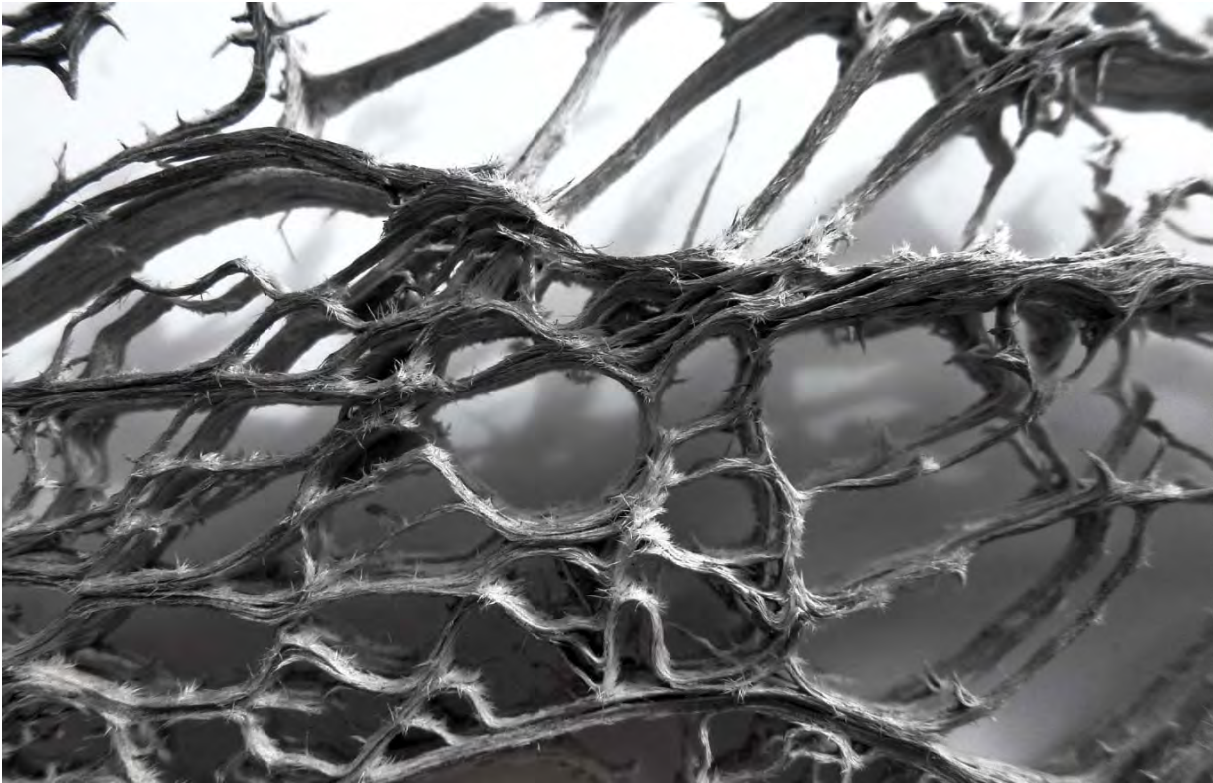


“OpuntiaGenesis”

The Hybrid Generating Plant



The Fibrous Organisation of the Opuntia (Aquadro, G, 2013)

Gabrielle Aquadro _ aqdgab001

MArch(Prof) 2013 _ APG5059F _ Design Dissertation

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OpuntiaGenesis
The Hybrid Generating Plant

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Rob de Jager
Francis Carter (Second Semester)

This dissertation is presented as partial fulfilment of the degree of Master of Architecture (Professional) in the School of Architecture, Planning and Geomatics,
University of Cape Town

16/10/2013

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Acknowledgements

I would like to express my sincere appreciation to my four supervisors: **Professor Jo Noero, Associate Professor Nic Coetzer, Rob de Jager and Francis Carter**; for their invaluable contribution and guidance throughout this yearlong Design Dissertation.



Figure 1: Image by author: *Opuntia-genesis: The Energised Landscape*
A system based on the life cycle and structuring of the *Opuntia ficus-indica*

Abstract

“To think about the origin of form and structure, not as something imposed from the outside on an inert matter, not as a hierarchical command from above as in an assembly line, but as something that may come from within the materials, a form that we tease out of those materials as we allow them to have their say in the structures we create”

_ Manuel Delanda

This design dissertation explores the possibility of creating a piece of architecture from a singular biological parameter (the *Opuntia ficus-indica*/Prickly pear), that is both the fuel and the generator of the architectural programme, materiality, spatiality and structure. The main intention of this architectural investigation is to explore a range of alternative processes, strategies and facilities that can be used to uplift the community of Sutherland as well as the greater Hoogland municipality. The key programmatic feature is a result of the viable and celebrated capacity of the *Opuntia* species to be used as the main digester feed during *anaerobic decomposition* (biogas generation). This characteristic of the *Opuntia* species has informed the development of a sustainable closed-loop programmatic system that consist of the production of biogas as well as the generation of all the *Opuntia* by-products, including; medicinal, food, liqueur and alternative building materials. Whilst the programme is driven by the physical attributes of the *Opuntia* species, the architectural interrogation is a result of a series of *biomimetic*, *parametric* and *materialecological* investigations of both the *Opuntia species* as well as the *site* at a macro and micro scale. With this in mind the product of such a system hopes to become an *Energy Lab* that is not only based on the production of energy, but a lab that's very layout, fabric and structure is fueled by the animation and optimisation of *Opuntia* matter. Moreover it is essential to recognise that *Opuntia* matter is a product of ambient energy, making the treatment of light the essential tool in the development of this architectural design dissertation.

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Figure 2: Images by author January 2013: The treatment of canvas becomes an extension of the overarching concept of the piece

Preface

“The universe in its entirety can be regarded as one gigantic process, a process of becoming, of attaining new levels of existence and organization, which can properly be called a genesis or an evolution”

(Thomas H. Huxley, 1825 – 1895).

Facing a blank canvas is always an overwhelming affair. There are so many options or rather approaches that one can take; the canvas can become your lover or your foe, you can touch it with the slightest of hand or you can devour it in an abundance of expression. Whatever approach you choose to use, more often than not the chosen treatment becomes a tool for which you can give expression towards your own reaction of a specific subject matter or theme. In this way the chosen treatment of canvas becomes an extension of the overarching concept of the piece. I think about architecture in a similar way to which I think about art. The site is a type of canvas, equipped with its own character and bundled with stimuli whilst the materials (the generators of form) become the language of the overriding concept and programme of the piece. Then, we as the spectator, the occupier and the iterator are free to engage and perceive the building, its forms and voids through one’s own spatial understanding and engagement with the overriding concept of the piece. I believe an important; if not dominant way of understanding the world in which we live is to see it, following Manuel Castells, as “*an Information Society*”. We are in these terms surrounded by “data, facts, ideas, insight, opinions and analysis’ in ways that were not quite conceivable even twenty years ago. It is this so called “Rise of the Network Society (2000)” that drives contemporary economic and social development. Have you ever stopped and wondered about the *Market of Architecture*; its nooks and crannies, its driving forces and just what makes it stably progress through time? You will realise that the system is dynamically conservative; or as Hunter Lovins describes it, “it is a market that works extremely hard to stay in the same place.” Like all consumerist systems, the *Market of Architecture* is driven by the trendiest and most current niche forces; and consumers, entrapped by the forgoings of their imposed lifestyle have no choice but to follow these trends like a frolicking flock of bedazzled sheep. The *Viridigenous* (Green) movement is without question the main driving force for most 21st century architecture. It is human nature to be self-consumed and tactically adaptive. This *Viridigenous* movement is ignited by the growing need to maintain the planet and its resources, to ensure the survival of the Homo sapien reign. This is a compelling quest, and yet many of the imposed solutions have been found wanting. Perhaps this is because we attempt to regulate and define our architectural realm with materials that in their very nature suppress or limit the possibilities we have in creating responsive architecture. For this reason I believe that we should be redefining what an architectural material could be, by experimenting with the characteristics of natural matter and just what properties allow for these particles to become structurally and functionally adaptive.



Figure 1: *Image by author: Opuntia-Voronoi Landscape*

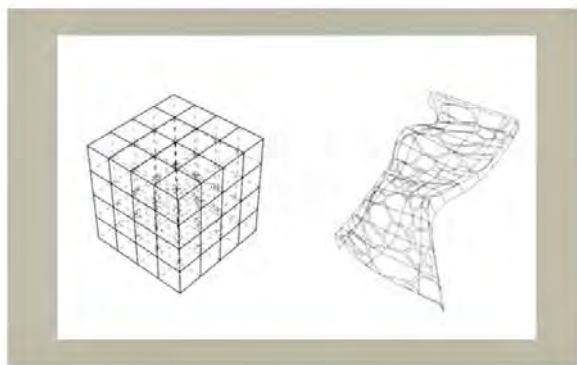


Figure 2: Cartesian plane vs. Voronoi pattern (Reiser, J., Umemoto, N., 2006)

Introduction

“Nothing is permanent. Everything is in constant flux and change. Through the day and night, through summer and winter, year after year, from birth to death, life flows in a timeless cycle – life in the soil, on the ground, in water and air, life of man and animal and plant – always in change and transformation, in rise and fall, in growth and decline, so that in all nature nothing is the same at the day’s end as it was at the day’s beginning.”

(Feininger, A., 1966)

Structured as a yearlong design investigation this dissertation attempts to condense and relay the key stages of its development by following the flow of the year. This development can be categorised into six concurrent phases; *The Initial Investigations, Programme & Site Development, Technical and Theoretical Development, Responsive Design Development* and finally analysing the *Final Design*. This architectural investigation is rooted in *biomimetics* and *materialecology*, two approaches where forms are a *result* rather than an *implementation*. To develop a system where forms *result*, I turned to Reiser & Umemoto’s “*and-and*” argument a diversion from Venturi’s mannerist hierarchical approach, as it takes into account and responds to complex multiplicities that are site specific. With this in mind, form should *result* from the interactions of several equally important conditions; including its site, its materials, its program and its social environment. Furthermore by turning to nature with the knowledge of the advanced technological systems that are available, I veered away from an *essentialist* idea that “matter” is an inert vessel in the generation of form. Instead my intention is to develop a system that exposes the Opuntia’s climatic, structural and material adaptations which can then be coupled with site specific parameters in order to generate the architecture. To develop such a system I turned to *computationally aided form finding (parametricism)*; a technology where forms result from the careful strategizing of the different site specific and programmatic parameters. In this way the final architectural form is not limited to a controlled Cartesian plane, instead the design has been generated through the use of a highly specialised Voronoi grid and hexagonal tessellation strategy that is the result of the amalgamation of the Opuntias’ natural patterns of organisation and the topography of the site. In this way, this Voronoi strategy attempt merges the programme and site into a singular scheme that allows the building to *grow* out from the site and to be in constant conversation with the forever changing localised natural forces. Located in an arid climate, 2kms East of Sutherland and in close proximity to S.A.L.T (South African Large Telescope) this architectural systems main parameters include the careful treatment of water and light through the use of a range of alternative materials. In this way this dissertation explores a design approach that allows for the generation of an architectural system that is a product of a multifunctional strategy that deals with climatic, social and structural challenges as a unified sustainable system

Initial Explorations

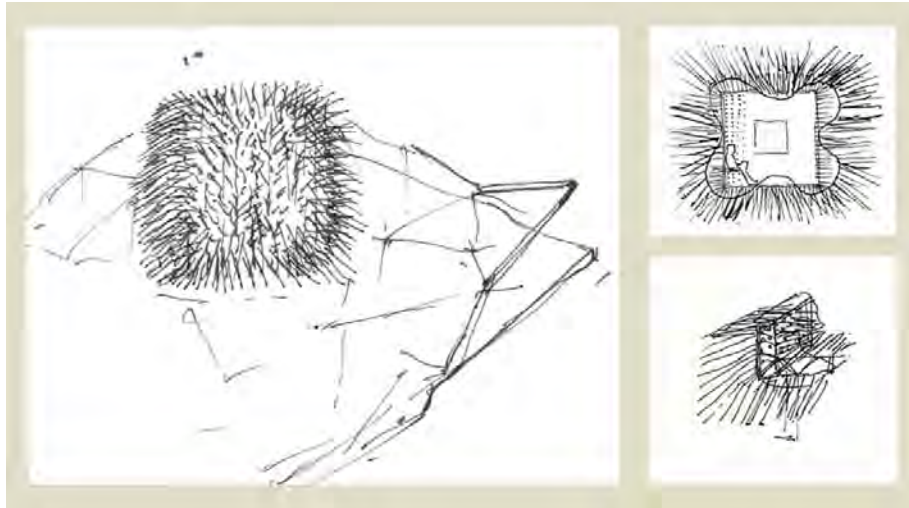


Figure 3: Images by author: Sketches of Thomas Heatherwick's Seed Cathedral

Thomas Heatherwick's Seed Cathedral ignited my interest towards *architecture of an event* or rather *the event of architecture*; driven by re-interpreting fibre-optics into a temporary architectural celebration of light and natural forces.

Initial Explorations

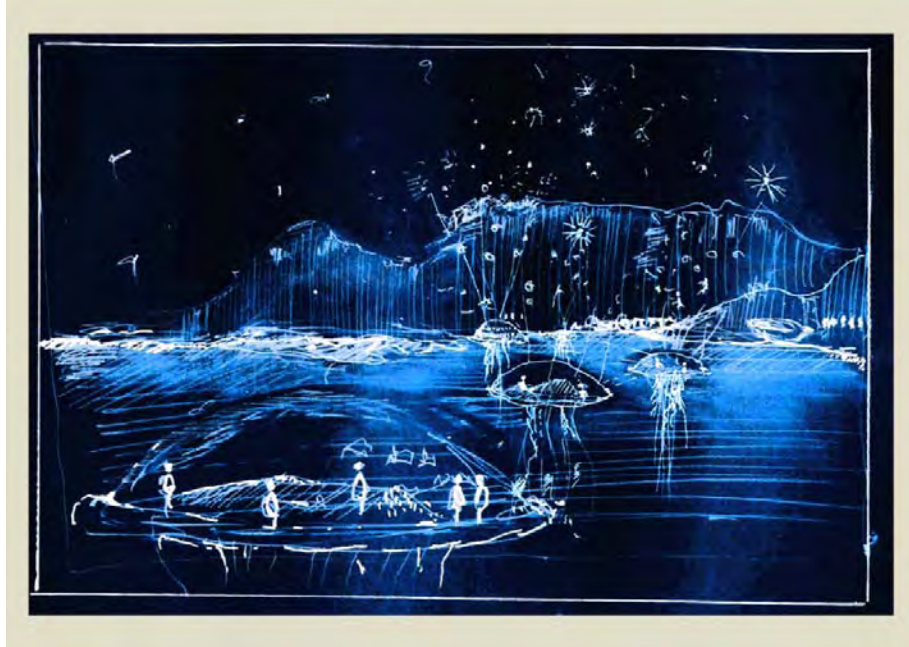


Figure 4: *Images by author: Eco Optic celebrations, Floating phosphorescence farms*

Re-imagining an Eco-Optic New Year's display in Cape Town; using excess phosphoresce from an offshore algae bio-textile and energy farms as an alternative to conventional fireworks

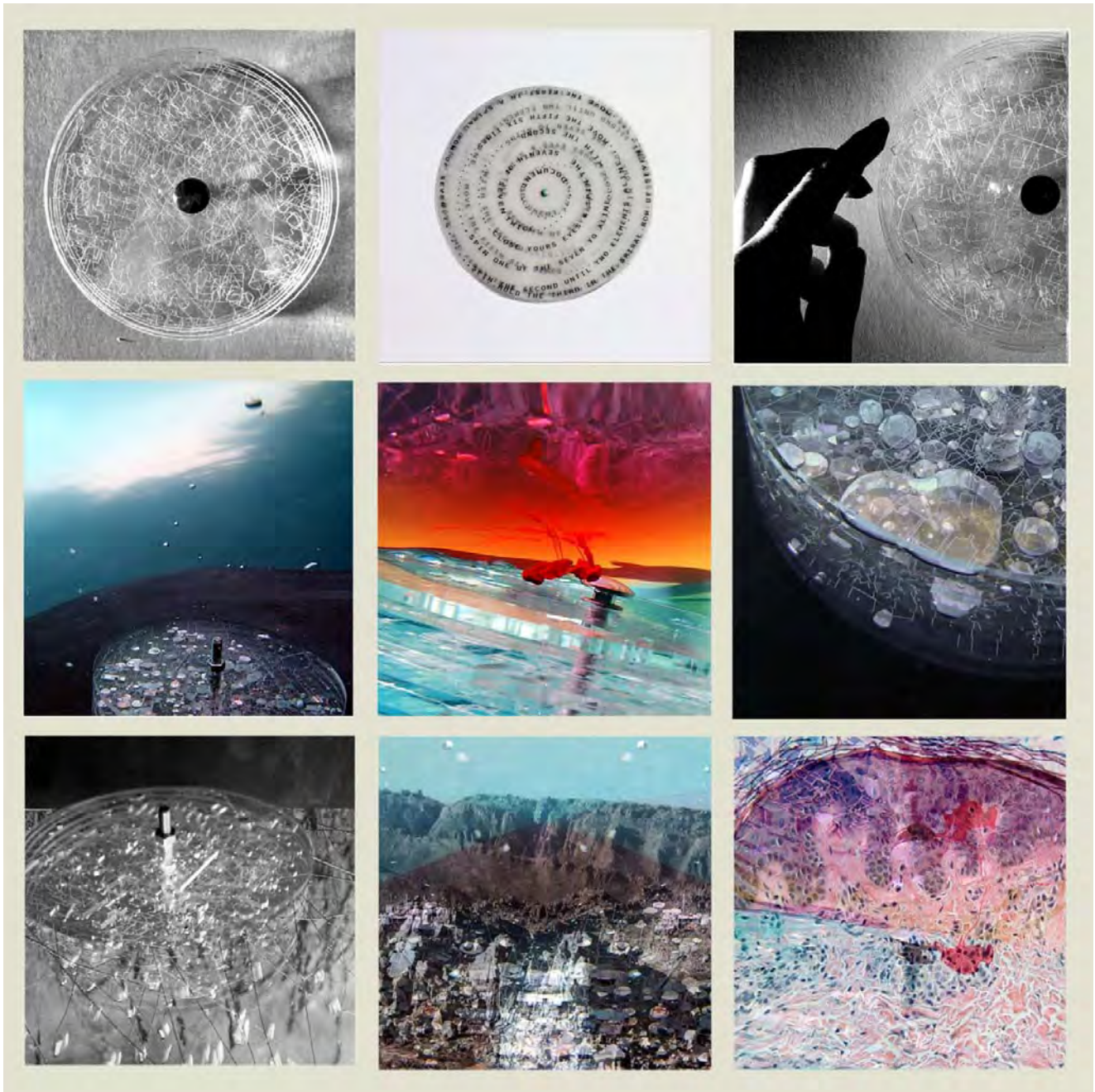


Figure 5: Images by author: from top to bottom, left to right, a representation of a few of the images created during the transmutation tasks.

Image 1: The initial *abstract object*. **Image 2 & 3:** The results of *Task 1: Geography*; make your object as either a tectonic or stereotomic system. **Image 4 -6:** The result of *Task 2: History*; Represent your artefact as either a comedy (maybe parody), and also a tragedy. **Images 7-9:** The results of *Task 4: Natural sciences*; Apply a range of graphic filters to your artefact establishing multiple ways in which it can be estranged

For more insight on these tasks please refer to **appendix A**

In retrospect, it was our first official set of academic tasks that had the most profound influence in the channelling of my initial interests towards this specific architectural inquiry. For this set of tasks performed in the same way as *automatic writing* and *games of chance*, two well-known Surrealist tools that allow their creator to free his or her subconscious so that they are able to freely extract their main intention or attitude towards a theme. In this instance the task was to create an abstract object that displayed one's initial architectural interests. For this I developed an object (*figure 7*) that represented my interest towards interactive architecture, palimpsests, cellular matter, cybernetics, arts, tectonics, brutal simplicity, site, light, forms and materiality. This object was then mutated according to four unique sets of instructions that fell under different themes. The four main themes that I chose my instructions from are: *Geography, History, Art and Literature* and finally *Natural Sciences*. The outcomes of these tasks and the actual task instructions can be found in *appendix 1*. All four sets of tasks have proved to be invaluable in the development of this thesis, however there are a few standout observations that I would like to highlight. *Task 1* required me to transform my object into either a tectonic or stereotomic system. This set of instructions introduced me to the theories of Gottfried Semper who defines a *tectonic system* as the light weight linear components of a building which are the product of human skill. Kenneth Frampton then goes on to define a *tectonic system* as the "skin" of a building, whilst the stereotomic system makes up the *mass/frame* of the building. Both Semper's and Frampton's definitions prompted an irrefutable interest within me with regards to tectonic architecture or rather "skin" architecture. The *historically* driven task lead me to discover an interest in dynamic stability permeability, porosity, osmosis and infiltration through the capturing the tragic sinking of the artefact (refer to *appendix 1*). The final task under the topic of *natural sciences* resulted in the initial object becoming estranged by exposing it to different graphic filters associated with cells, materials, colours, time, scales and different sites. This final set of filtered images gave rise to the visual creation of a series of semi-living systems that literally grow and live off the site. In other words this set of images prompted the next set of investigations towards the potentials of *neoplastic architecture*.

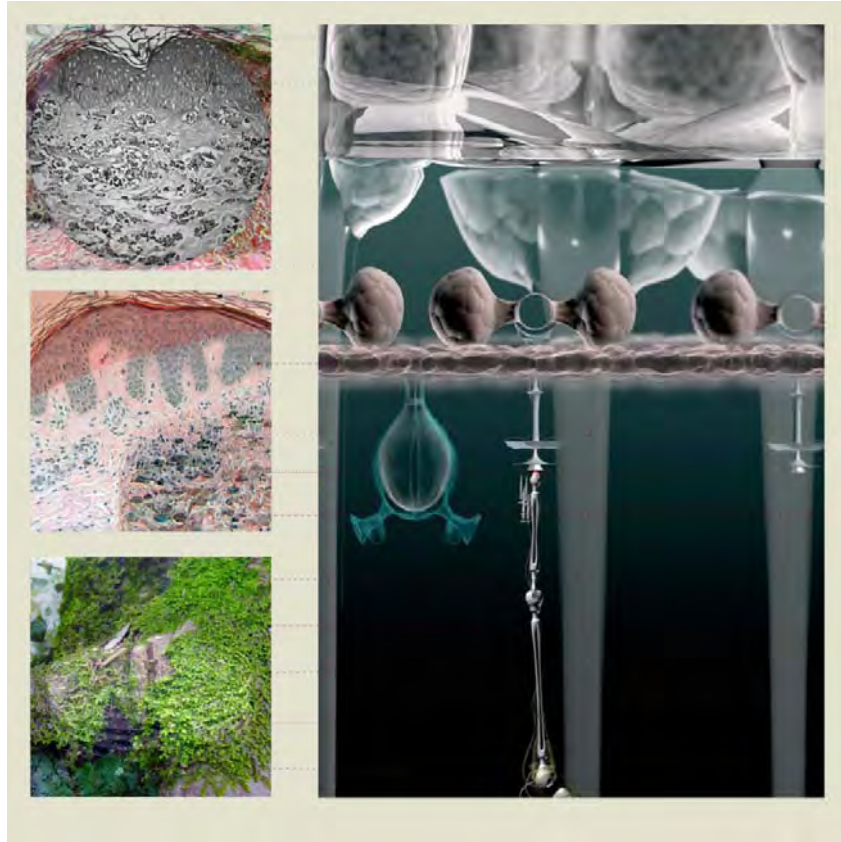


Figure 6: 3 Images on the left by author: a representation of a few of the images created during the natural sciences transmutation task (*appendix A*).

Image on the right: (Cruz, M., & Pike, S., 2008) Neoplasmatic Design

Neoplasmatic Architecture

_ An Exploration of semi-living architecture

What if a building was literally able to adapt and react under different stimuli because it was in fact a living organism?

I was completely fascinated by the potentials of such a question. If there was a material that could literally morph and adapt to stimuli I can only assume that it would result in the most responsive type of architecture.

But what stimuli would this responsive architecture want to adapt to, and why?

Heat, light, pollution, water, wind..... If a building's skin could be evolved into something that was able to perform, something like a mammal's skin, with vascular constriction to maintain core temperatures during cold conditions but that is also able to perform a type of tweaked sweating process to cool the building down if needed. For this type of skin to occur the building would have to function as an organ/organism designed to undergo metabolic processes. There are already many experiments being made to allow for the creation of such a "responsive" type of architecture. These investigations are being driven by an experimental group of designers headed up by Marcos Cruz (Director of the Bartlett School of Architecture, London) and Steve Pike. These two designers use this interdisciplinary design methodology to give rise to new hybrid technologies, new materiality and hitherto previously unimaginable potentially living architecture (Cruz, M., & Pike, S., 2008).

But what model of skin would such an architectural skin be modelled upon?

At this point in the investigation I was reminded of a type of skin closer to home, a skin condition that results in a super sensitive skin type. This condition is known as *Urticaria Pigmentosa* or *Mastocytosis*. This condition results in the development of an excess number of mast cells. Mast cells are the cells in our skins that react to stimuli. Thus if one could genetically create an architectural skin equipped with such a cellular mutation it would most likely result in the development of an invaluable environmentally sensitive, responsive, architectural skin. Unfortunately my investigations of neoplasmatic architecture could not be taken further in this design dissertation; as pursuing such an approach could only result in the development of a highly speculative design response at this point in time. Although the basic ideas of this type of architecture are still found throughout this design dissertation and the idea of the *mast cell* still has a strong presence within the final design (pg. 50-52).

Why the fascination with the *skin*?

"Natural ecosystems have complex biological structures: they recycle their materials, permit change and adaptation and make efficient use of ambient energy".

_ John Frazer

What drew me towards *neoplasmatic architecture* was not the fact that I wanted to construct semi-living organisms but instead I was interested in material optimisation. Nature is a grand material engineer, it knows how to organise matter; giving rise to a never ending array of structures that contain highly specialised performance criteria. We are all well aware of biological metabolism; as it is this process which underpins the fundamental essence of life. The questions that I am posing here is how can the ideas associated with cyclic metabolism be implemented into an architectural schema, and whether or not we should be looking at implementing such ideas in architecture. It was at this point during the initial investigations that I stumbled upon a series of unusual energy sources that can be harvested for human requirements. I was particularly drawn to a process that extracts energy from a plant species known as *Opuntia* (Prickly Pears). This system is intriguing as the *Opuntia* species is able to produce its' own energy by harvesting ambient energy, which then results in the generation of a biological structure that is able to then emit an exceptionally large ratio of biogas when exposed to the process of anaerobic decomposition (Elqui global energy, 2013) More titillating still was the range of *Opuntia* by-products overlaid with the turbulent history of this plant species in South Africa, particularly in the Karoo. It was after these discoveries that I realised that I needed to pursue the potentials of *generating* this piece of architecture. From this point it became clear that I did not only have to develop a programmatic system whereby all the *Opuntia* by-products could be harvested but I also had to interrogate the *biomimetic* and *materialecological* potentials of such a *Plant* in order to develop a holistic architectural system at both a macro and micro scale.

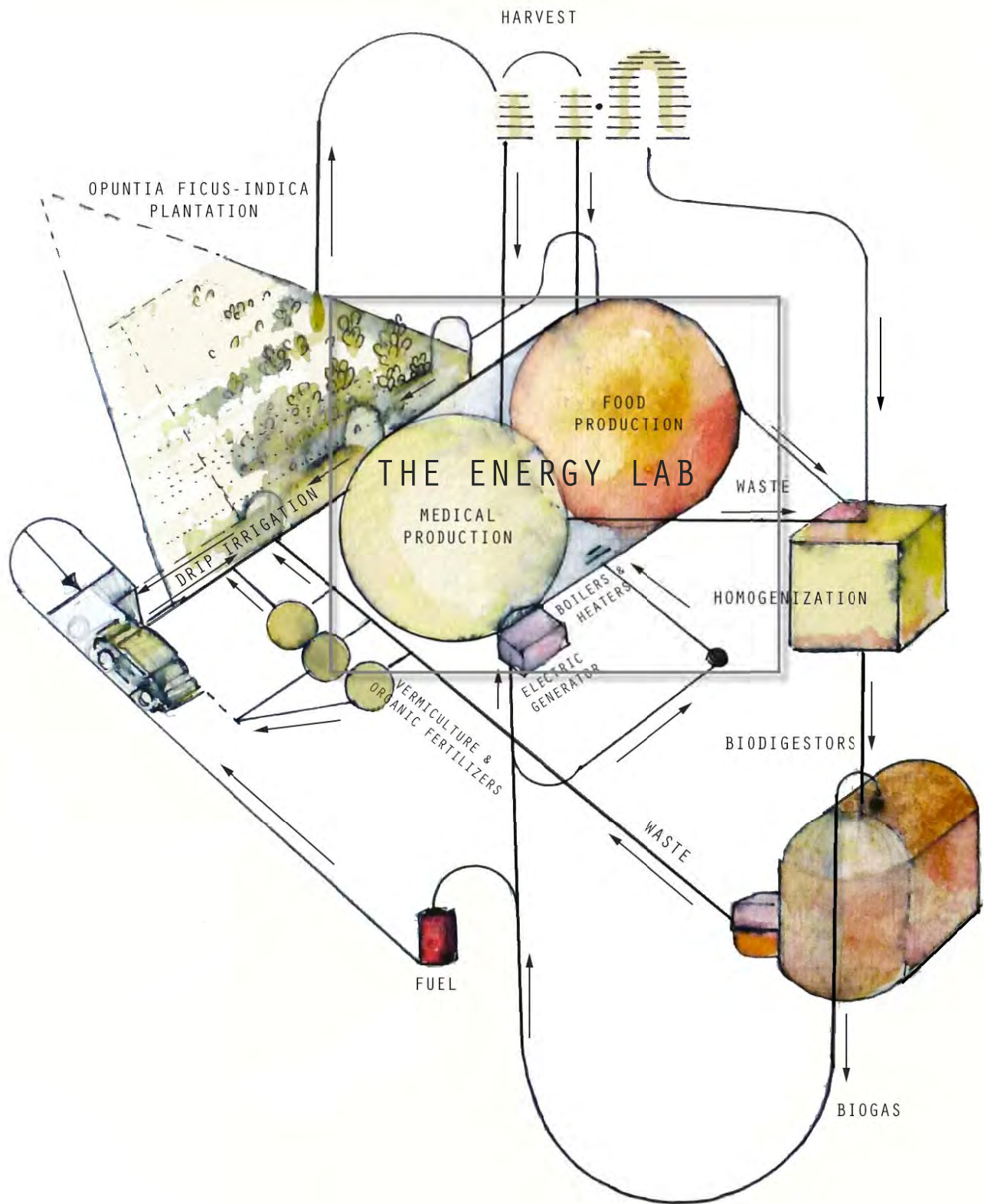


Figure 7: Diagram by author: The Opuntia Plexus –developing the programmatic requirements

Developing the Programmatic System

We regard human society as a vital process, a continuous development from atom to nebula. The reason why we use the biological word metabolism is that we believe design and technology should denote human vitality. We do not believe that metabolism indicates only acceptance of a natural, historical process, but we are trying to encourage the active metabolic development of our society through our proposals."

_ Kiho Kurokawa, 1977

How can a piece of architecture be generated, programmed, structured and sustained by a single entity that is exposed to continuous transformation?

From the onset this design dissertation has been rooted in the development of a programmatic strategy that is inspired by organic models of growth and transformation. In this way this dissertation explores a similar set of ideas to those outlined by the *Metabolists* in the late 1950s; who used biology as the point of departure for their architectural schemes. In this way their projects were designed to allow for the constant expansion and replacement of elements by applying *biomorphic* models of growth. This movement had its roots in the traditional Japanese and Buddhist understanding of "*samsara*" (Collins, G., 1979), meaning, "the cyclic movement between, death, decay and rebirth." This dissertation's programme captures this idea of "*samsara*" as it consists of a closed-loop system (*figure 9*) that optimises the potentials of the *Opuntia* species defined by a never ending cycle of:

- *Death* - The Crop & Harvest,
- *Decay* - Anaerobic Decomposition,
- *Rebirth* - Sustainable energy & products.

At this point this flow diagram is not yet site specific. In order to fully understand this set of systems and to narrow down its site I shall attempt to systematically analyse the processes outlined in *Figure 9*, by following the flow of the diagram itself. Thus this investigation shall begin with the analysis of the primary crop (the *Opuntia ficus-indica*); which will then be superseded by the basic outlining of the quantities, structures, processes, materials and spatial arrangements, as well as the statistics required for the successful *harvesting*, *digesting* and the *generating procedures* shown in *Figure 9*



Figure 8: *Photographs by author:* Opuntia Components, fibrous structuring, cladodes, the fruit, the flowers and the epidermis

Stage 1: The Crop

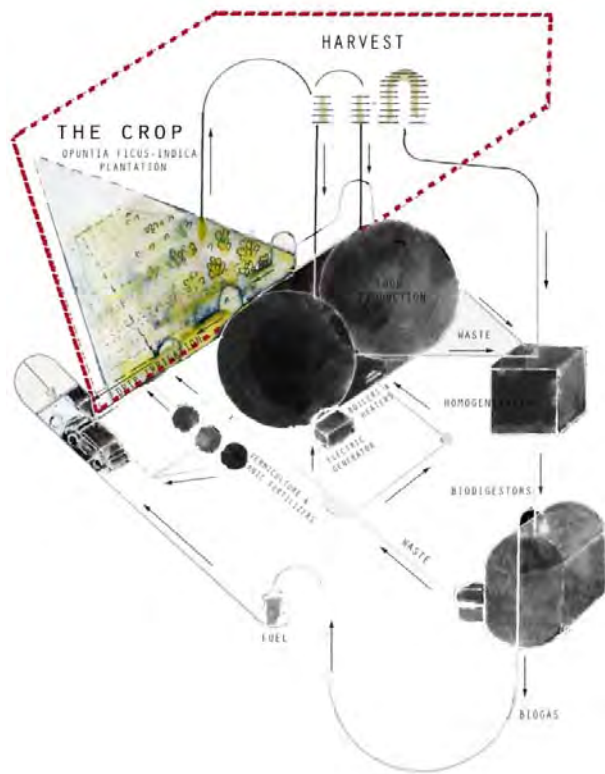


Figure 9: Diagram by author, Stage 1: The Crop

Opuntia Dissemination

There are over two hundred species of prickly pear found worldwide. The system shown in **figure 9** has been designed to use the spineless variety of *Opuntia ficus-indica*, as it is the only species of prickly that is allowed to be cultivated in South Africa under our environmental laws (*please see appendix B* for the specialised list of local biological control strategies for this plant species). This species of Prickly pear is currently cultivated in more than 30 countries worldwide and is mainly used for animal fodder (*USDA, 2009*). The beauty of this plant species is that it thrives in areas with poor soil conditions as well as areas that receive erratic rainfall. Thus this agro-crop would flourish and has flourished in areas such as the Karoo. The *Opuntia* itself is a slow growing perennial shrub that reaches a height between “3 and 5 meters” (Henderson, L., 1995). Its’ root-system spreads horizontally, and the cladodes sprout directly from these roots. *Opuntia* cladodes form the main structure of the plant, as they function as both the leaves and the stem of the plant. *Opuntia* cladodes differ in size and shape according to their different species. The *Opuntia ficus-indica* species cladodes’ are thick, succulent and generally oblong in shape. The dimensions of the cladodes usually range between “30-45cm in length and between 18 and 30cms at their widest points” (Henderson, L., 1995). Their epidermis is extremely thick and waxy, which makes it both water repellent and sun reflecting. The spineless variety of *Opuntia ficus-indica* has been genetically modified to reduce its capacity of becoming an invasive spreader. An *Opuntia* plant will usually begin to flower between one and two years of age. The product of these flowers is a succulent fruit that is typically reddish in colour. These fruits are normally about “7cm long” and both the cladodes and fruit are edible (Henderson, L., 1995). The *Opuntia ficus-indica* crop can be harvested 3 years after its’ seeding and this crop is able to produce between “800 to 1080 tons of biomass, per hectare, per year” (Elqui global energy, 2013). In good conditions, “4000 t/ha of dry matter can be achieved and fruit yields of up to 20 t/ha are feasible” (Ecocrop, 2009). The current consensus seems to be that *Opuntia* plantations are becoming increasingly valuable as they are seen as having an extremely important role in sustainable agricultural systems in arid and semi-arid zones. The diagram on the left hand side of the page (**Figure 11**) shows a strategy of farming and production that will allow for the optimization of an *Opuntia* plantation. To understand the processes and equipment required for such a scheme I shall attempt to unpack the core elements of the *Opuntia* species that make such a system viable and just what equipment is most suitable to use for a plantation that is situated to 2kms east of Sutherland, South Africa.

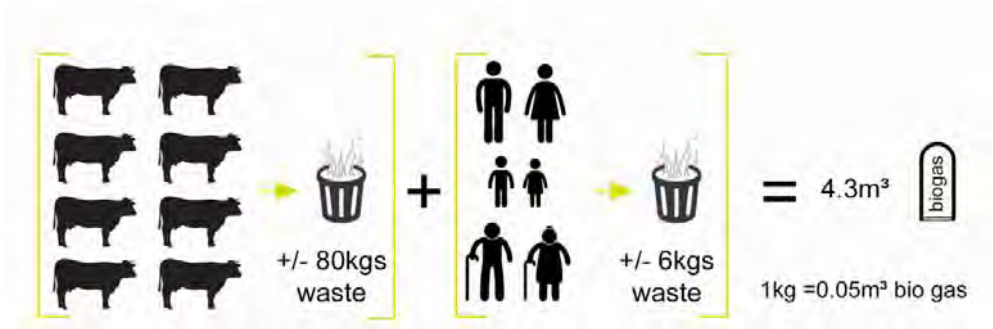


Figure 10: *Diagram by author, a representation of a 3-cubic meter gas plant* as prescribed by (Breslin, W, R. VITA, , 2013)

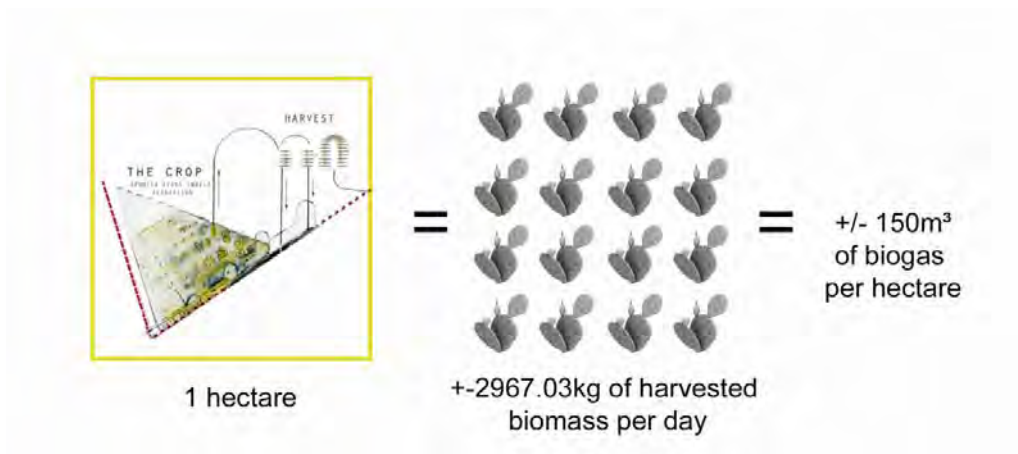


Figure 11: *Diagram by author, the quantity of Opuntia biomass that can be harvested per day per hectare*

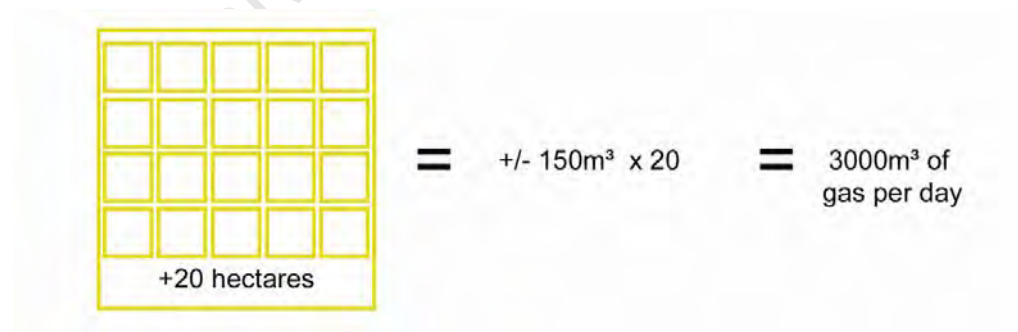


Figure 12: *Diagram by author; the quantity of biogas that can be produced per day for a 20-hectare farm*

Stage 2: The Harvest – The Statistics

In order to establish and understand the ratios needed for such a system I turned to the statistics of a basic “3-cubic meter gas plant” (Breslin, W, R. VITA, , 2013). This model is based on a system requiring the waste from “8 cattle (+-80kgs) and 6 people (+-6kgs)” in order to generate 4 cubic meters of gas per day. In terms of biogas; “1 kg of waste is able to create 0.05 cubic meters of gas.” This means that the basic model described above is capable of generating **4.3 m³** of gas per day $((8 \times 10 \times 0.05) + (6 \times 1 \times 0.05))$.

How much energy is required to run a system outlined in figure ()?

According to this manual a person requires on average “0.6 m³ of gas per day for heating and cooking. An engine pump requires 0.45 m³/ha of gas to run per hour.” Thus for one hour of pumping, an engine needs “1.35 m³ of gas per day.” These are the most elementary energy requirements and can be achieved by the basic “3-cubic meter gas plant.” As previously mentioned a prickly pear plantation produces between 800 and 1080 tonnes of biogas per hectare per year (Elqui global energy, 2013). There are 52 weeks in a year; this means that a 20767.2kg can be harvested per week $((1000 \times 1080) \div 52 = 20767.2\text{kg biomass})$. Then if we take this number and divide it by 7 we get approximately 2967.03kg of harvested biomass per day. $0.05 \times 2967.03\text{kg} = \pm 150\text{m}^3$ of biogas for 1 hectare. Thus if a farm consists of 20ha you will be able to generate almost 3000m³ of gas per day. According to Rex Zietsman a leading biogas specialist in SA this amount of gas is suitable for running all the processes outlined in (figure 9). Zietsman also states that it takes 1 person to harvest 2ha of Opuntia feedstock per week, thus an Opuntia plantation is extremely energy efficient in both its production as well as in its harvesting.

Stage 3: Part 1 _ After the Harvest?

Anaerobic digestion has a complex history that stretches all the way back to the 17th Century; when Robert Boyle and Stephen Hale noted that a “flammable gas was released when one disturbed the sediments of a stream or lake.” Despite its early discovery it wasn’t until the 1930s that anaerobic digestion gained academic recognition. During this period research was undertaken that led to the discovery of the anaerobic bacteria. Thus one was able to identify and separate the microorganisms that facilitate this type of digestion. This in turn led to a series of experiments that investigated the different climatic conditions required to cultivate methanogenic bacterium.

There are four key stages in anaerobic digestion. These phases are known as: For more insight into these different phases please see *Appendix C*

1. Hydrolysis
2. Acidogenesis
3. Acetogenesis
4. Methanogenesis

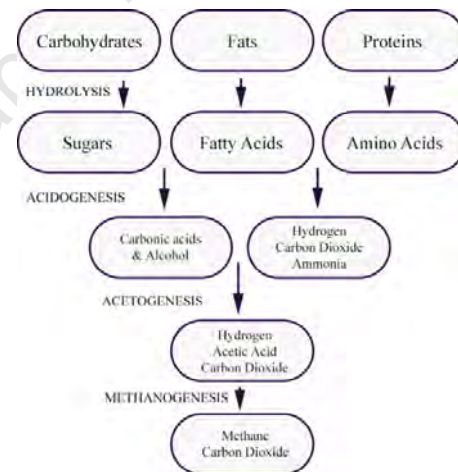


Figure 13: Flow diagram by author: Stages of Anaerobic decomposition

Digesters are specifically engineered to carry out the above phases; however there are a number of different digester operating configurations (*Appendix C*) available to choose from; these include:

- Batch or Continuous
- Mesophilic or Thermophilic
- High solids or Low solids systems
- Single stage or Multistage systems

These systems have been engineered for optimal performance under different climatic zones as well as the digestion of different materials. For this reason before I could establish which type of digester to use I had to establish where the site was going to be.

Site Analysis

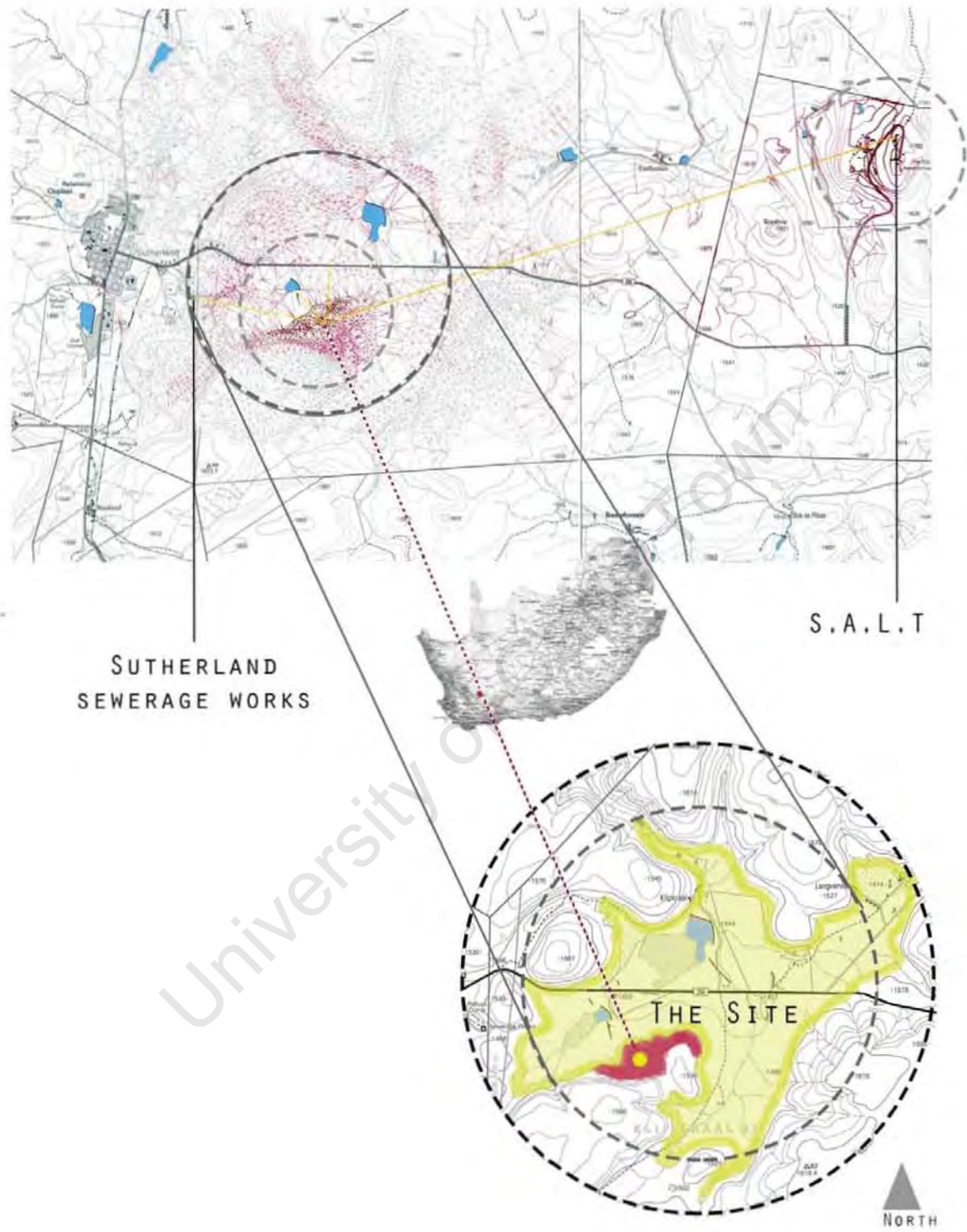


Figure 14: *Images by author:* Site Analysis_ Locating the site_2km East of Sutherland



Figure 15: *Images by author*: Delaunay triangulated Site model, the main site is highlighted in yellow

Topographical Qualities of the Site

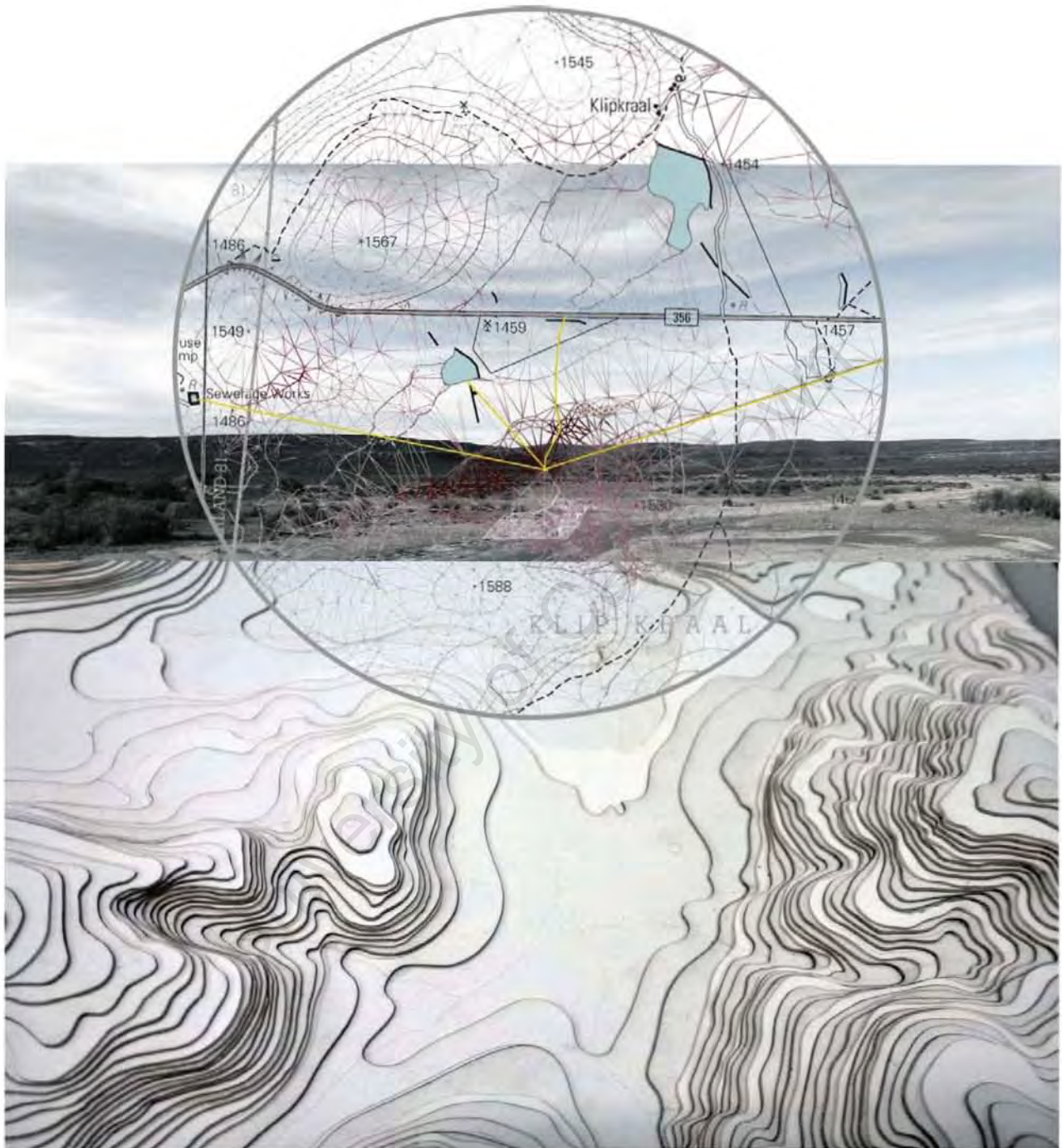


Figure 16: *Image by author:* Mixed-media Site Analysis, topological quality of the site

The Site

The properties of the *Opuntia* species allow for this system to be developed in an arid climate. The Karoo takes up one third of South Africa's surface area; however, due to its harsh conditions this land has limited use. It is also a widely known fact that this area is poverty stricken largely as a result of this unforgiving climate. For this reason the most socially responsible location for such a system (outlined in *figure 9*) would be to place it close to a settlement with a large unemployment rate and that would further benefit from the availability of an alternative fuel, food and skills development. The search for such a location drew me to a series of potential sites between Sutherland, Matjiesfontein and Laingsburg in the Karoo. The site was finally narrowed down to a site 2kms East of Sutherland after a five day physical and social exploration of the different sites. The deciding factors for choosing this site included:

- its **proximity to Sutherland** to positively influence local employment opportunities whilst offering a range of skill development strategies. Furthermore its proximity to an established town allows for the easy collection of basic supplies on a regular basis.
- the **availability of water** systems already present on the site,
- its proximity to the **Sutherland Sewage works** which offers a potential for future expansion
- Its positioning on South Africa's **scientific and alternative energy strip** that falls between Sutherland, Fraserburg and Carnarvon.
- and, finally its **proximity to S.A.L.T** (South African Large Telescope) which requires an extremely sensitive handling of the site and proposed architectural systems specifically with regards to light emissions and sound pollution.

The Demographics of Sutherland

Sutherland, Fraserberg and Williston make up the Karoo Hoogland municipality. This municipality is divided into four wards; Sutherland is the fourth ward. The most current stats of these three towns are outlined in the 2009-2011 IDP Karoo Hoogland (KH) municipality document. An IDP (Integrated Development Planning) document is a record of the strategic processes outlined by the municipality to positively improve an area over a period of five years (2009-2015). This specific document prioritises the five main areas where growth is needed as:

- **Tourism, i.e. eco-tourism, agri-tourism and astro-tourism**
- **Existing infrastructure, i.e. basic services and roads**
- **Youth i.e. economically, socially**
- **Apprenticeships & skills development**
- **Churches and social organisations**

This dissertation offers a programmatic strategy (pg. 32) that specifically responds to the highlighted areas above; whilst also addressing other problems such as the *housing backlogs, the poor economic growth rate* of the area, *unsustainable energy practices* and insufficient *public resource facilities* (outlined in the tables below). These issues have been addressed by implementing a range of alternative skill building strategies, research & teaching facilities and the large scale production of alternative energy; thus providing a wide range of different job opportunities which will positively increase Sutherlands economic growth rate. (All tables refer to the KH municipality population of 12 588 people, 2011.)

Housing Backlog

Town	Number of Shacks
Williston	60
Fraserburg	116
Sutherland	39

Table 1: Section 3.8.1 of the KH municipality document (2009-2011)

Housing Backlog (Housing Waiting List)

Town	Housing Need	Disability
Williston	300	
Fraserburg	340	
Sutherland	240	

Table 2:* the specific needs of disabled people must be catered for in future housing projects
Section 3.8.2 of the KH municipality document (2009-2011)

Strategy Guidelines

	Growth Rate
Provincial growth rate target	4% - 6%
Current economic growth rate of the KH municipality	1.8%

Section 4.2 of the KH municipality document (2009-2011)

Energy Consumption

Energy Source	Cooking	Heating	Lighting
Electricity	58,5%	46,4%	46,4%
Gas	13,4%	4,9%	0,3%
Paraffin	3,2%	3,2%	0,6%
Solar	0,9%	1,5%	11,9%
Candles	0%	0%	22,2%
Wood	22,6%	38,4%	0%
Coal	1,3%	1%	0%
Animal Dung	0%	0,1%	0%
Other	0%	0%	0%
None	0,2%	4,5%	4,5%

Table 3: taken from Statistics SA, 2011, KH municipality

Access to Internet

Access	Percentage
From home	6.5%
From cell phone	12.1%
From work	2.3%
From elsewhere	1.1%
No access	77.9%

Table 4: taken from Statistics SA, 2011, KH municipality

Public facilities that are currently needed in

Sutherland and in the Greater Municipal Zone

Project NR	Project Name	Location	Target	Completion	
5.10.7	Agricultural tourism route Feasibility Study	Sutherland	R 150 000, 00	25 /06/ 2009	No
5.10.8	Edu-tourism route (geology, paleontology, astronomy, biology)	Sutherland	R 500 000	25 /06/ 2009	No
5.10.11	Community computer training centre for K-H	Sutherland	R 1 500 000	09/10	Yes
5.10.12	Outdoor community recreational facility	Sutherland	R 245 000, 00	25 /06/ 2009	No
5.10.13	Renovation of tourism office Sutherland	Sutherland	R 80 000, 00	25 /06/ 2009	No
5.10.17	Tourism training and awareness	All wards	R 50 000	25 /06/ 2009	No
5.10.18	Karoo Highlands Tourism Route	All Wards			
5.10.22	Social Development Programmes	All Wards	R 2 000 000, 00		No
5.10.25	Indigenous Plants Poster	All wards	R 100 000, 00	09/11	/
5.10.28	Spinning & Weaving	All wards	R 200 000, 00	09/11	/
5.10.33	Gateway to the universe – MeerKAT & SKA framework	All wards	R 60 000	09/11	/
5.10.36	Develop support base for health services in KHM	All wards		09/11	/

Table 5: Section 5 - of the KH municipality document (2009-2011). The areas outlined above relate specifically to the programme of this dissertation

“The Electric Landscape” Integrating Ecology,
Biology, Astrology and Tourism



Figure 17: *Photographs by author*; The Electric Landscape of Sutherland



Figure 18: *Photographs by author; Building typologies associated with the area of Sutherland, from rural farm dwellings to SKA & S.A.L.T*





Figure 19: *Photographs by author;* Building typologies associated with the area of Sutherland



Stage 3: Part 2

_Deciding on the Type of Anaerobic Digester

What Type of anaerobic digester is most suitable to use for a site 2kms east of Sutherland that deals with the decomposition of *Opuntia ficus-indica* species?

After a thorough investigation of the types of Anaerobic Digesters that are appropriate for such a climate and function it is clear that the most appropriate option for the digestion of the *Opuntia* species, located in Sutherland would be: A *High-solids(wet), two-stage, Continuous, Mesophilic* system. This system would need to be properly designed by a specialist engineer, to ensure the optimal production of the plant; although I shall later discuss the possibilities to extend the design of such a digester into an architectural element by re-examining and re-imagining the possible forms and materiality of such a system.

For the full analysis of the different types of Anaerobic systems please refer to *appendix C*

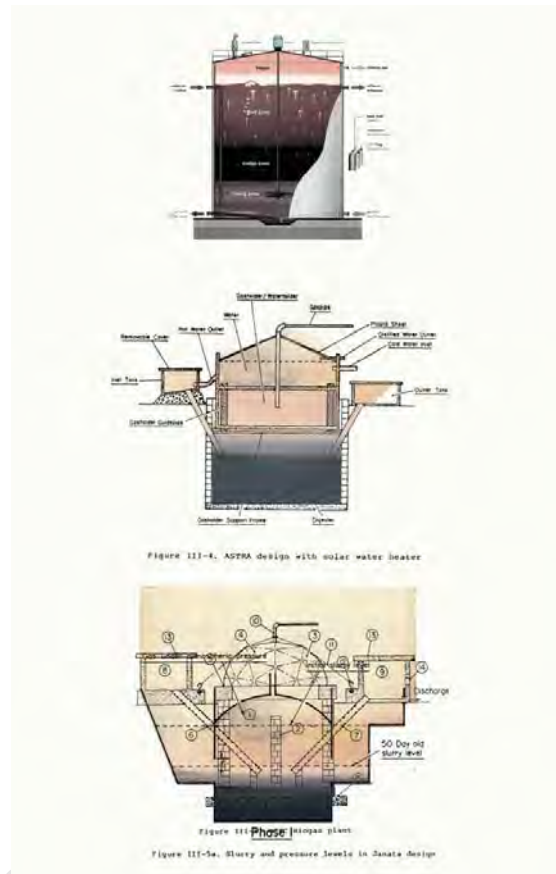


Figure 20: Different forms of anaerobic digesters: Fixed domes and floating dome systems (Ahring, B. K. , 2003)

Stage 4: Integrating the Digestate

Biogas is the main product of *Opuntia* anaerobic digestion however several other by-products are also produced during this process; these include: a fibrous sludge (the remains of the digester feed), Acidogenic digestate and methanogenic digestate (liquid) and water. Acidogenic digestate is a stable, organic material which is comprised mainly of lignin, cellulose and a matrix of mineral components. This waste can be used as compost or it can be used to make low-grade building products, such as fiberboard. The solid digestate can also be used as feedstock for ethanol production. The liquid methanogenic digestate is rich in minerals. This liquid can also be used as fertilizer. The further settlement of water can be used for drip irrigation. The highlighted area in the diagram on the right shows how the waste products should be pumped back into the *OpuntiaGenesis* system. The waste from the food and medical production houses (*Energy Lab*) can also be handled in a similar way.

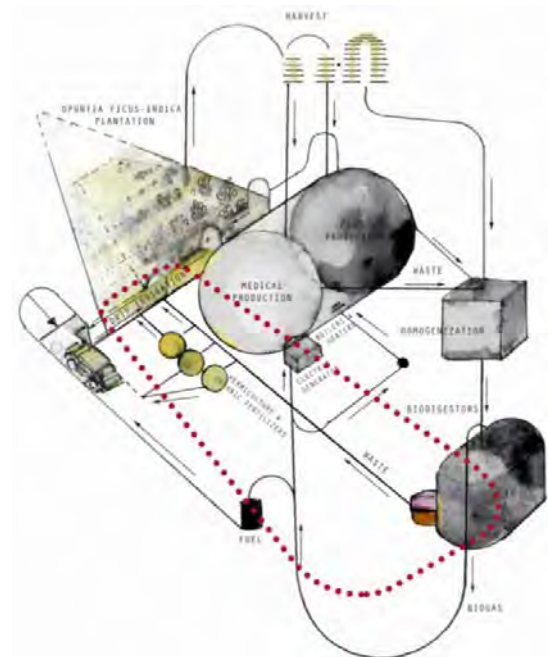


Figure 21: Diagram by author, showing the uses of waste

Stage 5: The Design Development of the *Energy Lab*

The *energy lab* shown in *figure 9* refers to the main architectural scheme.

To allow for the optimisation of the systems outlined in stages 1 – 4 the architectural programme can be divided into five key zones or cores areas, namely:

1. **Farm Production**
2. **Alternative Material & Energy Harvesting**
3. **Food Production**
4. **Botany and Biological Production**
5. **& Local Craft Development + Tourism Facilities**

Each core is comprised of complex array of functions contained in a multifaceted Voronoi grid strategy (*figure 34*) These five cores all make up one large building (the Energy Lab: “The Plant”), but they are capable of functioning on their own if certain areas of the building are closed. This strategy has been implemented to lessen the amount of light emitted during the night, by allowing areas associated with daylight to be removed from areas that are used during the night (*figure 55*). Thus each core is equipped with its own night access point and basic amenities. As this building has such a complex programmatic production system it requires a multifarious accommodation schedule including: generating rooms, gas storage, digesting rooms, digestate separation rooms, battery rooms, kitchens, workshops, biological labs, greenhouses, craft & seminar rooms, exhibition space, a tourism office and café. (For the full accommodation schedule please refer to (**appendix D**))

5 a. The Theoretical & Technical Design Approach

Applying a Materialecological Approach

*_*Reassessing the Ontology of Matter and its Role in
the Creation of Form

This design dissertation is driven by a materialecological approach. Materialecology refers to a design research initiative that incorporates “architecture, engineering, computation, biology and ecology” (Oxman, N, 2006). It is an approach to design that is deeply concerned with the organisation and performance of materials across all scales. When using this approach as prescribed by Neri Oxman, a *material* can be interpreted as “any physical entity that corresponds and reacts with its environment.” This approach to architecture seeks to stimulate and outline a design research agenda which is ecological in nature, in ideology and in its material practice. Furthermore it attempts to embrace the ever changing social, technical and environmental constructs associated with our highly diversified network society. It encapsulates a methodology that has been inspired by the *form finders* of the seventies, such as Frei Otto and Buckminster Fuller; who generated forms through the optimisation of materials in their specific environments (Morris, 2010). A *materialecological* approach extends this idea of *material optimisation* by questioning “*what the material wants to be?*” (Oxman, N., & Rosenberg, J. L. , 2007) rather than “what the form should be;” but how does one begin to digest a material into a form? Does one need to take the material components back to their atomic state and create spatial algorithms based on their genetic make-up or does one dissect their spatiality at a cellular level and scale up their proportions to a size suitable for human production? To approach, and to understand these questions I turn to an extension of Venturi’s “*both-and*” argument, by siding with Reiser & Umemoto’s “*and-and*” argument. Reiser & Umemoto’s “*and-and*” argument is a diversion from Venturi’s mannerist hierarchical approach as it takes into account and responds to complex multiplicities that are site specific. With this in mind, *form* should result from the interactions of several equally important conditions; including its site, its program and its social environment.

Strategizing with Nature's *Non-Linearity* to Generate Form

When one thinks about the theory of “non-linearity” there are two names that immediately spring to mind; *Gilles Deleuze* and his contemporary, *Manuel Delanda*. Both these men have done extensive studies on the connectivity’s of “non-linearity” through their “material philosophies” and “mathematical studies.” These new studies and philosophies were made possible through recognising and understanding that Earth is in its very nature is a “non-linear” system. If we then turn to the writings of Reiser & Umemoto (*Atlas of Novel Tectonics*) we are made aware that in order to fully understand our place within a non-linear system we need to undergo a series of radical shifts in our thinking about the creation and placing of architecture. One of the key points that they bring to light is that: “our universe can no longer be defined by a fixed field of unchanging essences, but must now be seen and understood as a field of matter that is defined through its local interactions.” When architecture is placed within this field of *matter* it becomes animated by natural energies such as light, wind and fog. This is not a new observation; these energies have animated architecture since the dawn of classicism; however Reiser & Umemoto recognise the need to explore and harness the properties of *matter* that are affected by such energies, in order to create an architecture that “renders itself ambient.” We are all well acquainted with Aristotle’s elements, “earth wind, fire and air” as well as our three states of matter; but we are less familiar with the characteristics of *matter* that are inherently useful when applied to architecture. To tease out the more architecturally valuable characteristics of matter I shall refer back to Deleuze’s philosophies of “*matter and form*,” where he starts off by questioning the very genesis of form. One of his main propositions is a design philosophy based on the structure of *matter*. He recognises this as a valuable approach as *matter* in its very essence is “already pregnant with morphogenetic capabilities.” Thus *matter* is capable of generating form on its own; Deleuze defines this ability, as “*divergent actualisation*.” Deleuze then goes on to identify that if *matter* has such qualities we should be attempting to generate materials that follow such laws; or at the very least implement systems that are able to “adapt and transact” (Novak, M, 1998) when faced with different stimuli. *Reiser & Umemoto* expand upon these ideas laid out by *Deleuze* by recognising that architecture can no longer be “the brooding and silent witness to the flux of *tempo*, as it is as much *matter* and structure as it is atmosphere and effects.”

How Can The Properties of Matter Be Form Generators?

For this I turned Henri Bergson’s theory of “*divergent actualisation*” described by Deleuze as the ability of topological forms to give rise to many different physical manifestations, as matter is seen as possessing its own power to generate form. This ability to generate form is not a miraculous power that matter has; instead it is the way in which the particles of matter react with each other under *Newtonian Laws*. By acknowledging that *matter* has both *form* as well as a *generating capacity* we veer away from the *essentialist* idea that matter is an inert vessel in the generation of form. In other words architects like Mies Van Der Rohe and Gerrit Rietveld, regarded matter as something *formless*, and instead used geometry to generate/regulate the forms that they produced. We as architects are now submerged in an epoch that concedes the importance of *matter* and its structure, as a key to alternative design solutions, with one of the trends being the acknowledgement of *biomimetic design* as a design philosophy.

Turning To Biomimetics

What is Biomimetics?

Biomimicry or *biomimetics* is an approach that examines “nature, its systems, processes, models and elements, in order to solve or suggest solutions to human problems” (Guild, B. 2008). In the 1950s, Otto Schmitt, an American inventor and academic, coined the term *biomimetics* to describe the transfer of ideas from biology to technology. In 1974 the term *biomimetics* entered the Webster’s Dictionary, and is defined as:


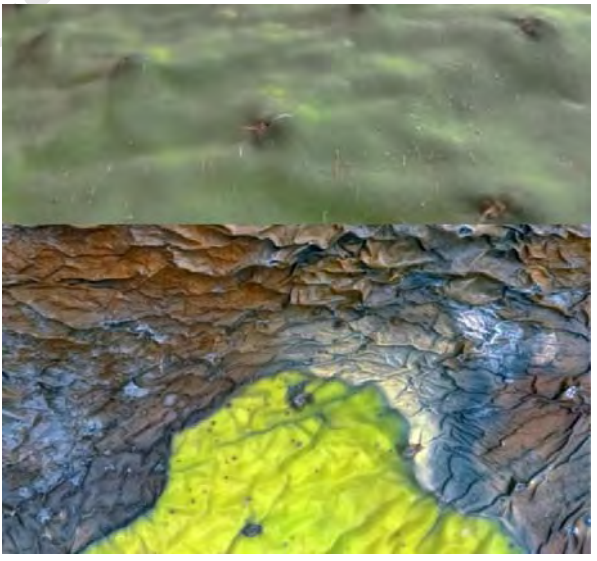
“the study of the formation, structure, or function of biologically produced substances and materials (as enzymes or silk) and biological mechanisms and processes (as protein synthesis or photosynthesis) especially for the purpose of synthesizing similar products by artificial mechanisms which mimic natural ones.”

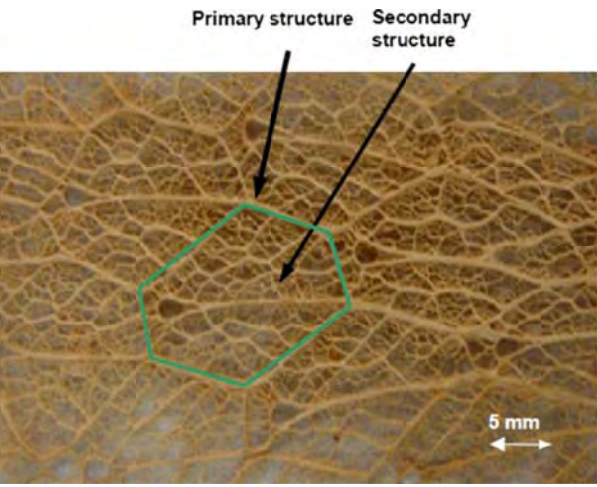

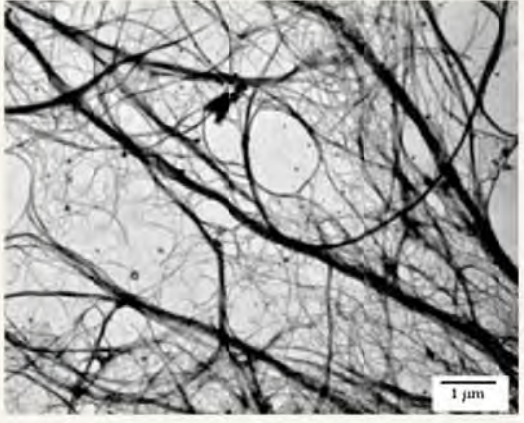
The development of this architectural scheme has been heavily influenced by several characteristics of the *Opuntia* species. In order to extract these main characteristics an intense biomimetic, structural and theoretical analysis of the *Crop* took place. This analysis is comprised of a systematic breakdown of all the plants components from the plants rhizomes to the structuring of its epidermis and spines. During this investigation I tried to establish the key features/strategies of the *Opuntia ficus-indica* that could be beneficial if applied to an architectural system (**Appendix E**). The key features/strategies that I chose to develop architecturally include:

1. Applying the material properties of the *Opuntia* cladode that makes it water repellent and sun reflecting into a strategy which can be used for the skin of the building.
2. Applying a cladophyll water collecting strategy as an architectural system to harvest water.
3. Designing an architectural system that allows for the expansion and contraction, which *Opuntia* skins are able to perform.
4. Applying its fibrous hexagonal lattice structure as a planning and structural system in the building
5. Giving the architectural skin the same qualities of the *Opuntia* Epidermis, thus architecturalising the process of photosynthesis into a social strategy that allows light to animate and energise the building.
6. The physical use of the remaining digestate fibre as a building material.

I shall now relay exactly what these *Opuntia* features include and how and why they were chosen to be developed.

Deconstructing *the Crop* through Biomimetics to establish possible Structural and Material Design Strategies

<p>1 & 2</p>	<p>The Skin Qualities of the Opuntia Cladode</p> <p>One of the key biomimetic features of the Opuntia species stems from an analysis of its cladodes. The epidermis of its cladode is thick and waxy making it sun reflective and water repellent; however the actual form of the cladode allows water to travel over the epidermis in channels which are directed into spinal pores by the glochids (spines). These glochids are also covered by a layer of microscopic hairs which allow for the collection of dew in arid climates. This functional structuring of the Opuntia offers valuable insight towards what architectural skins should be doing in arid conditions. In a single solution, architecture should be able to “transform and transact” (Novak, 1998) to climatic conditions whilst harvesting rare resources such as water.</p>	 <p>Figure 22: Photographs by author: showing the sun reflecting and water repellent properties of an Opuntia's epidermis</p>
<p>3</p>	<p>Designing To Allow For Adaptation</p> <p>The Opuntia Cladode is further structured in such a way that allows for expansion and contraction when put under different environmental constraints. In <i>figure 25</i> you can clearly see the different responses of a cladode skin. In these photographs the shrunken vein-like part of the cladode has sacrificed its nutrients towards the greener area of the cladode. What you cannot see in this image is that the area below the brighter green section is where a new set of roots are forming. In this way, biological structures epitomise Marcos Novak's theories of “<i>transactive space</i>” as they comprise of “<i>transactive materials</i>.”</p>	 <p>Figure 23: Photographs by author; heat and water adaptations</p>

<p>4</p>	<p>How Is The Opuntia Structured?</p> <p>During 2012 Bouakba, M., Bezazi, A., Boba, K., Scarpa, F., & Bellamy, S. conducted a study as a joint effort between the Department of Aerospace Engineering, University of Bristol and the Laboratoire de Mécanique & Structures (LMS) BP. This study is entitled <i>Cactus fibre/polyester biocomposites: Manufacturing, quasi-static mechanical and fatigue characterisation</i>. This Study is specifically based on the properties of the Opuntia ficus-indica species of Cactus and how its fibres have the potential to be used in applications such as <i>fibreglass</i>. During this study The Opuntia species was found to contain three main types of fibres. These three main types can be characterised by their different pore sizes and thickness. A series of SEM images produced during this study proved that the primary structure of all three types of fibres consist of a single hexagonal lattice that is bundled together in parallel layouts, making the fibres cross section recto linear (Bouakba, M. Bezazi, A. Boba, K. Scarpa, F. & Bella,y, S., 2012).</p>	 <p>Figure 24: The structure of Opuntia fibres (Bouakba, M. Bezazi, A. Boba, K. Scarpa, F. & Bella,y, S., 2012)</p>
<p>5</p>	<p>How Can Light Be Used To Energise The Building In The Same Way That It Is Able To Energise The Opuntia During Photosynthesis.</p> <p>This application of light is the driving component of this design dissertation and will be specifically dealt with in the <i>design development</i> stage. The process of photosynthesis converts light energy into chemical energy. This strategy is converted into an architectural strategy that results in the buildings program being animated by different light celebrations. The main parameter is to release very little light from the building during the night because of its location to S.A.L.T. thus resulting in an inverted light celebration, affected by the exterior changes in light and colour but that does not impose on the exterior its own internal workings. Thus like the photosynthesis the building takes in light energy and does not release light energy back into its environment.</p>	 <p>Figure 25: Image by author but reworked from Willem Boshoffs' Highveld, 2010: the parallel layering of Opuntia fibres to create a Roof-scape light experiential feature</p>
<p>6</p>	<p>Can the Physical Fibres of the Opuntia Be Used As an Alternative Building Material?</p> <p>As previously mentioned during 2012 study on the <i>Cactus fibre/polyester biocomposites: Manufacturing, quasi-static mechanical and fatigue characterisation</i> was produced. This study proves that Opuntia can be used as an alternative fibre in epoxy; resin and polyester construction One of the by-products of Opuntia anaerobic decomposition is a fibrous sludge that comprises mainly of lignin. Thus this leftover lignin can be used as an alternative and sustainable fibre in materials such as fibreglass. Alternatively several studies have been done which prove that these fibres can also be used for insulation purposes or in low grade fibre boards (Elqui global energy, 2013). Furthermore the liquid of a prickly pear is also one of the most common additives of plaster. This liquid (containing pectin) increases the plasters adhesion helping it to set, whilst also making the plaster more waterproof and durable, giving it greater resistance to the build-up of dust (SustainableSources, 2013).</p>	 <p>Figure 26: Image by: (Malainine, 2011) "Low dose TEM observation of homogenized cellulose microfibrils suspension obtained from Opuntia ficus-indica;" Opuntia Fibreglass</p>

University of Cape Town

Design Development

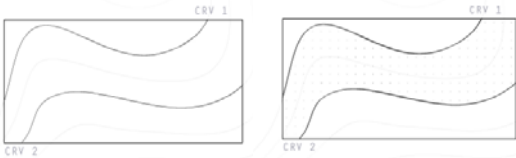
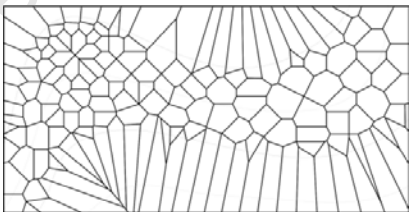
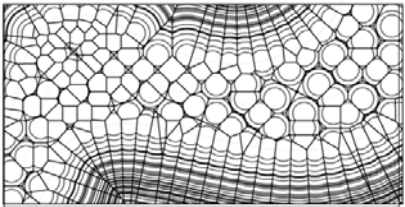
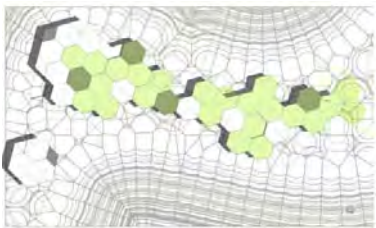


Figure 27: Image by: (Reiser, J., Umemoto, N., 2006) assessing scale

The above analysis exposes the key adaptive features of the *Opuntia* species that would be beneficial if incorporated into an architectural system in an arid climate. However, following a *materialecological* approach of design you cannot simply impose these strategies onto a site. Instead these systems need to be integrated with the site parameters in order to generate a holistic and site specific response, which is a *result* not an *implementation*. At this point we also need to recognise that there are two main sets of forces that affect the way in which biological materials react; being “*intensive*” and “*extensive*” forces. *Reiser & Umemoto* define “*intensive forces*” as the “properties of matter that contain *invisible difference*, such as weight, elasticity, pressure, heat, density, colour and duration.” They then go on to define “*extensive forces*,” as the forces that contain “*divisible differences*, such as measurements, mass, volume, time and constraints.” In this way we are able to recognise that *intensive forces* are separated from the scale of *matter*. Instead these *intensive* gradient fields are understood as being “trans-scalar and flexible” (Reiser, J., Umemoto, N., 2006). *Reiser & Umemoto* then note that “in order for these fields to operate architecturally they must be precisely scaled via the coupling of these forces with an *extensive model*,” as *extensive* models are effected by *scale*. In this way *extensive units* “form limits, tympanum against which the creative forces in the *intensive* space resound.” Thus we cannot simply scale up the proportions of analysed *Opuntia matter* into a piece of architecture (*Figures 24-28*); just like we cannot re-scale a small animal into a larger one without adjusting its composition, its distribution of weight and its other intricacies to allow for its same functionality, as the Marxist geneticist and biologist J.B.S. Haldane points out in his paper “On Being the Right Size.” By developing homogenised materials like the projects of Neri Oxman we are able to expand upon the possibilities of bringing together these *intensive* and *extensive* forces at scales appropriate for human requirements. For this reason I shall now expose the sites’ main parameters and how the *Opuntia intensive* strategies can be coupled with *extensive* material strategies in order to generate an appropriate architectural solution.

Developing the Plan

(This table stretches across two pages and must be read from top to bottom)

Site Parameters (Primary)	Strategies taken from the Opuntia	Material/technical parameters	Design Development	
<p>Developing the Plan</p> <p>General Parameters</p> <ul style="list-style-type: none"> • Proximity to Sutherland to positively influence local employment opportunities whilst offering a range of skill development strategies. • Furthermore its proximity to an established town allows for the easy collection of basic supplies on a regular basis. • its proximity to the Sutherland Sewage works which offers a potential for future expansion <p>Physical parameters</p> <ul style="list-style-type: none"> • The sites gradient • The systems proximity to a natural water source • Climatic conditions _ extreme temperatures • and, finally its proximity to S.A.L.T which requires an extremely sensitive handling of the site and proposed architectural systems specifically with regards to light emissions and sound pollution. <p>Programmatic Parameters</p> <ul style="list-style-type: none"> • Digesters need to be exposed to the maximum amount of daylight to as heat speeds up the processes of anaerobic decomposition (Elqui global energy, 2013) • The system needs to accommodate all the requirements outlined in the accommodation schedule (<i>appendix D</i>) <p>Social Parameters</p> <ul style="list-style-type: none"> • To use light as a material that animates the building and its programme so that visitors and employees may celebrate one of Sutherland's greatest assets, it clear and skies. • Design a system that requires hand crafted items _increasing the skill level of those involved in its making and running 	<p>Primary Parameters</p> <ol style="list-style-type: none"> 1. Primary structure as a singular hexagonal lattice 2. A recto linear cross-section 3. A parallel layering of the primary structure with deviation experienced where it meets the epidermis. (Bouakba, M. Bezazi, A. Boba, K. Scarpa, F. & Bella,y, S., 2012) 	<p>The minimum size of a regulated grid would be 10/10 meters as this is the minimum size of the Opuntia digesters required to produce enough energy for the systems programmatic requirements</p> <p>(outlined in Stage 2 of this dissertation)</p>	<p>Stage 1: Regular 10 by 10 grid over the physical contours of the site</p> <p>Using parametric design as a design development tool</p> <p><i>CRV</i> represents the contours <i>Points</i> represent the basic 10x10 grid</p>  <p>Figure 28: Diagram by author</p>	
			<p>The form was developed using <i>Voronoi tessellation</i>, also known as <i>natural neighbor interpolation</i> a system that formalises naturally occurring patterns of <i>cell division</i></p>	<p>Stage 2: Using Voronoi coding (<i>neighbor interpolation</i>) to establish an organic system between the regular minimum grid requirements and the physical layout of the site. Allowing the form of the building to become an extension of the site.</p>  <p>Figure 29: Diagram by author</p>
			<p>Anaerobic digestion tanks need to be radial so that the digestate does not get stuck corner</p>	<p>Stage 3: Radial coding of the same parameters in stage 2 to establish further connections between the regular minimum grid requirements and the physical layout of the site</p>  <p>Figure 30: Diagram by author</p>
		<p>Primary structure as a singular hexagonal lattice. (Bouakba, M. Bezazi, A. Boba, K. Scarpa, F. & Bella,y, S., 2012)</p>	<p>S.A.L.T is comprised of a hexagonal lattice system</p>	<p>Stage 4: Hexagonal coding of the same parameters in stage 2 & 3 to establish the primary structure of the building as seen in the Opuntia species as well as in the S.A.L.T's structuring.</p>  <p>Figure 31: Diagram by author</p>



Grasshopper Codes

Design Development

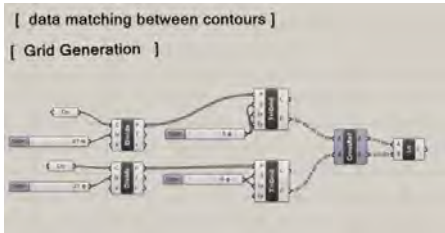


Figure 30a: Code by author: Voronoi and contour grid generation code

Basic Voronoi generation code using of points of the grid and the contour geometries above.

The triangulated Voronoi pattern was achieved with box and point geometries in the Voronoi code highlighted below

Radial geometries where achieved by substituting box geometries for radial geometries in the same Voronoi code highlighted below

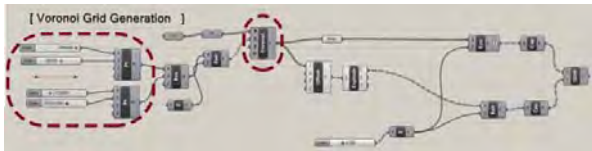
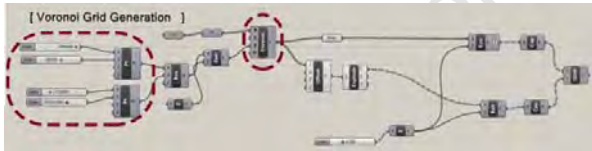


Figure 32a: Code by author: Radial Voronoi grid generation

The Point systems highlighted on the left represent the points of the contours which are defined by data matching code at the top of the page

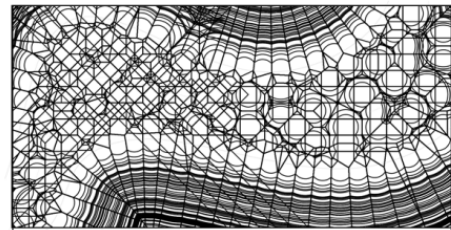
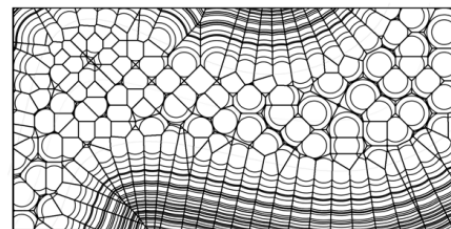
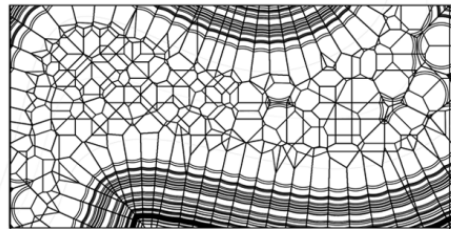
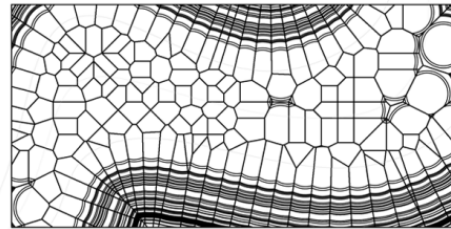
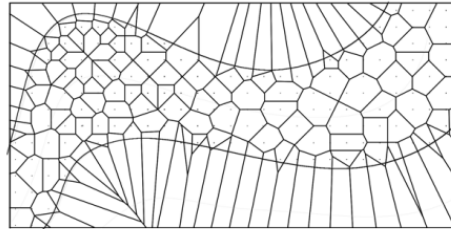
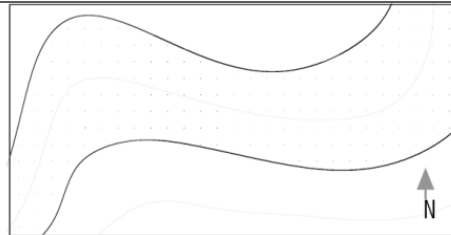


Figure 32: Diagrams by author: Plan Development

Phase 1: DEVELOPING THE BUILDINGS' SKIN

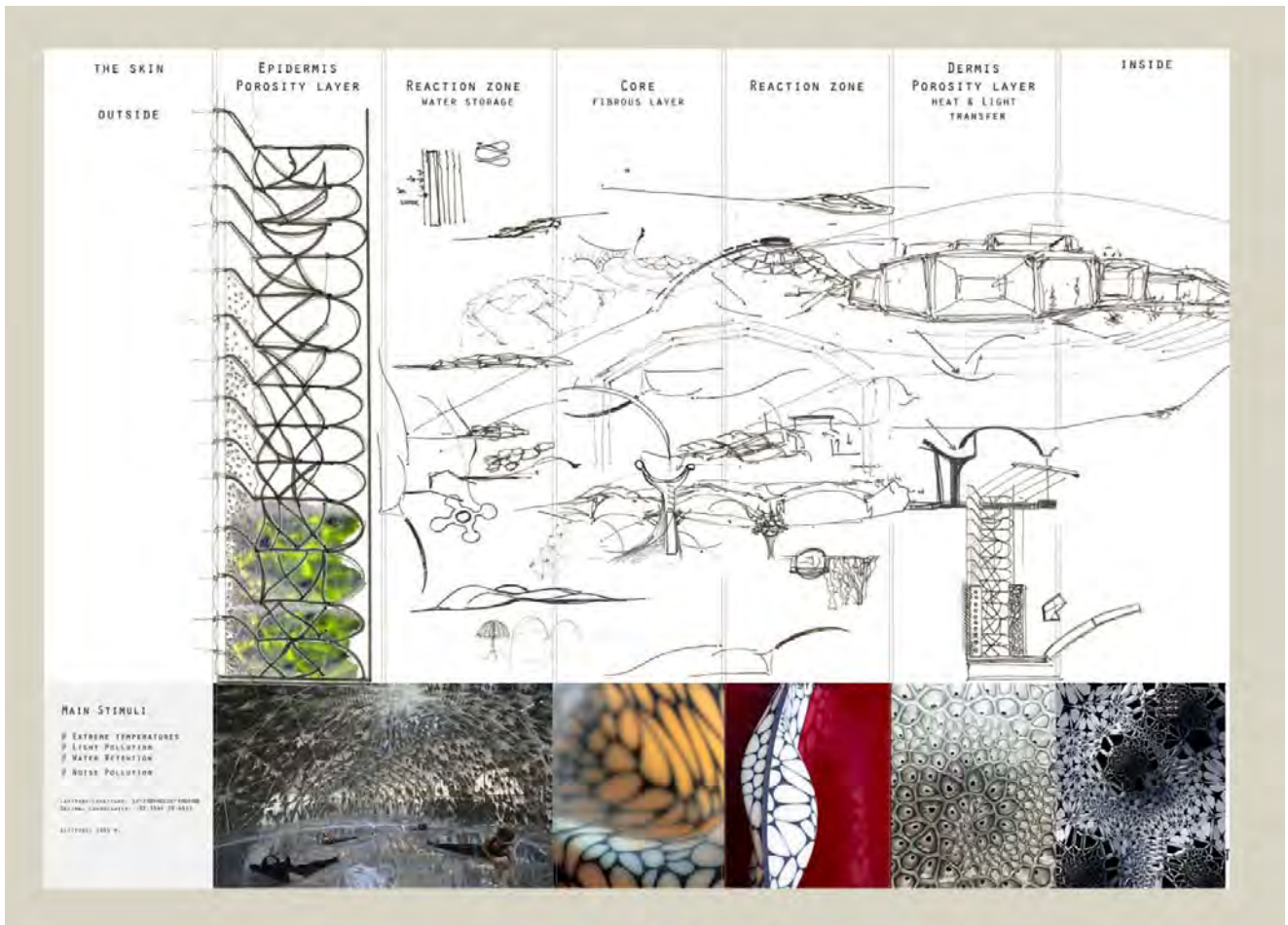


Figure 33: Top Diagrams by author, sketch design of building skins, Bottom: materialecological explorations by Neri Oxman

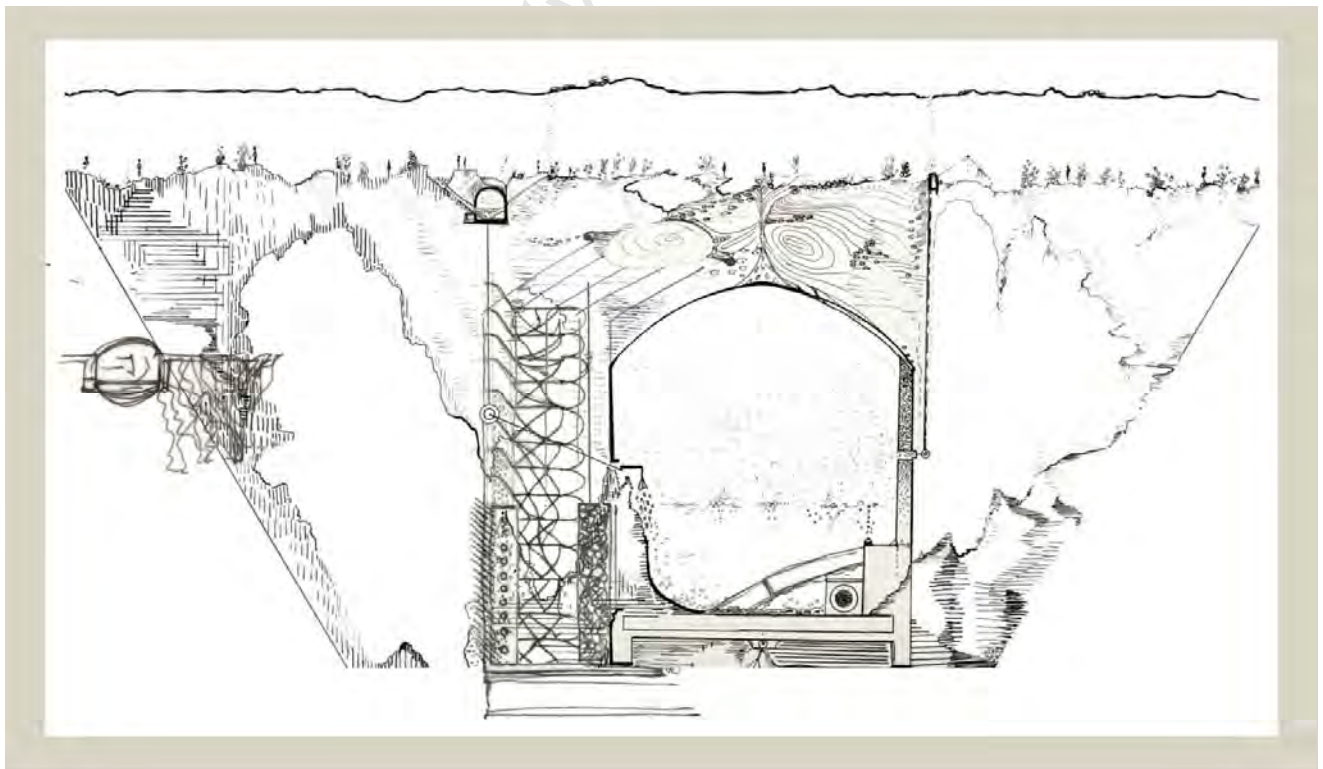


Figure 34: Diagram by author, Landscape of Production

Phase 1: SKETCH DESIGN:

<p>Developing the Building's Tectonics (Skins)</p> <p>Integrating Site Parameters with the Intensive forces of the Opuntia and Extensive Material Applications</p>	
<p>Design Development:</p> <p>Phase 1: SKETCH DESIGN:</p>	
<p>Site Parameters (Primary)</p>	<p>Developing The <i>Skin/Tectonics</i> Of The Building as a system.</p> <ol style="list-style-type: none"> 1. Its Proximity to S.A.L.T requires the development of a series of design strategies to limit the amount of light emitted at night 2. The building should become a celebration of its sites' poetic landscaping as well as a celebration of its dark and clear night skies. 3. The skin of the building needs to be an extension of the buildings plan but also needs to be its own system for construction purposes. The overall design of the building must consist of the holistic merging of its tectonic and stereotomic systems.
<p>Strategies taken from the Opuntia</p>	<p>The climatic adaptations of the cladodes epidermis</p> <ol style="list-style-type: none"> 1. The layering of the Opuntia cells in a singular hexagonal lattice in plan, with a rectilinear section (Bouakba, M. Bezazi, A. Boba, K. Scarpa, F. & Bella,y, S., 2012) 2. Water storage / water collection points 3. Sun reflecting materials
<p>Material/technical parameters</p>	<ol style="list-style-type: none"> 1. Phase 1: To design a living skin under a <i>neoplasmatic</i> approach to architecture, superseded in phase 2

Phase 2: PARAMETRIC EXPLORATIONS

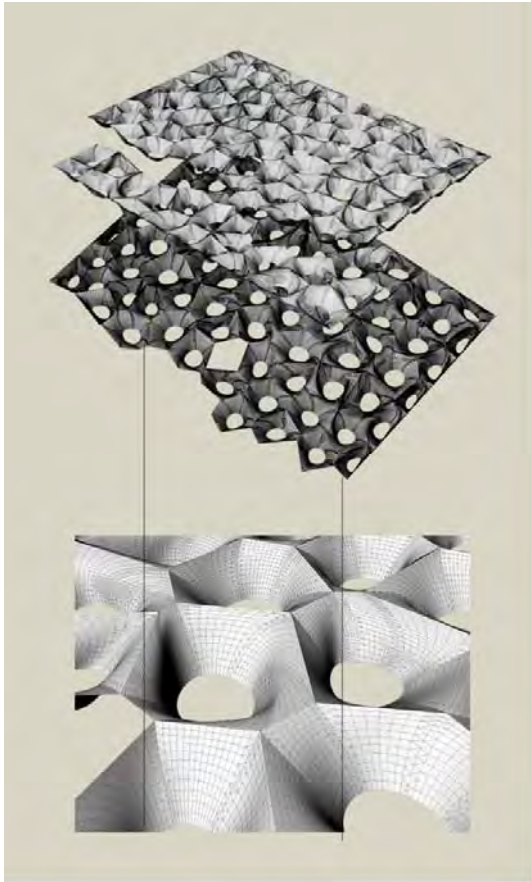
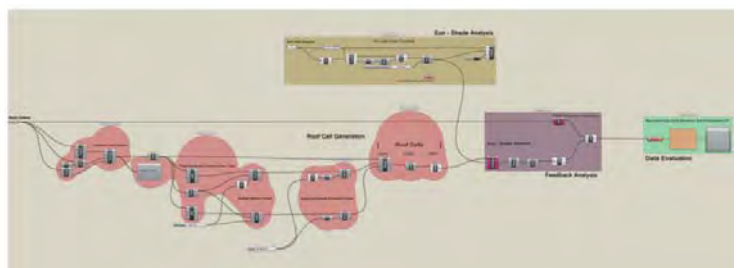
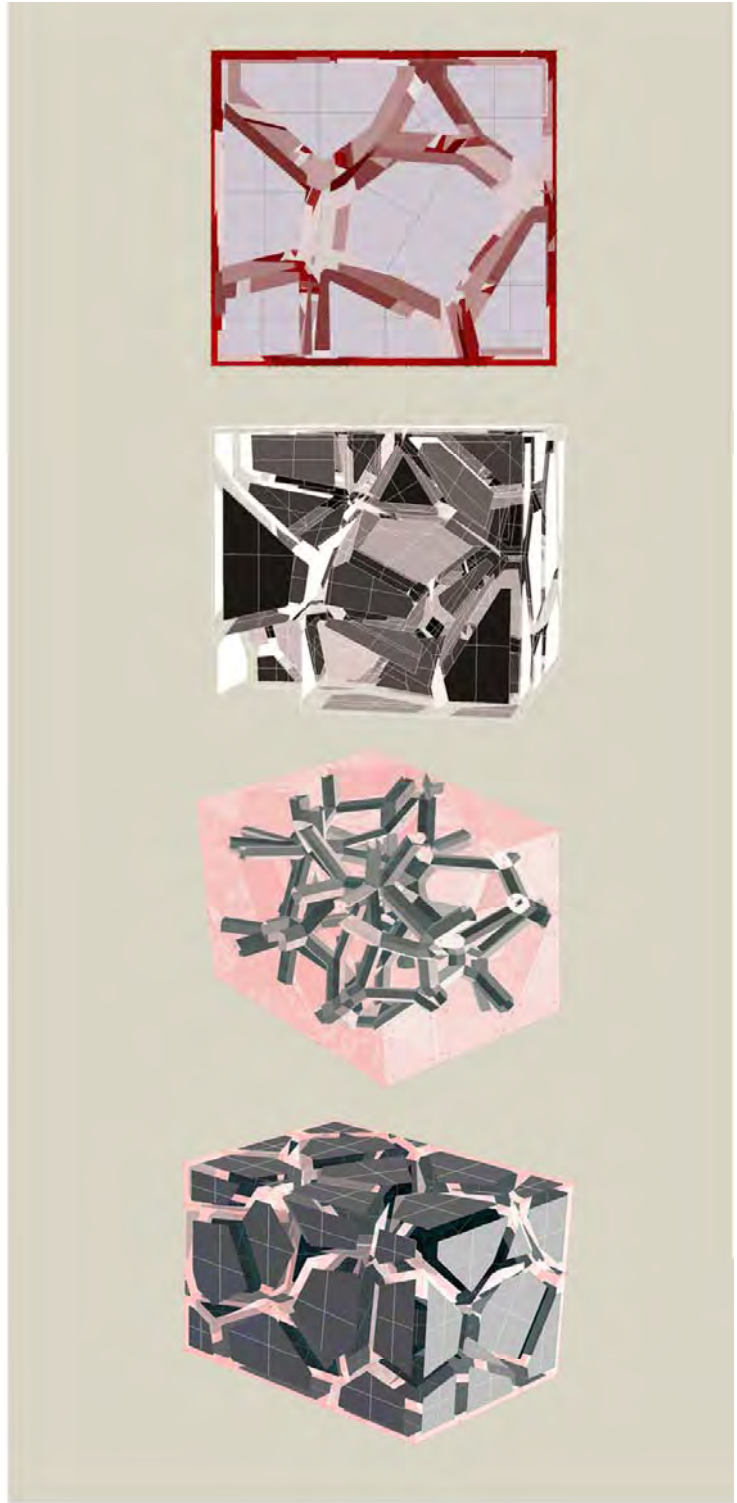
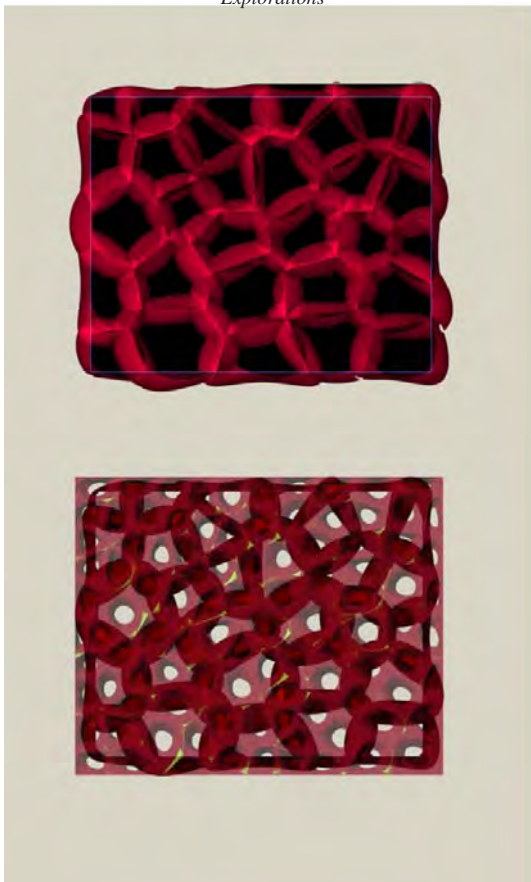


Figure 35: *Diagrams by author, Voronoi 3D Population Explorations*



Phase 2: PARAMETRIC EXPLORATIONS

Developing the Building Tectonics (Skins)

Integrating Site Parameters with the Intensive forces of the Opuntia and Extensive Material Applications

Design Development:

Phase 2: EXPLORING PARAMETRICISM & ALTERNATIVE CONSTRUCTION TECHNIQUES

<p>Site Parameters (Primary)</p>	<ol style="list-style-type: none"> 1. Using thermal mass as a passive heating and cooling strategy/ Creating a subterranean building 2. Re-purposing the displaced volume of soil into the primary material for the building; being Opuntia and sand 3D printing. This material strategy is superseded into strategies such as Eco bricks, Berms, localised concrete and Opuntia fibreglass construction.
<p>Strategies taken from the Opuntia</p>	<ol style="list-style-type: none"> 1. Exploring the idea of Opuntia fibres being homogenised and then calcified to allow for the 3D printing of the building and then applied to a building skin shown on the upper left hand side of the page. 2. Exploring 3D Voronoi populations
<p>Material/technical parameters</p>	<ol style="list-style-type: none"> 1. Using grasshopper to create a roof structure that reacts to different stimuli 2. 3D printing using an Opuntia fibrous Composite 3. One-way internalised reflecting mirrors as a strategy to keep light in the building at night

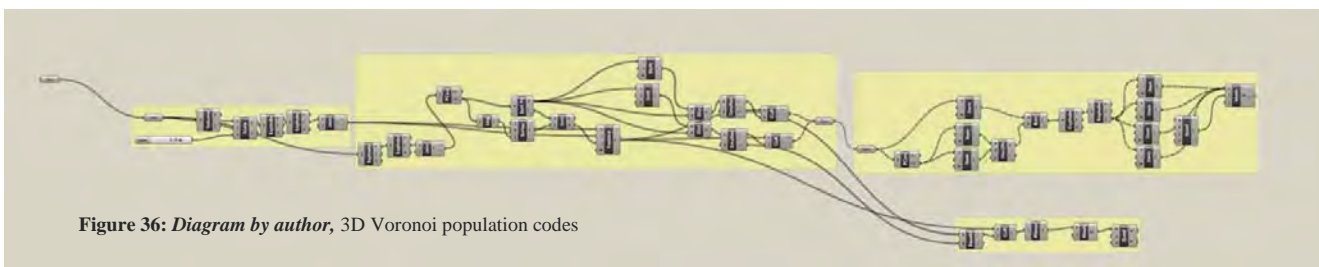
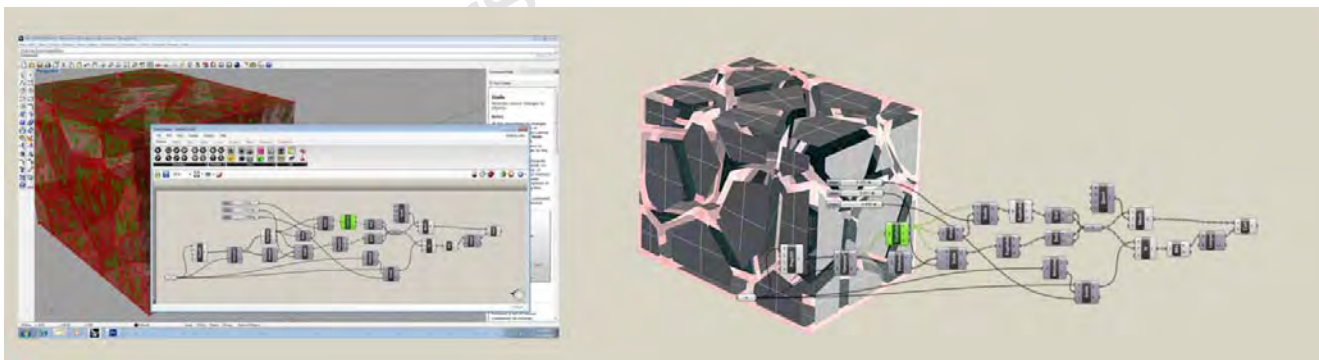


Figure 36: *Diagram by author, 3D Voronoi population codes*

Phase 3: INTEGRATING HUMAN CRAFT INTO THE SKIN OF THE BUILDING

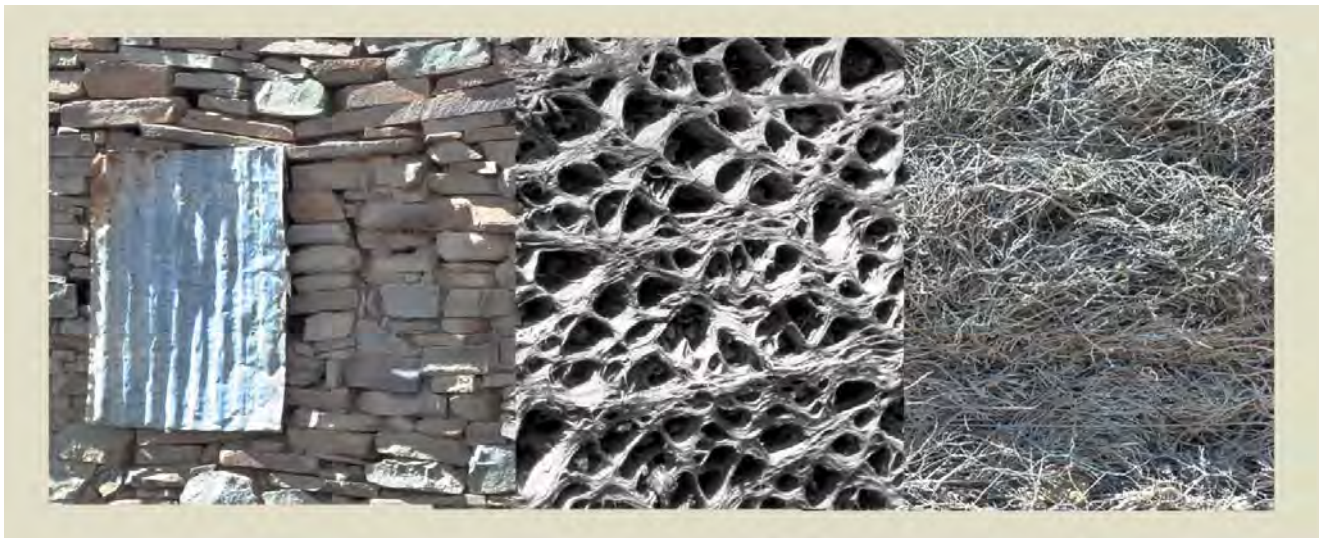


Figure 37: *Photographs by author:* searching for local materials and methods of construction which can be incorporated into the building's design: stone masonry, Opuntia fibres, and wire & roughage boma walls

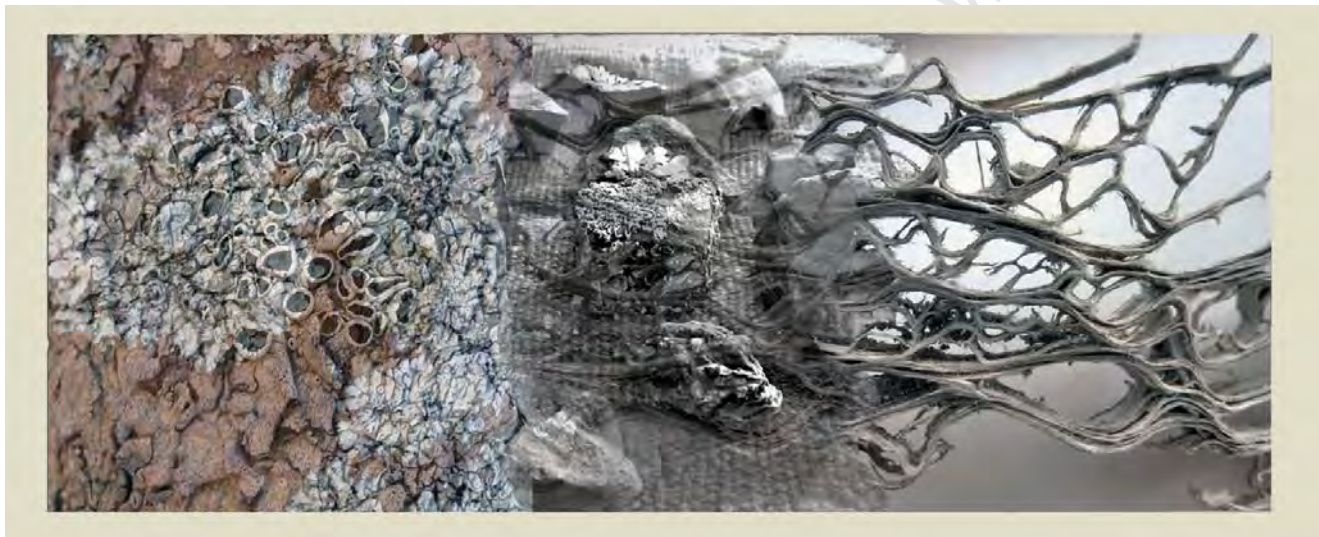


Figure 39: *Photographs by author:* hybridising localised building materials into alternative methods of construction



Figure 38: *Images by author:* creating a landscape fuelled by Opuntia matter

Phase 3: INTEGRATING HUMAN CRAFT INTO THE SKIN OF THE BUILDING

<p>Developing the Building's Tectonics (Skins)</p> <p>Integrating Site Parameters with the Intensive forces of the Opuntia and Extensive Material Applications</p>	
<p>Design Development:</p> <p>Phase 3: INTEGRATING HUMAN CRAFT INTO THE SKIN OF THE BUILDING</p>	
<p>Site Parameters (Primary)</p>	<p>1. Integrating Natural Site Materials:</p> <ul style="list-style-type: none"> • Grasses - weaving • Stone - stone masonry • Sand - eco bricks <p>2. Designing a construction system that allows for maximum skill development with localised materials to develop strategies to cope with some of the social issues such housing backlogs (<i>tables 1-6</i>). This project hopes to give people the tools and the materials with a strong community base, so that Sutherland has the potential to <i>go off grid</i> and become a generative town, using local skill and materials to counteract their limited resources by addressing such problems in a holistic manner.</p>
<p>Strategies taken from the Opuntia</p>	<p>1. Turning an insulation strategy (using Opuntia fibres) into a light feature by using local artisan craft to develop poetic roof panels</p>
<p>Material/technical parameters</p>	<p>1. Using a translucent roof material to reduce energy consumption during the day.</p> <p>2. Areas used during the night have to have a different roof treatment as excess light cannot be emitted during the night because of its proximity to salt</p> <p>3. Potential materials, Opuntia fibre glass, polycarbonate, an air barrier with Opuntia fibres as an insulating layer, Sculptural layering of Opuntia fibres as <i>phenomenological</i> light installation.</p> <p>4. Eco- Bricks, re-purposing the displaced soil from quarrying to create <i>Eco-Bricks</i> on site using sand, bacteria, calcium chloride and urea. (Treacy, 2010)</p> <p>5. Cactus juice as a binding agent in plaster (SustainableSources, 2013)</p>

Phase 4: MATERIAL & DESIGN DEVELOPMENT

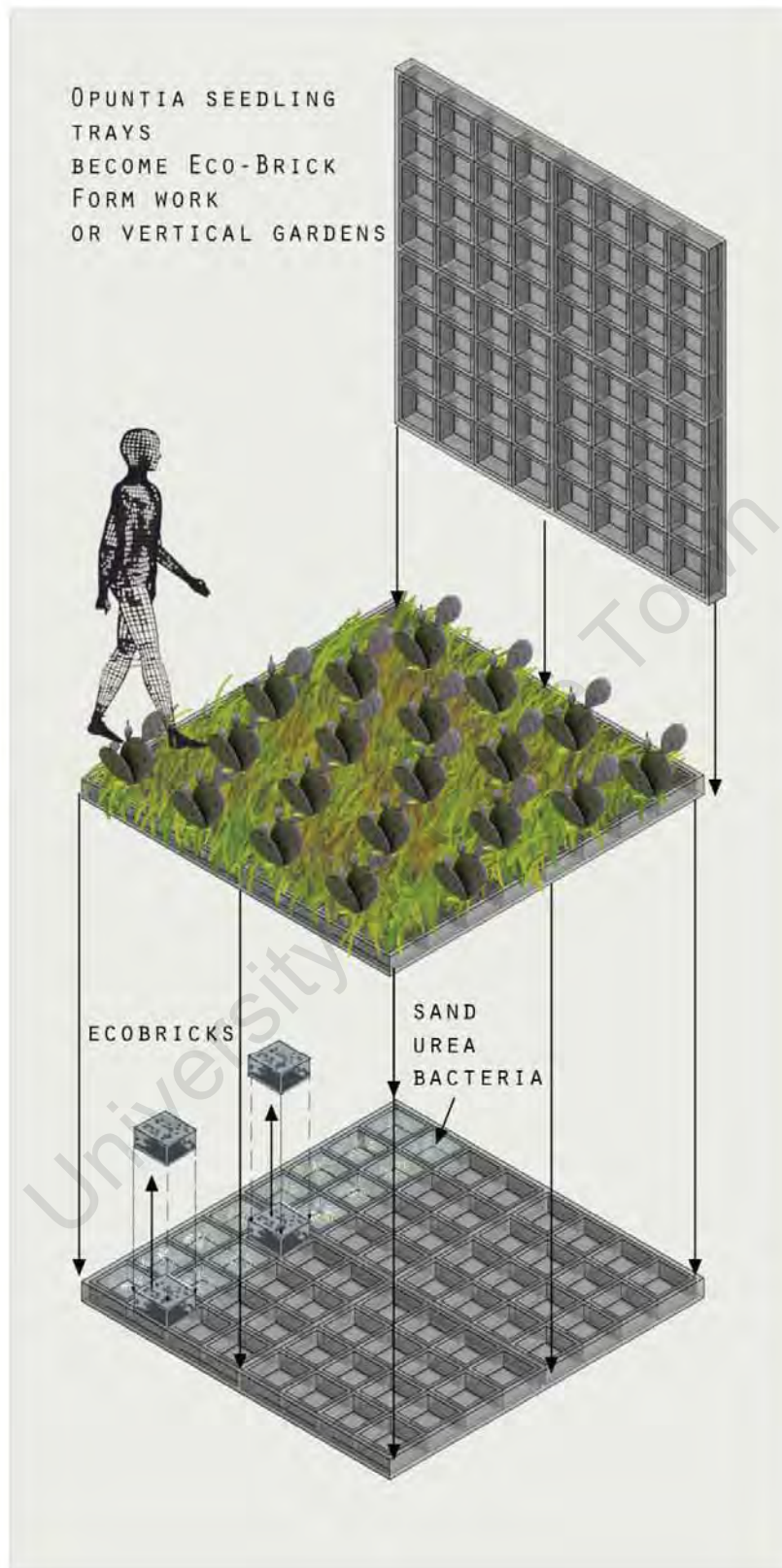


Figure 40: Images by author: re-using seedling trays as Eco brick formwork, designing systems that require human skill

MATERIAL & DESIGN DEVELOPMENT



Figure 42: *Images by author:* Opuntia Fibre form Models experimenting with light quality



Figure 41: *Models by author;* experimenting with mirrors and Opuntia Forms

MAKING TRANSACTIVE ARCHITECTURE

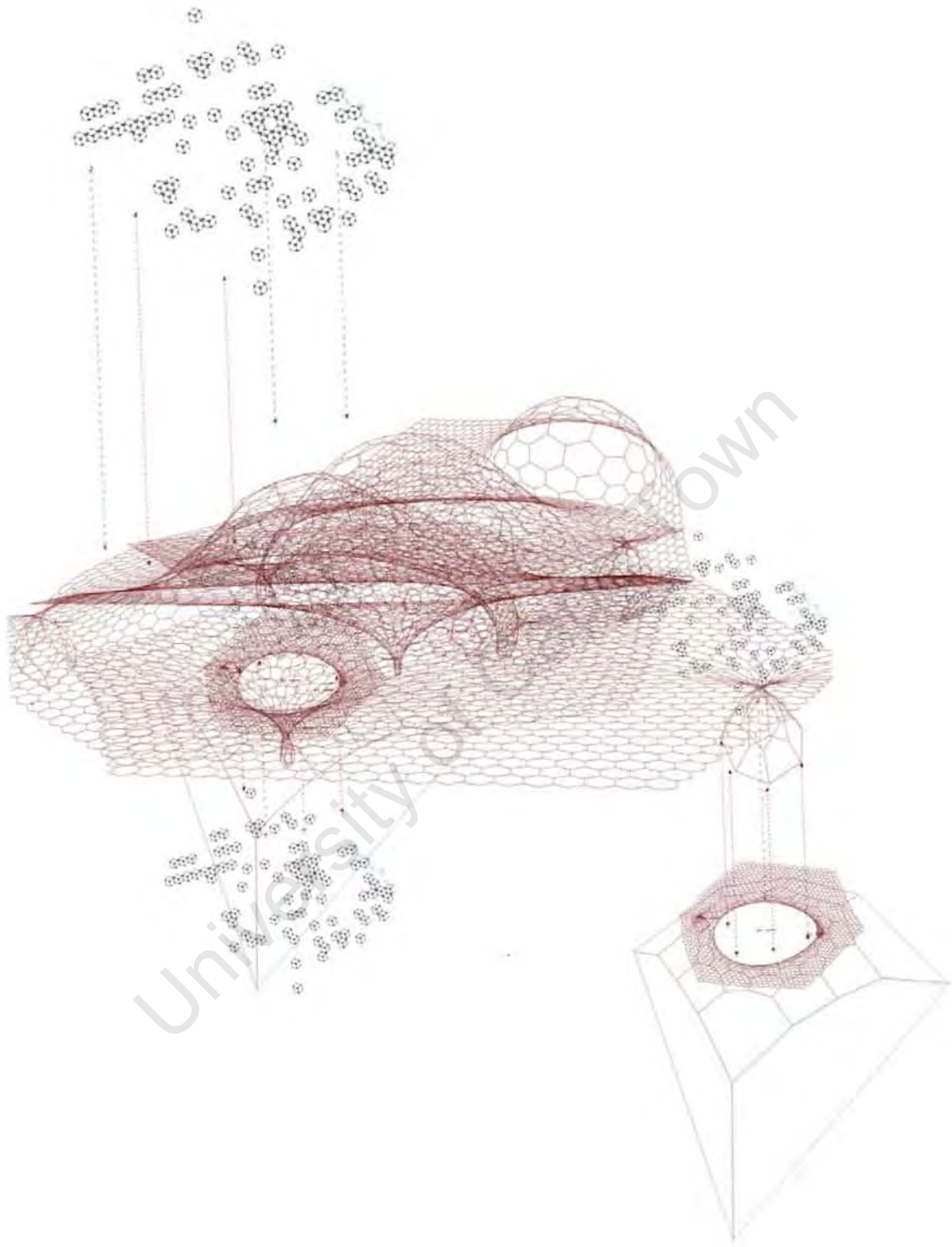


Figure 43: *Images by author*: creating a transactive digester landscape that react to stimuli indicative of a mast cell

Phase 5: DIGESTER ROOF TESSELLATIONS

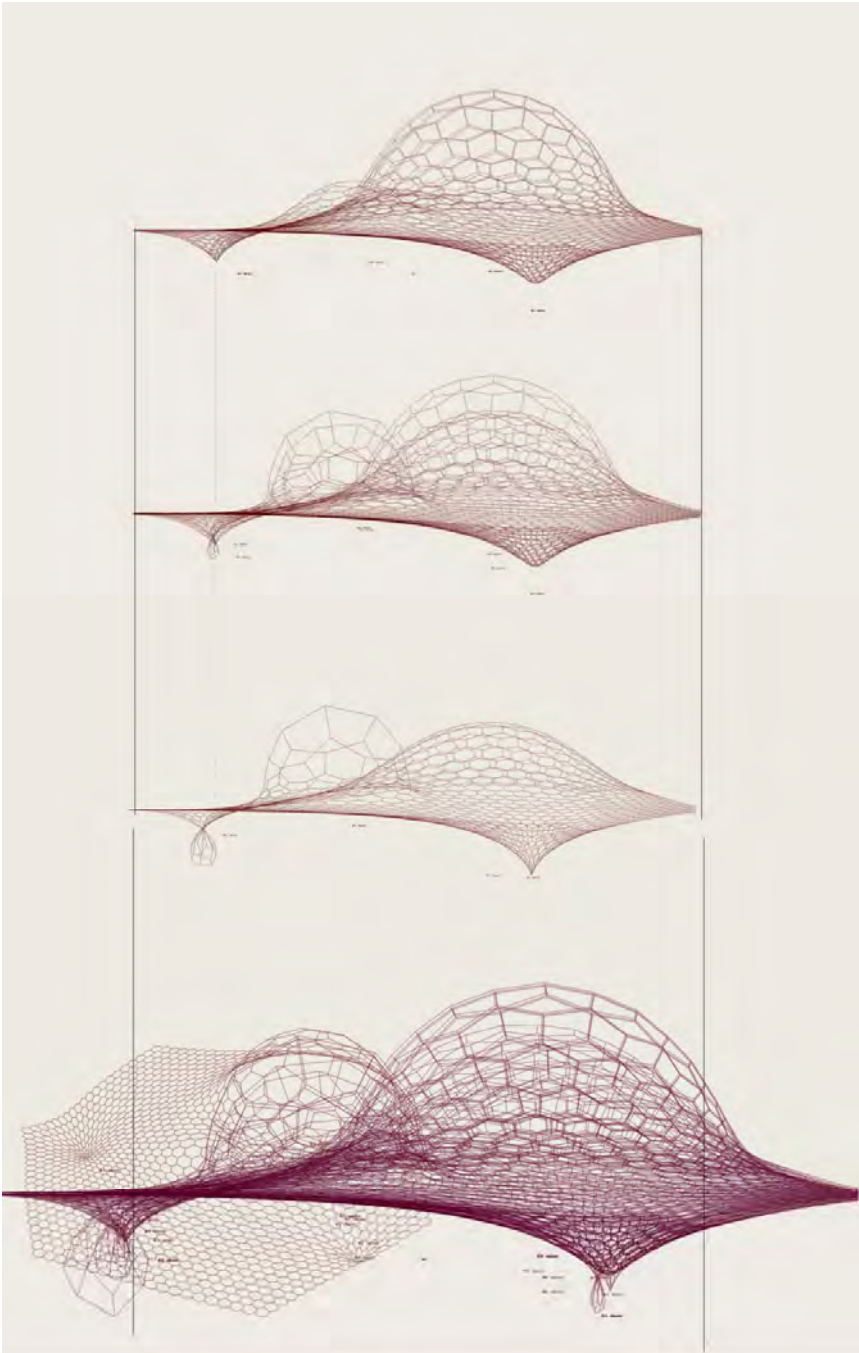
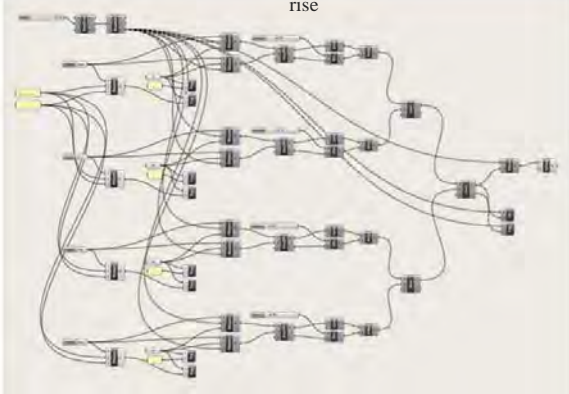


Figure 44: Images by author: Generating a hexagonal lattice that reacts to stimuli, such as water collection and heat rise



Phase 5: DEVELOPING TESSELLATIONS

Design Development: Phase 5: THE DEVELOPMENT OF A DESIGN SYSTEM THROUGH TESSELLATION PATTERNS	
Site Parameters (Primary)	<ul style="list-style-type: none"> • Designing a system to allow for the repetition of design details to allow for ease of construction. • The development in of a 3D hexagonal tessellation as a roof system which is an extension of the Opuntia's structure as well as the structure of S.A.L.T (<i>Appendix G</i>) as both these structures are founded upon a hexagonal lattice
Strategies taken from the Opuntia	<ul style="list-style-type: none"> • Expanding the hexagonal lattice into a modulated roof system that collects water through its undulations, mimicking a cladodes water collecting strategy
Material/technical parameters	<ul style="list-style-type: none"> • Let's Tessellate _ using tessellations to allow for climatic adaptations • Combining radial, hexagonal and Voronoi tessellations to creates 3D transitional and transactive spaces that are a direct result of the buildings singular biological entry point (the Opuntia) and its context.

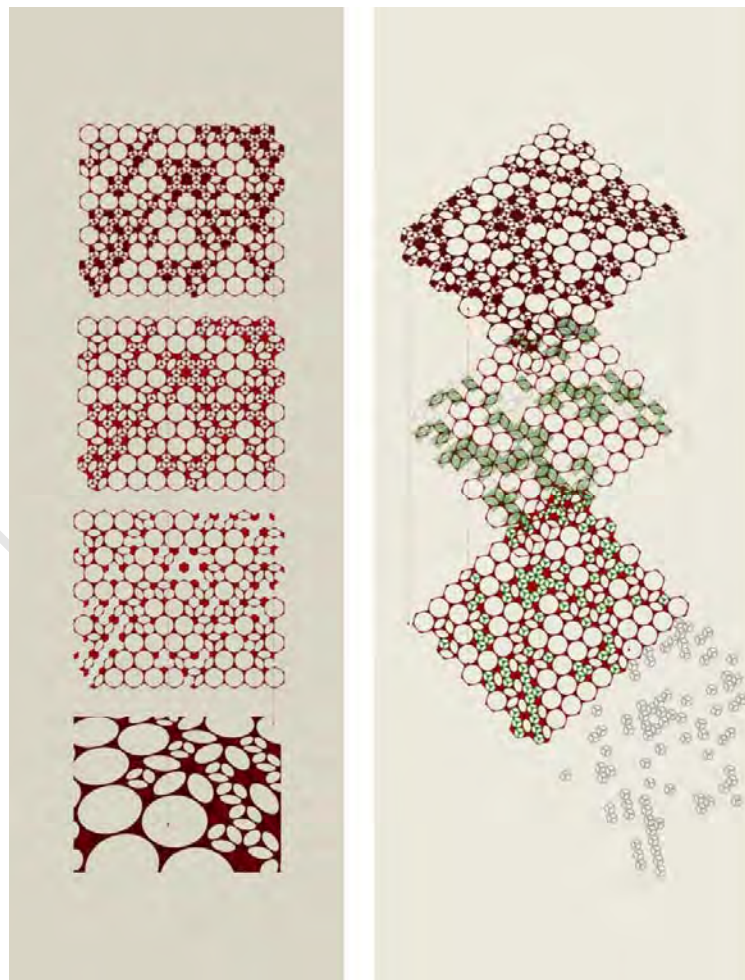
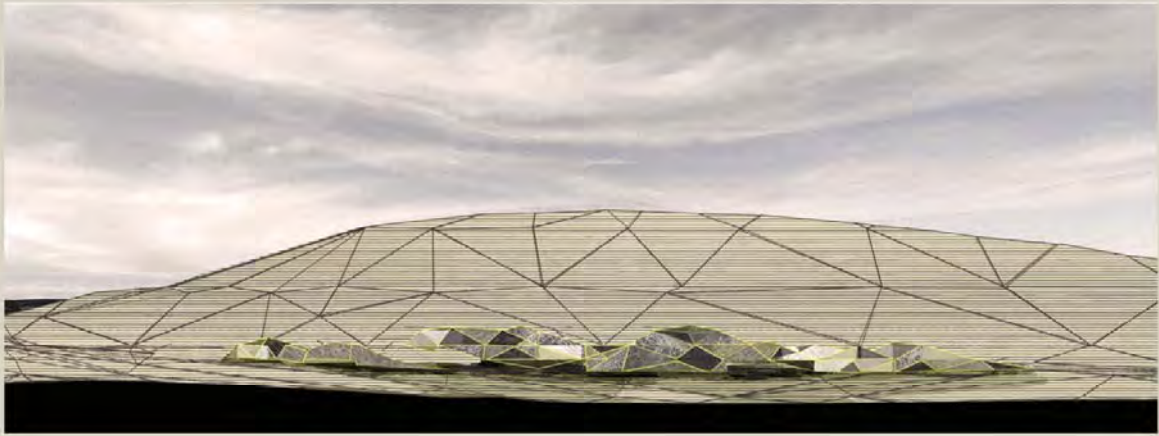
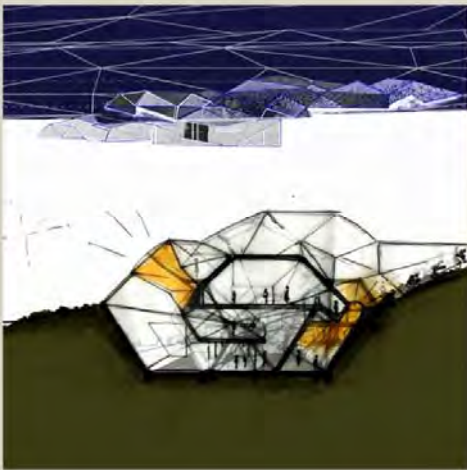


Figure 45: *Images by author:* Generating a hexagonal Voronoi and radial adaptive tessellation



1



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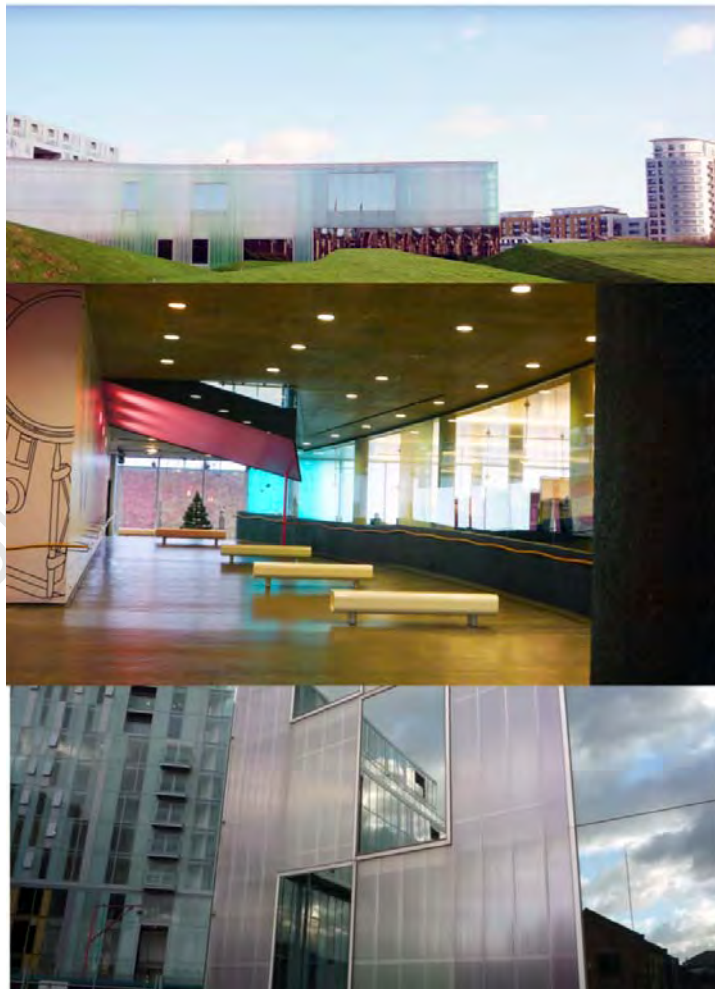
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Figure 46: Images by author, showing the Design Development



Figure 47: Photographs by author: Top: *Sagrada Família* by Gaudi, Bottom: Herzog and De Meuron's *Laban Centre* in London



The Final Design

When you can design with a material that has properties which are rampant in spatial solutions you are truly able to push the boundaries of *phenomenological* architecture. As Steven Holl writes in his book "*Parallax*," spaces should be "*ineffable*" in order to induce different responses amongst different users. These responses could be the result of *spatial transitions*, that take you from the darkness and lead you towards the light (like in the works of *Sir John Soane*); or they could be the result of the way in which certain forms have been manipulated to prompt an emotional response within the end user. The spaces that have had the most effect on my emotions have been where the architects' use of form and materials act as a singular entity. I have never felt more alive or spirited as when I entered Herzog and De Meuron's *Laban Centre* in London or the *Sagrada Família* by Gaudi in Barcelona (*Figures 49*). These two pieces of architecture use form and materiality to manipulate spaces in the most unfathomable way. The insides of both these buildings become an aura where boundaries between natural elements, movement, forms, and spaces become completely blurred and you as the user enter a zone that can only be described as a type of enlightenment. I have attempted to create a building that uses light and an unusual series of forms to try and generate this zone of enlightenment from the very materials that drive the architectural programme.

University of Cape Town

Exploring the Final Design:

The Master Plan: Acknowledging the Greater Scheme

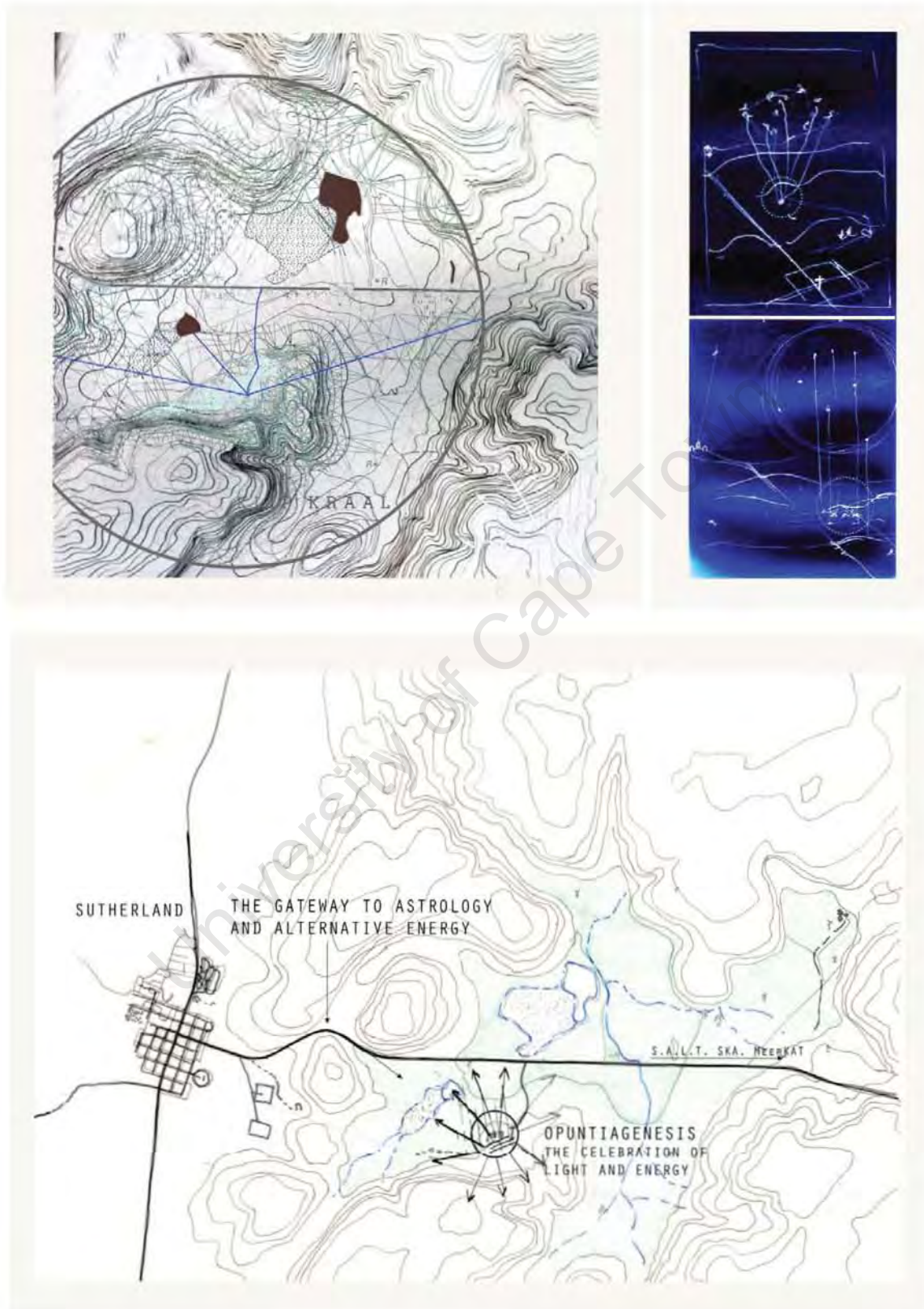


Figure 48: *Images by author:* Establishing *OpuntiaGenesis* as a tourism landmark, marking the gateway to South Africa's tourism and astrology route between Sutherland, Fraserburg and Carnarvon

Exploring the Final Design

Internal one-way glass and polycarbonate and Opuntia roof system

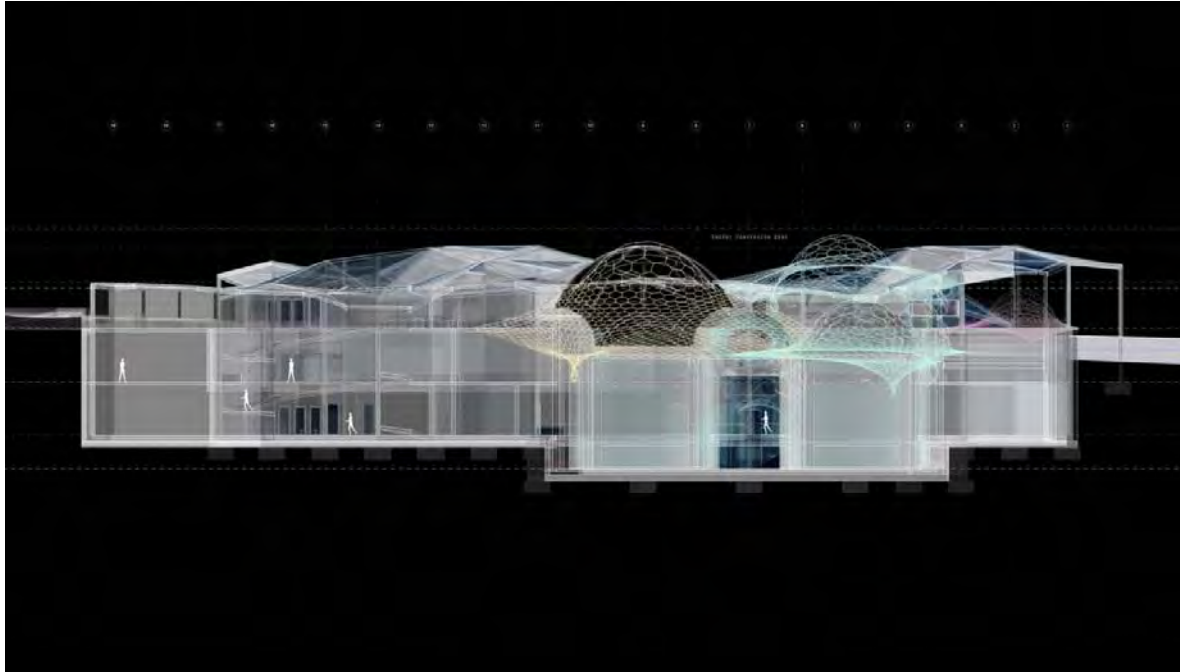


Figure 49: *Images by author*: section through the energy harvesting core of the building



Figure 50: *Images by author*: Spaces are fuelled and animated by different light experiences

Exploring the Final Design

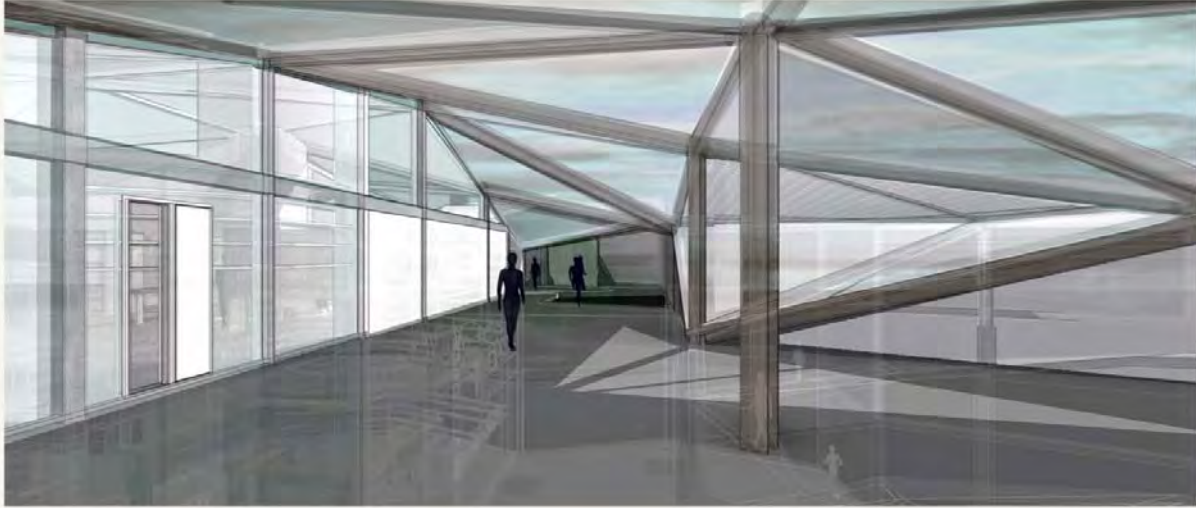
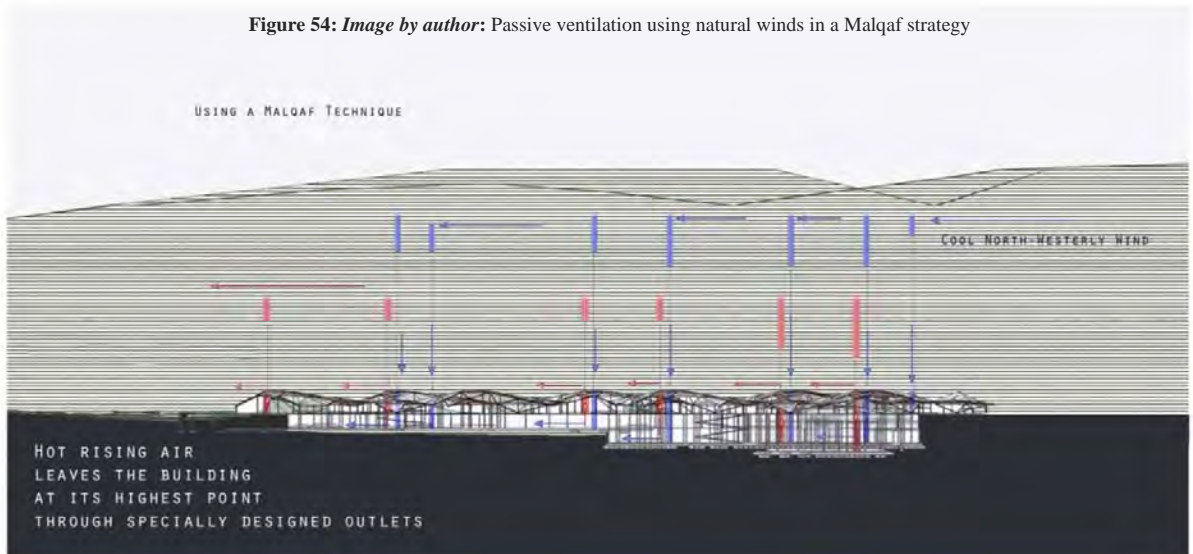
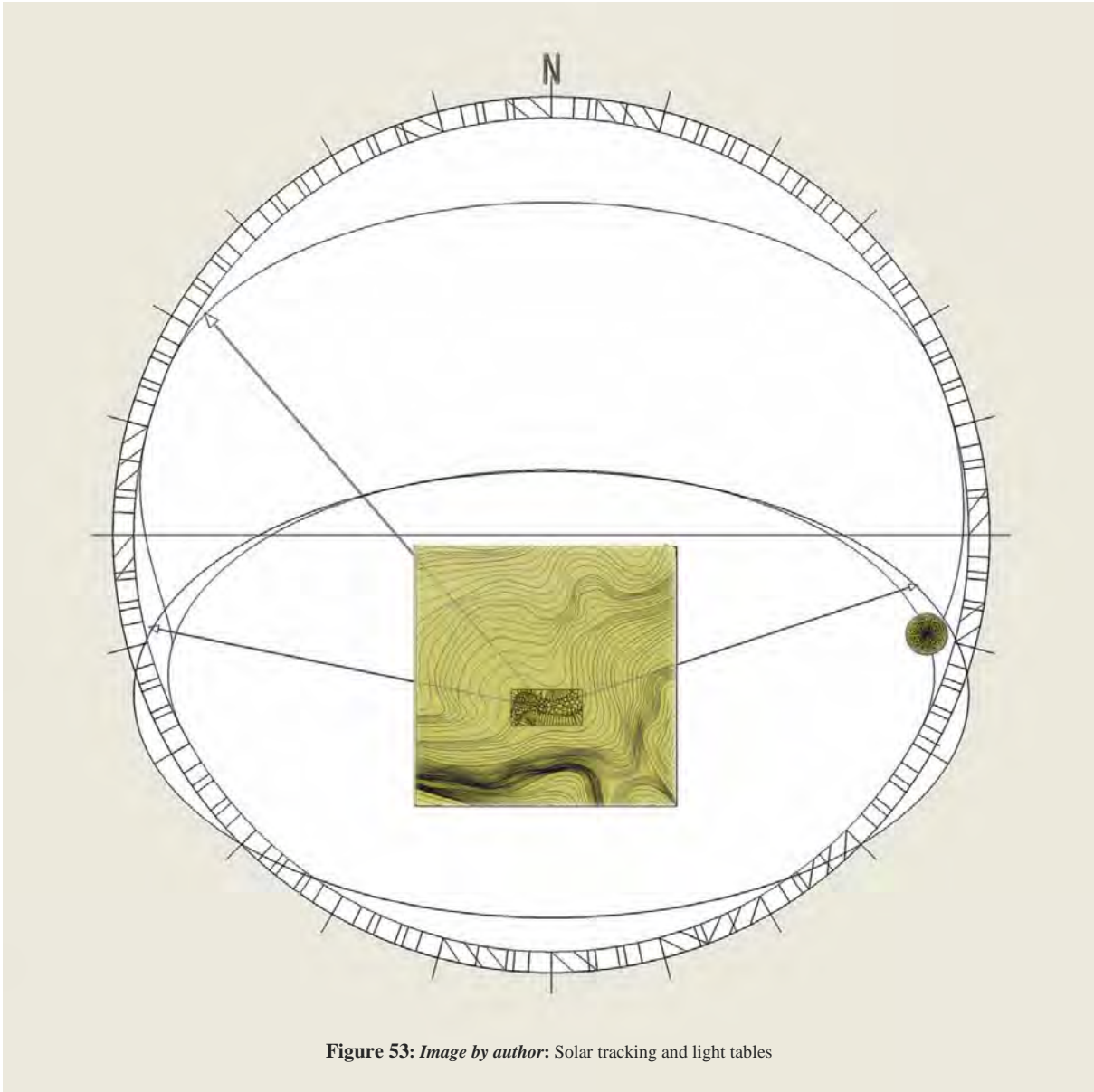


Figure 51a: *Images by author:* To the Left, The Food Production Core; Internal Public Pathways are animated by natural lighting

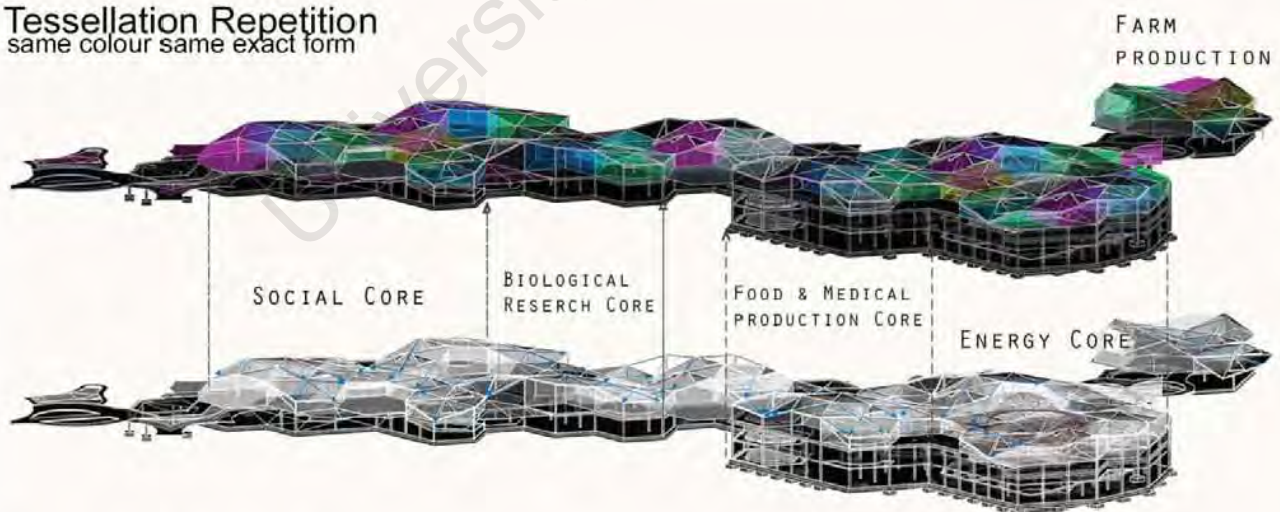


Figure 52b: *Images by author:* Interior view of the Lower Ground level of the *Social Core* bordering the botany and biological greenhouse: Spaces are fuelled and animated by different light experiences





Tessellation Repetition
same colour same exact form



Rain Water Runoff

Directed into Storage Tanks, Excess to runoff building in channels informed by the Voronoi Plan

Figure 55: Image by author: grey water systems and rain water harvesting strategies to allow for the optimisation of service systems

Building Sketch Plans

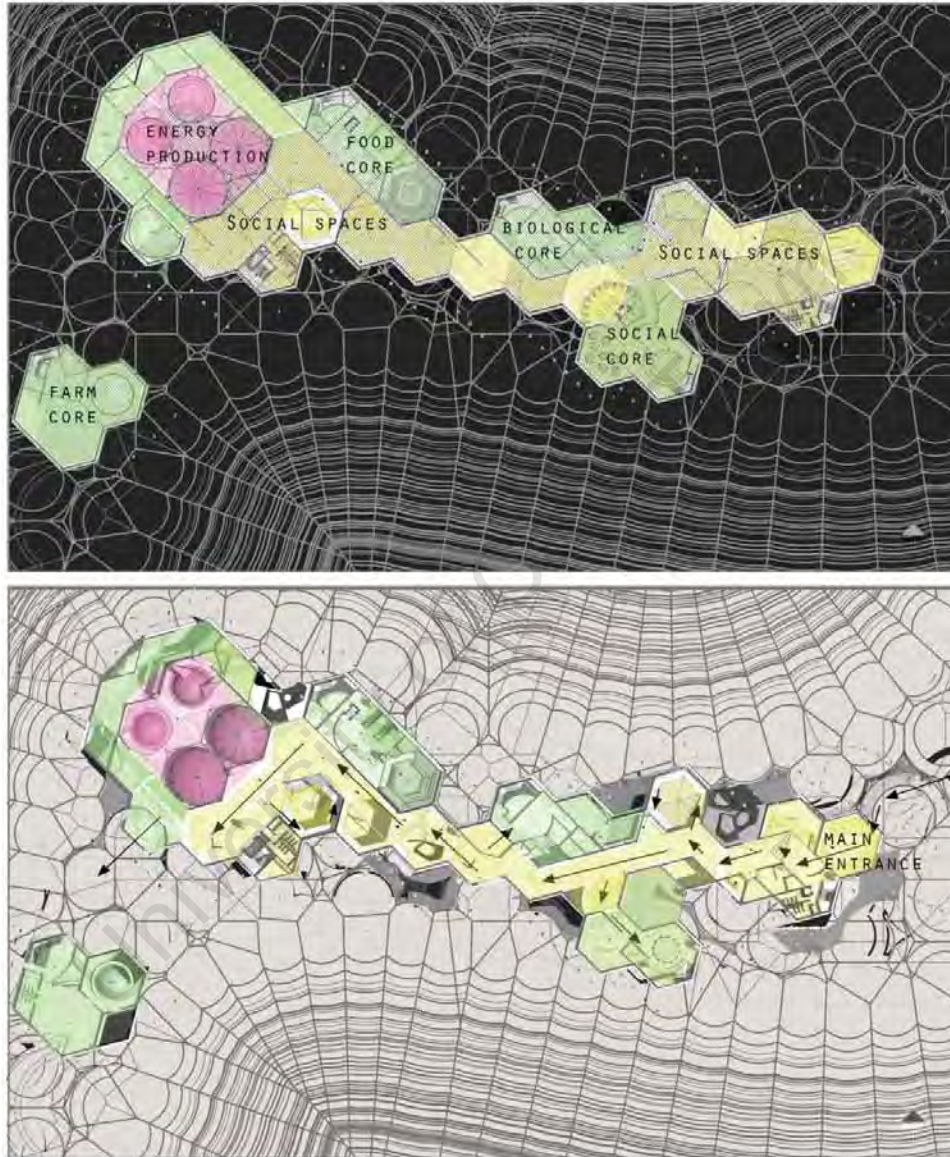


Figure 56: Image by author: Basic sketch Plans, showing lower ground and ground levels, production cores and routes through the building

Energy Conversion Zone

A celebration of the production of energy

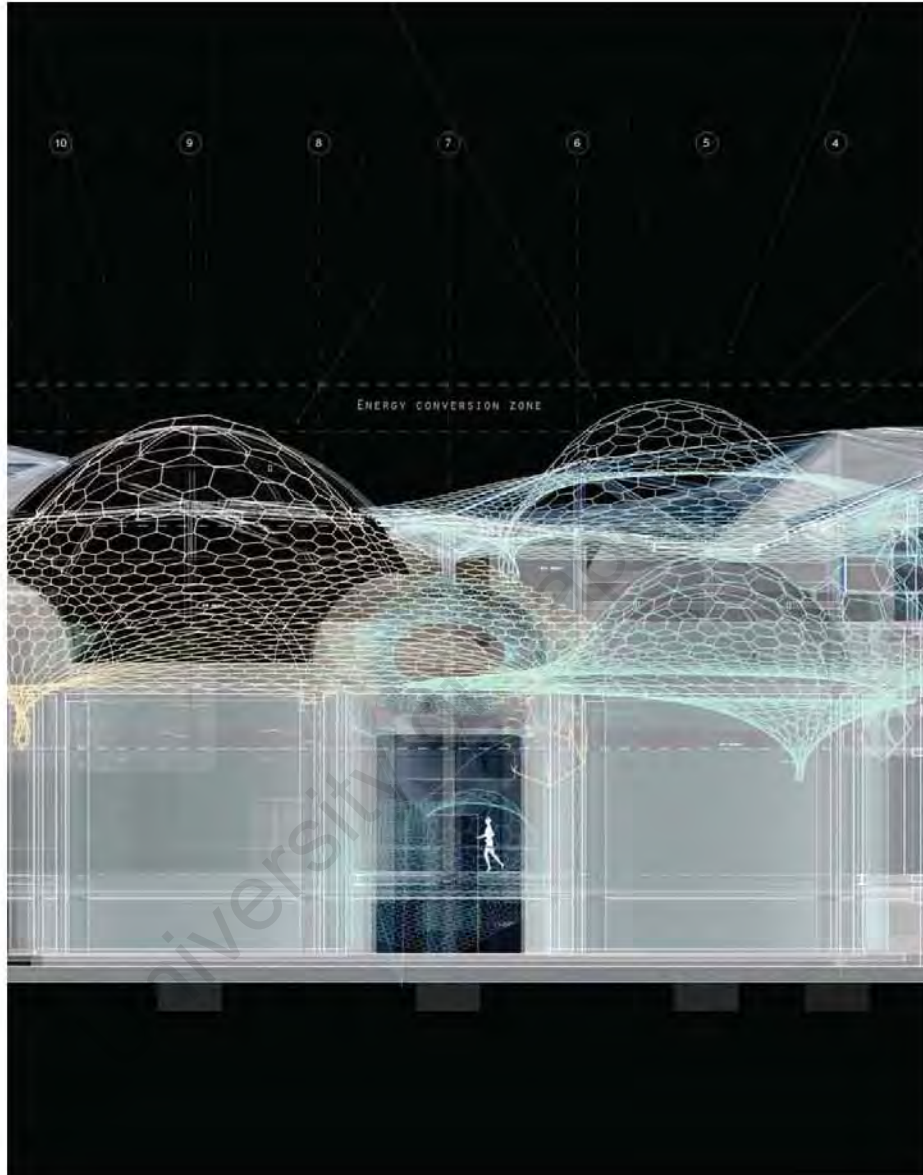


Figure 51: *Image by author:* Sketch design through the Energy Core of the Building, *The Energy Conversion Zone*

Conclusion

OpuntiaGenesis is a design exploration founded upon the notions of human vitality. Driven by the need to explore environmentally conscious systems; this dissertation attempts to expose ways in which energy, matter, programme and structure can be the resultant of one biological structure (the Opuntia). The *internet age* has instilled the idea of connectivity which drives our highly diversified communicative plexus of contemporary society. This society recognises that we are components of a greater system. For this reason an energy plant can no longer just be an energy plant, it needs to be contained in a sustainable and balanced system that recognises the importance of optimisation. A *materialecological* and *biomimetic* design approach recognises this need for optimisation by re-interpreting architecture as a great body, or an assemblage of bodies, that cut across a wide range of scalar and material regimes. By following a *materialecological* and *biomimetic* approach I was able to re-establish and redefine what an architectural material could be, by exposing the qualities of an Opuntia matter which could be inherently useful when applied to an architectural system that is founded upon this *plant species*. In this light, this dissertation explores Delanda's observation that there is a growing need "*to think about the origin of form and structure, not as something imposed from the outside on an inert matter, not as a hierarchical command from above as in an assembly line, but as something that may come from within the materials, a form that we tease out of those materials as we allow them to have their say in the structures we create.*" To help extract such a *structure* from Opuntia matter I turned to parametricism with the understanding that *intensive* forces of matter are trans-scalar and can thus be reconfigured into an architectural design. Such *intensive* forces include lustre, malleability, ductility and conductivity. Thus I tried to establish that the systems and qualities of Opuntia matter that would be the most beneficial when coupled with this dissertation's programmatic strategy (*figure 9*). This unusual programmatic strategy called for the creation of a highly diversified yet self-similar structural web that could be used to house its complex array of functions. By applying tessellations into this design I was able to generate a range of self-similar repeated components that can be mass produced allowing for a unique configuration of highly specialised experiential spaces. The result is a design that exposes the optimisation of the Opuntia species at all scales. In this way this building is the amalgamation of new and highly specialised processes of organisation which allow for the system to be in a constant state of regeneration, indicative of all natural systems. In this world where everything veers towards a "universal" it is our duty to explore alternatives and not settle for the accepted, the easiest or the most accessible.

Glossary of Terms

Biomimicry:	Biomimicry or biomimetics is an approach that examines nature, its systems, processes, models and elements, in order to solve or suggest solutions to human problems.	Morphogenetic:	a characteristic that allows a form to change shape or appearance under different stimuli
Extensive forces:	" <i>extensive forces</i> " are the forces that contain " <i>divisible differences</i> , such as measurements, mass, volume, time and constraints." (Reiser, J., Umemoto, N. , 2006)	Permaculture:	Permaculture is a design <u>philosophy</u> that seeks to exploit and imitate naturally occurring patterns and systems. It combines ecological design, ecological engineering and environmental design to create sustainable architecture and self-maintained horticultural systems.
Intelligent Environments:	In this paper intelligent environments are defined as spaces in which computation is seamlessly used to enhance ordinary activity. (Novak, 1998)	Plant:	Is both the <i>biological plant</i> (Opuntia) as well as an electrical <i>production plant</i> .
Intensive forces:	" <i>intensive forces</i> " are the "properties of matter that contain <i>invisible difference</i> , such as weight, elasticity, pressure, heat, density, colour and duration." (Reiser, J., Umemoto, N. , 2006)	Plexus:	A structure in the form of a network.
Materialecology:	"Materialecology is an interdisciplinary research initiative that undertakes design research at intersection between architecture, engineering, computation, biology and ecology. As such, this initiative is concerned with material organization and performance across all scales of design thought and practice. Material is interpreted merely as any physical entity which corresponds and reacts with its environment. As such, it seeks to promote and define a design research agenda which is ecological in nature, in ideology and in material practice; it aims at embracing the evolving elements of change in both (and indeed related) social constructs and environmental descriptions of the ever changing built environment"	Rhizome:	Under the conditions of this paper a rhizome has a dual meaning. In this paper it is not simply a biological structure associated with the root of a plant, but also a philosophical concept developed by Deleuze and Guattari in their Capitalism and Schizophrenia
		Topia:	Is a place, rather than an ideal place
		Viridigenous:	The production of "greenness"

List of Figures

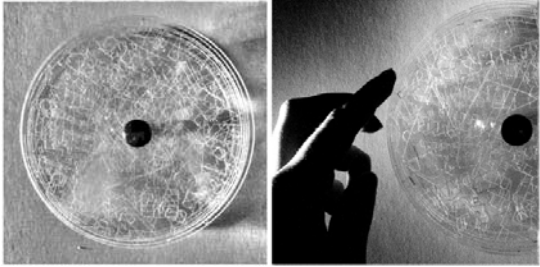
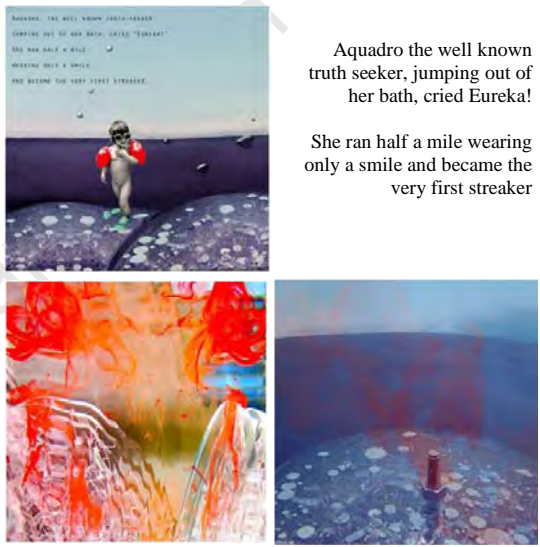
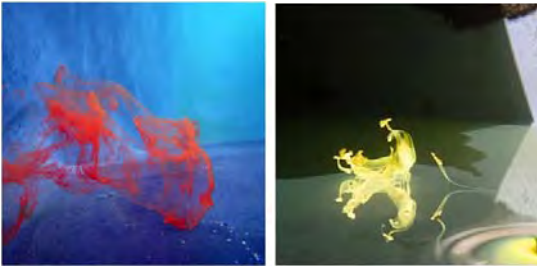

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Appendix A

Creative Transmutations		
Task	Description	Visual Outcome
<p>Geography _10</p> <p>Make your artefact as either a tectonic or stereotomic system</p>	<p>INTERACTIVE TECTONICS</p> <p>Gottfried Semper defines a <i>tectonic system</i> as the light weight linear components of a building which are the product of human skill. Kenneth Frampton goes on to define the tectonic system as the “<i>skin</i>” whilst the stereotomic system is the <i>mass/frame</i>. Under these conditions this artefacts the tectonic system is comprised of the seven layers of engraved Perspex. Under natural conditions a geographical tectonic system relies on the movements of the Earth’s crust, resulting in the shifting of plates. This artefact has been placed under the conditions of a spiral poem to induce tectonic interaction with the object. In this way the poem is the catalyst whilst the user takes on the role of the shifting plates. In this way the end condition cannot be preconceived but one knows that changes will occur similarly to that of an earthquake.</p>	
<p>History _10</p> <p>Represent your artefact as either a comedy (maybe parody), and also a tragedy.</p>	<p>UNFOUNDED COMPANY _THE STORY OF LOSS AND MANIFESTATION</p> <p>Traditionally a <i>tragedy</i> is coupled with death, whilst a <i>comedy</i> normally ends in a marriage.</p> <p>How can one cause the death of an abstract object and how does one represent that death?</p> <p>The two ways in which one could physically represent the death of an object would be if one was to cast that object in stone or if one was to sink the object so that object be forgotten amidst times abyss. One chose to do the later. Isolated, yet still intact the object sinks capturing air through its openings. Porosity, vulnerability, instability, osmosis, infiltration and the loss of human interaction all form part of this tragic plot.</p> <p>Can the creation of a tragedy result in a comedy?</p> <p>By opening the object up to weakness through an analysis of its creation and a miss-reading of its <i>place</i> in “<i>time and space</i>” one is able to create and expose the object to a light-hearted manner; which hopefully some will find humorous.</p>	<p>Aquadro the well known truth seeker, jumping out of her bath, cried Eureka!</p> <p>She ran half a mile wearing only a smile and became the very first streaker</p> 
<p>Art and Literature _10</p> <p>Consider your artefact as a system of rhythmic notation, and represent a series of emotive aspects.</p>	<p>UNFOUNDED COMPANY _THE STORY OF LOSS AND MANIFESTATION</p> <p>A movie of the sinking of the object</p>	
<p>Natural sciences _10</p> <p>Apply a range of graphic filters to you artefact establishing multiple ways in which it can be estranged</p>	<p>ESTRANGED ABSTRACTIONS</p> <p>The object is exposed to cellular, material, colour, time, scale and natural abstractions. In one image the object is seen as a living structure, sprouting tentacle-like roots which gain energy from bubbles; whilst in the next the object has been superimposed onto the rocky landscape of the Cedarburg creating a strange futuristic scene. All the scenes are dependent on the viewer’s own interpretation and are thereby defined under one’s own spatial memories.</p>	

The Bugs - Biological Control

In South Africa prickly pears are regarded as an invasive species. For this reason *bio-control* has been implemented in order to try and control their intrusive spreading. The main method for combating such spreading is the use of insects which feed off the plant. The main insects that are used are:

- The cochineal insect
- The cactus moth
- & two other species of stem boring beetles

These insects were introduced to control the spreading of the *Opuntia* species; however the spineless variety of the *Opuntia ficus-indica* that will be used in this plantation, is not an invasive spreader. In order to prevent these insects from attacking the plantation you can simply introduce a large quantity of lady bugs into the area, as "lady bugs are these insects' natural predators." (Dodd, A. P. (1940).



Figure 57b: *Pictures form JohnHoffma*: Images of the Karoo, before and after the introduction of bio-control

Anaerobic Digester Design Systems	
Question	Description
How does one design a system to exclude oxygen?	During anaerobic digestion, gaseous oxygen is prevented from entering the system through the use of specially designed sealed systems. Although anaerobic digestion takes place during the absence of oxygen, the anaerobes still require Oxygen. This Oxygen is held in within the organic matter that enters the digester.
What are micro populations?	Like all living systems, it takes time for the microorganisms' population to establish themselves. To speed up their development one can employ a technique known as "Seeding" (Mattocks, R.). During this type of "seeding," sewage or cattle slurry is added to the digesters to quickly increase the micro populations.
What types of Anaerobic Digesters are available	
Batch or Continuous Systems	<p>Anaerobic digestion can be performed as a batch process or a continuous process. In a batch system biomass is added to the reactor at the start of the process. The reactor is then sealed for the duration of the process. In its simplest form batch processing needs inoculation with already processed material to start the anaerobic digestion. A problem occurs when you open the system before digestion has completed. If this happens it will often result in an extremely unpleasant odour. There is an advanced type of batch processing that has limited the odour issues by integrating anaerobic digestion with "in-vessel composting" (Mattocks, R.). In this approach inoculation takes place through the use of "recirculated degasified percolate" (Mattocks, R.). After anaerobic digestion has completed, the biomass is kept in the reactor which is then used for "in-vessel composting" before it is opened. Batch digestion is the simplest form of anaerobic digestion, this means that batch systems are often cheaper and easier to manage compared to the other types of systems.</p> <p>In a continuous digestion process, organic matter is constantly added to the digester. In such systems there is a continuous supply of biogas. Single or multiple digesters in sequence may be used. Examples of this form of anaerobic digestion include: "continuous stirred-tank reactors, up-flow anaerobic sludge blankets, expanded granular sludge beds and internal circulation reactors" (Mattocks, R.).</p>
Systems based on Temperature	<p>The temperature of a digester is determined by the species of methanogens used in the digester.</p> <p>Mesophilic systems: In these systems digestion takes place optimally around 30 to 38 °C, or at ambient temperatures between 20 and 45 °C. Mesophiles are the primary microorganism used in such systems.</p> <p>Thermophilic systems: Digestion takes place optimally around 49 to 57 °C, or at elevated temperatures up to 70 °C. Thermophiles are the primary microorganisms present in these systems.</p> <p>The "Mesophilic species" of bacterium outnumber "thermophiles," as they are more tolerant to changes in environmental conditions (Zietsman, 2013). "Mesophilic systems" are, therefore, considered to be more stable than "thermophilic digestion systems" (Ahring, B. K. , 2003).</p>
Basing systems on their Solid Contents	<p>Typically there are three different types of operational parameters associated with the solid content of a system.</p> <ul style="list-style-type: none"> • High solids (dry—stackable substrate) • High solids (wet—pumpable substrate) • Low solids (wet—pumpable substrate) <p>High solids otherwise known as dry digesters are designed to process materials with a solids content between "25% and 40%" (Ahring, B. K. , 2003). High solid digesters are designed to process solid substrates without the addition of water. There are two main styles associated with dry digesters, these are "continuous vertical plug flow" and "batch tunnel horizontal digesters." Continuous vertical plug flow digesters are upright, cylindrical tanks that are constantly fed from the top of the digester. The feedstock then flows down by gravity. In batch tunnel digesters, the feedstock is deposited in tunnel-like chambers with a gas-tight door. Neither approach has mixing inside the digester. The amount of pretreatment required for both these systems depends upon the type of feedstock used. When agro crops are used there needs to be a degree of homogenization before it enters the digester. The main type of homogenization is a process that reduces the size of the feedstock particles that enter the digester. This technique is known as <i>grinding</i>, and is extremely beneficial in continuous vertical systems, as it accelerates digestion.</p> <p>Wet digesters can be designed to operate with either a <i>high solid</i> content or a <i>low solid</i> content. <i>High solid</i> digesters process thicker slurry which requires greater energy to process the feedstock. The thicker slurry also puts greater stress on the digesters themselves. These digesters need to be hardy to withstand the possible abrasion. <i>Low solid</i> digesters require significantly lower energy inputs in comparison to <i>High solid</i> digesters. However, <i>low solid</i> digesters require a larger amount of land than <i>high solid</i> digesters due to the increased volumes associated with the increased liquid-to-feedstock ratio of the digesters. There are many benefits associated with "wet" digestion, as liquid environments allow for greater circulation between the materials and the bacteria; Thus resulting in a higher gas production.</p>
Systems based on Complexity	<p>Digester systems are configured according to their complex needs. Under this notion there are two main types of digester systems that one could implement. One can use either a single-stage digestion system or a two-stage digestion system.</p> <p>Single-Stage Digestion System</p> <p>In this type of system all of the biological reactions occur within a single, sealed reactor or holding tank. These systems have lower construction costs but mean that you have less control over the reactions occurring within the system.</p> <p>Two-Stage digestion system (Multistage)</p> <p>These systems are configured using a plexus of digestion methods to bring about maximum control over the bacterium reactions taking place within the system through the separation of the four main processes associated with anaerobic digestion. Typically hydrolysis, Acetogenesis, and Acidogenesis occur within the first reaction vessel. From there the organic material is then heated to the optimal heat depending of the bacterium used before it is pumped into the methanogenic reactor. This type of system is far more stable but requires greater skill to run it.</p>

Appendix D

Accommodation Schedule				
Size (m)	Quantity	Room Type	Public/Private	Check
Core 1: FARM PRODUCTION: <i>equivalent to a type of barn</i>				
10 x10	1	Homogenisation Room	Private	
5 x 10	1	Opuntia storage and sorting room	Private	
15 x 10	1	Farm equipment storage room	Private	
10 x10	1	Workshop + Store	Private/accessible	
3x4	2	Site Offices	Private/accessible	
8 x 6	1	Ablutions block	Semi-public	
2 x4	1	Fuel Room	Private	
10 x 10 x 8	2	Experimental Digesters	Private	
	1	Emergency stair case		
Core 2: ENERGY & MATERIAL HARVESTING				
10 x 10 x 8	4	Main Digesters	Private/ below ground level	
10 x 10	4	Digestate filtering system	Private/accessible	
10 x10	1	Rain water storage dam for digesters	Private/accessible	
4 x 10	2	Bio waste store	Private	
2 x 5	2	Gas store	Private	
5 x 4	1	Control Room/ solar battery room	Private	
4 x 4	1	Digester Feeding room	Private	
6 x10	1	Generating room	Private	
2 x 4	1	Manger Office	Private/	
40 x40	1	Energy viewing area above the digesters – experiencing the merging of solar energy into chemical energy	Public	
	2	Emergency stair case		
8 x 6	3	Ablutions block	Semi-public	
Core 3: FOOD PRODUCTION				
10x15	3	Kitchens/ Commercial food production	Private/ semi private	
5 x 4	2	Product Room	Private	
5 x 4	4	Basic Stores	Private	
5 x 4	3	Cold Store	Private	
5 x 4	2	Medical store	Private	
5 x 4	3	Sterilization room	Private	
8 x10	2	Green houses	Private	
3 x 4	2	offices	Private/accessible	
	1	Emergency stair case		
8 x 6	1	Ablutions block	Semi-public	
Core 4: BOTANY AND BIOLOGICAL PRODUCTION				
4 x 5	4	Offices/2 permanent biologists 2 temporary biologists	Private/accessible	
10x15	2	Main Bio labs/ medical	Private	
5 x 4	2	Office supply rooms	Private	
5 x 4	3	Culture labs	Private	
2 x 4	2	Imaging Rooms	Private	
5 x 4	3	Equipment rooms	Private	
10 x10	2	Greenhouse & sampling area	Private	
5 x 4	3	Sterilization room	Private	
2 x 3	6	Stores	Private	
10 x 5	1	Computer lab/skills development lab	Private	
	1	Emergency stair case		
8 x 6	1	Ablutions block	Semi-public	
Core 4: Local Craft Development + Tourism Facilities				
10 x 10	1	Public foyer/reception area	Public	
10 x 8	1	Café and fresh produce store	Public	
	1	Opuntia sculptural tea garden	Public	
10 x10	1	Voided Gallery 2 floors	Public	
8 x 20	1	Experimental gallery	Public	
8 x 8	2	Seminar room	Public	
4 x 2	2	Offices	Private	
10 x 8	2	Craft studios	Semi-public	
10 x 8	1	Environmental, craft and historical library	Public	
10 x 8	1	Computer Room	Semi-public	
4 x 4	4	Material stores	Private	
	2	Social open learning spaces	Public	
8 x 6	3	Ablutions block	Public	
		Indigenous gardens	Public	
		Site ecology trails	Public	

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Appendix E			
Part Of The Plant	Properties For Successful Propagation	Biomimetic Qualities	By-Products
<p>ROOTS</p> <p><i>_Rhizogenic Propagation</i></p>	<p>The <i>Opuntia</i> species is not only propagated through seeds; as fallen <i>cladodes</i> have a property that enables them to root themselves too. This characteristic allows for a vast production of crops to be grown with fairly little effort.</p>	<p>The structuring of a cladode as a rhizome exposes an organisational system that can be re-interpreted into a planning strategy if so desired. In a biomimetic reading, a “rhizome” can be interpreted as a structure that is able to apprehend “non-hierarchical multiplicities” as observed by Deleuze and Guattari in their “Capitalism and Schizophrenia (1972-1980). In this sense a “rhizome” represents a model that goes against the “arborescent model” of architectural thinking; as a <i>rhizomes</i>’ conception of knowledge is founded upon “planar and trans-species connections” rather than it being limited to the “binary choices and dualist categories” that encompass the “arborescent model” of thinking. In this way a closed system associated with permaculture can be read as having the same characteristics as a rhizome, as each element of the process is as equally important as the next. Thus a system based on permaculture is seen to function as a plexus of never ending semiotic chains that favour “nomadic systems of growth and propagation” (Reiser, J., Umemoto, N. , 2006).The processes associated with permaculture are cyclical, as they are heavily reliant upon systems that are defined by climatic conditions. As previously mentioned the proposed site experiences extreme weather conditions; thus crops such as the <i>Opuntia</i> are extremely valuable as they are able to adapt and survive in regions with extreme temperature differences where water is scarce.</p>	<ul style="list-style-type: none"> • Anaerobic digester feed
<p>CLADODES</p> <p><i>-Cladogenesis</i></p>	<ul style="list-style-type: none"> • Functions as a rhizome • Main structural support 	<p>Although <i>Cladodes</i> are only found on succulent plants their structuring systems and patterns of growth are extremely valuable if you overlay their basic principles with systems associated with architecture. <i>Cladodes</i> grow off from each other, thus they all essentially branch from a common ancestor. This characteristic offers several advantages particularly in regards to planning; as we can look to the layout of the <i>cladodes</i> for clues of how to spatially arrange the systems and processes outlined in (Figure 2). We can also look at the materiality of the <i>cladode</i> and just what qualities make them water repellent and sun reflecting; which are two qualities that are highly useful, in fact essential when designing for a desert terrain. If we apply all these relative observations to an architectural approach such as “<i>materialecology</i>” (Oxman, N, 2006); it will result in the creation of highly valuable, multifunctional architectural solutions that can be implemented in a project that is designed under the conditions associated with (Figure 2).</p>	<ul style="list-style-type: none"> • Animal fodder • Human consumption • flours, • meat replacers • sherbet” • Anaerobic digester feed, biogas
<p>SPINES</p> <p><i>_Spinal Ectogenesis</i></p>	<p>As previously mentioned the <i>Opuntia</i> species can be genetically adapted to become spineless. The spineless variety of <i>Opuntia ficus-indica</i> is the only species of prickly pear allowed to be farmed in South Africa under our environmental laws. By removing the spines, the entire plant becomes more manageable as the spines are in fact a real nuisance and can result in injuries if not handled correctly. However, the structuring of these spines holds architectural value; for this reason I will still discuss their properties in the next paragraph.</p>	<p>Unmodified <i>Opuntia</i> cladodes are covered in two types of spines; glochids (the larger stiffer bristles) and an abundance of smaller spines. The glochids are positioned in such a way that they are able to attract dew into the pores of the cladodes. It is not just their positioning that allows for this collection of dew but also their microscope structuring; as every glochids is covered in tiny fine hair-like structures that attract dew drops. This functional structuring offers valuable insight towards what architectural skins should be doing in arid conditions. In a single solution, architecture should be able to “transform and transact” to climatic conditions whilst harvesting rare resources such as water. If you were to couple these properties within an architectural material you will be entering the world of “<i>transactive architecture</i>,” as described by Marcos Novak, who uses this term to describe <i>intelligent architectural</i> solutions that not only “interact, but then transact and transform both the end user and itself.”</p>	
<p>EPIDERMIS</p> <p><i>_Epidermis Ectogenesis</i></p>	<p>If you examine the material properties of the <i>Opuntia ficus-indica</i> species, you will see its materials and their structuring allow for several climatic adaptations. Their most prevalent adaptations are the way in which they transform under different temperatures constraints and how they can adapt when water is not easily available. This allows them to grow well in extremely harsh conditions.</p>	<p>The <i>Opuntia</i> Cladode is further structured in such a way that allows for expansion and contraction when put under different environmental constraints. In <i>figure 8</i> you can clearly see the different responses of a cladodes skin. In these photographs the shrunken vein-like part of the cladode has sacrificed its nutrients towards the greener area of the cladode. What you cannot see in this image is that the area below the brighter green section is where a new set of roots are forming. In this way, biological structures epitomise Marcos Novak’s theories of “transactive space” as they comprise of “transactive materials.”</p>	
<p>THE FRUITS & ITS FLOWERS</p>	<p>One cladode can produce anywhere between “10 and 25 prickly pears in a single season” (Elqui global energy, 2013). An <i>Opuntia</i> normally consists of a number of cladodes, thus each plant can produce anywhere between “25 and 300 prickly pears in a season” (Elqui global energy, 2013). The flowers also encourage the promotion of bee populations in more arid areas. Bees are highly valuable creatures and so are their products. By introducing bee hives to such a plantation you will be able to harvest honey along with all the other by-products.</p>		<ul style="list-style-type: none"> • Beverages • Liqueurs • Jams • Skin products • Sherbets • Prickly-pear prickles • General fruit • Digester feed _ biogas • Treatment for obesity • Treatment for hypoglycaemia • Treatment for high blood pressure • Treatment for diabetes.

Material Possibilities *for both the Processing Energy Lab and well as the Anaerobic Digester*

Figure 58: Diagram by author: The basic principles of collecting gas



Construction & Materiality of an Anaerobic Digester

The harsh terrain and soil conditions of Sutherland mean that one has to use hardy materials in order to create the sub-terrarium tanks of the anaerobic digesters. Two conventional base materials would be brick and mortar, or the onsite pouring of concrete. Although one can buy ready-made digestion tanks, the generic tanks on offer will not allow for the desired generating capacities for such a specific system in such an extreme climate. Thus these digester tanks will need to be specially designed and constructed. For the design of these digester tanks one needs to apply basic principles for the collection of gas, as shown in *figure 16*. In this figure we can distinguish that there are two main structures needed when collecting biogas. There needs to be a solid area where the reactions take place, and an expandable area where the gas is collected. Most systems combine these two elements together as a method of optimisation; however you can design a system where these two elements become separate entities if so required.

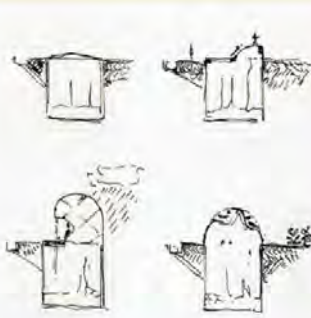


Figure 59: Conceptual sketches by author: exploring possible forms of anaerobic digester domes

Forming the Tank

Digester tanks can be free standing or they can be sunken into the ground. In an area like Sutherland it is better to create sub-terrarium tanks as the earth's bio mass can be used as a temperature controlling agent. If you do use a free standing tank in Sutherland you would have to spend a lot of money on the insulation of the tank; as Sutherlands' temperatures are so extreme. As previously mentioned an Opuntia farm of 20ha is capable of producing up to 3000m³ of gas per day; thus the reaction tanks will need to be able to hold such a volume and must be able to withstand an excess volume of gas and digestate. There is no limit to the shape that these tanks must be, however one of the key aspects of design is to allow for the removal of digestate. For this reason curved surfaces are the preferred choice; as corners encourage the buildup of digestate and corners are hard to clean with the limited access that one has to anaerobic digestion tanks. It is also a good idea to split the volume of these tanks into several digesters rather than having one large tank. By working with multiples you are able to maintain the productivity of the farm at varying scales and it also allows for the continuous production of energy when one tank is being cleaned or maintained. Most rural anaerobic digesters structures are formed out of simple brick cylinders with brick domes (*Figure 60*); however there are many other materials that can be used instead of this basic method.

Forming the Expandable Dome

Firstly, the expandable energy holders do not need to be domes. They could be completely round or cone shaped. In fact these expandable holders can be comprised of any shape, so long as the shape reaches a point whereby all the gas can be collected; as it is at this point where the gas will be redistributed into storage tanks. *Figure 60* displays two different examples of fixed digester domes that can be used. All of the digesters on the market seem to comprise of only one function (the function of gas storage); for this reason I believe that there is room for the exploration and redevelopment of digester "domes." What would be the result if you were to re-imagine the shape and the positioning of the domes to allow for human interaction? *Figure 59* explores the idea that this "dome" could expand differently under different conditions; providing shelters, seating, play areas...etc. The materiality of this gas collector is usually a high performance polymer that is able to expand and contract, similar to that of thick rubber. If this material was thick enough with a protective layer then it would be possible to design a cyclic playground surface; comprising of the multiple digester domes. If designed correctly this surface would be able to shift and morph during the different stages of anaerobic decomposition. Whilst reading Reiser and Umemotos' *Atlas of Novel tectonics 1* was drawn to an image entitled *Galleria of Fog* (*figure 18*). What was written by its side was: "The mist that glides daily into the galleria animates its vast silent form with the life that has animated architecture since the advent of classicism." Architecture has always been heavily based on its interactions with external stimuli; for this reason and in response to Reiser and Umemotos' description should we not be exploring and harnessing the energy that comes from within the architecture itself or so that animation can be found within the very matter of architecture; instead of architectural forms being animated by external stimuli. If one could develop intelligent materials that adapt to *intensive forces* and couple this with a process capable of generating its own energy, then the resultant architecture would not only be animated by its materials but also by its program; thus is could be instinctually described as an Energy lab.

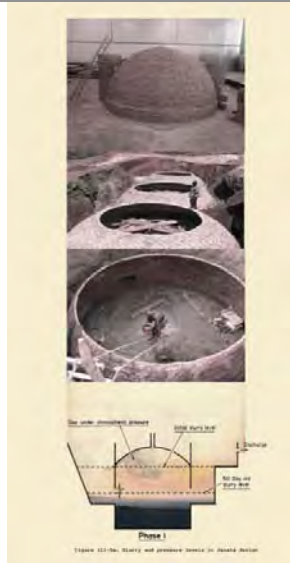


Figure 60: Images of Anaerobic Digester tanks constructed out of brick and mortar (Zietsman, 2013)



Figure 1: Image taken from: (Devitt, 2000) Structuring of S.A.L.T using hexagonal tessellations

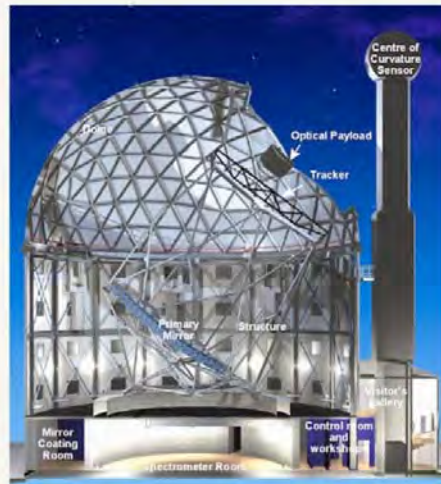


Figure 2: Image taken from: (karel, 2010): Learning from the tessellated structure of S.A.L.T



Figure 3: Image taken from: (Crause, 2010): Learning from the tessellated mirrored structure of S.A.L.T