for digital fabrication and digital design to converge to create complex forms is being realized across many fields. The challenge however does not lie in the design of complex geometry, but rather in the practical application of these tools, taking into consideration efficiency, budget constraints or any other specific parameters. The benefits that digital control systems and fabrication methods provide, are processing, precision, control and prediction which allows the designer to create something with less waste and which is more expressive, more precise and made with more control (Loveridge, 2012). Furthermore, the possibility of integration of 3D printing with BIM can help increase energy efficiency, be more cost effective and can attribute to better design (Sakin and Kiroglu, 2017).

2.5 CONSTRUCTION MATERIALS

Throughout the years there has been little change in the preferred material choice for building construction. Brick and mortar, steel and glass, wood and stone are still predominantly used in architecture. As technology continues to further influence architecture, designers are looking to various other fields to adopt other materials which may be more suited for a particular function, such as reduced thermal gain, or an alternative material which has less of a negative impact on the environment than traditional materials. The scale of materials in architecture is widening thanks to digital technology and digital production which means architects can begin to design more sustainable and innovative materials. 3D printing is enabling architects to use recycled materials in an innovative way, by mixing recycled plastics and metals into the printing compound. Collaborations with scientists and biologists can also create innovative materials, such as self-healing concrete which "heals itself" by filling cracks with sodium silicate. This can reduce carbon emissions through the prevention of maintenance as well as extending the life of the buildings (O'Keefe, 2017).

2.5.1 Emerging materials

2.5.1.1 Synthetics

Various types of "contemporary" materials have begun to emerge in architecture thanks to the discovery of techniques such as vulcanizing [1] (Loveridge, 2012). Modern plastic was developed using this method, but more importantly the ability to optimize material properties was discovered which has allowed for a vast array of unique materials with explicit properties. These materials are commonly called *synthetics*. Synthetic Lightweight Aggregates (SLAs) are created from recycled mixed plastics and fly ash and are a more environmentally friendly alternative to regular coarse aggregate (Swan, 2009).

[1] A chemical process of hardening rubber or related polymers by heating them with accelerators such as sulphur or equivalent curatives.

Figure 19: Synthetic Lightweight Aggregate can be used for paving and even as a substrate for green roofs. Source: carpetrecovery.org, 2015

2.5.1.2 Composite materials

Composite materials with explicit characteristics are created by combining multiple materials to form heterogenous compositions. These materials are specifically designed to respond to an external stimulus and are most often used in aerospace and automotive design where strength to weight ratio play a crucial role. 3D composites which fall into this category can be created by combining various materials with different compositions (flexible, hard, soft, etc.) which allows for a high performative structure. Cross Laminated Timber (CLT) is a composite material which is being used that is cost-effective, has improved thermal performance, reduced waste, improved design versatility and is also quick to install. Furthermore, the wood used for CLT is sourced from a variety of young trees, and essentially any locally sourced wood can be used (Pierce, 2017).

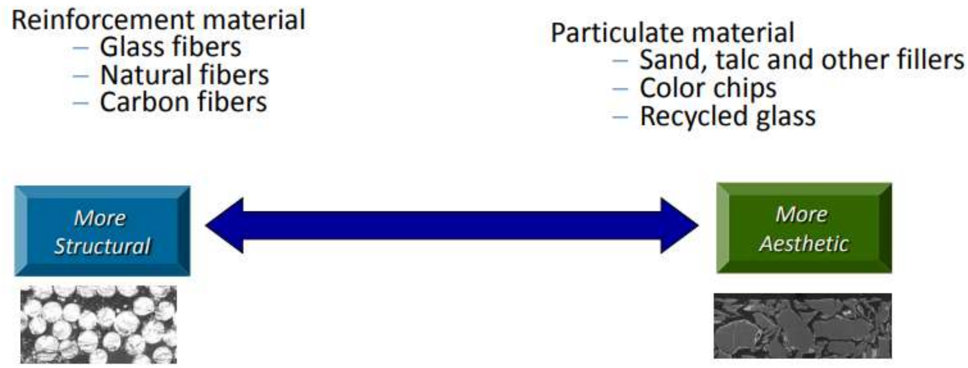


Figure 20: Polymer Matrix Composites are made from a reinforcing material such as wood, and a polymer which binds them together. Source: compositebuild.com, 2013

2.5.1.3 Re-engineered materials

Traditional materials which have had something added or subtracted from them to increase the performative qualities, are also known as *re-engineered* materials. One of the most common examples is ply-wood, which doesn't have the normal weaknesses associated with the directional grain of timber. Other types of re-engineered materials are flexible/bendable glass, fibre reinforced bendable concrete and translucent concrete. Spray Polyurethane Foam (SPF) is a product which consists of two components engineered at a molecular level and is most often used in insulating roofs, walls and below slab-on-grade. Furthermore, when SPF is applied to roofing systems, it increases the wind uplift resistance rating (Harris).

2.5.1.4 Biomaterials

In the natural environment, materials respond to external stimuli by modifying their shape or material properties e.g. plants which rely on sunshine for photosynthesis will point their leaves in the direction of the sun/light source to ensure the maximum amount of coverage exposure. These methods of adaptation have influenced the field of biomimetics which seek to replicate these systems. Advanced materials have been created through biomimetics, such as synthetic spider thread and self-healing concrete (Brownell, 2016). By using digital technologies, these kinds of systems can be incorporated into skins, systems and structures of architecture. Biomaterials can significantly reduce the waste and impact of construction (Becker, Brownell, 2016).

Figure 21: Alulight, a lightweight aluminium foam with extraordinary structural properties. Source: transmaterial.net, 2007

Biomaterials have low-embodied energy, are renewable and make use of waste repurposing. These factors can significantly reduce the impact of construction on the environment.

2.5.2 Smart materials in environmental architecture

According to Philip Ball (1999) Smart materials represent the epitome of a new paradigm of material science whereby structural materials are being replaced by functional ones. Smart materials are designed materials which respond to changes in their environment, such as light, temperature, stress, moisture and pressure (Kamila, 2013). These materials rely on their intrinsic values to perform tasks. Thermochromic glass is an example of a passive smart material, which darkens in response to heat. In response to environmental challenges however, active smart materials are where things get exciting. Active smart materials are part of a system which is controlled by an internal signal as well as external forces (Smith, 2003). An active smart system relies on feedback which allows the system to respond and adapt to a changing environment instead of being controlled passively by external forces (Smith, 2003). Smart materials such as 'shape memory alloys' (SMAS), return to their original shape after deformation. This can happen due to the crystal structures changing when heated. This is incredibly useful for operating ventilation louvres or heating/ventilation diffusers. These types of louvres do not require any energy or electronic systems to operate and provide an alternative to the usually pneumatic or motor-based systems (Arup, 2013). The extensive use of glass in building envelopes and the challenges of solar protection that accompanies it, is a challenge which shape-memory alloys are equipped to respond to. These types of louvres have the potential for shading, increased thermal performance in both hot and cold weather, as well as reduced energy consumption (Arup, 2013).

2.6 CONSTRUCTION TECHNOLOGY

The process of making a building is just as complex as the various stages of design and requires coordination between a multitude of specific fields outside of architecture. This process is managed more efficiently through the use of Building Information Modelling (BIM)[2], a digital method of collaboration between consultants. Arguably the most powerful feature of BIM is the visualization of workflow and with it the ability to see and respond impromptu to problems (fig.19). Digital tools have the ability to save time through efficiencies in production, which in the construction industry equates to money. Construction technology can play a major part in environmental architecture and sustainability and can be categorized into three main types which will be discussed below.

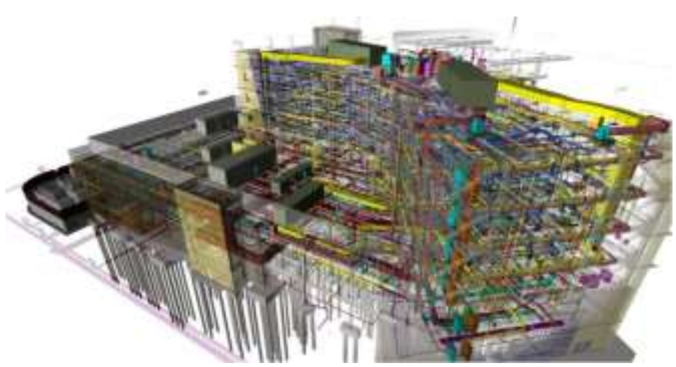


Figure 22: The 3D Modelling of BIM encourages teamwork between the various consultants to ensure that all systems have the proper location and clearance from other systems. Source: http://detailingexpress.co.za, 2015

[2] Specifically, the use of virtual 3D Models

2.6.1 Assembly

When something is assembled, it means that various parts are put together in a logical process defined by instructions. In turn, efficiency is maximized. In assembly, the complexity of the parts and the order in which they are assembled are the main parameters which need to be solved. Digital tools are able to solve these issues before they occur on site through customized, unique connections which can only be joined in one possible way, and through more common methods of specialized labelling. Thus, the design of assembly in conjunction with digital tools can have a pronounced effect on the efficiency and speed of construction, as well as the quality of the project (Loveridge, 2012). Off-site production is seen as a viable method to increase sustainability by manufacturing most of the operations and on-site works in a controlled environment. This greatly increases production efficiency whilst having less impact on the environment (Zhai, et.al, 2013).

2.6.2 Robotics

Robotics has played major roles in industrial manufacturing, the automotive and aero-space industries and through the trickle-down effect is slowly being introduced into the architecture profession. In a society where terms such as “hand-crafted and “unique” are trending, the appeal of robotics and the impression that products created by them are mass produced and not of high quality are some of the reasons why robotics has taken so long to appear in architecture. Of course, robotics does not represent the industrial machines used to mass produce consumer products. The use of robotics on a construction site still has limited use, mainly due to it relying on positioning information. A robot needs to operate from a known position or point (often a fixed position) from which to execute tasks from. The adaptability of programming as well as the movement flexibility are tools which provide certain capabilities too good to overlook by the avant-garde architect. The flexibility of robotics allows it to be used as both a tool for mass production, as well as a tool for mass customization. Robots are becoming more economically feasible thanks to evolving software and flexible working configurations.

Figure 23: In-situ fabricator, NCCR Digital Fabrication. Source: robohub.org, 2015

2.6.2.1 Flight assembled Architecture

Architecture created by flying robots has been envisioned in various screen productions and ultimately culminated in the production of “Flight Assembled Architecture”, an installation by Gramazio & Kohler and Raffaelo D’Andrea at the Fonds Regional d'Art Contemporain (Regional Contemporary Art Fund) du Centre in Orléans, France. This project is a combination of biomimicry in the form of swarming algorithms with networked, block carrying drones. This type of technology is an answer to the site constraints which apply to regular robots. Flying machines do not have the same constraints and have a much larger space in which to operate in. This makes it feasible for the machines to work at a 1:1 scale opening up a new framework for architects to realize their designs (Augugliaro *et al*., 2014).

Figure 24: “Flight Assembled Architecture”, Gramazio et.al,
FRAC Centre, Orléans, France. Source: http://editions-hyx.com, 2011

2.6.3 Design precision

Whilst the precision of digital technology is unquestionably one of its biggest traits, the compatibility of tolerances on a construction site can be problematic. Unpredictable conditions on site may cause pieces which have been machined with low tolerances to not have the flexibility to fit together during site irregularities, whilst too high of a tolerance may equate to poor construction. Ultimately it is the responsibility of the Architect and the construction supervisors to determine the correct tolerances, which can be helped with the use of BIM, simulation and digital modelling.

2.6.3.1 Pre-fabrication

The manufacture of sections, components or even entire projects in an industrial setting, then packaged and transported to site for quick assembly on site is called pre-fabrication. The advantages in this method include being able to produce each component in all of its complexity which can minimize complications on-site as well as reduce cost due to the speed of assembly. As mentioned above however, complications can arise due to unpredictable on-site tolerances which may result in a pre-fabricated component not fitting (Loveridge, 2012).

2.7 Conclusion

Digital technology covers a wide spectrum of uses within the built environment. Some of these are still being developed, such as robotic construction techniques and new, composite materials. It is clear however that the strength lies in the power of the computer.

Being able to manipulate form so easily has opened the doors for innovation in almost every aspect of design. With computing power constantly evolving, complex problems can be solved more quickly and efficiently than ever before. Additionally, the scientific input in the creation of stronger, more sustainable and biodegradable materials is largely thanks to the ability to shared data between many different professional fields simultaneously.

Chapter 3 will discuss how these types of technologies may directly impact environmental architecture with regards to water use, energy harvesting, lighting and building envelopes, before analysing specific water harvesting techniques and the technology that is currently used.

3.0 INNOVATIONS IN ENVIRONMENTAL ARCHITECTURE

3.1.1 Introduction

In environmental and sustainable design, digital innovation is the process of utilizing digital tools to improve architectural design and to innovate sustainable solutions of building projects. These new design processes refer to methods which are computationally mediated rather than conventional paper-based methods (Ramilo, Embi, 2015). A building's exterior envelope in many cases represents the architecture within and it is also the buildings envelope which controls the interior climate. This is the reason why many innovations in architecture have been around the buildings envelope. Being able to control the interior climate using the building's façade is an extremely effective way to create an environmental responsive architecture. Other innovations in architecture have occurred in a variety of ways including in the design tools, materials, visualizations, lighting, water, and energy and thermal properties.

3.1.2 Water use

Water use varies between different types of buildings; however, the majority of water usage is still attributed to bathrooms and toilets. To reduce the amount of water used in bathrooms, many innovations have happened in plumbing fixtures to reduce the amount of water needed to flush a toilet or the amount of water being released through a showerhead.

Structural water saving features, and designs which utilize rainwater to substitute their water needs have a direct impact on the architectural design. These innovations often rely on roofs and gutter systems to catch and store rainwater.

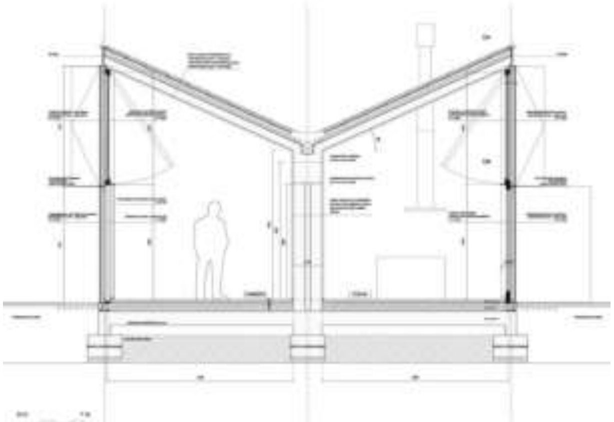


Figure 25: House in the Countryside by Herreros Arquitectos in Spain.
Source: Archdaily, 2008

House in the countryside (fig.24) presents a modern, updated take on an innovative design strategy to maximise the amount of rainwater which can be collected, by utilizing a butterfly style roof which encourages all of the rain which falls on the roof to be directed into one catchment area.

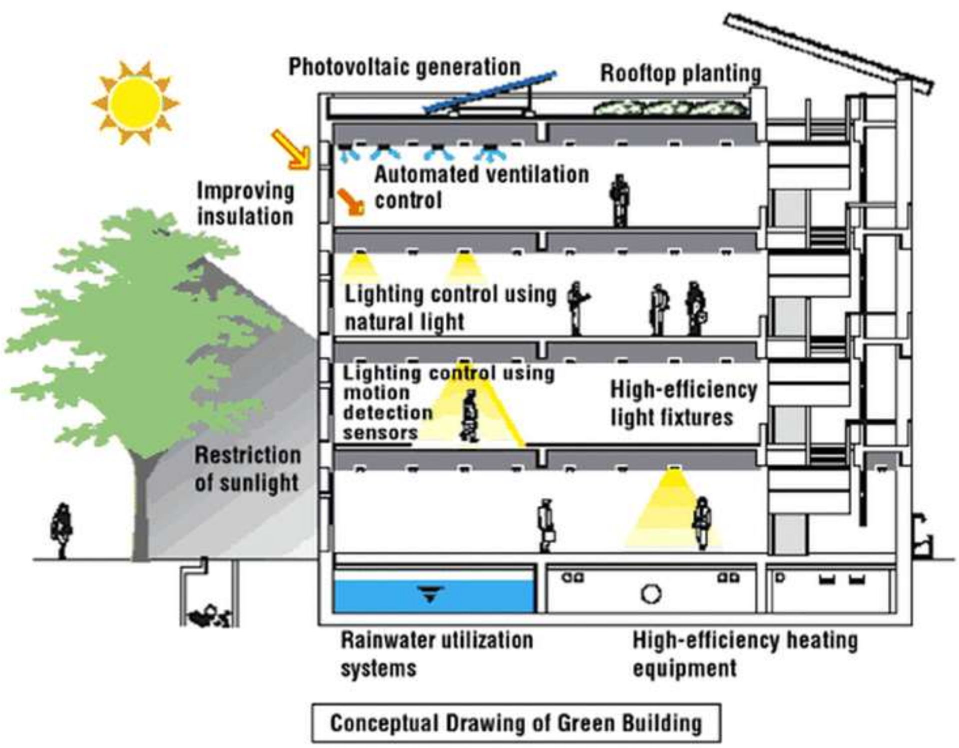


Figure 26: Innovative technologies in buildings. Source: http://www.e2econsulting.co.za, 2017

Figure 25 depicts various innovative solutions to deal with challenges involving light, water, energy and insulation in buildings.

3.1.3 Integrated energy harvesting

Innovations in building materials allow buildings to convert energy from the sun into electricity. Photovoltaic cells which convert energy from the sun into electricity are already being used worldwide. Building Integrated Photovoltaics (BIPV) form part of the architecture and can be integrated into walls and roofs. A company has developed a product called Solar Squared, which is similar to a normal glass block. These blocks however, have smart optics which allows rays from the sun to focus onto small solar cells. This enhances the overall energy generated by each individual cell. The electricity that is generated can be used to power the building or it can be stored (Phys.org, University of Exeter, 2017).

Figure 27: Solar Squared block can convert the sun's energy into usable electricity. Source: Solar Squared, phys.org, 2017

3.1.4 Artificial Lighting

Light is considered to be one of the most important features in architecture as it has a great influence in how we perceive spaces and objects. Filling a building with natural light is a big priority for sustainable architecture in order to reduce the amount of artificial light needed. Artificial light has however been greatly improved on, both in energy consumption, as well as quality of the light itself. Light Emitting Diodes (LED's) are the most sustainable light choice currently available (Ellis, et al., 2013). LED's do not contain any harmful chemicals and have a long lifespan of up to 20 years or more. Furthermore, they emit much less heat than other light sources and use much less energy than other types of light bulbs. LED's have revolutionized the way spaces can be illuminated by being able to integrate them into architectural components, thanks in part to their low heat-emitting properties.

3.1.5 Adaptive and Kinetic Facades

Excess solar gain in hot dry climates can often result in high energy consumption due to the use of mechanical cooling systems, such as air-conditioning, as well as cause occupant discomfort. Sun control is an integral aspect in energy efficient building design strategies and digital, computational tools allow the possibility of accurately simulating thermal and solar conditions to facilitate the design of a responsive shading system.

Adaptive and kinetic facades essentially allow parts of a buildings envelope to move in response to environmental conditions. Of these facades, movable shading devices have become the most widely used, reportedly being able to decrease the load of energy on a building (Lee, et al., 2016).

Recently, kinetic facades have taken on the role as an environmental mediator. The strength of kinetic facades lies in its adaptability; energy requirements can be lowered if the façade can response to diurnal changes in temperatures (Alotaibi, 2015). Furthermore, the quality of indoor daylighting can be greatly improved with the use of kinetic shading devices as opposed to static shading systems (Sharaidin,2014). It is however important to note that interaction between the occupant and the shading system is necessary to ensure occupant satisfaction.

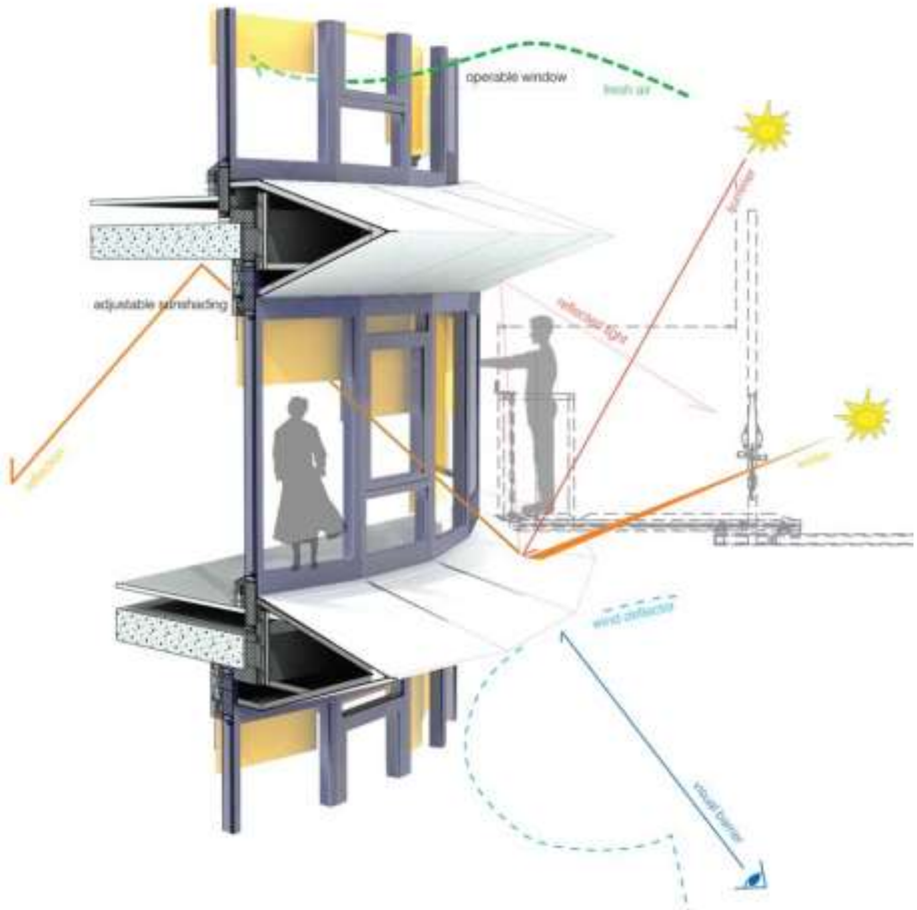


Figure 28: Detail of a Kinetic facade and its adaptations to various external environmental factors.
Source: hoaarchitect.wordpress.com, 2011

In order to ensure that a kinetic façade performs well, the design and evaluation needs to be extensive. Kinetic facades are complex systems which involve three-dimensional interactive elements which are constantly changing (Sharaidin,2014). The strength of digital simulations allows designers to overcome many limitations and is a very cost-effective and efficient way of testing. Facades and envelopes can be multifunctional, and have been used in buildings to harvest wind energy, water, and solar energy.

The Sony City Osaki Building in Tokyo provides an innovative use for the buildings envelope, by using specialized louvres made from ceramic to funnel rainwater through the system, which acts like a sprinkler and cools the air of the surrounding building (materialdistrict, 2016). Traditional Japanese techniques for cooling air such as Uchimizu, a water spraying technique, and bamboo shading screens are what inspired the ‘BioSkin’ concept.

Figure 29: Sony City Osaki Building utilizes a BioSkin to cool the surrounding air. Source: materialdistrict.com, 2016

Rainwater is funnelled into the pipes on the façade (fig. 28) where it penetrates outwards and evaporates. The evaporating water then cools the surrounding air by 2 ˚C. The excess water is released into the ground below.

On the Southern side of the façade, solar panels are used as shading devices, helping to power the building whilst keeping it cool.

Building envelopes and facades can effectively contribute to a buildings performance and efficiency by utilizing the environment in innovative ways. The below chapters will introduce the concept of fog water harvesting and its implementation in architecture.

3.2 TECHNOLOGY IN FOG WATER HARVESTING

3.2.1 Introduction

Fog water harvesting has been used for centuries, as noted by the remains of historic structures in different countries such as the Middle East, North Africa, North America, India and China (Diehl, 2010). Most of the methods used are known as fog drip, which forms when atmospheric water vapor passes over objects allowing tiny droplets of water to coalesce into bigger drops, which eventually drip down and can be collected (Qadir et al., 2018). In ancient Palestine, honeycombed walls were built surrounding plants and vines so they could have immediate access to the precipitation from mist and dew (Olivier, 2002). Ancient Greeks were reportedly able to supply the entire city of Theodosia (Ukraine, Feodosia, Crimea) with water collected from fog (Nikolayev et al., 1995). These ancient methods of collecting fog usually consisted of mounds made of earth and stones which would allow water to trickle down the centre (Diehl, 2010; Olivier, 2002; Olivier, 2004).

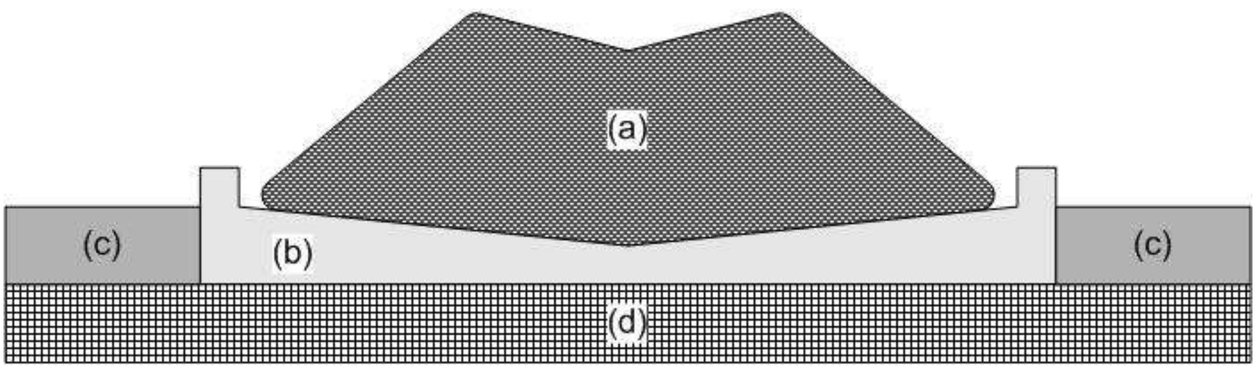


Figure 30: Zibold dew condenser a) beach pebble cone, 20m diameter at base and 8m diameter on top b) concrete bowl from which a pipe leads to a point of collection c) ground level d) limestone base Source: Cornelius, 2009

Figure 31: Zibold condenser in 1912. Source: Tougarinov, 1931

Figures 29 and 30 depict Zibold collectors, which had a 20m diameter at the base and 8m diameter on top, and was named after the engineer and forester. Zibold built the condenser to prove that dew could be collected in it, and to prove that the mounds found in Theodosia could have been dew condensers (Diehl, 2010).

3.2.2 Fog collection technology

Fog collection technology has since then advanced and become more effective, however, the basic principles remain the same; Fog passes over or through an object on which it condenses, the fog droplets coalesce to form larger drops, which through the pull of gravity drip down into a gutter and get stored in a reservoir. The appeal of fog-water harvesting lies in the simplicity of the apparatus, and the cost to performance value. Standard Fog collectors (SFC), the most widely used collectors, are cheap to manufacture, easy to install, and produce good results, and cost can be further minimized by the use of local materials and labour (Molina, Escobar, 2008).

Traditional methods of harvesting fog water involve the use of a simple apparatus, consisting of a mesh collecting surface (commonly made from a carbon impregnated polypropylene mesh) strung between two poles (like a volleyball net) and planted in the ground in an area containing frequent fog. Whilst effective, this method is not adaptable to extreme wind conditions, with high wind speeds damaging the apparatus; A higher fog density is situated higher up in the stratosphere which means that the collecting surface needs to be in a higher altitude or suspended between long poles to increase effectiveness and is thus easily destroyed. The Van Schoor fog water collector was a prototype developed in 1993 which was designed to withstand gale force winds by fixing the aluminium frame to concrete foundations (Olivier, 2002). Whilst effective at low heights, collectors which stood higher than 2 meters were unstable and required steel guide cables. Furthermore, the gutters and collecting surfaces are often blocked with sand and other debris which pollutes the water and greatly decreases the amount of water collected (Olivier, 2002). The amount of water collected largely depends on the direction of the wind, which means if the wind is not blowing directly into the collecting surface then very little water will be produced (Schemenauer, et al.,1994). This low-tech approach has been proven effective in good to near-perfect conditions, however there are too many variables which ensure it does not operate at its full potential. There are regular requirements of ensuring the collecting surface is clean and the gutters are unobstructed, height restrictions due to material strength and design, repairs to damaged apparatus as well as the inability of the system to respond to wind direction are all factors which might be addressed with certain technological implementations.

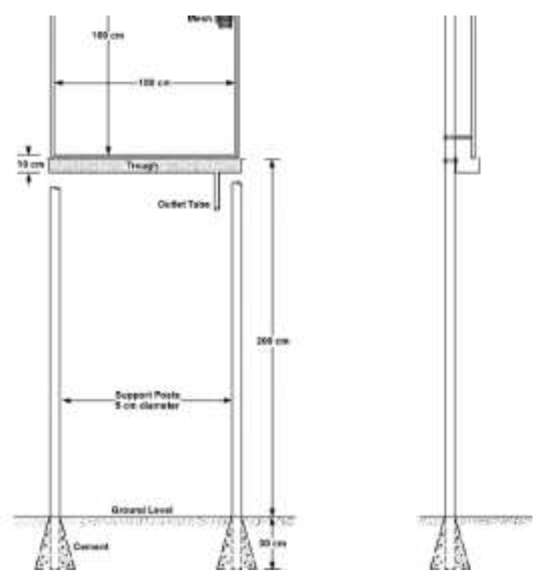


Figure 32: standard fog collector (SFC) Source: Schemenauer and Cereceda, 1994

Figure 33: Standard fog collectors in the Atacama Desert, Chile, consisting of Raschel nets spanned between two upright posts and a horizontal gutter, and anchored with cables. Source: quemaoviejo.com

Digital technologies impact in fog water harvesting can be seen in updated and improved versions of SFCs.

Figure 34: The DropNet Fog Collector can collect between 10-20L of water per day, Source: inhabitat.com, 2010

The DropNet Fog Collector (fig. 29) designed by Imke Hoehler, is a versatile modern take on traditional fog collectors. Its tent-like structure makes transport easy, and is extremely simple to set up (Paul, 2010). The tent-like structure could easily be assembled by local communities in a variety of terrains and the improved strength of the synthetic materials reduce the amount of maintenance that the system requires.

Further advances in Fog collection are made possible by GIS, regional, historical and local climatological data. Using interpolation methods, Garcia and Zarraluqui (2008) created a fog database which is capable of generating fog prediction maps. Furthermore, the expanding use of computer modelling and simulation can show how fog can be affected by external conditions, such as agricultural irrigation. Models demonstrated that the humidity caused by irrigation can be related to the formation of fog (Diehl, 2009).

Storage tanks play an important part in fog water collection. After water has been collected, it requires a place to be stored. Above ground storage tanks and underground storage tanks are two main types. Of these, the above ground can be ponds or reservoirs whilst underground storage tanks may include aquifiers and cisterns (Prinz, 2002). The quality of lightweight storage tanks has thanks to technology greatly improved over the years, with new tanks being made from various eco-friendly synthetic materials. These tanks are more resistant to ultraviolet rays, are lighter, and some even have built-in filtering systems. This ensures that the water is kept purer and extends the life of the fog harvesting system. Furthermore, these types of tanks are disposable and recyclable (Matos, 2013).

Digital technologies power is evident again in its direct mediating effect on design, as well as its ability to analyse data and create accurate models for the prediction of fog in various locations.

3.2.3 Techniques used for harvesting water

Harvesting water from fog is best achieved using three main techniques:

1. Drop coalescence
2. Chemical absorption and desorption processes on devices
3. Condensation on cold surfaces

Of these techniques, two main groups emerge: large fog collectors (LFC) and standard fog collectors (SFC). The typical sizes for these are 1x1m for SFC's with LFC's having no specified size, generally being much larger and rectangular in shape to compensate for aerodynamic purposes (Caldas et al.,2018). Plastic gutters collect water droplets which have condensed on the nets and are pulled down by gravity, and directed into a storage tank, usually located on the ground. Polypropylene Raschel mesh is the current material of choice (Klemm et al.,2012) however, other materials have also been successfully used. Researchers at MIT are currently experimenting with new materials which have so far produced excellent results. The material is made from stainless steel filaments, is roughly quadruple the size of a human hair, and densely spaced, according to the research team. Furthermore, the mesh is coated in a solution which decreases contact-angle hysteresis which allows droplets to slide more easily into the collecting gutter before they can be blown off the surface by wind (Buczynski, 2015).

Chemical collectors work through absorption and desorption of a desiccant installed on a specifically engineered system (Gandhidasan and Abualhamayel, 1996). The system is rectangular and is made of a heat-insulating layer at the bottom and a cover on top which is made of glass. Separated by a 450mm air gap, the device functions based on two phases: During the night, water is collected by harvesting fog and during the day the water is distillated using solar radiation. The desiccant used is generally calcium chloride due to its low toxicity and cost, its high thermal conductivity as well as its high resistance to thermal degradation (Caldas et al.,2018). This desiccant is applied to the surface at night to enhance fog capturing by providing an absorbent film. The tilted system allows the condensed water from the glass to drip to one side where it is collected. The temperature differential between the two surfaces allows water in the air gap to evaporate and condense on the inside glass face (Gad, Hamed, El-Sharkawy,2001).

Radiative condensers (fig. 34) take advantage of highly emissive properties of the material surface to allow the surface to cool quickly during the night, enhancing its dew collecting potential. The materials used require a high infrared emissivity to be effective and many variants of foil are used for this purpose. To enhance emissivity additives such as titanium dioxide and barium sulphate are added (Caldas et al.,2018).

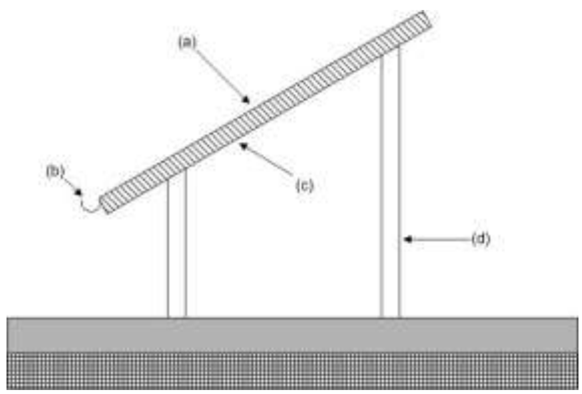


Figure 35: radiative condenser. a) condensing surface, b) collecting gutter, c) insulation, d) stand. Source: https://upload.wikimedia.org, 2016

To determine which of these methods is most suitable for building façade integration, the main technical features are compared and analysed. The collector type, location, relative humidity (RH) ranges and the yield were compared. According to the data, SFC and LFC mesh collectors perform much better than the other systems with consistently higher yields (Caldas et al.,2018).

Climatic factors do play a large role in the systems effectiveness with relative humidity and temperature and wind speed and direction affecting the results (Fessehaye et al.,2014; Caldas et al.,2018). Of the climatic factors, wind is the most relevant as it directly affects how much humid air is passed through the system. This needs to be maximized in order to achieve the best yields possible.

3.2.4 Merging Fog-Water Harvesting and The Built Environment

Combining fog-water harvesting and the built environment through the use of building envelopes and facades is a concept intended to improve both the function of the fog-water harvesting system, as well as to adapt this system into an urban setting. Furthermore, the potential for decreased thermal and solar gain for better internal comfort utilizing fog-water harvesting systems as shading devices is explored. The usage of fog-water harvesting on building facades may also allow the water production to be available straight from the source, ensuring significant savings in the infrastructural system which is used.

3.2.5 Integrating fog harvesting on building facades

Providing an additional function to a building's façade such as fog water harvesting as well as adaptive shading and lighting, provides an innovative solution to a host of sustainability challenges. The most effective fog-harvesting systems as indicated above are the SFC and LFC, which are relatively simple in nature and easily attached to buildings via various types of sub-frames. The low-cost of SFC (around 150$ the cost for the materials for an entire setup) is an aspect which may influence design choices. Considering the complexity of the chemical and radiative condensers and the cost to yield ratio, these types of systems would not be ideal to implement in building design.

One of the most important things to consider is the maintenance and risk of failure in these systems, and pairing it with a kinetic system may impose an even higher risk and maintenance requirements. Mesh collectors have had maintenance issues, specifically in areas affected by strong winds which can tear the fabrics, however, collectors have been designed specifically to be more resistant to wind loads (Hamed, 2001).

The complexity of chemical condensers can result in ultimate system failure with the malfunctioning of just one part, which ultimately renders them an unsuitable system for façade use. Radiative condensers also are susceptible to damage due to high wind loads, reporting high incidences of foil breakage. The cost to replace foil is however much higher than the cost to replace mesh.

Moving parts in kinetic systems are also susceptible to damage from wind loads, requiring careful, precise engineering. Corrosive environments such as coastal areas may also lead to the seizure of mechanisms requiring the intelligent use of corrosive resistant materials. The complexity of the façade should be very carefully balanced in order to reduce potential failures and having a manual overriding system may be necessary to ensure the building continues to operate effectively. The adaptability of the façade should also be considered, as replacing such a system to cater for a new function can be very costly.

Large surface areas of building envelopes may be successfully exploited to harvest water considering the number of successful projects of harvesting fog water. The simple and affordable LFC and RFC's with their potential for high yields from 3-8l/sqm per day, have a lot of potential.

3.2.6 Biomimicry in Fog-harvesting

Nature has the most efficient designs, adapted over millions of years, to cope with the stresses of the multitude of climatic factors. Leaves and insects have the most efficient water harvesting systems on the planet, which have adapted in areas where water is very scarce. These systems often make use of the moisture found in air and have allowed these species to survive in some of the driest regions in the world (Martorell and Ezcurra, 2002).

The Namib desert beetle survives the harsh conditions of the Namibian desert by harvesting the little moisture that is present in the air with its body (Naidu, Hattingh, 1988). Tiny grooves and bumps on its shell help condense and direct water towards the beetle's mouth. Hydrophilic and hydrophobic zones on the shell help to increase the water harvesting efficiency.

Figure 37: The Namib Desert Beetle collects and drinks dew which has formed on its body.
Source: asknature.org/strategy/water-vapor-harvesting, 2017

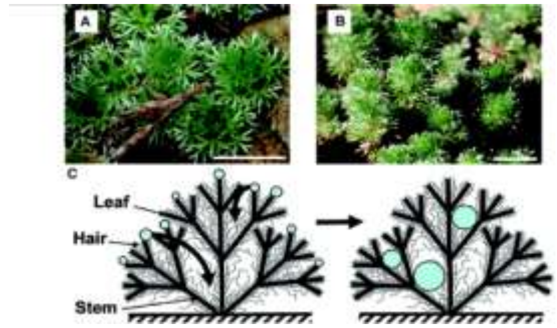


Figure 36: a) dry plant; b) wet plant; c) the Cotulla fallax hierarchical water collection system.
Source: Andrews et al.,2011

Various processes to optimize the process of collecting fog-water haven their roots in mimicking nature. The different approaches of doing this include the creation of certain materials which replicate the conditions found on plants or insects like the Namib beetle (Caldas et al.,2018). Nano-textured materials which promote condensation through the cone and pillar-like surface for enhanced yield are being explored. These patterns can be printed onto surfaces of panels, such as kinetic shading systems, and even onto regular façade panels. According to Wang (2015), this can increase the drop accumulation as well as the direction of collected liquid. Other technologies which mimic nature are still being developed, such as plate-based collectors which take inspiration from feeding mechanisms of birds who collect water on their beaks (Heng, Luo, 2014).

The Cotula Fallax is an indigenous plant to the Western Cape in South Africa and is classified as a fynbos species. This plant has a complex microstructure on its leaves which allows it to generate small drops of water (Andrews et al.,2011).

In an attempt to tune the mesh material, McKinley studied and modelled different types of meshes and how condensation formed on them. The results led to increased efficiency through the optimization of the geometry of the fibres, the radius of them, and the size of the holes between. The yield with this optimized mesh increased from the maximum of 6L/sqm to up to 10L/sqm, an increase of 67% (Park et al.,2013). These mesh systems are highly dependable on wind to drive the fog through them and are thus limited for use on cliffsides or hills. Biological or nano-textured materials on the other hand do not require the presence of wind and are thus suitable for use in a variety of climatic conditions, although the presence of wind would increase their already extraordinary ability to collect fog (Parker & Lawrence, 2001).

The strength of Nanotechnology lies in its capability of nanoscale patterning to mimic a multitude of biological structures and has proven to be extremely effective at collecting water from fog. There is a caveat however; nanotechnology processes currently are expensive and simply not cost-effective to be used on a large scale such as building envelopes.

3.2.7 Conclusions

Digital technology has become ubiquitous in our lives, manifesting itself in every means possible. Whilst the well-known "The Terminator" franchise forebodes the day that "Skynet" (its net-based, superintelligence system) becomes self-aware and attempts to erase the human race might be unlikely, the prospect exists for digital technology to become indistinguishable between everyday life. From what has been observed historically however, technologies influences in architecture have always been subtle and tentative. In a discipline where there is reluctance to try new things, digital technologies most influential traits have been in the management, design and procurement stages of projects.

Where digital technology has seemingly had a big impact on is the buildings envelope, as one of the most important ways of saving energy in a building is through its façade (Ahmed et al., 2015). The envelope and facades of buildings directly control the interior climate of the building, and therefore, innovative strategies to enhance the interaction between the external and internal have been experimented with in many ways. Building envelopes now are not perceived as static shells to keep bad weather out, but rather as adaptable mechanisms which have the ability to utilize the environment, in order to enhance the buildings functions — whether its harvesting wind, water, or regulating temperature and light.

The research uncovered some key findings about digital technology and fog harvesting, and the integration of both of these into a building. It demonstrated that fog water harvesting can be very effective under the right conditions, and that the influence of digital technology was able to enhance the effectiveness of the standard fog harvesting systems to produce higher yields. Some technologies, such as nanotechnology, are able to produce excellent yield results, however the high cost to manufacture the material renders it ineffective.

As stated in the delimitation, the focus of the research is the impact that digital technology may have on sustainable and environmental architecture. The literature has indicated that fog harvesting technology can greatly benefit from the influence of digital technology, and that it is viable in implementing into buildings. The following chapter will explore Fog water harvesting around the world and then in Namibia, before leading into a case study for Cape Town.

The following chapter will look at Fog-water harvesting around the world in order to assess where it commonly takes place, what factors determine why it is a water harvesting technique that is used, the conditions required for it to be successful and how successful this alternative method of producing water really is. Chapter 4 then provides a case study of fog-water harvesting in the Western Cape and Cape Town.

3.3 FOG-WATER HARVESTING AROUND THE WORLD

3.3.1 Introduction

Geographic features, such as mountains, affect fog (Garcia, Zarraluqui, 2008). Additionally, the amount of water that can be collected from fog depends on the local topographical and climatological conditions (Schemenauer et al., 1988). Urban development, proximity to the coast, wind patterns and temperature all affect the frequency of fog occurrences (Diehl, 2009; Teixera, Goncalves et al., 2008).

The table below provided by Diehl (2009), shows the altitude of ideal fog collection sites around the world. According to the United Nations Environment Programme (1998), (UNEP), optimal fog collection happens at altitudes of between 400-1200m. These altitudes are optimal conditions and it is still possible to harvest fog water at lower heights, although the water yield might be impacted.

Table 2: Altitude of Fog collection Sites. Source: Diehl, 2009

Altitude (in meters above sea level (masl))	Site	Citation
1550 – 1850	Southern Colombia in the Andes	(Molina & Escobar, 2008)
240 – 1122	Czech Republic	(Fisak, Tesar, Rezacova, Elias, Weignerova, & Fottova, 2002)
352 – 464	Namib Desert in Namibia	(Shanyengana et al., 2002)
550 – 600	Falda Verde in northern Chile	(Larrain et al., 2002)
1000	Iran	(Mousavi-baygi, 2008)
1650 – 2800 most productive sites located between 2000 to 2200	Yemen	(Schemenauer, Osses, & Leibbrand, 2004)
1800 – 3185	Montane cloud forest in southern Ecuador	(Bendix et al., 2004)
850 – 1340	Spain's Canary Islands	(Marzol Jaén, 2002)
600 – 800 to 1600	Madeira, Portugal	(Nascimento Prada & Oliveira da Silva, 2001)

The atmospheric phenomenon of fog is directly affected by wind speed and direction, which vary at different altitudes (Abdul-Wahab, Lea, 2008). The droplets of water in the atmosphere are so small that their mass is essentially unaffected by gravity. They do however have a falling velocity of 1-5sm/s which causes them to move horizontally through the atmosphere, making vertical objects ideal for capturing them (Abdul-Wahab, Lea, 2008).

Fog collection is considered viable if 2.5 or more litres of water can be collected per meter squared of collection surface (Diehl, 2009). The below table depicts the various amounts collected from Different countries.

Table 3: Amount of fog collected from various countries globally. Source: Diehl, 2009

Average Amount	Place	Water Issues	Source
8.5 $L/m^2/day$ (coastal) 1.1 $L/m^2/day$ (inland)	Tarapacá Region, Chile	Not tested	(Cereceda et al., 2002)
2.51 $L/m^2/day$	Eucaliptos, La Cruz de Santa, Dominican Republic		(Schemenauer et al., 2001)
10 $L/m^2/day$	Southern Coast of Peru	Not tested	(Semenzato, 1996)
3 $L/m^2/day$	Northern Chile		(Schemenauer & Cereceda, 1992)

Table 2 demonstrates that altitude is very important when collecting fog water. Advection sea fog has to be intercepted at a minimum of 200m above mean sea level. The table demonstrated that the lowest effective altitude was at 240m in the Czech Republic. Along the South West Coast of Africa, ideal altitudes for collecting fog water are above 300m above mean sea level.

Table 4: Amount of fog collected from various countries globally. Source: Diehl, 2009

Average Amount	Place	Water Issues	Source
7.1 L/m^2/day	Mount Boutmezguida, Ifni, Morocco		(Marzol & Sánchez Megía, 2008)
2.0 L/m^2/day	Boulaalam, Ifni, Morocco		(Marzol & Sánchez Megía, 2008)
5.0 L/m^2/day (data taken from the highest yielding collector)	Andean Mountain Range of Southern Colombia		(Molina & Escobar, 2008)
0.53 L/m^2/day	Khorassan, Northeast Iran		(Mousavi-baygi, 2008)
11.52 L/m^2/day (avg taken from 3 different experimental collectors	Dhofar Region, Sultanate of Oman	Conforms to WHO and Omani drinking water standards	(Abdul-Wahab, et al., 2007)
4.5 L/m^2/day	Mabijan, Hajja Governorate of Yemen	Suitable for drinking	(Schemenauer et al., 2004)
4.6 L/m^2/day	Lepelfontein, West Coast of South Africa	"excellent quality"	(Olivier, 2004)
2.5 L/m^2/day (assumed to be underestimated due to an error)	Cape Columbine, West Coast of South Africa	Suitable for drinking. Free from *E. coli*. Does contain heterotrophic organisms-these can be removed with a simple filter.	(Olivier, 2002)
4.0 L/m^2/day	Teno Rural Park, Island of Tenerife, Canary Islands, Spain		(Marzol Jaén, 2002)
1.43 L/m^2/day 7.81 L/m^2/day 0.93 L/m^2/day 8.26 L/m^2/day 3.36 L/m^2/day 2.98 L/m^2/day	Falda Verde, north of Charañal, Chile Alto Patache, Chile Cerro Guatalaya, Chile Cerro Moreno, Chile Paposo, Chile El Tofo, Chile	Not known	(Larrain et al., 2002)

The tables 3 and 4 demonstrate similar collection yields from countries around the world, and in most cases, the collected water is pure and safe for drinking. The cost for these systems can remain low, as expensive purifying and filtering systems are not required.

3.3.2 Fog water harvesting in Namibia

Namibia which borders South Africa in the south-western part of Africa, is an area which receives very little rain, and has no perennial rivers (Mtuleni et al., 1998). Fog occurs between 60 -200 days a year, which makes Namibia a viable location for harvesting fog water (Mtuleni et al., 1998; Seely & Henschel, 1998). The Central Namib Water Scheme supplies Namibia with the bulk of its water from aquifiers in the Kuiseb and Omaruru rivers, and groundwater reserves are dependent on rainfalls (Jacobson et al., 1995). More water has been consumed in the recent years than has been input and groundwater is running dry. According to Schemenauer (1994), fog water can be a reliable source of water for small-scale users, demonstrated in a case in Chile.

Figure 38: Fog from the Atlantic Ocean over dunes in the Namib Desert. Source: Martin Harvey, 2018

To test the quantity of fog water yield, fourteen Standard Fog Collectors (SFC) were erected near villages in six sites of the Namib Desert. The collectors were erected facing a north-west direction to take advantage of the winds blowing the fog in from the Atlantic. Three of the sites which were closest to villages that had the highest needs for water were chosen for the study. The villages were all within 50km of the sea, and at altitudes ranging 332m, 340m and 387m (Mtuleni et al., 1998).

The project data revealed the minimum yield per day to be 0.084 litres per square meter of collecting surface, and a high of 3.345 litres per square meter (Mtuleni et al., 1998). The quantities were lower than expected due to the strong winds which blow sand through the collection surfaces and disrupt how much fog water can settle. The conclusions were that the fog water harvesters should be designed appropriately to withstand wind speeds of 35m/s from an easterly direction (Mtuleni et al., 1998).

3.3.3 Conclusion

To conclude, it was established that it is viable to collect fog water for local communities, as long as certain parameters are met. It is only possible to collect fog water within 50km of the Atlantic Ocean, and at an altitude of 300m or higher. Namibia, Like Cape Town, borders the Atlantic Ocean and has a very warm landmass. Both Cape Town and Namibia are very prone to advection sea fog which occurs at similar altitudes. Cape Town City lies within 6km of the Atlantic which means that advection sea fog won't have travelled far and dissipated as much, unlike the sites tested in Namibia which are over 40km inland from the sea. Furthermore, the topographical nature of Cape Town ensures that the Fog can be intercepted quickly via Signal Hill, Lions Head, Devils Peak and Table Mountain, without being affected by too much pollution from sand, dust, and the City.

The findings presented in the literature review point to the effectiveness of current fog-water collectors and highlight the possibilities for the future with nanotechnology. It is assumed that the lower yields in Namibia are partly due to the systems being set up below 400m, but as stated above, the impact of sand and strong winds contaminating the nets and blowing the water droplets back into the atmosphere could also have contributed to the low yield. It concludes that fog water harvesting can be an effective technique in Cape Town above certain altitudes to supplement the supplies of water to local communities and even the City itself. Furthermore, the significant amount of water which can be collected with an enhanced version of the mesh from standard fog collectors, and the ability to implement it into building facades is truly innovative. Similarly, as technology progresses and bio-inspired materials become cheaper to produce, the potential exists to accelerate the field of fog harvesting and its implementation on a larger scale and as a possible material for building envelopes.

4.0 FOG-WATER HARVESTING IN THE WESTERN CAPE AND CAPE TOWN - A CASE STUDY

4.1 Introduction

As a semi-arid country, South Africa has always been more water stressed than other countries, with an average annual rainfall of 450mm, significantly lower than the worlds average of 860mm per year. Based on current water usage trends, it is estimated that South Africa will have exceeded availability of fresh water demands by the year 2025 (Department of Water Affairs and Forestry, South Africa, 2009).

Most of South Africa's fresh water originates in Lesotho, of which 10% of the natural runoff is available for use through dams, basin transfers and other countrywide water developments, enough to meet the countries total requirements (estimated in 2000) of 13.28 billion cubic meters of water (Department of Water Affairs and Forestry, South Africa, 2009). Design strategies to satisfy future water demands in the form of desalination plants can have a range of harmful environmental impacts, such as high concentrated brine discharges. Noise, visual impact, air pollution, impact on the aquifer, and disturbance of recreational areas are other environmental impacts on a more local scale (Brika, 2015).

4.2 Location and Climate

Cape Town is located on the south western tip of South Africa, at -33.93 latitude and 18.42 longitude and is the metropolitan hub and legislative capital of South Africa. The city of Cape Town is surrounded by Table Mountain, Signal Hill and Lions Head, and Devils Peak on one side, and borders with the Atlantic Ocean and Table Bay on the other side.

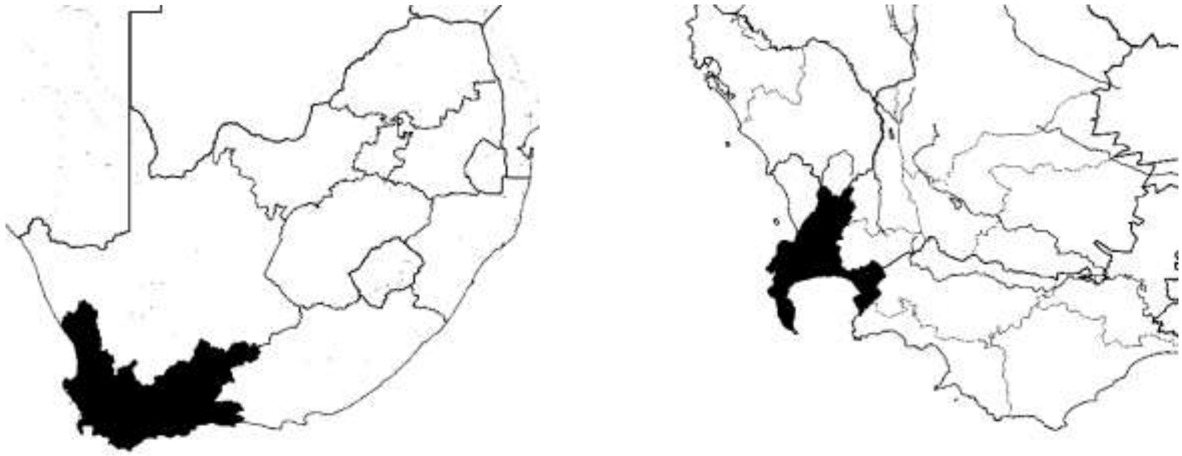


Figure 39: Map of the Western Cape and Cape Town. Source: Author, 2018

Cape Town has a Mediterranean climate, with temperatures peaking at an average of 26.9˚C in February, and17.7˚C in July with the lowest averages being 9.1˚C in July. The average rainfall has been 560 to 1400mm around the mountains of the Cape Peninsula (Tadross, Johnston, 2012). Cape Town is known for its strong winds, however, a study done between 1995 and 2014 indicated that the coastal wind speeds are actually decreasing (Wright, Grab, 2017). Figure 40 shows that wind speeds are highest in the summer months and lowest during the winter months between April and July.

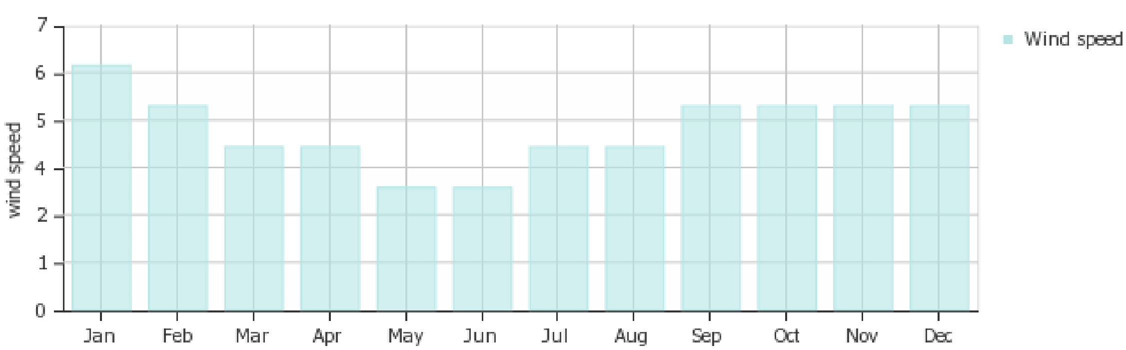


Figure 40: Monthly wind speed in Cape Town in m/s. Source: weather-and-climate.com, 2016

South Africa's Mediterranean west coast is prone to severe water shortages which occur regularly each year. The current drought is one of the worst recorded droughts in Cape Towns' history, however, the City has endured many more throughout its history. In 1652 when the Dutch first arrived in Cape Town, the colony was supplied with water which came from streams running off Table

Mountain. Eventually these streams were dammed and the first reservoir was built (The History of Cape Town's Water Supply, 2012). As the Colony grew and the demand for water increased, 5 more dams on the back of Table Mountain were built. Despite the reservoir and these new Dams, water restrictions were rampant in the Summer months. Throughout the 20th century, various augmentation schemes were constructed to assist in the supply for water of the growing city built (The History of Cape Town's Water Supply, 2012).

Dams filled by rain have become unreliable as the population of Cape Town has continued its rapid expansion. Many rivers which are also a large resource face many threats of pollution from fertilisers, mining, waste water treatment plants, and face excessive loss from leaking pipes. Water is an irreplaceable resource and cannot be substituted with anything else.

Even though rainfall is mostly limited to the months of July through to August (www.worldweatheronline.com/cape-town-weather-averages), Cape Town experiences frequent occurrence of fog and low clouds, which may prove to be a source of fresh water to supplement the City's supply. The population increase in the City as well as the booming tourism

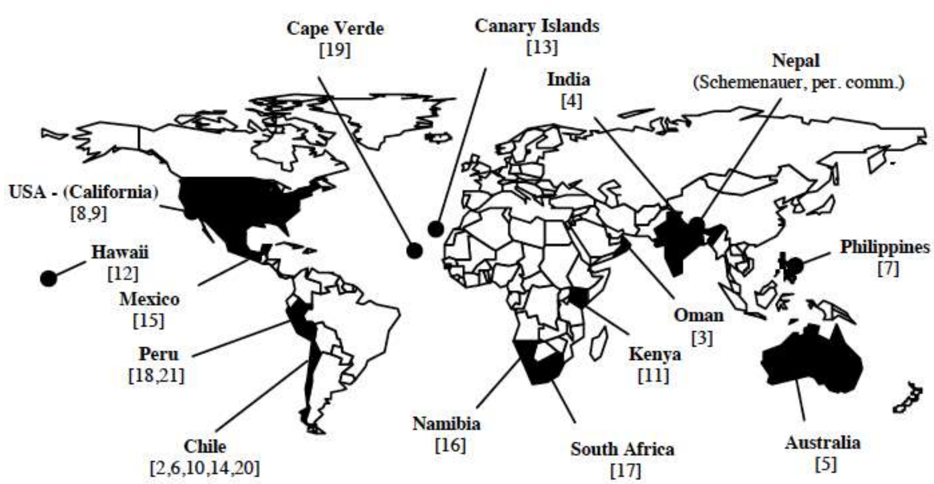


Figure 41: Fog water harvesting around the world. Source: Furey, 1998

industry, the reliance on rainfall and dams as the sole suppliers of water needs to be addressed. Almost all Cape Town's municipal water is supplied by 6 dams (in order of size): Theewaterskloof, Voëlvlei, Berg River, Wemmershoek, and Steenbras Lower and Upper (Water services and the cape Town Urban Water Cycle, 2018). Theewaterskloof dam has an unfortunate problem in its size to depth ratio; a large amount of water is lost through evaporation.

Another method of gaining water is through groundwater aquifers, of which Cape Town has three main supplies: The Table Mountain Group aquifer (TMG) is the largest and runs through the Western Cape up to Kwazulu-Natal. The Cape flats aquifer which is located on the Cape flats, and the Atlantis aquifer, just north of the City. Whilst drilling for ground water is an affordable way of acquiring clean drinking water, not enough is known about how aquifers work; there could be serious implications of using it. Drying up an aquifer by extracting too much water could cause it to fill up with sea water, creating a different type of ecological crisis (Morris, 2003).

Alternative sources of water need to be identified, however, water from fog is largely ignored by authorities from the water provision, due to misguided perceptions of relatively small yield, and the fact that fog harvesting systems have only been implemented in small scale communities. There is a lack in existing studies proving that the amount of water collected is enough to sufficiently supply large communities and even cities. Fog water harvesting however was a method used extensively in ancient times, albeit in other countries (Olivier, 2002). There is unfortunately not enough information to establish if fog harvesting techniques were used by tribes native to the Western Cape.

Figure 42: Topographical map of Cape Town. Source: Author edited from googlemaps.com, 2018

Figure 42 depicts the close distance between Signal Hill and Lions Head to the Atlantic. These Hills intercept any fog blown in from the North-west. Accessibility to Signal Hill is the easiest, with Signal Hill road leading to the top, and multiple pedestrian/hiking routes allowing easy pedestrian access.

The Peninsula Formation Sandstone (PFS) is part of the Table Mountain Group within the Cape Supergroup and is made up of quarzitic sandstone. It is a very hard and erosion resistant layer which has allowed it to remain as the highest peak in the Western Cape (Joubert, 1992).

Signal Hill is comprised mainly of rocks and is part of the Malmesbury Group from the Tygerberg Formation. The Malmesbury group consists mainly of Shale ranging from a grey to green colour, siltstone, and fine to medium grained greywacke (Joubert, 1992).

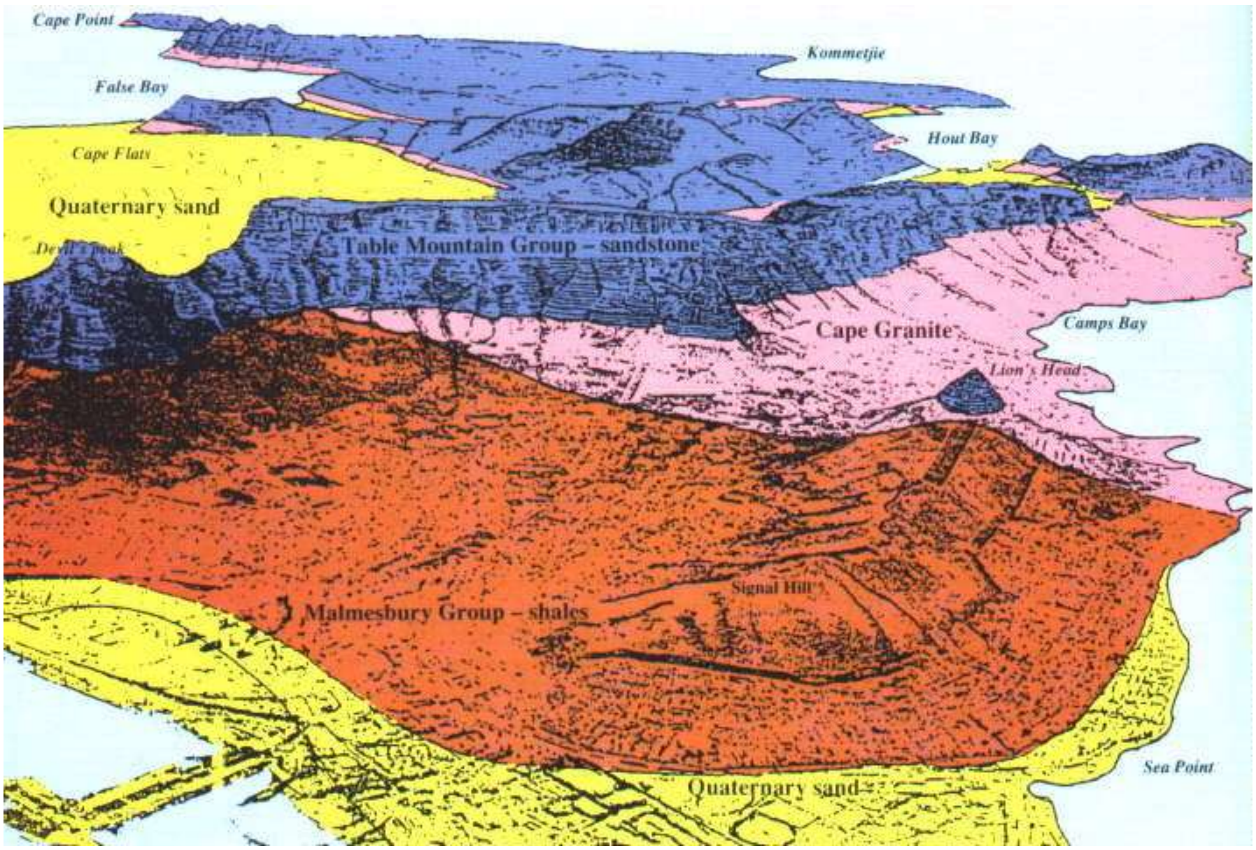


Figure 43:Schematic geology of Cape Town and Table Mountain Nature Reserve. Source: UCT Dept Geological Science, 2015

The terrain is steep, gravelly and rocky and consists predominantly of <30cm topsoil of rubble, consisting of 15-20% clay. Fynbos coverage is marked as sparse with an average of 15 species/sq. although at the summit the coverage is much less. Each variety of sand and rock types has its own variety of fynbos species. One of these species, the Cottula Fallax (fig.36), discussed in chapter 3.2.6, utilizes water from fog to survive the dry months.

4.3 Types of Fog

According to Olivier (2002), the feasibility of implementing fog water collection is reliant on the quality and the expected yield thereof. These depend on the type of fog which can vary in moisture content and in the duration and frequency. The speed of the wind also plays a crucial role (Nagel, 1956). These factors are dependent on altitude and regional climatic factors, such as sea surface temperature as well as pressure distribution. The direction and speed of the wind are also affected by the type of terrain and on the microtopography of the area (Schemenauer et al., 1987; Cereceda and Schemenauer, 1988) These factors determine which fog is the most ideal for collecting water and also determines the ideal location of harvest. The two most common types of fog in Cape Town are briefly discussed below.

Advection sea fog, also called sea fog, occurs when moist air moves over a cold surface which results in the near-surface air to cool below its dew-point temperature. Due to the regions hot land surface and the cold sea surface temperature (13˚-15˚) fog is formed on average on more than 50 days/year (Olivier and Van Heerden 1999), which has been deemed as a viable amount

Figure 44: Table Mountains infamous "table cloth" is a result of orographic lift. Source: New York Times, 2014

Figure 45: advection sea fog rolling through the city of cape town. Source: M. Eloff, 2015

Up-slope fog occurs when air is pushed over sloping terrain where it is cooled to its dew point and saturation. This is also known as orographic lift and is the reason why Table Mountain in Cape Town is often covered in what is called the "table cloth". This type of fog can maintain itself at higher wind speeds because of increased lift and adiabatic cooling, which is a result of a parcel of air encountering the mountain and being forced upward. The resulting decrease in air pressure with altitude causes the air parcel to expand, which in turn causes air to cool to its dew point. When this happens, the water vapour in the air condenses and becomes visible as a cloud (weather.gov.,2018).

4.4 Method and Data

J Olivier (2002) from the department of Anthropology, Archaeology, Geography and Environmental Studies at the University of South Africa, did a study documenting the feasibility of fog water harvesting along South Africa's West Coast (fig 46). The data came from the Weather Bureau publication, SAWB, 1986, as well as 11 weather stations located within the region. The mean annual Fog Day Frequency (FDF) from each station was transferred onto a map in order to link similar FDF values.

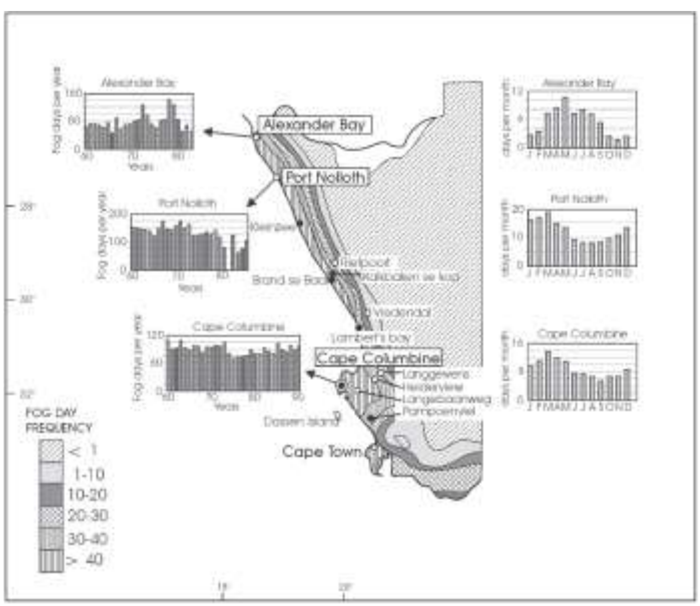


Figure 46: the resulting map highlighting fog distribution patterns along the Western Cape. Source: Olivier, 2002

In the Cape Peninsula, Cape Point has a distinct summer-autumn fog season whereas stations located further inland such as Cape Town International airport, Kirstenbosch and Observatory have autumn-winter fog maxima (Olivier and Van Heerden, 1999). According to Olivier (2002), this occurrence is likely due to radiation fog on winter mornings with low temperatures and high atmospheric humid temperatures.

4.4 Fog Duration

Although it is difficult to document the precise commencement and cessation of a fog episode, it was observed that the occurrences lasted between 2 to 6 hours (Olivier, 2002). Due to advection sea fog being more persistent, the fog in Cape Town can be expected to last longer. In higher latitude and longitudes, some episodes lasted over 30 hours with the longest recorded incidence in Rooiheuwel lasting 55 hours (Olivier, 2002).

4.5 Fog Collection

The fog water was harvested four locations in the Western Cape, Kalkbaken se Kop, Brand se Baai, Cape Columbine and Lamberts Bay using what is called the Van Schoor collectors, which consisted of a flat, rectangular carbon impregnated polypropylene mesh screen of around $4m^2$. The screens three-dimensional properties were designed to create [3]vorticity to increase particle circulation through the mesh (Olivier, 2002). The mesh was suspended between an aluminium frame which was anchored to the ground. During a fog episode, tiny droplets of fog impinge on the screen, form larger drops and run down into a gutter which transports the water into a storage tank. This is the most common and currently most efficient method for harvesting water from fog however is not suitable to regions with high wind velocities. Wind velocity in Cape Town (fig.40) is lower during the months in which fog is most prevalent, however, wind gusts can still be quite high and cause damage to the structures. To avoid damage to the fog nets, sensors which detect wind velocity can be installed in the structures, allowing the structure to essentially fold up when high wind gusts are

[3] Clockwise or counter-clockwise spin in the troposphere

detected, thus reducing damage to the system (fig47). Using simulation, the structural elements as well as the fog net can be put under wind load to evaluate the performance under different wind speeds. The materials and the design can then be optimized using the data. The gutters, pipes and mesh are also prone to blockages from dust and sand which greatly decreases the ability to collect water.

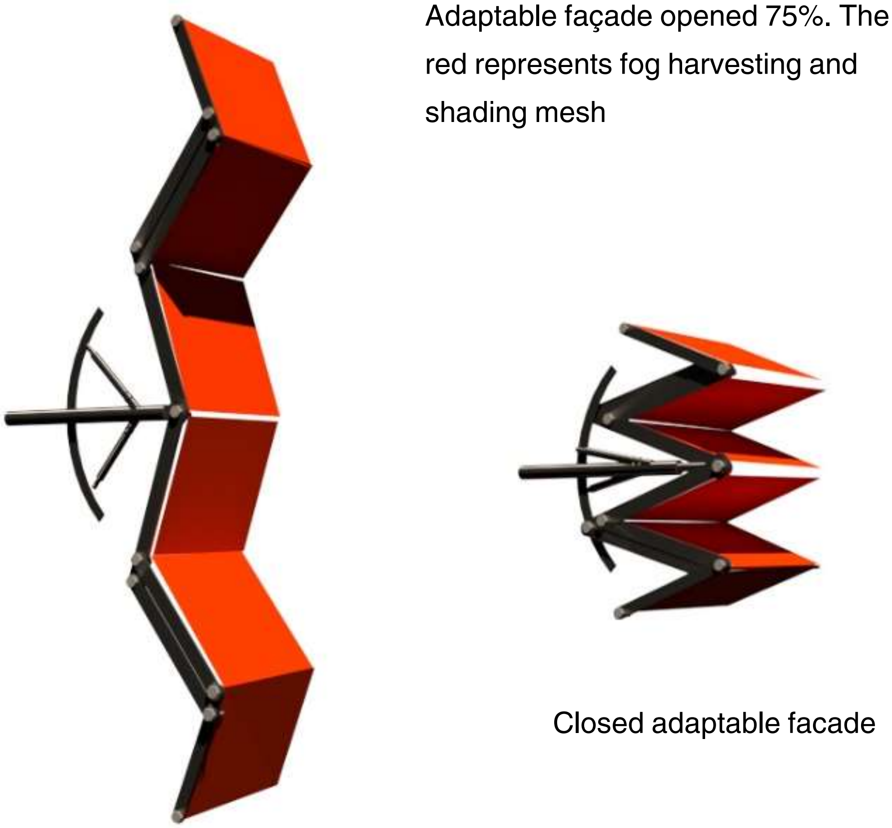


Figure 47: Adaptable, foldable screen and fog harvesting system. Source: Author, 2018

The information provided in the literature review proves however, that fog water harvesting is viable in Cape Town. The close proximity to the Atlantic Ocean, as well as the rapid change in altitude due to the Mountain ranges, ensure that Cape Town meets the fundamental guidelines required for successful fog harvesting. The Advection sea fog which is prevalent in the Western Cape has been tested, albeit further north, with good results.

4.6 Analysis and results

Olivier (2002) found that water yields could be as high as 5.7L/m^2 of surface collection and annually produced 2080L/m^2 of water. Using a low-tech method like the Van Schoor collectors can yield a significant amount of water, enough to make an impact on the people living in the area. The cleanliness of the harvested water was also tested in two different samples. Both samples were free from any disease-causing bacteria and thus did not constitute a health hazard.

Fog-water harvesting in semi-arid regions around the world has been tested and effectively used, and many of these stations are still operational. To determine suitability for this type of technology, the three most important factors are:

1. ***Frequency of fog occurrence.*** The entire west coast of south Africa, including Cape Town experiences a high occurrence of fog. Cape Town specifically experiences on average 50 days per year of advection sea fog alone.
2. ***Fog-water content.*** Not all Fog carries the same amount of water. Advection sea fog as well as clouds caused by orographic lift, however, contain a high percentage of water content which can be successfully harvested.
3. ***The Design of the fog water harvesting and collection system.*** The design has to take into consideration wind direction and velocity, topographic conditions, as well as the materials used.

4.7 Conclusion

The main disadvantages of this alternate method of sourcing water is the requirement for persistent community involvement in order to maintain these systems. Of the many fog-water collectors implemented, the majority of those that are no longer in use are due to a lack of community participation as well as difficulty to access the sites and cost (Qadir et al., 2018). However, with the implementation of digital technology and smart, active systems, it is possible to create an automated system which does not depend on human maintenance, and which is able to increase its surface area and orient itself to adapt to the site conditions in order to produce the best yield possible. Various smart/responsive materials which expand in certain conditions, orient themselves according to wind, as well as digital systems which can automate environmental and climatic responses based on external stimuli, are all methods which might be implemented into this type of technology in order to improve it.

Chapter 5 discusses and analyses three different precedents which were selected as examples and guides to be considered for the proposed building. They highlight a range of different technological implications, from very simple, to highly complex. Additionally, their design philosophies are aligned with environmentalism and digital innovation.

5.0 PRECEDENT STUDIES

5.1 Introduction

The trend of digital freeform and the awareness of environmental issues have propelled architecture to a higher level by comprehensively merging new technologies and green concepts. These observations suggest that we need a new structure for understanding the design process that integrates digital technology and the sustainable concept (Lee, 2010). In order to elevate the design process to a more comprehensive level, Lee (2010) maintains that the concerns with micro issues should be replaced with a concern for the fusion of overall interactions of sustainability and digital technology and a new design process with the resulting dogma being an intuitive and comprehensive design process.

Digital technologies and self-sufficient thinking have over time crept into the traditional approach of sustainability. The way in which architects and designers now approach sustainability has also been affected by new technologies. As Yeang (1999) aptly described an ecological building as a 'kind of living organism', environmental architecture is steadily becoming more responsive to its surrounding environment.

The digital techniques discussed in the above chapters, such as 3D computer modelling, CNC technology (Computer Numerical Control), laser cutting and even 3-D printing, provide cost-effective production methods for architectural applications. These methods allow building components to be pre-assembled which can save waste and reduces building cost. Furthermore, new technologies allow for experimentation for new materials which could suit environmental needs better (Lee, 2010).

The introduction of adaptable building components to account for external and internal conditions is also a concept which is being explored.

The following precedent studies represent digital technologies influences on environmental architecture through different design and conceptual approaches. The chosen precedents look at a variety of important factors discussed in the literature:

1. Digital technology does not need to be apparent in an architectural structure. It can be applied through almost any theoretical framework (phenomenology, critical regionalism). Additionally, it may enhance efficiency of purpose whilst respecting the context.
2. A building with a utilitarian function should still be beautiful, have optimal performance, and be able to enhance the natural environment. Additionally, computational design and new technologies can help to achieve these goals.
3. Digital design, simulation and documentation are vital to ensure that innovative designs perform as intended. Furthermore, high-end technological implementations that are environmentally friendly rely on the power of computers to ensure optimal efficiency.

The commonality between the precedents is the respect for cultural, environmental and historical context, the use of digital design tools and technology, as well as the contrastingly different architectural approaches taken. It is important to mention that each of the precedents also served a particular function:

a. collecting water
b. treating and purifying water
c. automatically regulating internal natural daylighting and temperature

The functions of these buildings and how they were designed and work are important to the research, and thus the method of analysing the precedents is more from a technological (the technological implications on the structures) standpoint, rather than analysing how they function spatially.

5.2 Warka Water
Ethiopia
Arturo Vittori

Introduction

In a country where 61 million people lack access to safe drinking water (Keredin et.al, 2016), the Warka Water tower provides relief to many people suffering from water deprivation. Created by Architect designer Arturo Vittori and his team of architects, the tower collects water from dew, rain and fog. It was designed using digital technologies, specifically parametric modelling in order to maximise its efficiency.

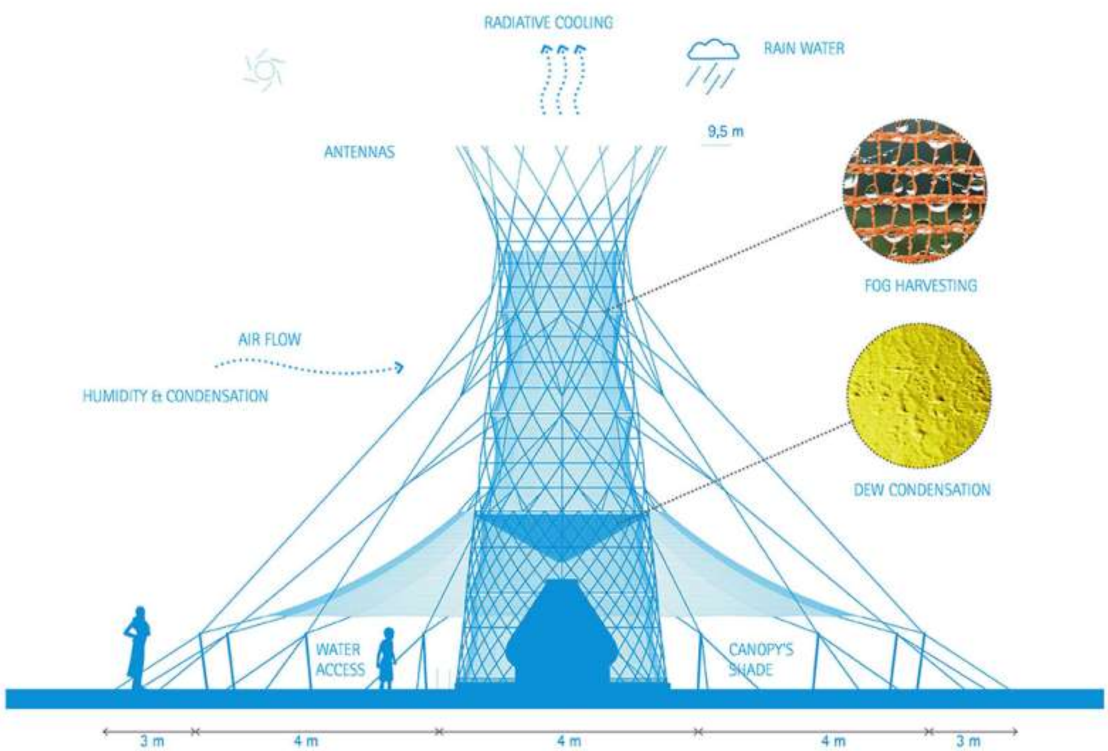


Figure 48: WarkaWaters passive technologies to collect water were made more efficient through the use of parametric modelling Source: www.dezeen.com, 2016

Design Intent

Taking its inspiration from the Warka tree, a wild fig tree native to Ethiopia, the WarkaWater tower can collect up to 100L of water a day and according to Vittori can be assembled in just a few hours. It is low cost, requires no electricity and is constructed from bamboo lashed together, which ensures the tower is easily packed and moved. *"WarkaWater is a philosophy that is looking at the environment and different possibilities to collect and harvest water in a sustainable way" (Vittori, 2016).*

Figure 49: Warka Water Towers are designed in such a way as to let the local communities learn how to build it themselves and replicate it as needed. Source: www.dezeen.com, 2016

The 12-metre-high structure was designed in a way in which it could be erected without needing scaffolding and machinery by separating it into 5 different components which were essentially prefabricated and then stacked on top of each other. According to Vittori (2016), the cutting-edge technology required to meet this design challenge came in the form of parametric modelling software which allowed design improvements to occur with only minor design alterations. The project is open source, meaning the people can be trained on how to construct the tower and are free to replicate it wherever as needed. The Warka Water tower is furthered designed to be used as a community meeting point, much like the Warka tree, with shade cloth spanning the circumference of the structure, encouraging social gatherings.

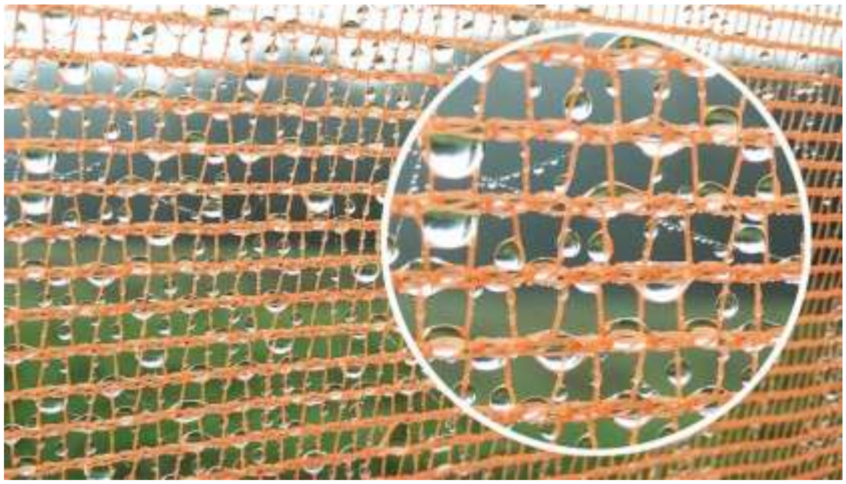


Figure 50: dew droplets form on the hydrophobic meshes and coalesce to form bigger droplets of water. Gravity pulls the pure water droplets down the nets and into a reservoir. Source: warkawater.org, 2016

Structure and Materials

The effectiveness of this technology was enhanced by the designer's ability to take advantage of digital technological power during the design stage to tweak the design throughout the process to provide maximum efficiency. Furthermore, the components' attributes modelled using this technique have real-world behaviours which means the performance can be simulated and adjusted accordingly. The result is an environmentally friendly, sustainable architecture which responds to the challenges of a water starved country. The Warka Water Tower is an excellent example of an environmentally responsive architecture which has been enhanced by the influence of digital technology in a very subtle way.

Whilst the structure is seemingly low-tech, the design of it was influenced heavily by digital technology (fig. 51).

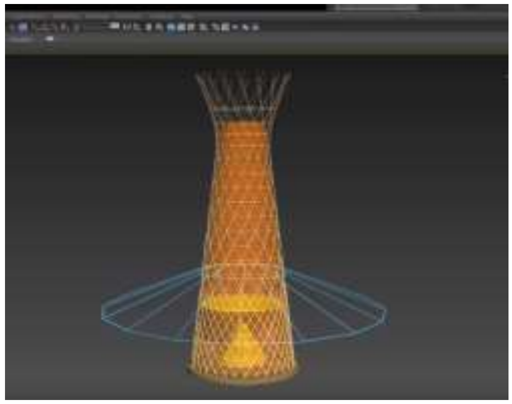


Figure 51: The digital design of the Warka Water Tower is parametrically malleable. Source: Dezeen, 2016

Ethiopia has around one million hectares of untapped bamboo, making it the largest area in East Africa. Bamboo has excellent structural properties — its hollow stems ensure that it is lightweight, it is a natural composite material and has great tensile and compressive properties. Furthermore, it is cheap and easy to work with.

The design was created to incorporate as many triangles as possible (fig. 48) which ensures that the structure is rigid. The digital software was able to simulate which pieces were in tension and compression and then optimized which ensured that the joints did not lose any strength.

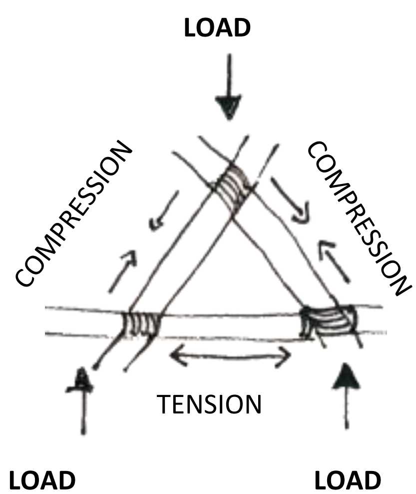


Figure 52: Warka Water Tower bamboo structural properties. Source: Author, 2019

Engineering, Craftmanship and Architecture

What separates architecture from engineering is sometimes difficult to define — engineering is driven by purpose and an ultimate objective whereas architecture contains artistic expression which does not need to be driven by purpose, but rather can hold a specific meaning or purpose. Designing with digital technology has incited concern that future architects are losing the connection to understand nature, history and culture as traditionally becoming an architect involved the process of studying the built and natural environments through sketching, painting and drawing. Digital technology however, is just a tool, like a paint brush or pencil, which provides different means of expression.

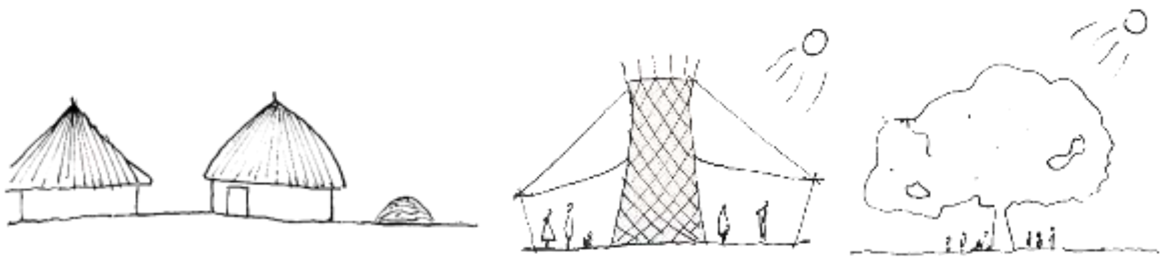


Figure 53: Local Ethiopian Huts, Warka Water Tower, Warka meeting tree. Source: Author, 2019

In Ethiopia, traditional crafts such as weaving, basketry and pottery (fig. 53, 54) are an essential part of every household. The Warka Water tower has managed to combine a purpose driven structure (collecting water), with local, biodegradable and natural material and form, which represents the traditional crafts of the local community.

The structure of the fog harvesting tower is purpose and function driven. It would exist for the purpose of collecting as much water as possible, driven by various parameters to ensure it is as efficient as possible. Embodying historical and cultural elements in it allows it to be expressed sculpturally and to challenge the notion of art versus architecture.

Figure 54: a villager in Ethiopia, shaping a clay pot. Source: Dezeen, 2016

5.3 Whitney Water Purification
South Central Connecticut, U.S.A
Steven Holl

Introduction

Below a vast 10 000m^2 green roof, lies a water purification plant and public park which uses water as its guiding concept for the design. Rated as one of the top ten green projects of 2006 by the Committee on the Environment (COTE/AIA), this water purification plant transforms a utilitarian function into a beautiful architectural statement. The facility serves as a reserve water source for the South-Central Connecticut Regional Water Authority and draws water from the nearby Lake Whitney.

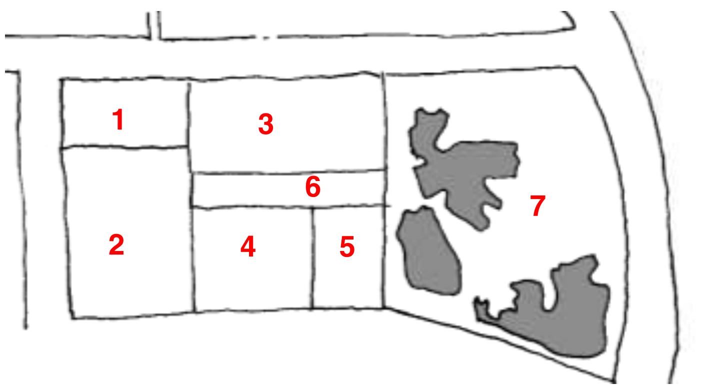
Figure 55: The 12-metre-long sliver takes its form from a water droplet. The steel shingles which clad the building reflect the environment whilst simultaneously dissipating any heat gain through the edges. Source: http://www.stevenholl.com, 2007

The striking exterior cladding of the building consists of interlocking stainless-steel shingles, which reflect the natural environment and sky, and the changing of light conditions along with the various seasons (Alter, 2007). The inverted drop of water indicates the function of the architecture which happens beneath it. The shape creates a curvilinear interior space which opens up to an expansive windowed view of the surrounding landscape with the exterior reflecting the landscapes horizon.

Design Intent

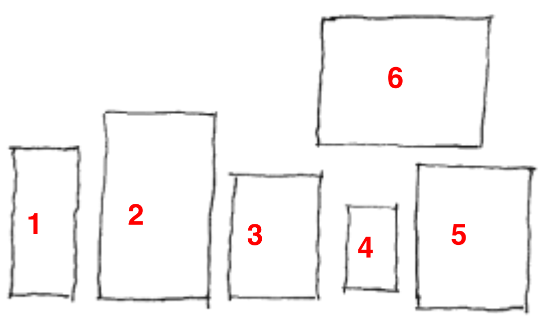
The public park is comprised of six sectors which are analogues to the 6 stages of the plants water purification and reflect the various changes in scale from molecular to the landscape above (Divisare, 2007). The micro to macro interpretation results in challenging material-spatial aspects, like bubble skylights which correspond to ozone bubbling and which allow light to descend into the treatment plant below.

1.Chlorophyll Garden
2.Wave Meadow
3.Turbulent Lawn
4.Bubbling Marsh (plant below)
5.Filter court
6.Administration
7.Wetlands pond



A

1.Rapid Mix
2.Flocculation
3.Dissolved air flotation
4.Ozonation
5.GAC Filtration
6.Clearwell



B

Figure 56: Whitney Water above ground**(A)** and below ground**(B)** layouts. Source: Author, 2019

The silver sliver (administration building) is the only hint that the natural environment surrounding it is part of a building. The layout of the building (fig. 52 **(A)**) was arranged in such a way so that the various gardens would enhance the filtering process of the pond. To respond to the filtration process, a public entrance is defined by vine wall elements on trellises. Figure 52 **(B)** details the layout of the plant and filtering process below, with each operation or area responding to the context above. This creates a meaning within the operation by demonstrating that there can be a connection between science and the natural environment. The buildings form is dictated by its function; the entire operation happens underground which allows the filtration and treatment process to be gravity driven, eliminating the need for electrical pumps.

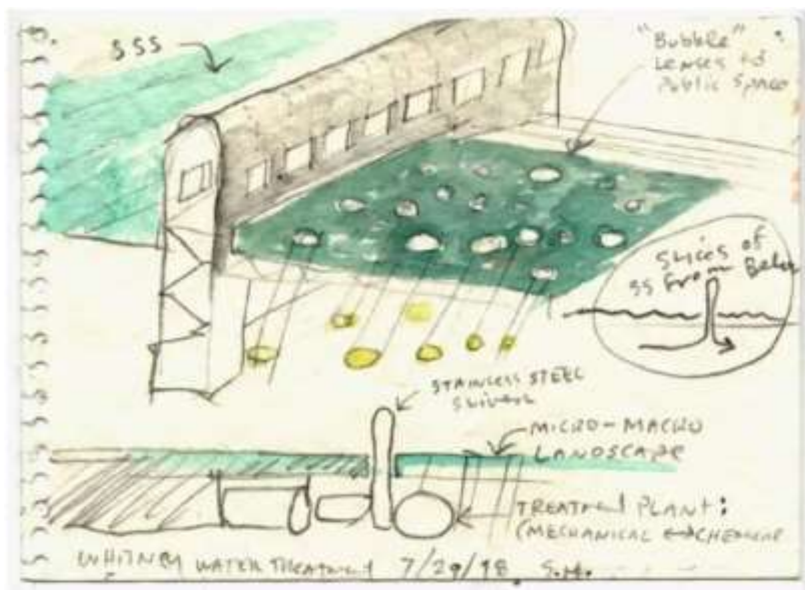


Figure 57: the architecture's impact on the environment is really only present and expressed through the stainless-steel sliver protruding from below the landscape. Source: Steven Holl Architects, divisare.com, 2007

Sustainable building and site development are fundamental to innovative design. Steven Holl Architects combine advanced mechanical systems with passive design strategies such as double walls and green roofs to emphasize these qualities. In order to minimize site disturbance, the existing conditions and natural vegetation are preserved and the landscape design supports biodiversity (fig. 52). Certain site features such as the wetland being a rest point for migrating birds has been document and this feature has been preserved and enhanced. The site flora is predominantly shrubs and native grass species which reduce irrigation and maintenance costs (Divisare, 2007). Implementing similar strategies in the proposed building in order to restore destroyed ecosystems and habitats is a big step in helping the natural wildlife as well as preserving the natural environment for the future.

Structure and Materials

Steven Holl's material library is always changing, with his primary material, light, influencing which matter best expresses it (Ferentinos, Olivares, 2013). The office's experiential nature often calls for materials which have not been used for construction purposes yet, prompting in the hard work of figuring out the technical means to utilize it. The water purification plant utilizes stainless steel shingles which were fixed onto a framing system which was fixed onto induction bent steel tube hoops which make up the frame for the sliver. The bespoke design required various digital means in order to produce the parts for the assembly, utilizing technologies outside the field of architecture, such as fabrication specialists.

Figure 58: the juxtaposition between the natural environment and the protruding sliver is downplayed by the reflective materiality of the building. The architecture has also not only allowed the flora to be preserved, but enhances it. Landscape. Source: Steven Holl Architects, divisare.com, 2007

5.4 Al Bahr Towers
Abu Dhabi
Aedas Architects

Introduction

The Al Bahr towers in Abhu Dhabi, United Arab Emirates, are the culmination of the aspirations to lead in the fields of sustainability and technological prowess. The 145m high towers remarkability lies in its innovative shading façade, developed by Aeda's parametric team. This responsive façade is inspired by the "Mashrabiya", a traditional Islamic shading device (Cilento, 2012).

Figure 59: Inspired by traditional Islamic shading devices, this kinetic facade responds to the movement of the sun to control the solar gain in the buildings. Source: https://www.archdaily.com, 2012

Design Intent

Nurturing innovation is fundamental for positive change in the built environment and in our lives. The project brief for the Al Bahar towers required that the building reflect prestige, the environment, and the architectural heritage of Abu Dhabi and the UAE, whilst utilising modern technology. The building should essentially become recognized as a landmark for Abu Dhabi.

Performance criteria

Environmental challenges are important concerns facing architects, and dynamic facades and building envelopes which respond to changes in climate are a real requirement. Adaptive facades can improve energy efficiency and provide the best comfort and indoor environmental quality with high effectiveness.

Figure 60: Dynamic mashrabiya are inspired from folding and unfolding, natural adaptive systems, as well as from technologies of the past. Source: Journal of Façade Design and Engineering, 2015

Adaptive facades such as the Al Bahr Towers' are high performance envelopes which are able to respond mechanically to the external climatic dynamics to meet the requirements of the occupants inside. The goal of the mashrabiya screen is to block direct solar rays from entering occupied work spaces, specifically from 09:00 until 17:00. Additionally, a daylight threshold ranging from 250 to 2000 Lux during the same working hours was required. This involved the use of sensors which would activate dimmers once light levels dropped lower than 250 Lux.

These ‘robotic’ devices sit on a separate frame 2m away from the building and were designed by the computational design team at Aedas. The facades panels were developed by simulating their operation in response to the sun exposure and the changing angles of incidence throughout the year. The parametric description allowed the panels to be adjusted without having to change the design which allowed a great degree of precision and an optimal design.

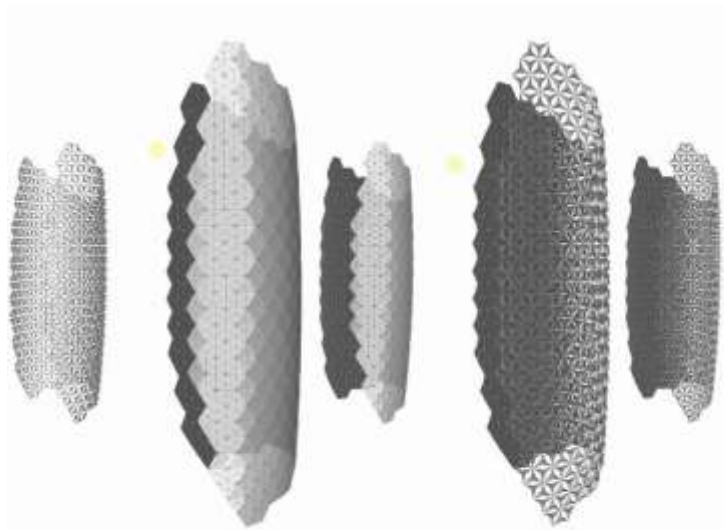


Figure 61: With the sunrise in the east, the facade will close along the east and continue closing following the suns path throughout the day. Source: Archdaily.com, 2012

The solar gain is reduced by up to 50% using this technology as well as reducing the requirements for air-conditioning. In a climate with average temperatures of over 30C˚ this results in substantial energy savings. The façade also allowed the Architects to use more naturally tinted glass which provides better views and reduces the amount of artificial light needed. Other systems of shading could include overhangs, horizontal and vertical fins as well as thermal, tinted glazing. In the case of the Al Bahar Towers however, the concept of the mashrabi makes a strong case for being the optimal solution within the buildings context.

Figure 62: Aesthetically, the façades expression is firmly rooted in the rich cultural context of the UAE. Source: archdaily.com, 2012

The shading system is separated from the curtain glass wall through a sub-structure which utilizes movement joints which allows independent response from the sub-structure (Attia, 2017). The triangular units which make up the shading system are made from polytetrafluorethylene (PTFE), a relatively new synthetic material best known for its non-stick properties and its use in Teflon. The material is hydrophobic, resistant to high temperatures, chemicals and weathering and is extremely versatile (Sawyer et al 2003).

There are 1049 1.5-ton shading devices on each tower, with 22 variations which made the manufacturing and assembly process challenging to manage. The shading devices are opened and closed once per day using a linear actuator and a pre-programmed sequence. On overcast and windy days, built-in sensors send a signal to the control unit to open all facades to allow more light into the building.

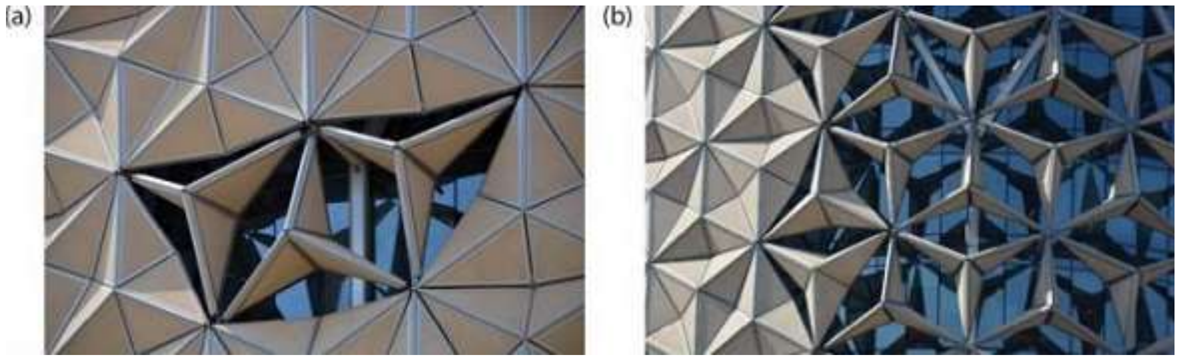


Figure 63: (a) Three fully opened shading devices allowing an open view during non-solar periods and (b) a group of fully opened shading devices. Source: photo courtesy of Terry Boake, 2012

The control unit or central Building Management System (BMS) can control each unit individually or in groups. Every 15 minutes the system is updated according to an anemometer and light meter on the roof and in overcast conditions the system is automatically overridden (Attia, 2017). The shading device has a service life of 20 years with the linear actuators having a service life of 15 years.

The nature of the façade dictated the requirement for a lot of testing in order to ensure proper functionality. The initial testing was done digitally, using simulation, animation as well as computational fluid dynamic (CFD) analysis to evaluate the performance. The kinematic and visual models were then set up and wind tunnel tests conducted on them. After completion, a 12-month monitoring system conducted to evaluate the real-world performance and to highlight deficiencies during the summer and winter seasons.

A survey was done on the users of the buildings comfort levels, specifically from zone 2 which is comprised of offices from levels 10 to 20. According to Attia (2017) 12% experienced very comfortable conditions, 42% of users experienced comfortable conditions whilst 32% experienced neutral conditions, 10% felt uncomfortable and only 4% were extremely uncomfortable. These results can be interpreted in a positive manner, proving that the façade design is effective. Interestingly, the main reason for discomfort was overcooling which was recorded from female occupants. Another main reason for discomfort was the actual movement and automated response of the façade, the regular opening and closing causing annoyance to occupants, as well as the inability to directly interact with the shading system.

5.5 Precedents relevance to research

Warka Water

Structures can serve more than just an engineering function intended to provide a resource (water, energy), but can also become architectural in that they also have to provide shelter as is the case with Warka Water — the water harvesting tower is also used as a communal meeting spot and provides shelter for the local communities from the sun. Additionally, the culture and history of the local communities, as well as the environmental context has been captured in the structure which directly contributes to, and enhances, its architectural value.

Whitney Water Purification

Steven Holl's Whitney Water plant has quite a utilitarian function which is often accommodated in large warehouses, however he decided to take advantage of technology to enhance the natural ecosystem of the site, and ultimately, the architecture. The purification plant is an example of how new design technologies can be used to influence architecture in a way which enhances the environment rather than imposing on it. It is a paradox where new technologies and the natural are juxtaposed but work together harmoniously in a manner which benefits the user as well as the environment.

The major influencing factors for this precedent are the way in which the form is dictated by the function, yet still achieves pleasing aesthetics. Furthermore, the utilitarian function that is a treatment and purifying plant, is elevated to something which encompasses much more than just treating water. It includes the restoration and conservation of local flora and fauna, as well as providing the public with a green, public space, as well as educational facilities to learn about the process of treating water. Additionally, the materials, design and construction method are heavily influenced by digital technology and largely made the building a possibility. The steel shingles not only provide a striking exterior, but their shape also allows the sun's rays to reflect and absorb, which reduce heat gain in the building. Additionally, the buildings thin profile allows easy access to daylight in all occupied areas.

The proposed building considers a fog water purifying plant, and the sensitivity of the site requires that its scale and visibility is heavily considered. Additionally, the site has suffered loss of endemic vegetation which needs to be restored. Whitney Water provides a number of strategies to tackle this variety of problems.

Al Bahr Towers

The Al Bahar towers are the culmination of traditional design fused with the power of digital technology. They highlight the importance of structure, sustainable principles, architectural form and digital technology as an ecosystem coinciding together, each dependent on one another. The successful collaboration between the various consultants was made possible through the use Building Information Modelling (BIM) and parametric modelling which allowed the process to become efficient and effective. The concept is ground-breaking and culminated in an Iconic architecture which set new standards for quality in the Architecture, Engineering and Construction industry.

The level of innovation required to complete the project was unprecedented — nothing similar had been done before and many of the structural and automated parts, as well as written programs had to be specially made and coded.

The high-performance and adaptive solutions of the Al Bahr Towers are designed to respond to the dynamic nature of context and the buildings user. The benefits of integrated dynamic systems and what they offer building design are important precedents to the proposed building which seeks to determine what the relationship between digital technology and environmental design is. The Al Bahr

Towers are an example of innovation beyond mainstream standards of building in which performance and aesthetics are equally prioritized.

The purpose of this chapter was to highlight the various ways in which digital architecture has influenced environmental and sustainable architecture in different climates. Whilst each building was very different and ranged from a seemingly low-tech approach to very hi-tech solutions, the design processes were very similar in that the main design tools used were computationally based. Whilst it was clear in two of the examples that some sort of hi-tech process had to have been involved in the process of creating the architecture, in one of the examples it was hardly noticeable, if even at all. This is very important if digital technology begins to play a larger role in architecture in the future, as it contributes to the values of sustainable principles.

The buildings which were analysed investigated the role that digital technology played in their specific contexts and whether their functions were enhanced and effective. The outcome made it clear that the innovation was only made possible through the use of digital design tools. These tools allowed the various systems to be tested in digital simulations which were able to prove the successes or failures before any physical testing needed to be done. It allowed the streamlining of design between various consultants and the tweaking and optimization without the need for redesigning entire systems. Furthermore, environmental impacts were reduced, and the “hi-tech” buildings achieved great green-star ratings.

The precedent studies and literature reviews have exposed vital information on which digital design strategies may enhance the functionality, practicality and effectiveness of the proposed building, and will be used to generate a design brief for the design of a Fog water harvesting and visitors Centre.

The following chapter will describe the analysis taken from the interviews, as well as the description of the interviews. It attempts to extract information relating to the research questions and objectives.

6.0 ANALYSIS AND DISCUSSION

6.1 Introduction

This chapter will report back on the analysis of the interviews, and how it responds to the research questions. The current state and progress of digital technology in our everyday lives is extremely fascinating, and the coalescence of these technologies and the built environment is a subject which is still relatively new in South Africa. The interview data was collected in order to gain a deeper understanding of the current and future implications of digital technology, specifically its implications for environmental architecture and sustainable practices.

6.2 Description of interviews

The interviews conducted with two staff members from Modena Design Centres as well as one engineer from Zipcord Industries (building automation, mechatronics) were very insightful and described the extents of digital technology in architecture and design in South Africa. Compared to many countries in Europe, America, China and Japan, South African companies have not yet adopted many digital and computational software tools. The interviews helped to gain a deeper insight into understanding the key question posed in this dissertation, and the possibilities of implementing solutions into the design proposal.

Speaking to an Autodesk engineering professional who provides support and training for BIM and various other newer software (such as Dynamo) revealed that South African professionals are using these tools to streamline very basic, menial tasks. The conversation revolved around how design professionals in the AEC industry are utilizing computational software and if and where parametric design fit in. It was explained that *"computational design is a long way off in South Africa", and*, surprisingly although some professionals are adopting these digital tools, they are being used for organization of files, keeping object libraries and families updated, creating real-time updates between excel spreadsheets and design data, and data management. In other words, for the most part, architecture professionals are not taking advantage of new technologies.

A big reason for this is the fact that there is little knowledge for how to use these programs, a large reason of which stems from the fact that architecture schools in South Africa still operate in a very traditional way. Many professors and academic leaders seem to view these "modern" processes as outlandish and an advanced and variety of software skill and knowledge is not something which is actively encouraged. Furthermore, many Architecture companies do not provide training for software which may or may not be utilized and learning them often happens through the persons own interest. This may also be attributed to software engineers, mechatronic engineers and structural engineers who collaborate with architects being the ones responsible for the components which require a more extensive knowledge of cutting edge design tools.

According to Garth Hamilton, managing director of SVA International, digital integration will ultimately in the future drive a new era of building practices and architecture in South Africa and the next ten years will inform a new and radical revolution. For now, the extent for digital integration lies in BIM, which has allowed the seamless collaboration on projects between various offices based throughout the country.

It is clear that the intentions for digital technological integration extend to streamlining processes between consultants, managing time effectively and speeding up various processes. Although there are certainly going to be professionals engaging with adaptiveness and automation in sustainable architecture, the interview below gives some insight into the direction of these methods.

A Zipcord Industries engineer noted that building automation is increasingly playing a big part in South African architecture. The conversation revolved around how building automation is currently being used in South Africa and the response revealed that there are a lot of Building Management Systems (BMS) being introduced into buildings such as Malls and various other large buildings which require constant monitoring systems. *"With automation in buildings, it's all about efficiency and optimization and security"*. HVAC systems for example do not need to be run constantly and programs which manage the system activate and deactivate it where necessary. Systems will be more intelligent and can even respond to things such as weather apps. *"The biggest thing however,* *is being able to review your data".* The smart systems will be able to monitor building performance data, such as energy performance, and adjust or alert the system accordingly. It can also detect changes or faults in mechanical and electrical systems which are installed, and in so doing ensure that preventative maintenance is minimized.

BMS can also monitor water usage in a building, detecting leaks or higher than normal usage, which can be rectified and optimized. Lastly, security is a big problem in South Africa, and automation has proven to be an excellent method of maintaining a high security level. Systems such as biometrics ensure that access to certain spaces is only granted to dedicated persons.

There is clearly a large variety of different circumstances that digital automation can be applied to, however, the ability to monitor energy and water and to collect data is crucial in ensuring that a building is running at the intended efficiency.

6.3 Analysis of Interviews and Findings

The research uncovered some key findings about digital technology and fog harvesting, and the integration of both of these into a building. The research demonstrated three key findings: the effectiveness of fog water harvesting, that it can be integrated into a building façade, and that the materials and systems can be enhanced using digital technology to produce higher water yields.

The interviews that were conducted were compared to the findings gathered from the literature review and the precedent studies, and provided a key insight into digital and technological innovations in our South African context, with regards to environmental and sustainable design. The literature and precedent studies presented effective and innovative solutions for environmental challenges utilizing digital technology in very innovative ways. The precedents demonstrated great technical knowledge and prowess in the use of advanced digital design tools from the various consultants who played a role in the design and construction of the buildings. The interviews demonstrated that there is a gap in software knowledge in South Africa, rather than technical skill. In order to construct a building which utilizes innovative, state-of-the-art, technological solutions, all consultants on the project would need to have similar knowledge in the various design tools, as such projects require intensive collaboration between a wide variety of specialists, such as mechatronic and structural engineers, building automation specialists, specialists in fabrication, construction companies and of course the architects. According to the interviews, there is a lack in software knowledge, and there is also a lack in forward-thinking clients, who are not willing to gamble on such "futuristic" projects.

Chapters 3.3 to 4.0 explored fog water harvesting, providing key findings on how to evaluate if the site is suitable, what technologies are most effective, how climatic factors can impact yields, various water storage systems, cost and feasibility, the types of fog which are most suitable, as well as how these technologies can be improved. It was uncovered that the coast of the Western Cape is susceptible to fog occurrences, and Table Mountains topographical nature creates its own separate climatic conditions. The Cape Town city bowl which lies in close proximity to the coast, is often affected by advection sea fog, which is especially suited for collecting water.

Table Mountain is more often susceptible to fog generated by orographic lift (as opposed to advection fog), as warm air from the city is lifted up the slope by updrafts, where it rapidly cools. This is what creates the "table cloth" or "blanket" which is often seen covering the top of the mountain. The strong winds on Table Mountain and fairly restricted accessibility are major drawbacks however to fog harvesting systems. Table Mountain can be a viable source for harvesting fog water, but challenges of accessibility and wind would need to be further researched.

Chapter 3.2 found that the possibility for integration into a building façade was viable, and that the building façade could further be responsive, in essence becoming multi-functional. The material and design choices have to be carefully considered however to account for corrosion and to reduce maintenance and mechanical failures. Different types of fog harvesting systems were also explored, and the findings proved that the most effective are standard fog collectors, using mesh as the condensing object. However, the properties of the mesh itself could be improved to achieve a greater yield. It was also discovered that the buildings envelope could be clad in a patterned skin, made with nanotechnology. These wall panels mimic various insects and plants' methods of collecting dew and moisture from the atmosphere. The drawback is that nanotechnology is still very expensive, although it might become a viable option for the future as digital technology progresses and manufacturing processes become cheaper.

6.4 Conclusion

The findings highlighted the state of digital technology in South Africa with regards to architecture, and showed that the type of digital technology and structural implications as discussed in the precedent studies are still slowly being developed. Unfortunately, the type of innovations which are highlighted throughout this study are complex and expensive, meaning only a select few high-profile architectural and engineering firms can utilize the digital design tools to their potential.

On the contrary, fog-water harvesting was shown to be an effective strategy in supplementing communities starved of potable water. Furthermore, this strategy was proven to be viable in the Western Cape. Finally, digital technology can greatly improve fog-water harvesting systems efficiency through optimized design and better material, and even implement them into architectural components and envelopes.

Chapter 7 will highlight how the outcomes from the findings and interviews have answered the research questions as well as the objectives, and provides design recommendations based upon these findings.

7.0 CONCLUSION AND RECOMMENDATIONS

7.1 Introduction

This studies outcome, based on all the research, has provided some key understandings into an avenue which is still being developed. Particularly in South Africa, the understanding of how digital technology can enhance environmental architecture is still a relatively new concept when faced with so many other economic and social complexities. However, addressing environmental crises through innovation with technology is not only crucial in preventing future environmental issues, but additionally paves the way to tackle a multitude of problems in the future.

7.2 Outcomes of Research Questions

> **1. How can digital technology and computational design inform an environmentally responsive architecture?**

Digital technology and computational design can inform environmental architecture in three major ways:

a. Design

The Al Bahr Towers, as discussed in the precedent studies, highlight how the design of an environmental architecture is conceived, not through a traditional linear process, but rather through a streamlined process in which many different fields work together simultaneously to find a solution to a problem, in this case, solar rays, heat and natural lighting inside a work space. This is possible because of Building Information Modelling (BIM), which allows designs and technical information to be updated and altered live, meaning all consultants will get direct feedback on any changes that are made, as they are made.

b. Simulation

Simulations are a powerful tool that allow the user to test a variety of systems including mechanical, structural and environmental processes. This can have a great impact on time and cost, as complex systems can be accurately modelled, tested and any faults rectified before being physically produced. Furthermore, it allows a buildings structural integrity to be tested in regions prone to earthquakes or high winds, and can simulate how a variety of different materials behave under various loads and stresses. All of these simulations and tests lead to a more optimized and efficient design. Simulations also have the ability to accurately predict environmental changes, allowing the designer to account for these changes during the design stage.

c. Fabrication

Digital fabrication, such as Computerized Numerical Control (CNC) machines and 3D printing, have the ability to manufacture large structural components as well as incredibly small parts. Subtractive manufacturing (CNC) and additive manufacturing (3D printing) are often combined to create a hybrid manufacturing as it is possible to manufacture incredibly complex parts, such as sensor systems. Additionally, this type of manufacturing allows a variety of materials to be used, providing great flexibility. Composite materials can be manufactured into structural parts, cladding, and a variety of other building components and furthermore many of these composites are environmentally friendly. The combination of new materials and being able to manufacture virtually any shape of component provide great possibilities for innovative strategies in enhancing environmental architecture.

These design methods were implemented in the proposed building, particularly in the design of the automated facades, as well as the form of the fog harvesting tower. The research showed that the facades of the building could also function as a fog harvesting element. Sensors detect levels of fog and the screens close up, creating a large collection surface. Additionally, the screens reduce energy requirements for cooling of the interior as well as lighting.

2. What water harvesting technologies have been implemented to inform an environmentally responsive architecture?

Current water harvesting technologies consist predominantly of rain water harvesting systems, designed to catch the water from the roofs of buildings or other surfaces. This is an extremely effective technique and is often used for irrigation, grey water, and in some cases even as drinking

water. Whilst extremely effective in the wetter parts of South Africa, semi-arid regions which do not experience much rainfall only marginally benefit from this technology.
The proposed building not only uses fog to harvest water, but also collects rain water from the large roof garden of the water bottling plant. Additionally, the mesh nets of the fog harvesting tower also collect rain which is transported directly into the water purifying and treatment facility.

3. What technologies in a South African context are relevant in order to facilitate an architectural response to the water crisis in Cape Town?

There has been a lot of debate around water harvesting and treatment systems such as desalination plants, which can provide fresh, potable water, but come with many unwanted risks such as noise, traffic, land-use, brine disposal concerns and energy consumption. Cape Town currently has three desalination plants running in Monwabisi, Strandfontein and the V&A Waterfront which accumulatively produce 8 million litres of water per day. Unfortunately, desalination plants cause a lot of environmental damage, and if not managed correctly can have disastrous effects.

Another technology includes recycling wastewater, which is used in many countries around the globe. Singapore provides 40% of the country's potable water from recycled wastewater. In South Africa, municipal wastewater systems collect high concentrations of microbial pathogens and chemical contaminants and would require complex treatment. Furthermore, several processes will be required to ensure public safety. Lastly, community perceptions on using recycled wastewater would need to shift. The research proved that in some areas of South Africa, alternative sources of water, such as water from fog, dew and rain, can be reliable sources of water to facilitate community supply. These still rely on traditional and older technologies which can be upgraded and have the potential for large yields. Innovative design, such as introducing water harvesting systems in the envelopes or facades of buildings has a lot of potential.

7.3 Achieving Aims and Objectives

Aims

The aim of the study is to facilitate a paradigm shift that considers digital technology as a strong proponent for environmental architecture and sustainable design. This in turn aims to drive a shift in paradigm which considers water scarcity as a chronic challenge by looking beyond conventional water supplies as a backdrop to address local water scarcity.

The studies aim which looked at both digital technology and environmental architecture, and the combination of the two in order to address water scarcity, was achieved by utilizing innovative strategies and technologies to take advantage of specific weather conditions from which water can be provided.

Objectives

1. *To explore how digital technology and computational design can inform environmentally responsive architecture*

Environmentally responsive architecture can be informed through a multitude of ways, of which the predominant methods are computational design, simulations, and materials and fabrication. These are manifested predominantly in facades, and structural systems and components.

2. *To explore the evolution of architecture within current technology*

Architectures evolution has always happened alongside technological innovations, as the many architectural movements and styles (such as modernism and postmodernism) over the decades have shown. How current technology is shaping architecture today, is evident in a variety of buildings which follow parametric or neo-futuristic styles, characterised by organic, free-form and curvilinear forms particular to digital design techniques. Additionally, architectures evolution is becoming manifested in environmental concerns, and as such, a buildings function relative to its context and its users has reached new heights. Many standards for environmentally friendly buildings which have been set by a number of 'green' building councils, require the use of digital simulations to show energy performance of a buildings system, in order to meet these requirements. This has a direct effect on spatial planning, as well as the structure and buildings envelope and facades. More and more architecture is taking advantage of sensors to allow automated adjustments to occur based on light, temperature, energy expenditure and water use. This can happen internally, or, be part of a buildings envelope and aesthetic as well as the structure.

3. *To contextualise digital technologies and environmentally responsive architectures in the South African context*

Digital technologies progression in South Africa is still very much in its infancy stage, however, there is great promise for the future as it continues developing.
Automation systems in buildings are very advanced and smart systems which have the ability to adapt to environmental challenges are already being utilized. This study highlighted the pro's and the cons of digital integration in the context of South Africa, which is that implementation of new technologies beyond streamlining existing processes is low, but developing.

7.4 Conclusions

The findings in the literature as well as the interviews conclude that the technical ability for building automation exists, and is implemented on a large scale. Where it is lacking, however, is in innovative sustainable solutions, on a large scale. Natural, sustainable resources are still not being taken advantage of in innovative ways. Environmental design in South Africa needs a built example which will inspire design professionals to consider the technical innovations possible with digital technology to enhance sustainable design in South Africa.

The literature review and case study indicated that fog harvesting is viable in Cape Town. Furthermore, it showed that fog water harvesting systems can be introduced into buildings, and that digital technology has the ability to enhance the effectiveness of the water harvesting process, and the architecture, as an interrelated ecosystem.

This means that integrating fog harvesting technology into a building will likely ensure that the building can be more energy efficient by a) the fog harvesting nets performing a double function by also acting as adaptable shading devices, responding to the movement of the sun to shade the interior appropriately b)the fog harvesting nets themselves will require less maintenance due to the adaptive nature of the system being able to detect bad weather patterns and respond appropriately by folding away, reducing cost of maintenance c)a direct source of water to the building, reducing the need for piping and other necessary infrastructure, d) a sustainable source of water which can be collected, stored and used to service the building and its users, as well as provide supplementary water to local communities.

The literature also indicated that altitude plays an important role in how much fog is available, effectively suggesting that the intervention should happen at a minimum altitude of 300m above mean sea level for the best results. Close proximity to the Atlantic Ocean additionally can increase potential water yield due to the fog not having dispersed as much. The ideal site would need to be a) accessible by vehicles and pedestrians, b) be close to the Atlantic Ocean, and c) be at an altitude. Whilst Signal Hill meets these requirements, the literature indicated that at least one part of the architectural intervention should be in the form of a tower to extend the height of the fog harvesting system for the optimal fog water yield.

Addressing the natural environment of Signal Hill, it is clear that the vegetation has suffered and requires restoration and protection. The Summit of Signal Hill is almost bare aside from a few Umbrella Pines. Various Proteaceae and Renosterveld fynbos can be re-introduced as a rooftop garden.

Regarding the buildings envelope, the literature showed that adaptive and kinetic facades are effective solutions for controlling the interior environment and to reduce energy consumption of the building. Users of the building should however be able to interact with the shading system to control their immediate environment, according to their preferences. Adaptive and kinetic facades should also not be overly complex as this can more likely lead to mechanical failures and malfunctions. Simple mechanisms to control the opening and closing of such facades would need to be developed.

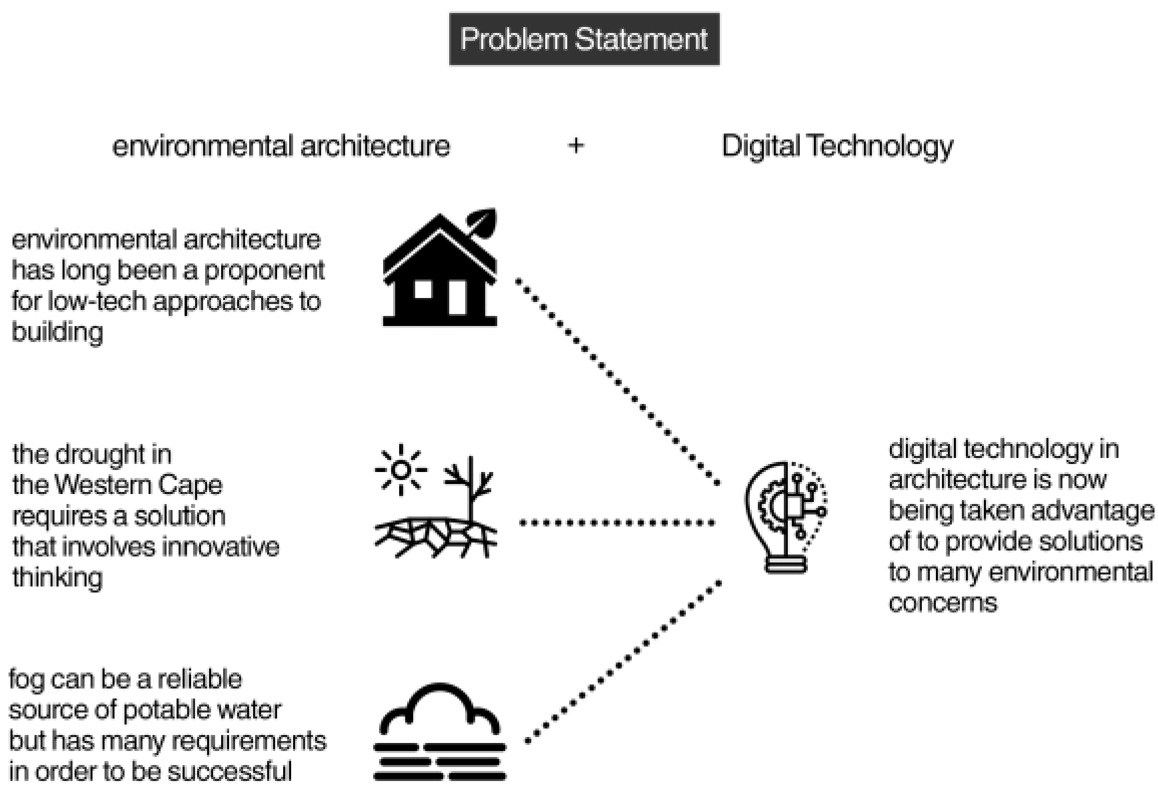
It is clear that environmental architecture in South Africa is a big priority. Digital technology is being used to collect data on building performance which is an effective strategy in monitoring the efficiency of the technologies which have been utilised. Essentially, data collection is very important as it helps to evaluate which technologies work and which ones do not. Understanding what is effective will eliminate the need for testing designs which can be costly and time consuming.

A successful blueprint for environmental and sustainable design already exists in South Africa, and digital technology has not yet become a major component of it. It is however only a matter of time before it will begin to play a larger role.

7.5 Recommendations

7.5.1 Introduction

This chapter will provide insight into the approach taken towards an architectural design which responds to the water crisis in Cape Town in an environmental and innovative way. The vision was to create awareness on alternative, sustainable sources of water and to provide an example of how innovations in digital technology can play a positive role in enhancing environmental and sustainable architecture. To achieve this, the environment and climate around Signal Hill had to be promoted in a way which would draw attention and interest and provide a backdrop for conversations on technological and environmental requirements towards a sustainable future. To do this, the architecture would have to be effective in its functions of harvesting water and for meeting new standards in sustainable design with technological innovations.



7.5.2 Design parameters — Who, What and Why

Who

The architecture is meant to impact local communities within Cape Town, local and international tourists, recreational users and the surrounding natural environment.

What

The most important part of the design needs to be the symbol for the alternate, sustainable source of water. This symbol should be interactive for the users, but also visible from a distance, to stand as a reminder of the fragility of our most precious resource. The architectural space should promote discussions regarding sustainable innovations for the future, as well as promoting responsible tourism behaviour.

Why

Water is our most precious resource and needs to be protected. Highlighting the fragility of this resource is important to create awareness for the current and future generations of people. By demonstrating how water can be successfully collected in ways which go beyond conventional means of collecting water, discussions can be fuelled on sustainable practices which provide solutions to other environmental challenges. Furthermore, with digital technology promising to become even more ubiquitous in society, the possibilities to harness this resource as a positive influence towards sustainable design needs to be marketed.

7.2.3 Client Proposal

The client, the Department of Environmental and Water Affairs of the Western Cape, as well as the Department of Economic Development and Tourism of the Western Cape, in an attempt to raise awareness for alternate water sources and environmental concerns has commissioned the architects to design a fog-water harvesting and visitors centre on Signal Hill in Cape Town which will make use of the regular occurrence of fog to harvest water. The building would function as both a tool to harvest water from fog, as well as being an iconic structure, new symbolic icon for Signal Hill, to stand at the forefront of innovative, environmental design for the city of Cape Town.

7.6 Site selection

For the building to be functional, the site had to meet specific requirements. According to the data established in the literature review and case study, the requirements for optimal fog harvesting conditions are presented as the following:

- The site has to be in a location which experiences fog at least 40 days per year. Cape Town receives advection sea fog and fog due to orographic lift around 50 days per year, ensuring the first and most important requirement has been met.
- The optimum altitude for collecting fog is above 300m above sea level, which requires the site to be situated on a hill or mountain.
- The distance from the Atlantic Ocean from which the advection fog is blown in from has to be less than 50km.
- The requirement for wind to drive the fog through the collecting surface is important as otherwise the fog would eventually just deposit onto the ground.
- Accessibility to the site is important for vehicles and pedestrians to ensure that the systems can be maintained easily, and for the interaction between the architecture and recreational users to happen.

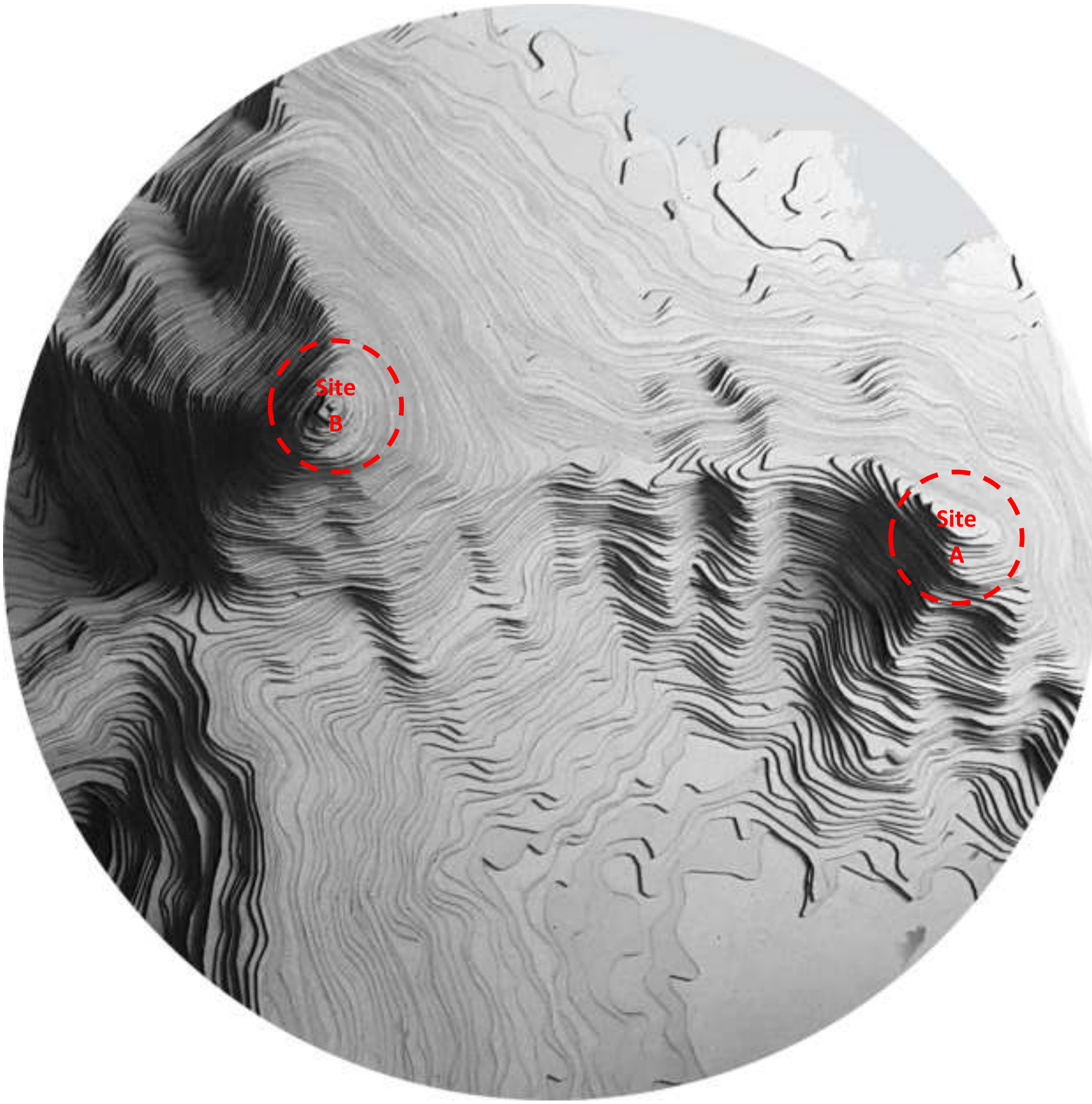


Figure 64: Site choices. Source: Author, 2018

The choices for the site were Signal Hill, site A, and Lions Head, site B.

Site B

Lions Head has a higher altitude at 669m above sea level at the summit. This is a good altitude for harvesting fog water, however, does not have vehicular accessibility. Lions Head has extremely rough terrain and also is a protected site. This would make construction difficult and would impose negative impacts on the natural environment.

Site A

Site A, Signal Hill, has an altitude of 350m at the summit, which is a good altitude for harvesting fog water. Its close proximity to the Atlantic Ocean ensures that It also is the first object at considerable altitude for advection sea fog to come into contact with. The benefits of this are reduced pollution of the fog. Furthermore, Signal Hill experiences updrafts from the North-West, which are used for paragliding, and which would help to drive fog into a harvesting system. Signal Hill is also accessible to vehicles and pedestrians via Signal Hill road. Signal Hill also has existing infrastructure on it, despite being part of the Cape Town Nature Reserve, and this will help to justify the architectural design proposal.

Figure 65: Site A presents itself as the optimal site for the design intervention. Source: MapData, 2018

7.6.1 Signal Hill – Site analysis

Figure 66: Signal Hill, aerial view. Source: Luke Maximo Bell

7.6.1.1 Location

Signal Hill is located in Cape Town, amongst Lions Head and Table Mountain. It lies within close proximity to the Atlantic Ocean and is flat-topped. At an altitude of 350m above mean sea level, it is one of the highest hills in Cape Town (fig 42).

7.6.1.2 Accessibility

The main access to Signal Hill is via Signal Hill road, which branches off from Kloof Nek Road/M62. Military Road which also branches off from Kloof Nek Road leads to the Noon Guns on Signal Hill. Kloof Nek road has several Bus stops which end at the beginning of Signal Hill road. Signal Hill road is primarily used by private vehicles, although public transport vehicles such as tourist buses and mini-van taxies also use it.

Alternatively, Signal Hill can be accessed by foot via the Lions Head path which begins at Upper Rhine road, off of Ocean View drive, or from Top Road, both in Sea Point (fig.61).

Signal Hill is a popular destination for people to watch the sunrise and sunset and during sunset especially, Signal Hill road sees a lot of traffic. Full moon hikes are also very popular and contribute to traffic on the hiking paths, albeit on Full-Moon days only.

Figure 67: map showing access points to Signal Hill. Source: Author edited from Google Maps, 2018

Signal Hill is also popular amongst extreme sports enthusiast such as Mountain Bikers and Paragliders, the latter of which have several stations just below the summit which is accessed via Signal Hill road.

The Lion Battery and the Noon Guns are a historical Landmark on Signal Hill, serving as a time signal. The correct term for these guns is in fact time-guns (Bisset, 1984). The Noon Guns as they are now commonly known, consist of two Dutch naval black powder cannons, fired alternatively at noon every day.

Fig 62. Shows the current time-guns which consist of two guns, one of which is used as backup if the first one misfires.

Figure 68: time-gun/noon gun on Signal Hill.
Source: https://www.sa-venues.com/attractionswc/noon-day-gun.htm

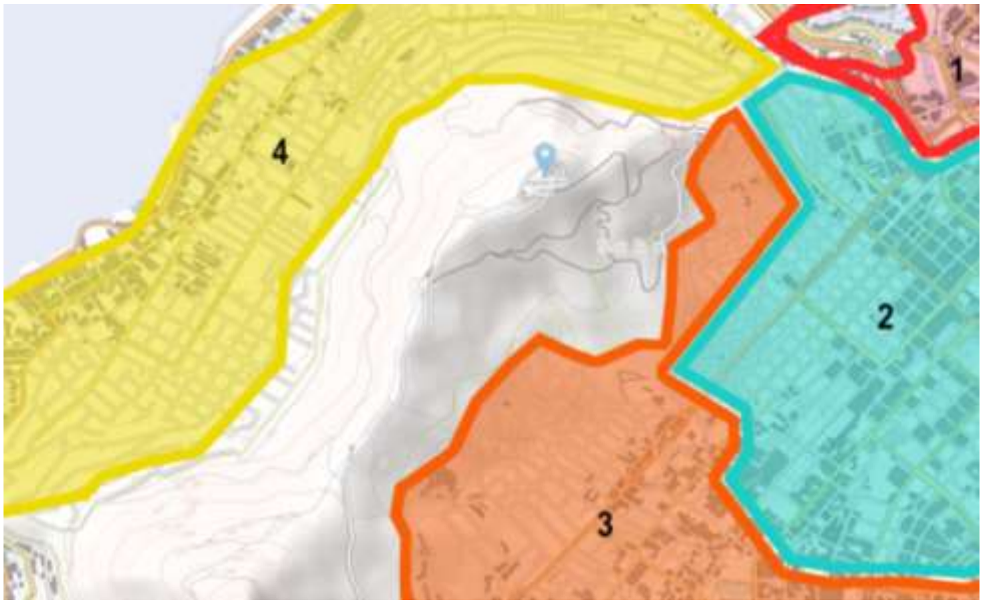
Fig 63. Is an image of a former time-gun, number 54, which had been secretly moved to the Lion Battery in 1945 after becoming unserviceable during an accident in which the re-venting tool had become stuck in the vent chamber.

Figure 69: time-gun no.54 outside the Lioness gateway at the Castle of Good Hope.
Source: Scientia Militaria, South African Journal of Military Studies, Vol 14, Nr 4, 1984

The combination of outdoor adventure, sports, history, tourism, fitness culture and recreational activities are what define the spirit of Signal Hill.

7.6.1.3 Context

Signal Hill and Lions Head, is also known as the Lion Couchant, a French adjective used to describe the position of the animal lying down with its head raised. It compares the mountain with the Lion, a majestic animal carrying notions of royalty and nobility (Botha, 2013, De Beer, 1987). These landforms along with Table Mountain and Devils Peek, have become iconic symbols and play a major role in how the culture of Cape Town is defined. The natural context of Signal Hill is in great juxtaposition to the surrounding urban context and holds various small fragments of culture, history and vegetation.



1. Industrial
2. Commercial
3. Mixed-residential
4. Residential

Signal Hill is predominantly surrounded by residential zones, with the CBD (zone 2) being in close proximity

Figure 70: Urban context surrounding Signal Hill.
Source: Author edited from google maps, 2018

The majority of the context surrounding Signal Hill are middle and high-income suburbs which account for a large percent of users of Signal Hill and Lions Head (Conservation Development Framework, 2001).

Signal Hill forms part of the Cape Peninsula National Park (CPNP) which was established in 1998 and represents a combination of cultural and natural heritage. The Cape Peninsula is nominated as a World Heritage Site and plays a vital part in identifying and embodying Cape Town's history, cultural diversity and memories.

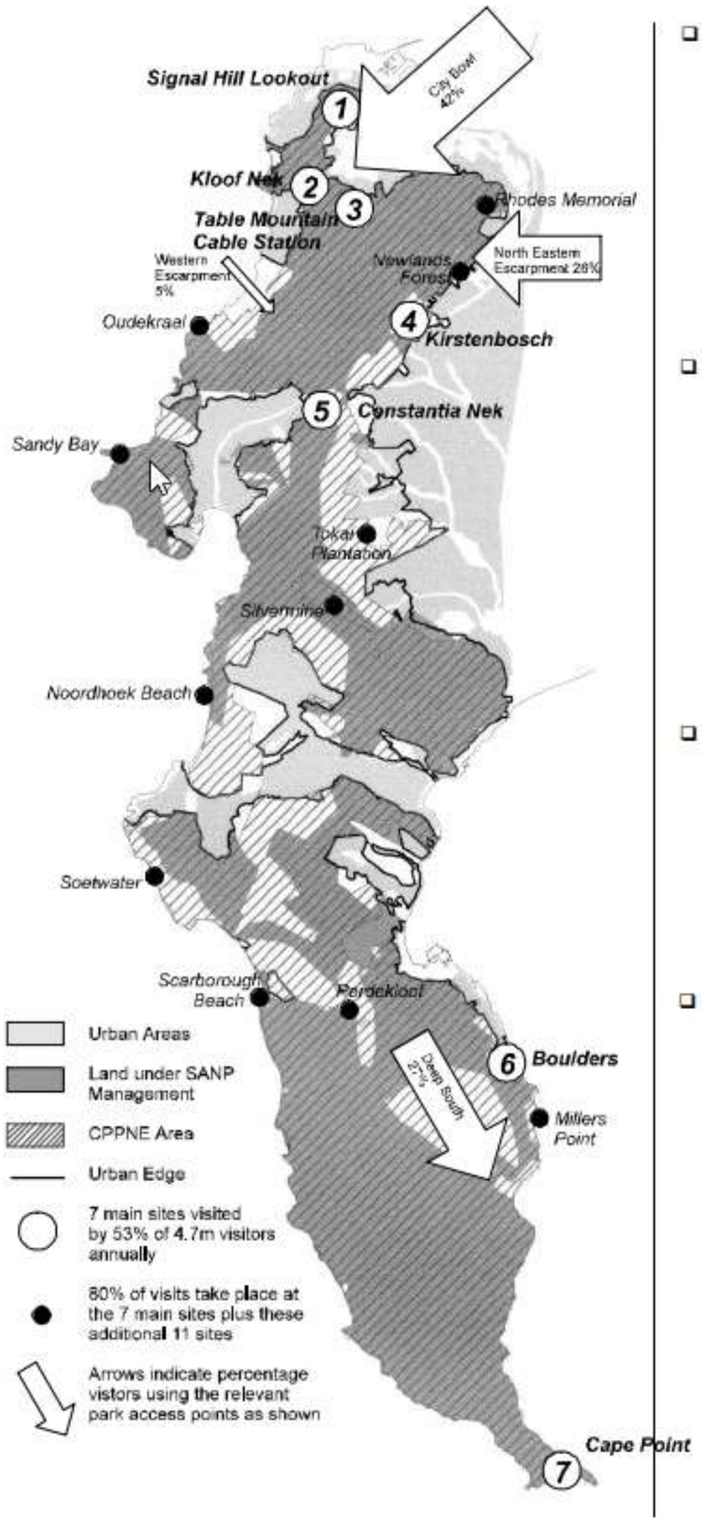


Figure 71: spatial distribution of visits across the CPNP indicates the primary access points (42%) being clustered around the City Bowl.

Source: Conservation Development Framework for the CPNP, March 2001

7.6.1.4 Topography

The Cape Peninsula is made up of three types of different rock with different ages. Signal Hill is part of the Tygerberg-formation of rocks which fall under the Malmesbury Group 1, also called Malmesbury Slate or Shale (Kisters, 2016). Signal Hills marine siltstones were dated using Zircon crystals which estimates them to be around 560 million years old, making them the oldest rocks in Cape Town.

Figure 72: Signal Hill and Lions Head geology.
Source: Author edited from https://en.wikipedia.org/wiki/Peninsula_Shale_Renosterveld#, 2009

Many of Cape Town's historical buildings from around 1666 are constructed of local natural stone, and the Cape Town castle (Cape Towns' oldest building) was built during this time using Malmesbury Slate. From 1850, Cape Granite and Table Mountain sandstone were utilized for building (Cole, 2018). This stone should be used in the proposed building to respond to the context and relate to part of the history of the development of Cape Town.

Figure 73: Cape Town Castle or the Castle of Good Hope was constructed in 1666 using Malmesbury Slate.
Source: www.portfoliocollection.com/visit/castle-of-good-hope-and-iziko-william-fehr-collection, 2015

The vegetation on Signal Hill was used for grazing before European settlement designated certain areas for foresting and cultivation (Joubert, 1991, 1992). The vegetation falls under the category of Fynbos and is broadly classified as West Coast Renosterveld. Signal Hill provides a unique West Coast Renosterveld however, due to the fact that it is the only part of the Malmesbury shale area that is influenced by coastal fog (Joubert, 1992).

Peninsula Shale Renosterveld is endemic to Cape Town's peninsula, which is a narrow strip that runs from Signal Hill south to the Cape point (see fig.65).

Some of the earliest descriptions of Signal Hill are from sea-men of which one described in 1702 as '*…Lion's Rump…is grown over with luxurious grass and a few trees…*' (Joubert, 1992, p.257).

Some descriptions of the flora on Signal Hill included fields of Proteas and according to Joubert (1992, pg.257), *'almost the whole of Signal Hill used to be covered with Proteaceae…'*. Today, most of the original vegetation on Signal Hill has been destroyed with the remaining vegetation consisting of gums, taaibos, pines and abundant grass.

(A) Peninsula Shale Renosterveld is the only type of vegetation that is evenly distributed across Signal Hill and is one of the two last remnants of the species in the world. (Joubert, 1992).

Figure 74: Renosterveld on Signal Hill.
Source: http://planet.botany.uwc.ac.za/nisl/bdc321/ekapa%20cape%20towns%20lowlands/module2/renosterveld.htm

(B) The Acacia Karoo tree was once abundant on the lower slopes of Signal Hill but has greatly diminished. A few still remain scattered around the bottom slopes.

Figure 75: Acacia Karoo tree. Source: https://www.seedsforafrica.co.za

(C) The Umbrella Pine or Stone Pine is abundant throughout the Cape Peninsula; however, it is not an indigenous species and was planted extensively in the 1700's. It has since become part of the landscape.

Figure 76: Pinus pinea, also called Stone Pine or Umbrella Pine.
Source: http://www.ridgwayramblers.co.za, 2012

The transformation of the vegetation on Signal Hill which includes the invasion of various alien and indigenous species, is evidence that in order to improve conservation of the highly threatened Renosterveld Shale, a certain extent of restoration is required.

Figure 81: Figure ground map of existing structures on Signal Hill. Source: Author edited from Google Earth, 20

Figure 79: Source: https://wp.wpi.edu/capetown/projects, 2013

(A) Public toilets with Enviro Loos and a radio tower **(B)** are situated close to the parking lot

Figure 78: Source: Google Earth, 2018

(C) Viewing platform made from timber provides a view over Seapoint and Lions Head

Figure 77:Source: https://www.morequarters.co.za, 2016

(D) Lift-off area for paragliders and sunset viewing area covered with a tarp.

Figure 80: Source

(E) The Appleton Scouts campsite was once a WWII RADAR base in 1941

Temporary infrastructure on the summit of Signal Hill included a public sculpture called the SunStar, designed by artist Christopher Swift, which was partially constructed from old fencing from the prison on Robben Island. The 25metre high, eight-pointed star would light up at night, a symbol of a brighter future. The LED's on the installation were powered by photovoltaic cells on top of a temporary shipping container. After a period of six-months it was permanently relocated to Sun Internationals' Sun City Resort.

Figure 82: the SunStar installation illuminated during the night by LED's powered by a series of photovoltaic cells.
Source: Simon Richmond, 2015

7.6.1.5 The people

Signal Hill falls under the Cape Peninsula National Park (CPNP) and as such is visited annually by Tourists, nature conservationists and locals from around Cape Town. According to the Conservation Development Framework (CDF) for the CPNP of 2001, park visits occurred predominantly at the City Bowl sites, which include Signal Hill. This has classified Signal Hill as a 'High Intensity Leisure Zone' where many human activities are accommodated. These zones are accessible by motor vehicle and often are the gateway to other zones. The CDF proposes that infrastructure such as restaurants, braai facilities, bush camps, formal/informal trading, and environmental facilities could be provided at these high intensity leisure zones (CDF for CPNP, 2001). Large scale tourist facilities should however preferably be located within the urban areas of these zones.

A high-volume site such as Signal Hill accommodates more than 100 000 visits annually, the majority of which are tourists (CDF for CPNP, 2001).

The building will look to respond to the proposal of the CDF and include amenities for tourists such as restaurants, an information centre, local community artwork workshops and exhibition spaces, and nature conservation including the restoration of endangered plant species and a response to the water crisis which will also serve as an environmental education facility.

A local community living on an abandoned military base in Tamboerskloof also called ERF 81 (fig 77.), have turned the abandoned plot of land into a home and work environment. The vibrant community consists of artists, writers and musicians, it serves as a foster home for abandoned children, a place to grow vegetables and has become a conservation area for animals who are facing an ever- increasing habitat loss.

Figure 83: ERF 81, Tamboerskloof, is home to a community who have been excluded from the City of Cape Town. Source: Author edited from Google Earth, 2019

Figure 84: Frog Nursery and Workshop.
Source: Ashley Walters, 2017

(A) ERF 81 Frog Nursery and Workshop.

Andre Laubscher, who began the ERF 81 community after coming across it whilst searching for pastures for his goats, decided he would have to stay after rain fell and he heard the croaking of frogs.

Figure 85: Treehouse, ERF 81.
Source: Ashley Walters, 2017

(B) ERF 81 Children's playground

Homeless children who found refuge within ERF 81 play amongst the trees, surrounded by animals.

Figure 86: Military Barracks, ERF 81.
Source: Google Earth, Deontjie, 2018

(C) ERF 81 Military Barracks

The military barracks on ERF 81 are now used as a type of informal housing

ERF 81 is a site of historical value and provides meaning to community members as well as the City of Cape Town. The proposed building may be able to provide support and further exposure to this farm, which is threatened by urban development. The design proposal is intended to create awareness around this community by providing exposure through workshops and art exhibitions. Additionally the community can be supplied with clean, potable water from the fog harvesting systems.

7.6.1.6 Wind and fog

Cape Town has a Mediterranean climate which means it experiences cold winters and hot summers. The dry periods are in January, February, March, November and December. Although rain in scarce during these months, fog still frequents the late summer months and occurs throughout the year.

Figure 87: Prevailing wind patterns over the Western Cape. Source: http://maritimesa.org, 2015

Figure 84 shows how the prevailing winds move over Cape Town. These wind directions are important because they push the fog that forms in the Atlantic through Cape Town. This fog is usually quite dense at an altitude of 300m and above and often engulfs Signal Hill. Additionally, the winds are required as they need to drive the fog through the water harvesting surface in order for the water to condense on the material.

The majority of fog which occurs around Signal Hill is advection sea fog, blown in from the Atlantic, although upslope fog does occur occasionally. The density of the fog will also increase with wind speeds of around 15 knots (27.78km/h).

Figure 88: time-lapse photo using long exposure showing how fog moves over Cape Town. The fog is most dense as it moves over the hill and exists at heights from 300-500m. Source: Eric Nathan, 2013

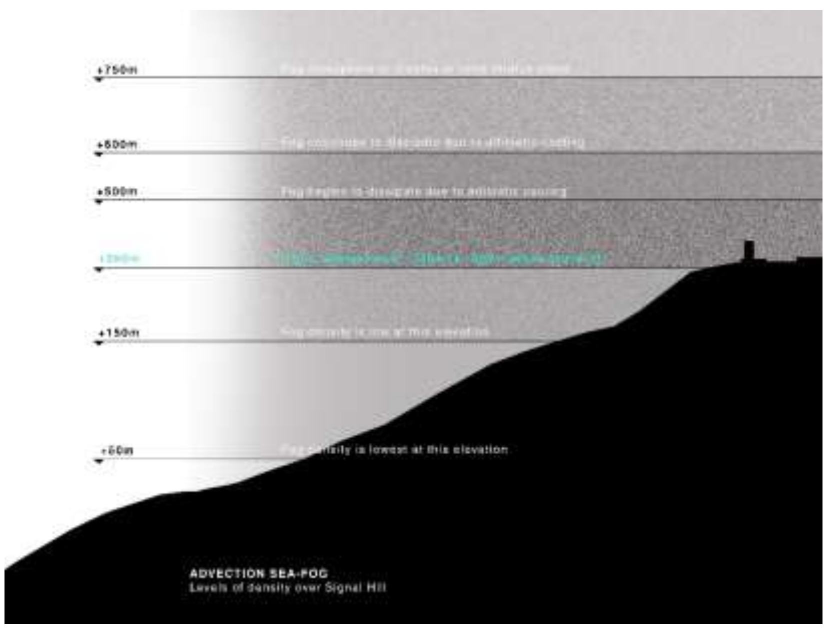


Figure 89: Most of the time, advection fog ranges between a few hundred meters in total depth, becoming thinner at its lowest and highest points as it dissipates. This can be observed when it gets pushed over mountains and hills. Source: Author, 2019

Conclusion

Signal Hills spirit is steeped in history, culture, nature conservation, tourism and recreational activities. It is a sensitive site which has to be treated as such. The following chapter will discuss how the proposed design will interact with the site.

7.7 Early design developments

Reaching the summit of Signal Hill on foot via one of the stony hiking paths would slowly reveal a sleek tower reaching out of the irregular landscape, glowing softly like a lantern. The fog harvesting tower reaches up into the sky, intercepting fog up to a 400m altitude. The journey would continue through a series of low-lying angular buildings, like the jagged rocks and stones which form part of the landscape. The visitors centre acts as a wayfinding and orientation point, as well as an information centre for tourists. Walking through the curved path, now with walls on either side, occasionally reveals glimpses of what lies ahead.

Initial design developments developed around the idea of a fog harvesting tower as the primary hierarchical element which would always be visible to serve as a symbol of the end of water scarcity as a chronic problem. It embodies the symbolism of Signal Hill as a beacon of hope for visitors and locals.

The Fog harvesting tower is a 50m high cylindrical structure which necessary to extend to a higher altitude to take advantage of the densest fog. The tower merges with the landscape which forms part of a rooftop garden consisting of a large variety of Fynbos and Renosterveld Shale species.

The tall, elegant cylindrical tower allows a great surface area for the substructure and its mesh nets, which condense the water vapor from fog events. As the tower is ascended via the helical staircase, the views are extended to the entire City bowl, and it is observed how the condensed fog water trickles down the nets to fill up the water reservoirs. The tower is regarded as the termination point of the physical journey, providing an overview of the various tactile and learning experiences.

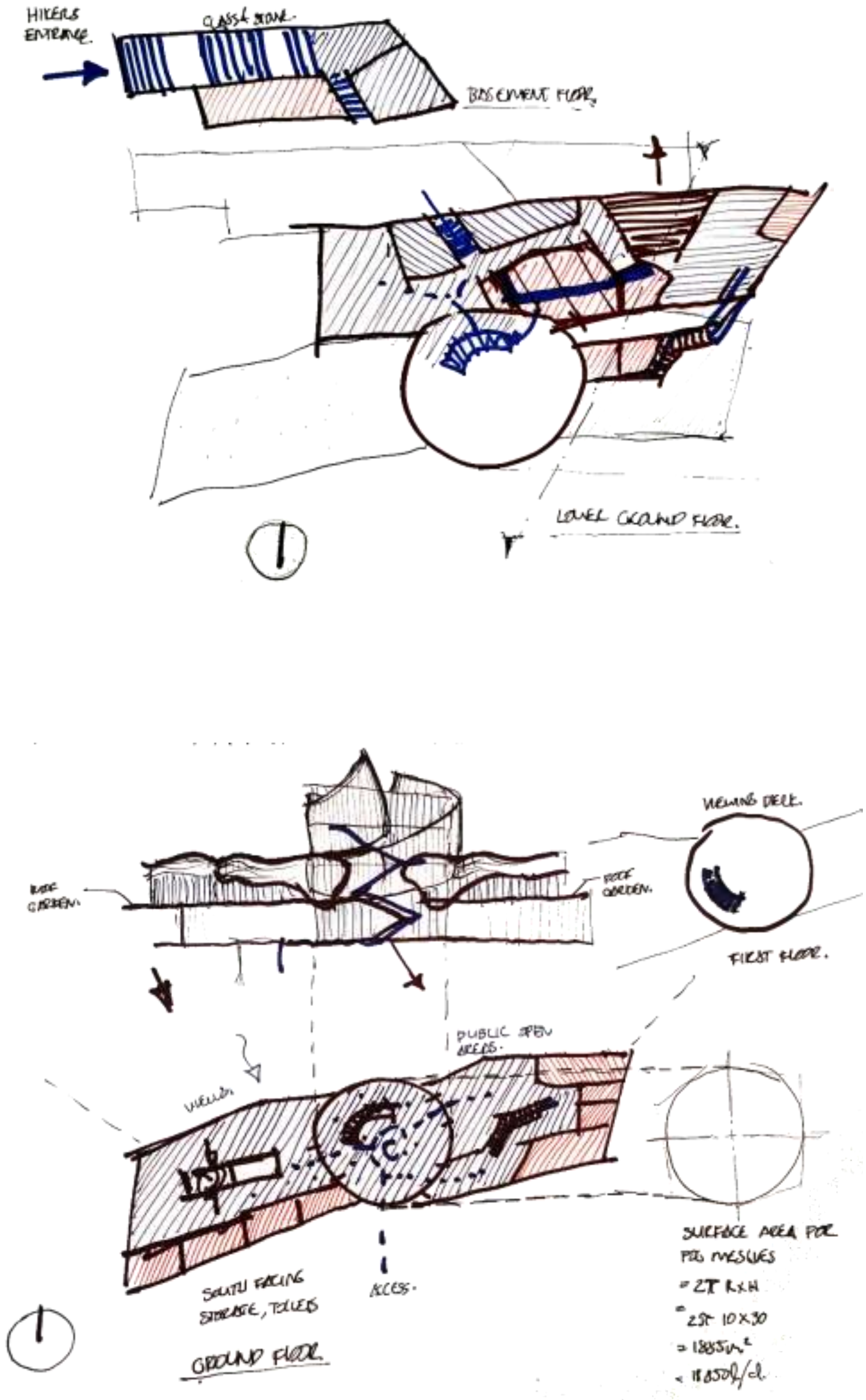
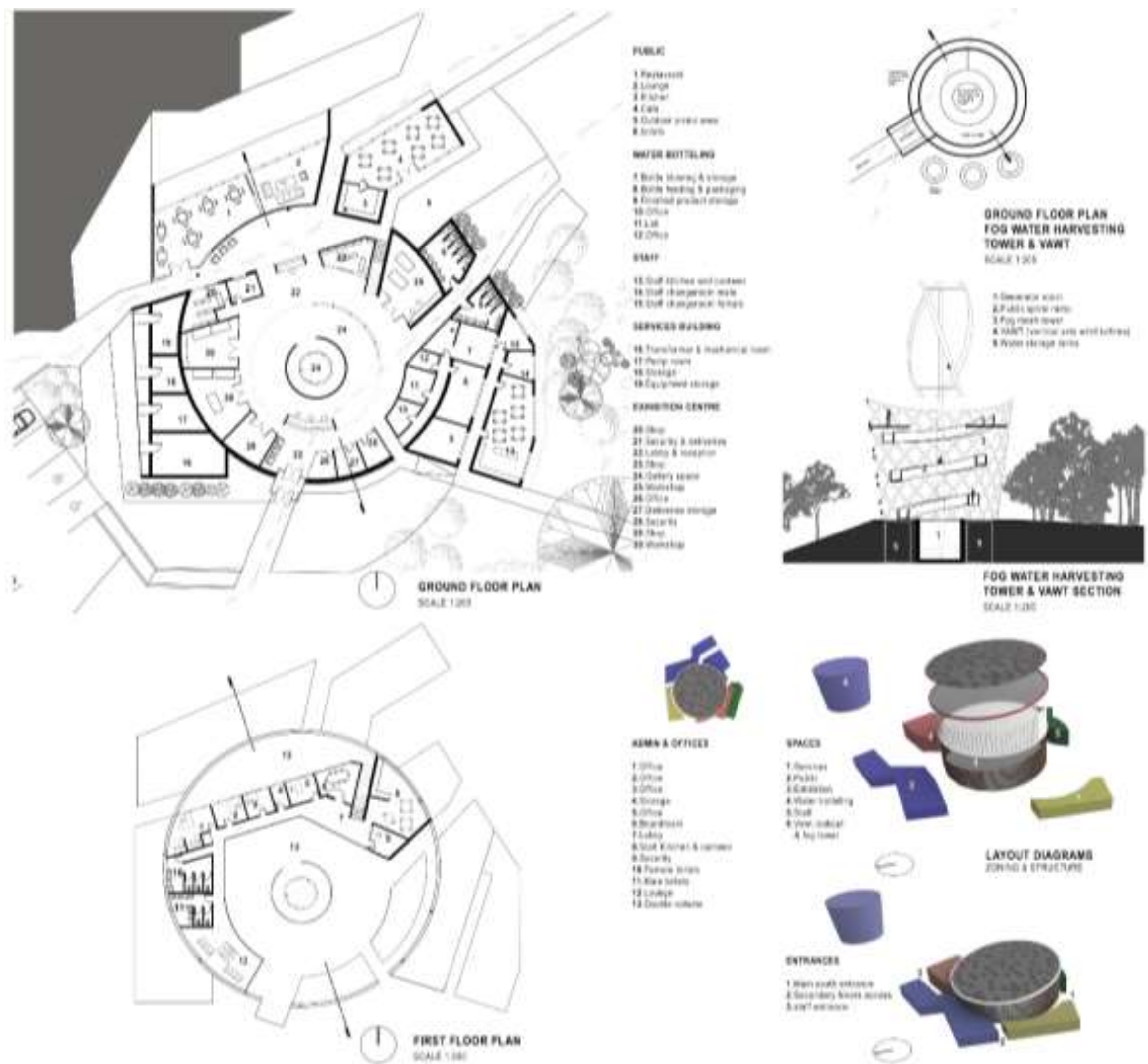
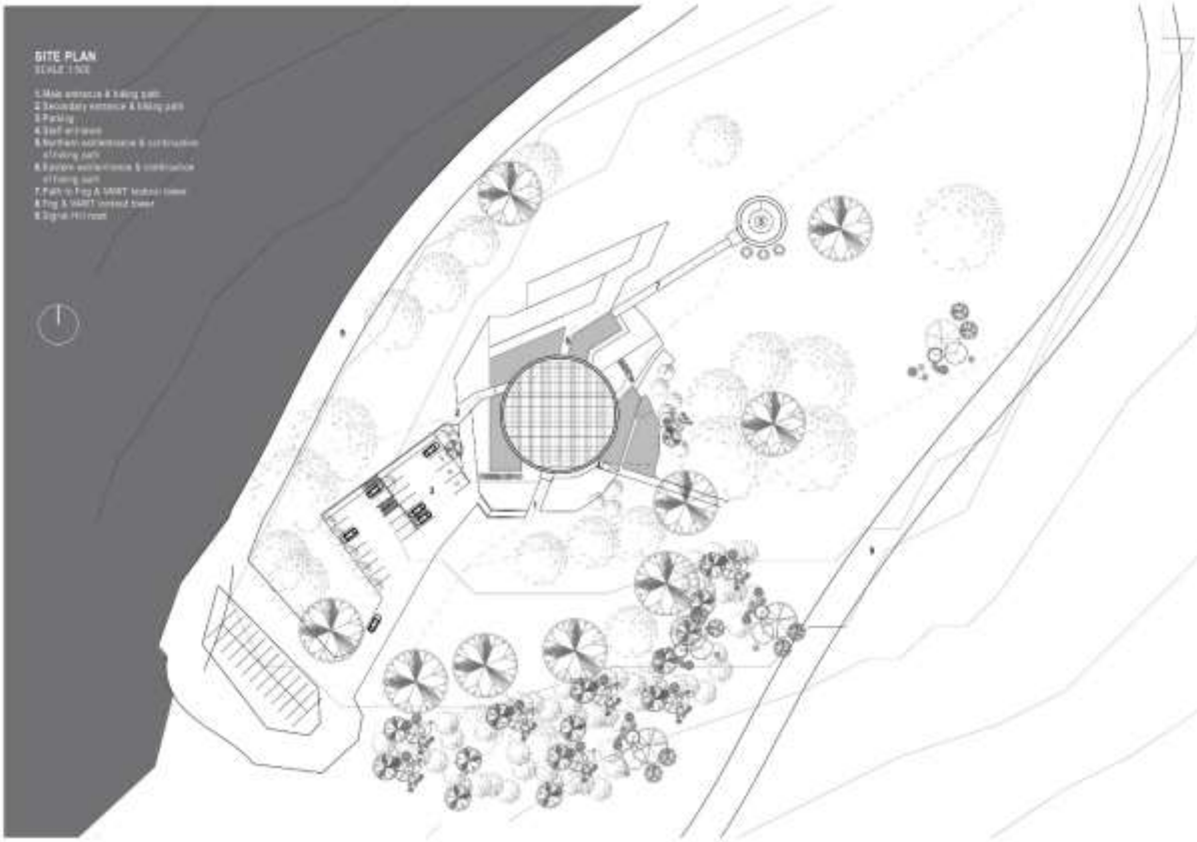
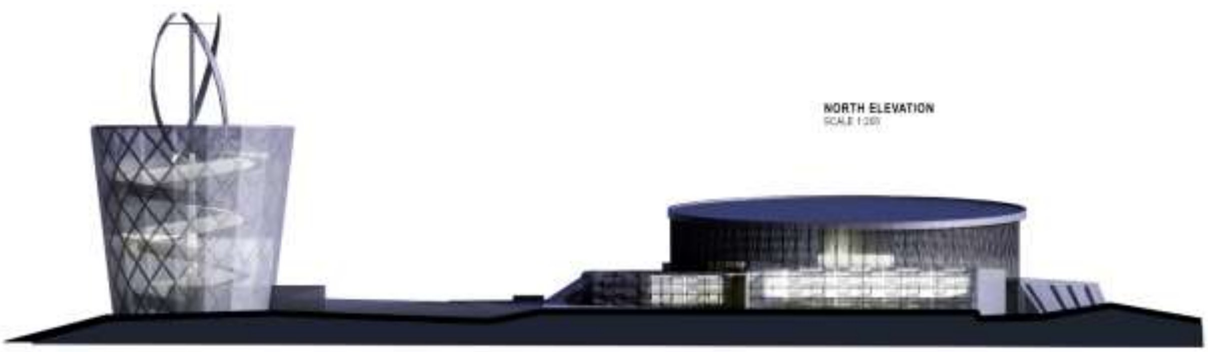


Figure 90: Initial design concept centred around the tower as part of the entire building. Source: Author, 2018


STRUCTURAL.
STABILIZERS IF NEED.
MESH.
LIGHTS INSIDE STRUCTURAL ELEMENTS.
ONLY LIGHT BREEZE
STRUCTURE CAN MOVE IN THE WIND.


PUBLIC
WATER BOTTLING
STAFF
SERVICES BUILDING
EXHIBITION CENTRE
GROUND FLOOR PLAN
GROUND FLOOR PLAN
FOG WATER HARVESTING
TOWER & VAWT
FOG WATER HARVESTING
TOWER & VAWT SECTION
ADMIN & OFFICES
SPACES
LAYOUT DIAGRAMS
ENTRANCES
FIRST FLOOR PLAN


SITE PLAN


NORTH ELEVATION


SOUTH ELEVATION

7.7.1 Developed Concept sketches

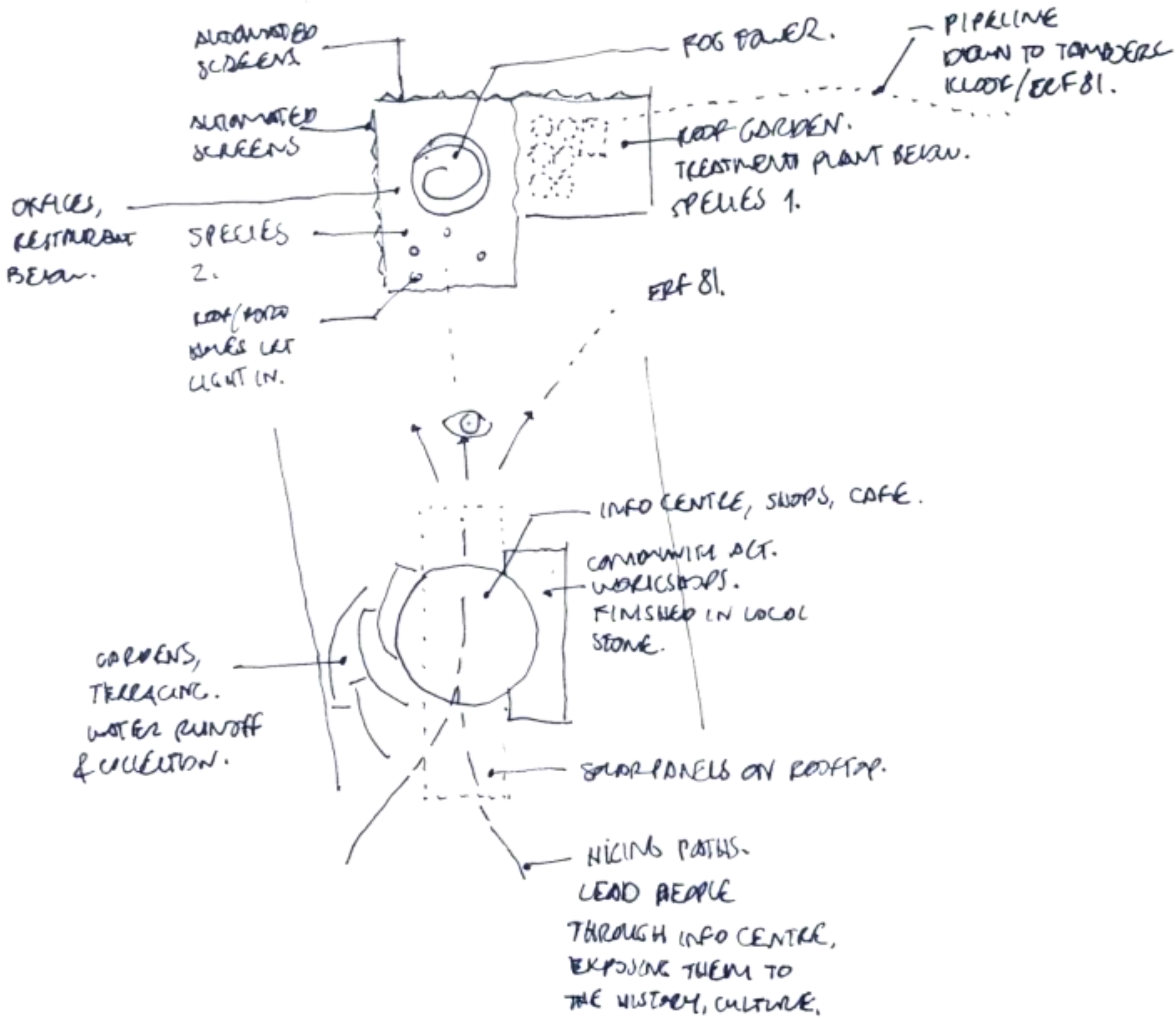


Figure 91: Concept design sketch laying out the various elements of the design. Source: Author, 2018

Figure 92: When wind hits the surface, vortices are created which swirl the fog around. If the tower is open, many small vortices can happen within, essentially trapping the fog and allowing it to pass through the mesh nets multiple times, allowing a higher amount of water droplets to settle. Source: Author, 2018

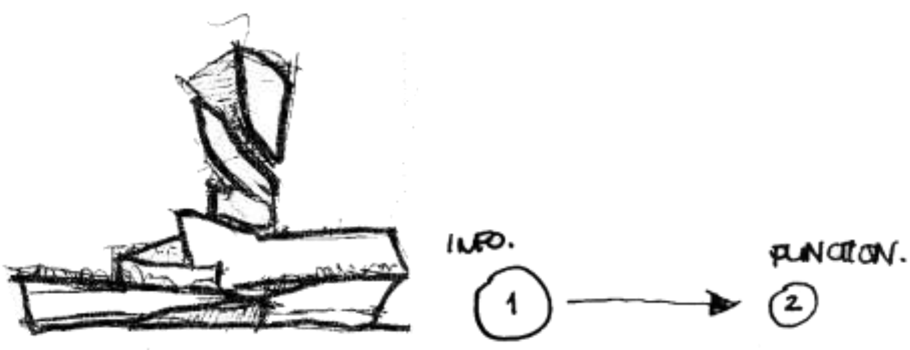


Figure 93: concept sketch with building rising from the ground and terminating in a vortex shaped tower. Source Author, 2018

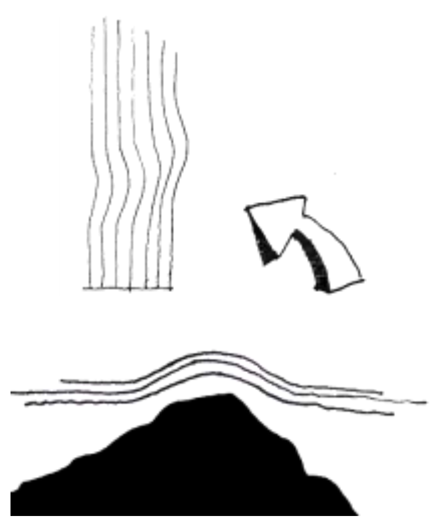


Figure 94: The towers form was inspired by how fog moves over hills. Source: Author, 2019

Fog density

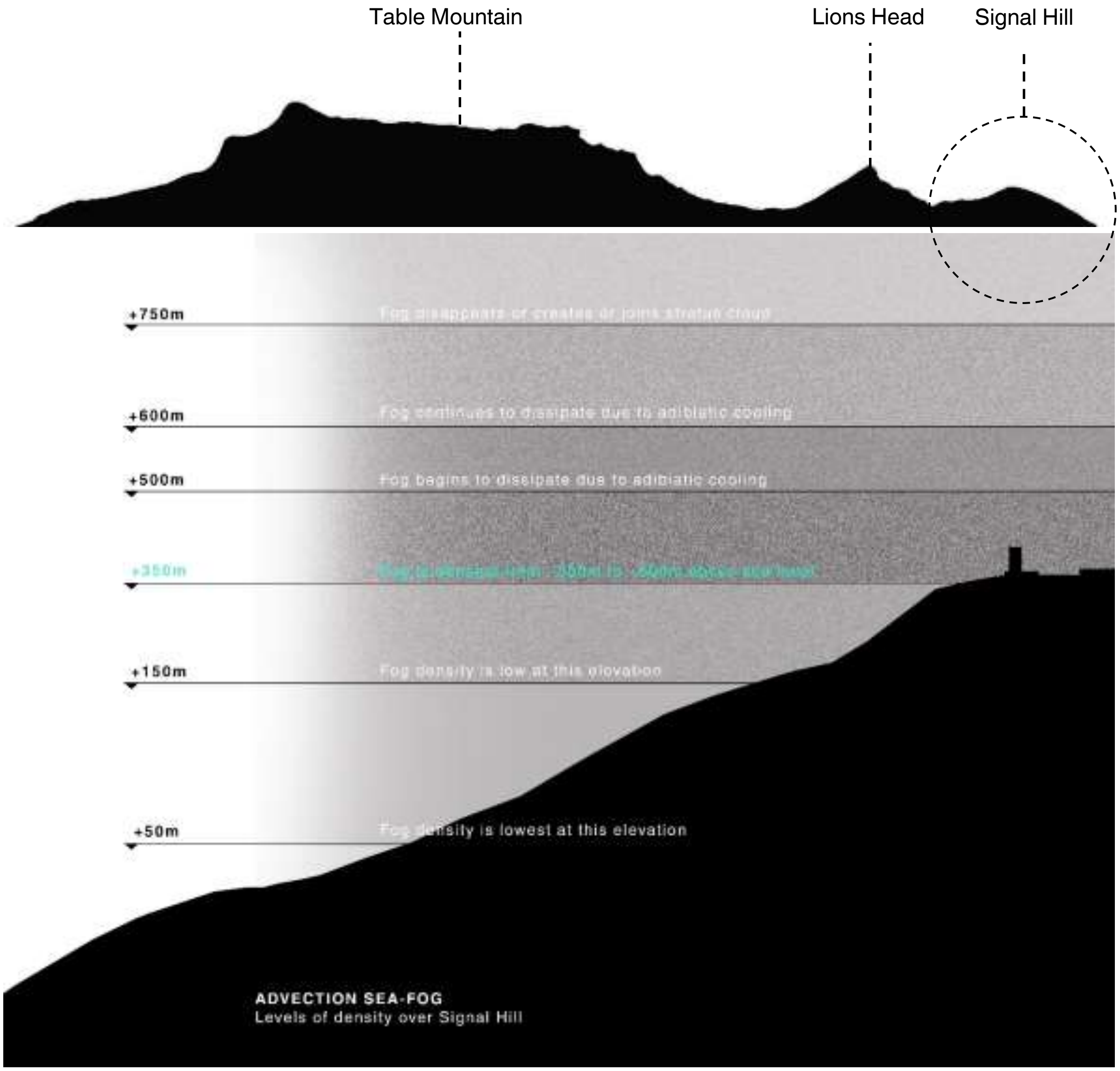


Figure 95: section through signal Hill showing fog densities at different heights. Source: Author, 2019

The majority of fog events which occur over Signal Hill are due to advection sea fog and are blown in from the Atlantic. Figures 95 and 96 depict the densities of fog at different altitudes. In order to maximise the amount of water that can be collected it is important to intercept the fog in the region where it is the densest. Fog density can range between 0.05 g/m3 of water for medium fog (visibility of 300 m) and 0.5 g/m3 for thick fog (visibility of 50 m).

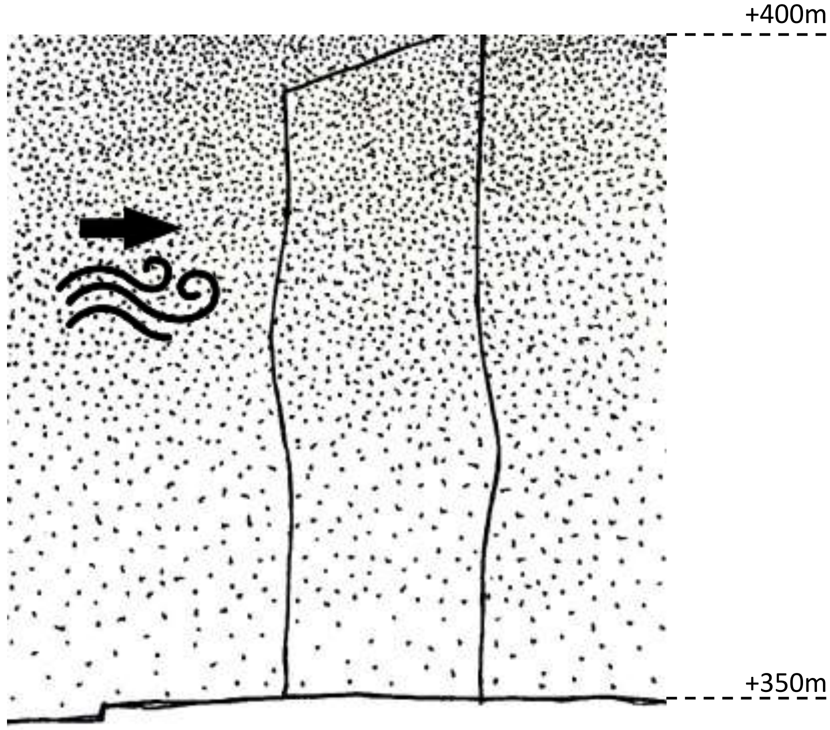


Figure 96: Fog Density on a micro scale, ranging from 350 to 400m. Source: Author, 2019

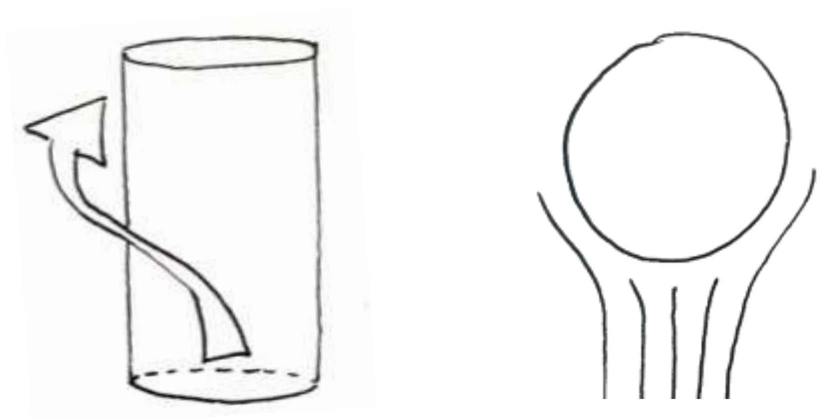
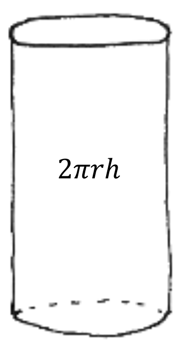


Figure 97: wind deflects around curved surfaces, greatly reducing drag compared to flat surfaces. Source: Author, 2019



Surface area of curved sides = $2\pi rh$

= $2356m^2$

Minus surface area of columns = 2356 - 625

= $1731m^2$

At $10L/m^2$ the tower can collect **17 310L/day**

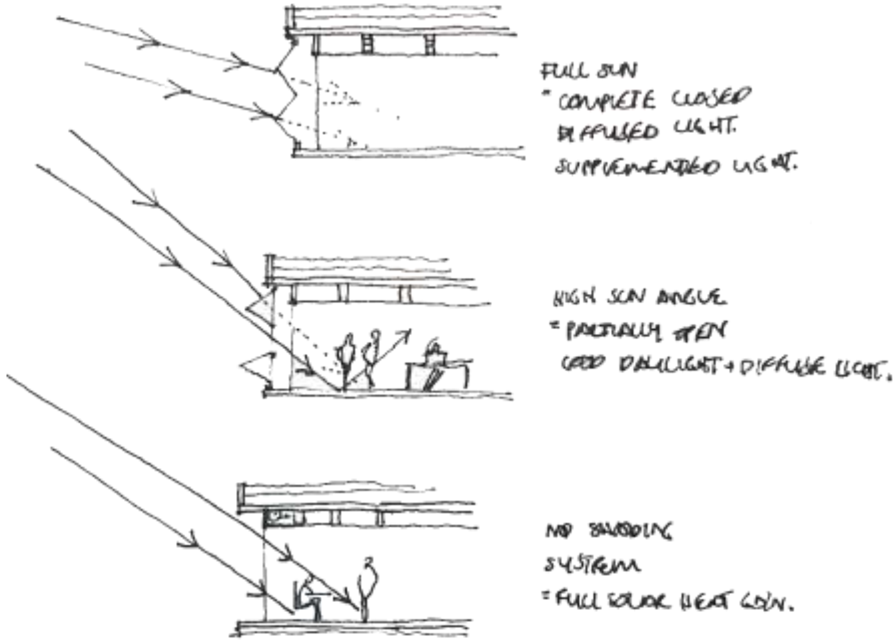


Figure 98: Automated shading screens open up the spaces according to the path of the sun and the luminosity. Sensors detect light levels, so on an overcast day screens will be opened fully to allow maximum daylighting. Source: Author, 2018

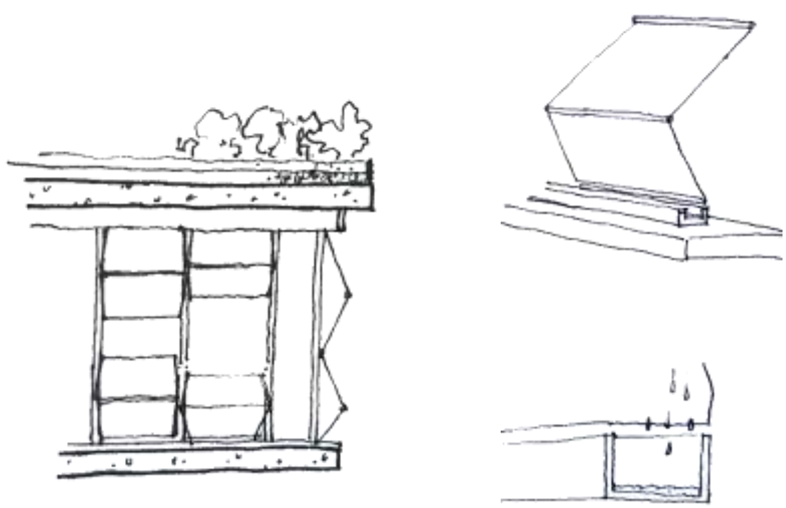
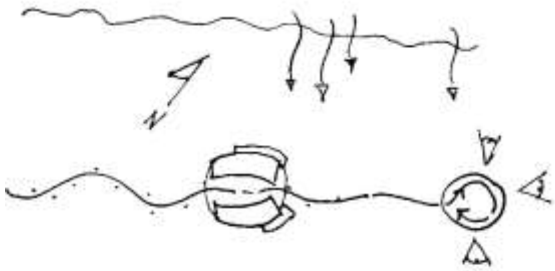
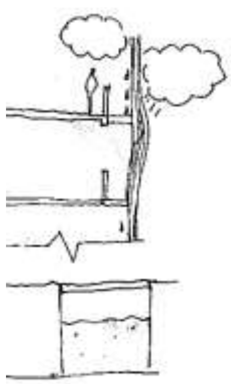


Figure 99: On foggy days the screens close, creating a surface for fog to settle on. The droplets of water run down into a gutter which is transported to a storage tank. Source: Author, 2018



-Hiking path leads into visitors' centre
-Path continues up to fog water tower
-Tower provides 360˚ views of the journey

-The water bottling and purifying plant is embedded in the landscape
- Fynbos roof garden disguises the building below and enhances the natural landscape



-The fog collects on the mesh and is guided down into storage tanks below ground. The entire process can be viewed by users of the building

-visitors centre rises out the landscape
-solar panels on the roof power the building
-Tower rises 50m to intercept the dense fog
-vertical axis wind turbine helps power the bottling and purifying plant below

-Fog water mesh/nets between the vertical columns of the tower

-The height and diameter of the tower allow a large surface harvesting area, maximizing yields. Yields up to one million litres can be expected annually.

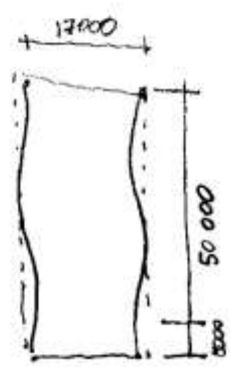


Figure 100: Concept design sketches. Source: Author, 2018

7.7.2 Accommodation Schedule

Water Purifying and Bottling Facility

- Water collection and storage tanks, capacity 1 000 000 litres
- Filtration and purification space
- Labs
- Research labs
- Bottle blowing and bottle storage
- Bottle feeding and packaging
- Mechanical and electrical rooms
- Reception and lobbies
- Clean room
- Waste storage
- Storage
- Equipment store
- Deliveries
- security
- Offices
- Staff change & bathrooms
- Staff canteen & kitchen
- Public space

Visitors Centre

- Public toilets
- Roof garden fynbos exhibition
- Viewing platforms
- Workshop x2
- Gallery
- Exhibition space
- Auditorium
- Restaurant
- Café
- Shops
- Office 3x
- Security
- Storage
- Lobby and reception
- Public toilets
- Generator room
- Mechanical and electrical room
- Equipment store
- Store
- deliveries

Technological Considerations

The impact of digital technology on the architecture is expressed in various ways. The research showed that some of the most effective implementations of digital technology are in the form of kinetic or adaptive facades, which respond to the path of the sun and adjust accordingly to reduce solar gain and control interior daylighting. Furthermore, the facades will also be used to harvest water from rain and fog.

In order to provide an optimal response to climatic conditions and solar gain, the facades of the building are automated in two ways. The main shell of the circular building consists of automated slats (fig. 101) which have been programmed to swivel as the suns path moves during the day. On overcast days, sensors on the roof will override the pre-programmed control and open all slats to allow for maximum daylighting. The slats can also be controlled to allow for air flow through the building.

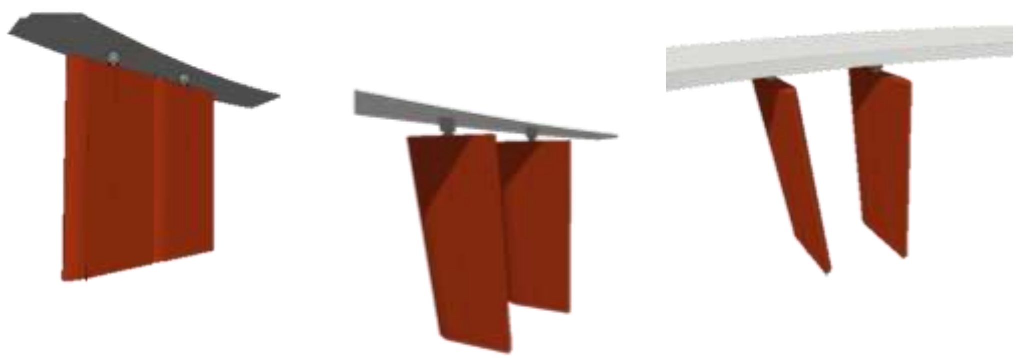


Figure 101: slats are able to automatically swivel according to the exterior conditions. Source: Author, 2018

A façade was developed for the Water purifying and bottling facility, which expands and collapses, similarly to an umbrella (fig 102). The system is made of aluminium with a polytetrafluorethylene (PTFE) fabric shade-cloth, which doubles as a fog-water collection surface.

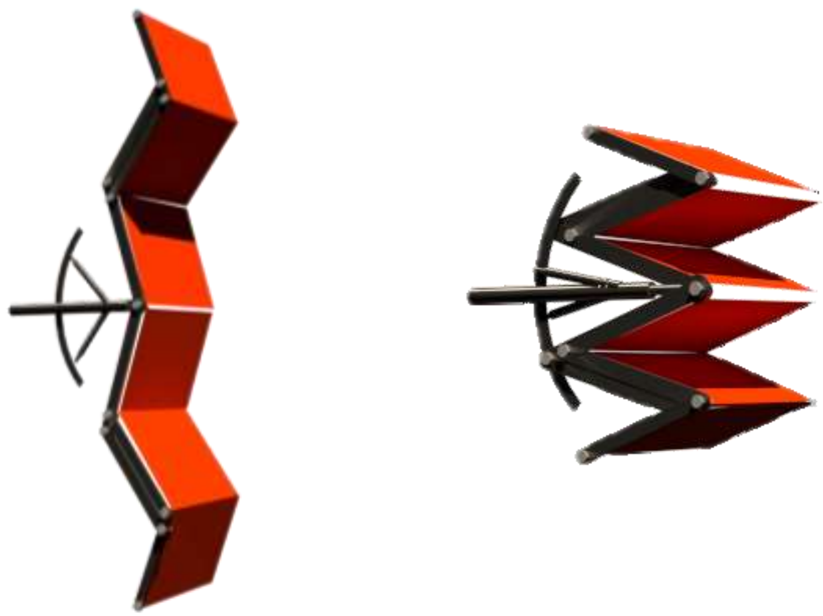


Figure 102: Kinetic facade panels. Source: Author, 2018

The main shell of the Visitor's Centre has a roof consisting of a combination of glass panels, solar panels and fynbos gardens. The solar panels have an output of 250kW each, averaging 1000 watts per day per panel (1kWh), with 4 hours of sunlight.

Material choices

The cladding of the Visitor's Centre consists of panels sourced from the local cape granite and slate rock formations on Signal Hill.

The stone acts as an insulating material and helps keeps the interior spaces cool in summer and warm in winter.

The stone finish also allows the buildings to rise from the ground as if a natural rock formation (fig. 103; fig 104, 1), and pays homage to some of the earliest buildings in Cape Town which were constructed using Slate and granite.

To juxtapose the heavy, grounded walls, glass with translucent insulation is used to elevate the upper floor of the visitor's centre (fig 104, 2) in order to provide an ethereal floating effect, which is inspired by the fog which 'floats' over the hill.

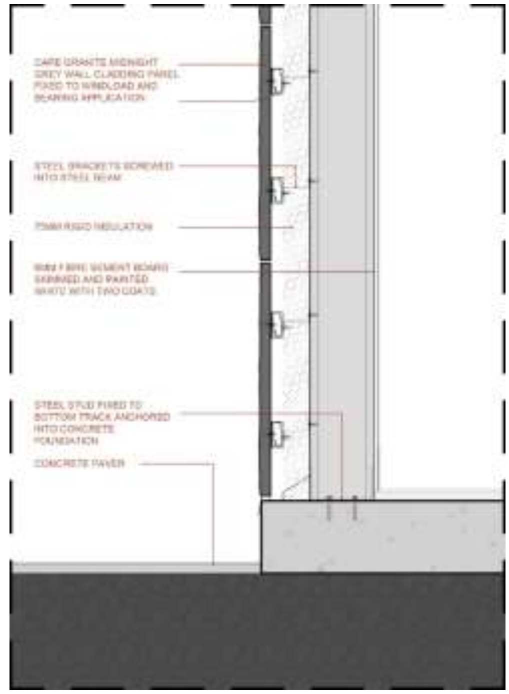


Figure 103: cladding detail for the visitor's centre consists of local cape granite and slate. Source: Author, 2018

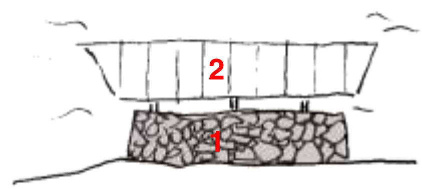


Figure 104: visitors centre sketch

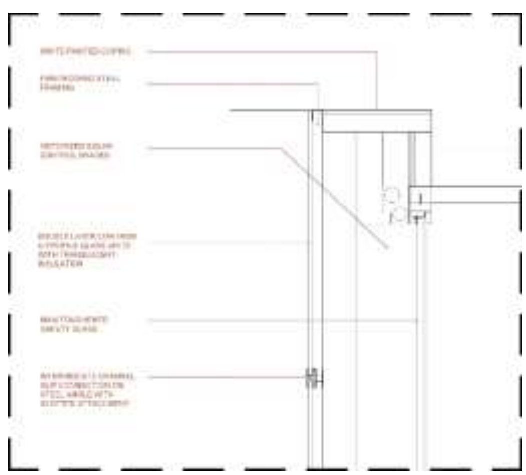


Figure 105: detail showing the facade system for the first floor of the visitor's centre. Source: Author, 2019

The water bottling facility and fog harvesting tower combines two structures — the bottling facility is underground, concealing its function beneath a garden of endemic renosterveld. The filtration system is aided by gravity. The north, east and south facades are exposed and daylighting and temperature are controlled by an automated façade system. This system also serves as a fog harvesting surface (fig. 107, 1; fig. 106), the mesh screens directing water into a storage system which supplements the buildings users drinking supply.

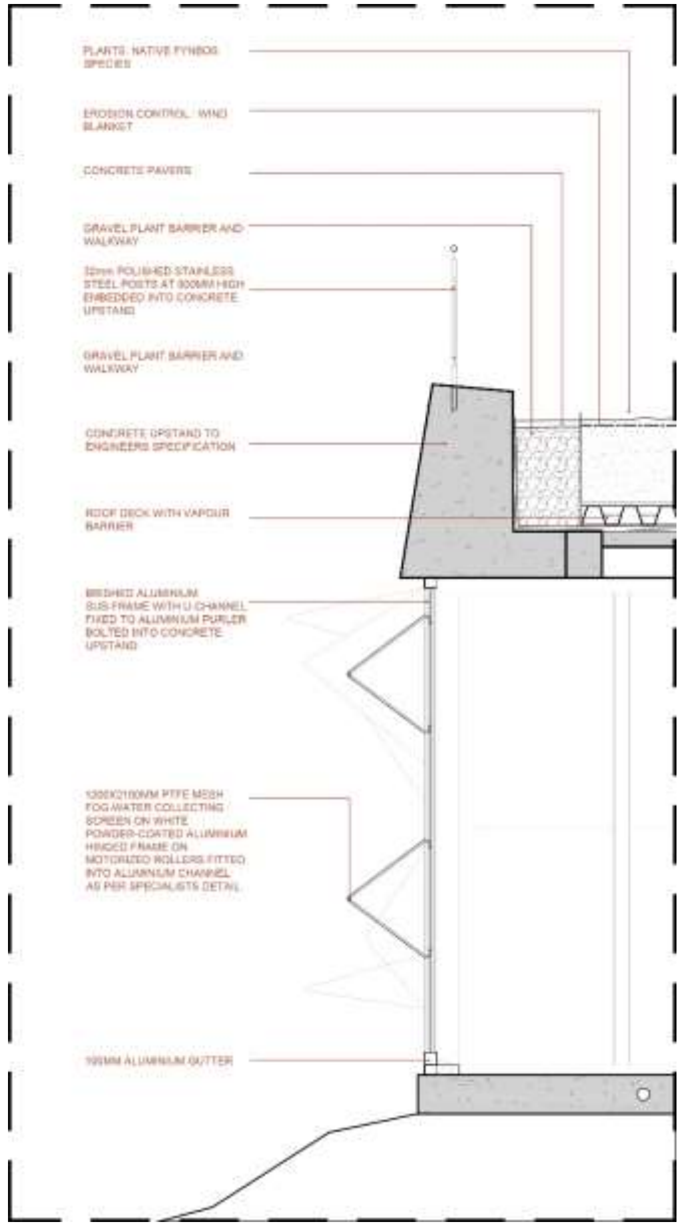


Figure 106: Bottling centre detail section. Source: Author, 2019

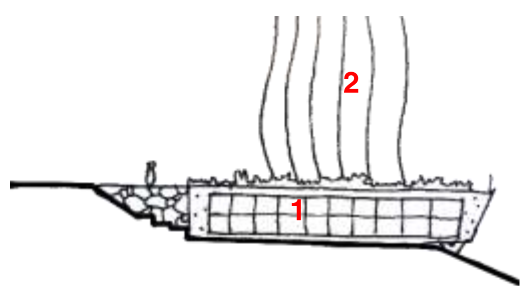


Figure 107: Water Bottling facility and Fog harvesting tower. Source: Author, 2019

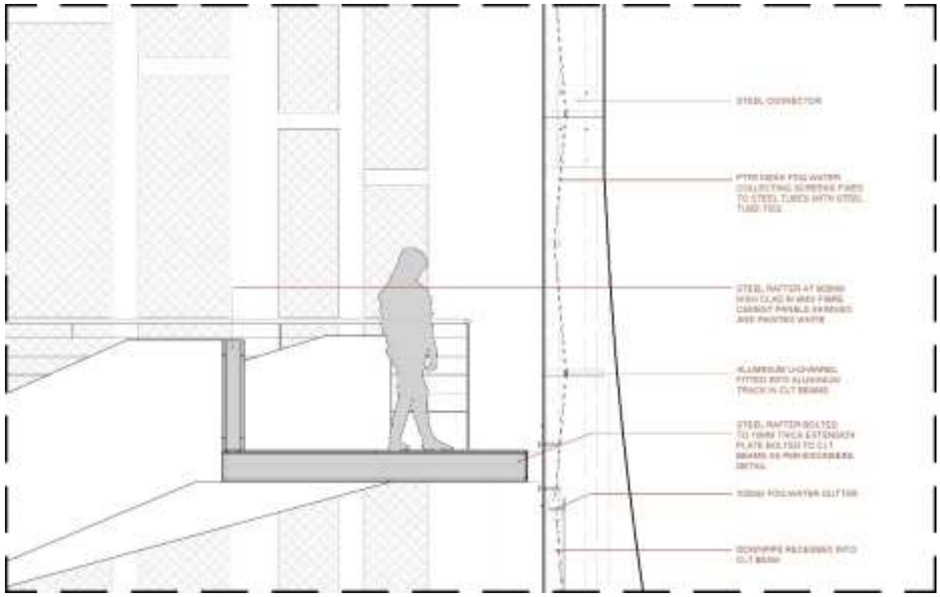


Figure 108: Fog harvesting tower detail section. Source: Author, 2019

The fog harvesting tower reaches up into the sky at a height of 50m. This is important as fog is densest at higher altitudes. The towers structure is made from timber beams which are assembled in parts. The fog harvesting mesh is spanned between the beams with steel rods (fig. 108). The droplets of water which condense on the mesh are pulled down by gravity into closed gutters, which transport the water down into the treatment, purifying and bottling plant. The cylindrical form of the tower and the gaps between the beams allow for a high resistance against wind as well as pay homage to the signal cannons. The fine mesh used to collect water is translucent but visible to birds, ensuring that they do not fly into it.

Structural Influences

Further influences came in the form of a parametric script created in Dynamo, used to design the fog harvesting tower (fig. 109). The tower is fully parametric, meaning everything is adjustable and configurable. The towers height, number of floors, structural components and shape can all be optimized according to wind loads and direction as well as structural stress factors.

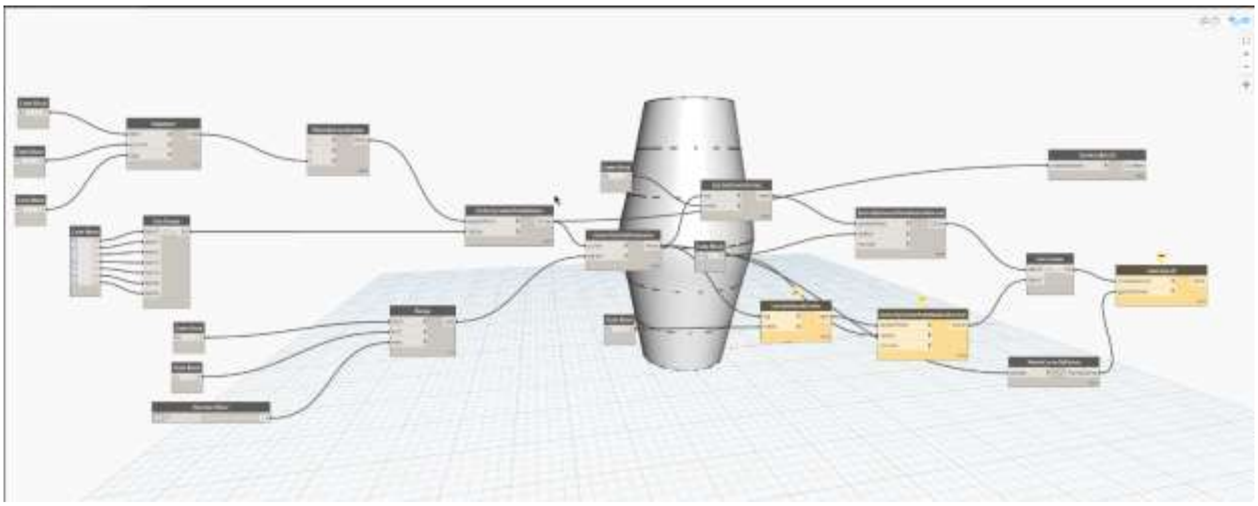


Figure 109: Parametric script for Fog harvesting Tower design. Source: Author, 2018

The cylindrical shape also takes inspiration from the Signal Hill cannons, a homage to its name.

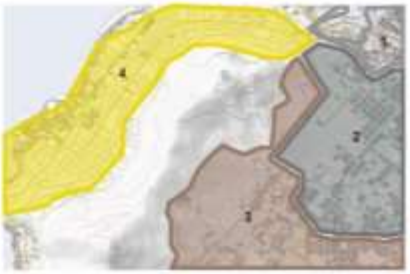
The proposal seeks to embody an innovative architecture by embodying various digital technologies in order to enhance the effectiveness of the design holistically. At the same time, it integrates with its surrounding context, both in form and in materiality. The result is a juxtaposition of natural materials with man-made materials, hardness and softness, lightness and heaviness, translucent and opaque.

The proposal acknowledges its position as a framework for contemporary culture, technology, art, and the issues of water conservation and sustainability in the future of South Africa.

Exploring the role of digital technology in enhancing an environmental responsive architecture

Towards a Fogwater harvesting and Visitors Centre in Cape Town

SITE DEMOGRAPHICS



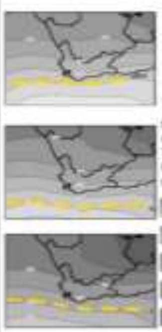
Multitude of Hiking routes

Steep terrain, <30cm topsoil consists of rubble with 15-20% clay

Vehicular access via Signal Hill road allows for services to be accessed & Parking

Sparse cover of Fynbos on site @15 species per square meter

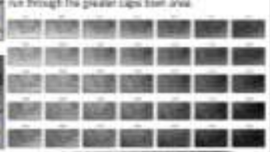
Medium level noise on site. Trees on eastern slope offer some buffering protection of city noise



SOM - Self Organizing Maps

The SOM is an algorithm used to visualise and interpret large high-dimensional data sets. In this case it is used with historical climate data to generate points of high fog probability

Historical climate data from 2392 days was arranged and used to train the SOM software.
The results depict areas in which a high frequency of fog occurs. We can see that the pressure differences run through the greater cape town area.



The water crisis in Cape Town has gained a lot of attention and created awareness on water conservation nationwide. With no rainfall imminent, alternative methods of harvesting water are being explored. Out of the 9 provinces in South Africa, Cape Towns climate is unique. Rainfall averages are higher in the winter months but lower during summer. This ultimately results in droughts when water is most needed. Not only is the climate unique, but the terrain and landscape offer a setting unlike any city in South Africa.

PROBLEM STATEMENT

Environmental architecture and sustainable design are not progressing in line with current technological advancements. Simultaneously the stigma that digital technology is a cause for disconnect with the natural environment must be challenged.

ARCHITECTURAL RESPONSE

Utilising digital technology throughout an architecture to enhance its environmental value. From energy conservations and human comfort levels to utilising specific regional climatic resources to their full potential.

WHY?

The connection between design and various other disciplines is either direct, as a design mediating tool, or indirect, as a platform for data or information translation. The combination of this is where the power of technology becomes apparent.

HOW CAN DIGITAL TECHNOLOGY ENHANCE ENVIRONMENTAL ARCHITECTURE?

DIGITAL FABRICATION

3D Printing & CNC machining have the ability to create incredibly precise components with reduced waste and using cutting-edge materials.

SIMULATION AND DESIGN

Simulations have the ability to accurately predict various structural stress factors as well as environmental impacts on the building. The advantage is that these factors can be addressed during the design stages.

RESPONSIVE ARCHITECTURE

Architecture which can respond to external environmental stimuli without human intervention is increasingly being allowed in order to optimise comfort levels for the user

THEORETICAL FRAMEWORK

ADAPTIVE ARCHITECTURE

adaptive architecture, like responsive architecture has the ability to adapt as conditions change, ensuring optimal living conditions at all times. It utilises smart materials and components which have the ability to respond to external environmental factors.

NEO-FUTURISM

Neo-futurism Draws Much of its Aesthetic from Imagining an Ideal Future The overall aesthetic of neo-futuristic architectural design can sometimes be seen as a rejection of pessimism and a reaching outwards toward a positive vision of the future.

PARAMETRIC DESIGN

The strength of parametric design is its ability for the design to adapt should any one of the parameters change. This means that if an improvement were made to a design component the entire design would not need to be reconfigured.

PRECEDENT STUDIES

Warka Water - Ethiopia
Arturo Vittori

[illegible]

Whitney Water Treatment Plant - New Haven, CT
Steven Holl

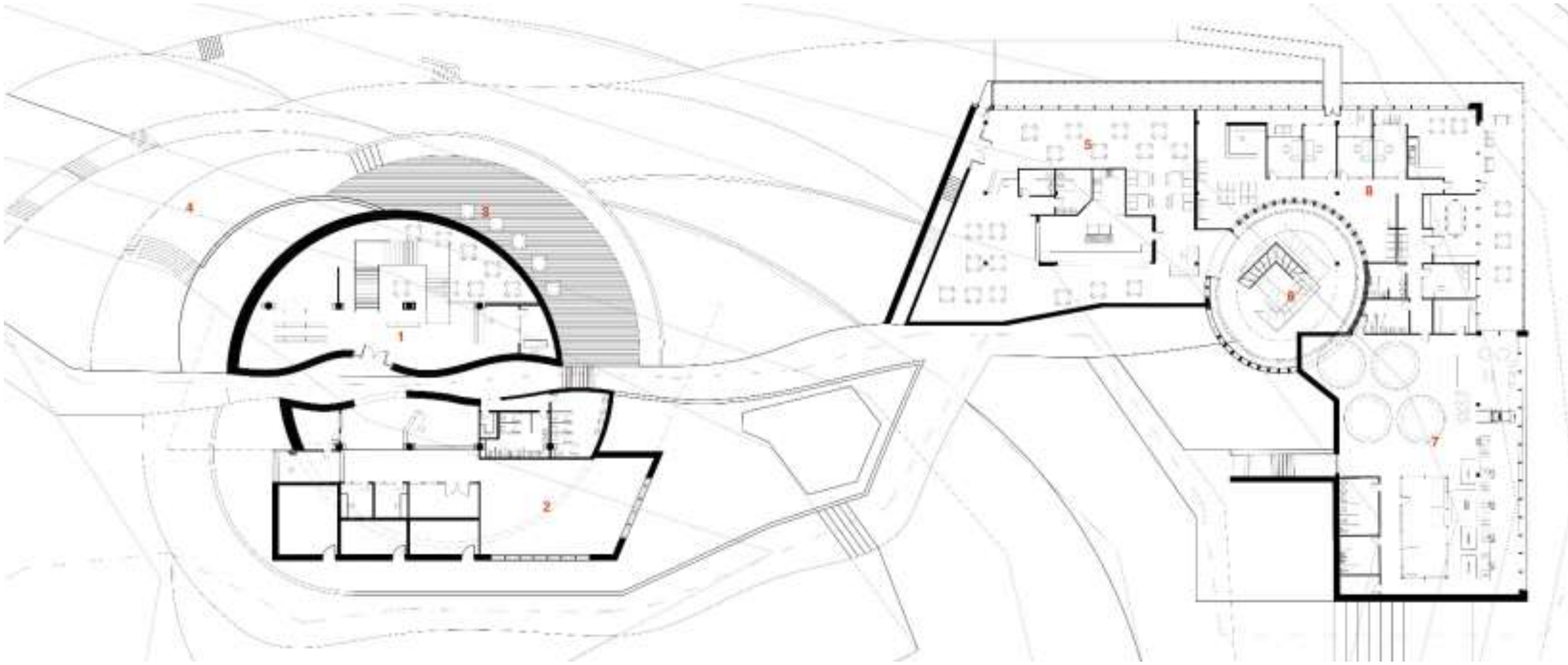
[illegible]

SIGNAL HILL ENGULFED IN FOG WITH ONLY LIONS HEAD PEAKING THROUGH

VIEW OVER THE EASTERN PART OF THE CITY BOWL

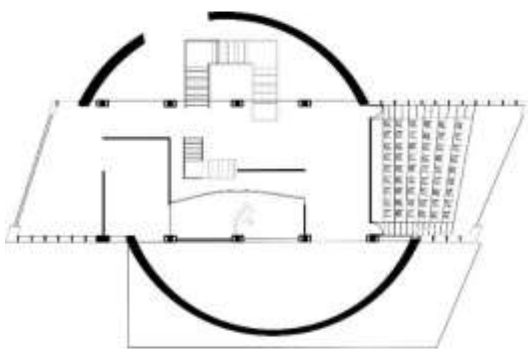
TABLE MOUNTAIN AS SEEN BEHIND SIGNAL HILL

THE SIGNAL CANNONS ON SIGNAL HILL PLAY A LARGE PART IN CAPE TOWNS HERITAGE



GROUND FLOOR PLAN

Visitors centre and Fog-Harvesting Tower and Water treatment and Bottling facility



FIRST FLOOR PLAN

Visitors centre – exhibition/gallery and auditorium

SECTION

NORTH ELEVATION

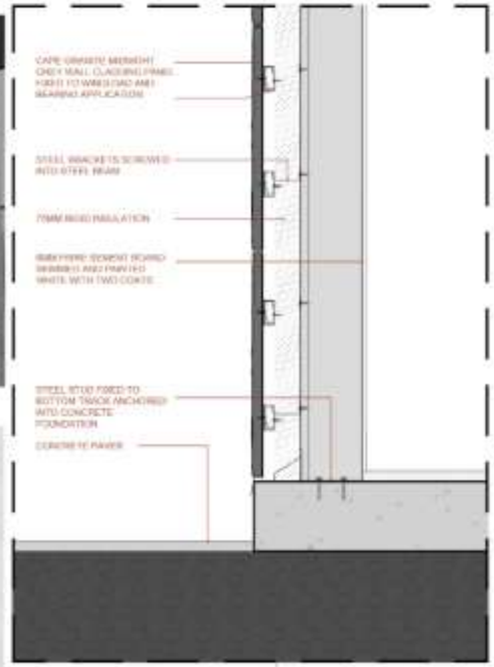

N
SITE PLAN
SCALE 1:500

The auditorium overlooks the Fog harvesting tower and the fynbos roof garden of the water purifying plant

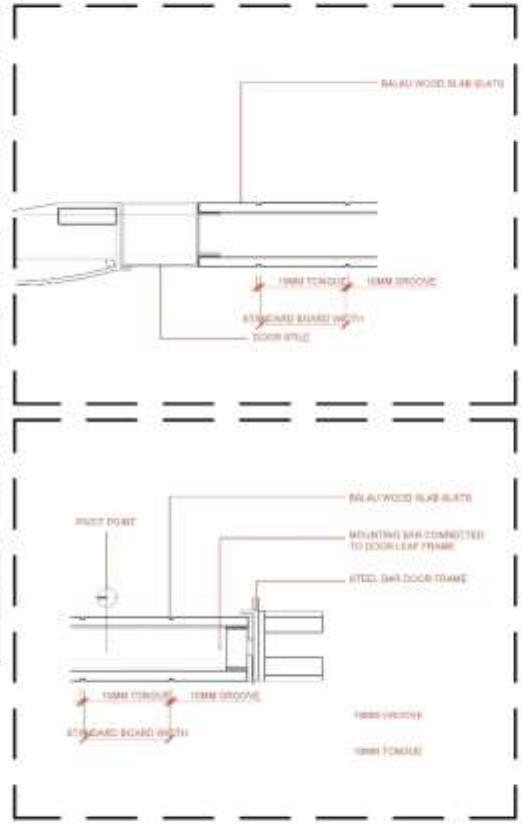
The shops and cafe of the visitors centre are shaded by automated steel slats which swivel according to the suns path.

The angled gallery draws pedestrians into the space below. The cape granite slab walls of the workshop juxtapose the smooth, light, gallery above whilst maintaing an anchored, grounded stance.

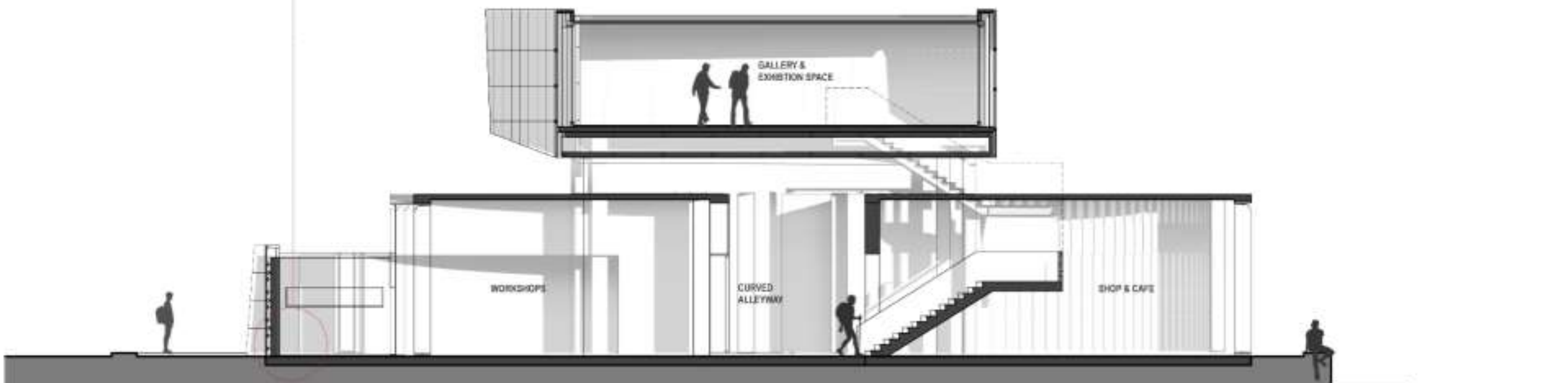
The natural hiking path is enhanced by the curved wooden paneled walls of the visitors centre which expose glimpses of twhat lies ahead.



STONE WALL CLADDING DETAIL
SCALE 1:10



PIVOT DOOR JAMB DETAIL
SCALE 1:10

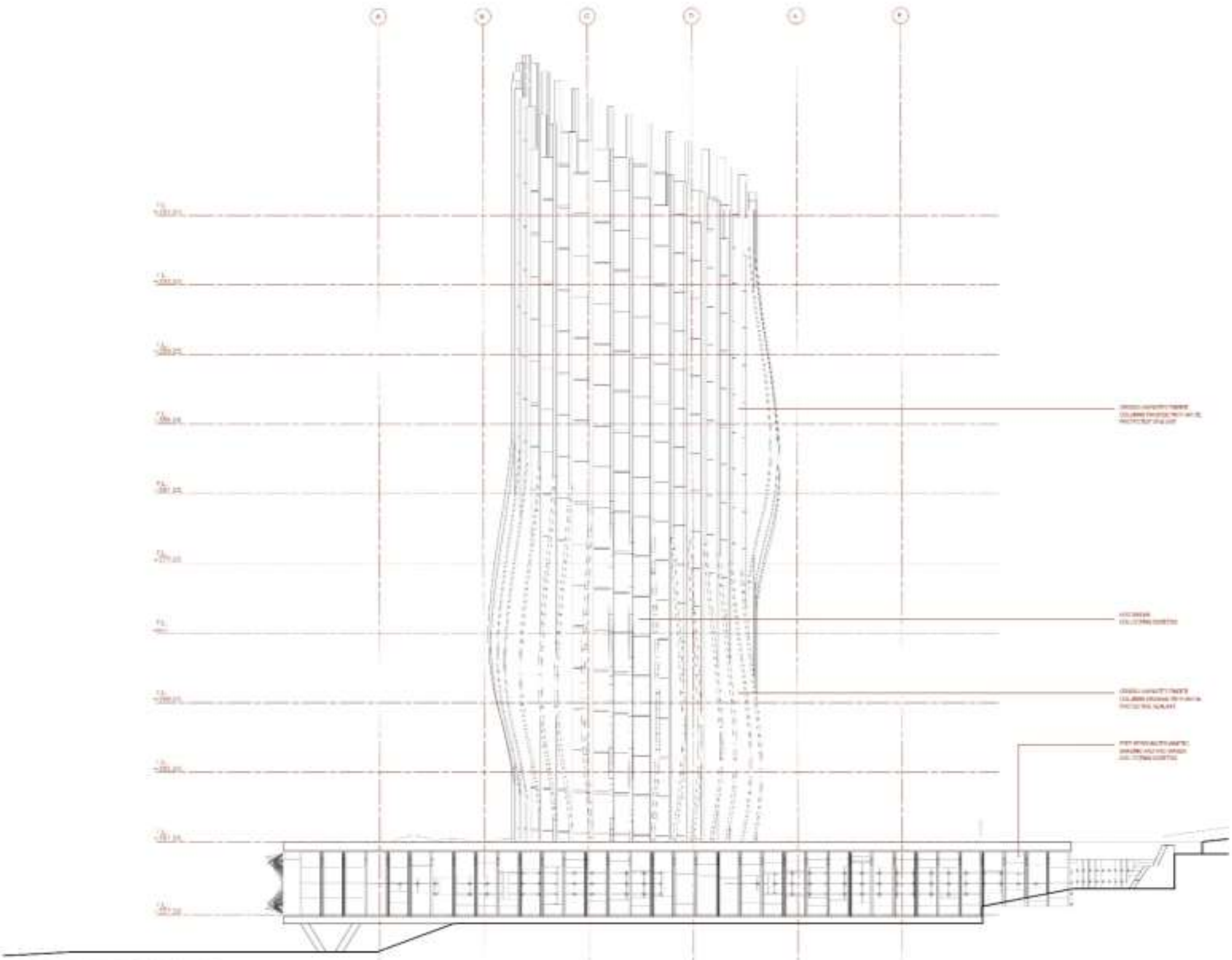


VISITORS CENTRE
SECTION A-A
SCALE 1:100

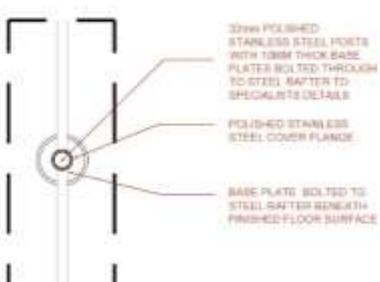
The visitors centre marks the beginning of the educational journey. The transition from the physical journey is marked by the upwards tilted gallery which exposes the winding textured path through the public spaces below. These zones act as a filtering system, dispersing the pedestrian traffic.

Lady Anne's voyage was a long one. After passing Madeira and the Canary Islands, and reaching the low latitudes of the Cape of Good Hope, the ship ... was blown into the ... of the southern Atlantic. Eventually, there came a change of wind and the 'joyful news' that land had been sighted. Alas, the sea mists and fogs were still so thick as 'not to permit us to enjoy its appearance till we were exactly placed in the Bay opposite to Cape Town... Then, as if by one consent the Lion's Rump whisked off the vapours with his tail; the Lion's Head ... and dropped the necklace of clouds which surrounded its erect throat, and Table Mountain over which a white damask table cloth had been spread half way down showed its broad face and smiled'.
[Excerpt from Tristram Hunt's book Ten Cities that Made an Empire, 2014]

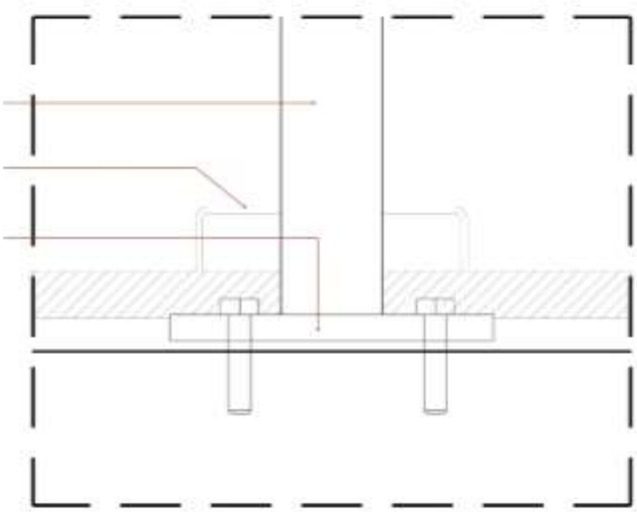
The visitors centre juxtaposes curvilinear and right angle forms, much like the winding paths that lead up the jagged mountainside. The core elements of design, context, digital technology and the environment are represented in the integration of natural materials with hi-tech materials.



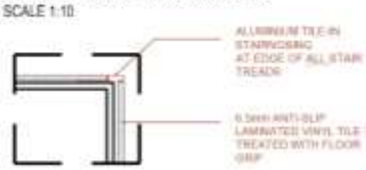
NORTH ELEVATION FOG TOWER
SCALE 1:100



TYPICAL DETAIL TOWER RAILING
SCALE 1:10



STAIRCASE TYPICAL RAILING DETAILS
SCALE 1:1



TYPICAL NOSING DETAIL
SCALE 1:10

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