Blueprints from Nature

Investigating a biomimetic approach to architecture.

Design Research Project APG5058S

Submitted in partial fulfilment of the requirements for the degree
Master of Architecture (Professional)

By

Wilhelmina Catherina Rust

October 2011

CONTENTS

GLOSSARY OF TERMS

Algorithms — An algorithm is a method with specific instructions used in mathematics and computer science to calculate a complex and often organic function.

Biomimicry — Innovation inspired by nature.

Biochemistry — The branch of science concerned with the chemical and physicochemical processes that occur within living organisms.

Biomorphic — The representational mimicking of form or pattern that resembles a living organism in shape or appearance.

Bionics — The study of mechanical systems that function like living organisms or parts of living organisms.

Cybernetics — The science of communications and automatic control systems in both machines and living things.

Interdisciplinary — Relating to, or involving two or more academic disciplines which are usually considered distinct.

Metaphysics — The branch of philosophy that deals with the first principles of things, including abstract concepts such as being, knowing, cause, identity, time, and space.

Sustainability — Relating to, or being a method of harvesting or using a resource so that the resource is not depleted or permanently damaged.

INTRODUCTION

Before the Modernist Movement it used to be so easy to identify different architectural elements within structures around the world; elements that were true and unique to that country or culture. However, since the start of Modernism, buildings around the globe have adopted a rather crude 'machine-like' nature, inspired by the new industrial technologies of the time. Consequently they have, despite their culture or climate, started to become more and more similar in form and structure leading to such universal aesthetic that it makes it difficult to distinguish whether a certain building hails from Europe, Australia or even Africa. This loss of regional distinction and uniqueness of place have prevented us from understanding and fully benefitting from what local culture and climate have to offer for the making of architecture.

The inquiry of this thesis started off with an interest in the making of an architecture that really attempts to achieve this sense of place and uniqueness. But how does one do this? It used to be commonly believed that technology was the primary obstacle to creating context sensitive architecture, but this thesis would suggest otherwise. Technology is not the drawback – in fact, the technologies we possess today can provide us with the tools needed to gain access to critical information to develop and analyze the world around us more efficiently and in greater depth than ever before. So what is needed is a change in our source of inspiration. Changing the metaphor of the machine to that of nature can provide us with a whole new world of undiscovered possibilities and solutions to design.

This metaphor for building (when applied appropriately) is one that respects regional differences and environmental health while embracing suitable technologies to provide the comfort, service and security we need. Yet, it is true that making use of this type of metaphor within an architectural context is not a new concept, but this idea has been used for centuries by famous architects like Vitruvius, Gaudi, Buckminster Fuller and Frei Otto. However, recently there has emerged a movement that has taken this idea to a whole new level. This movement is known as Biomimicry.

Biomimicry is a term frequently used in engineering and scientific research. It explores biological properties from the natural world and translates them into principles for the man-made world of design and science. Plus the term is not just limited to the fields of science and engineering, but has also been experimented with in art, business models, and of course architecture. One might say that the aim of it is to find a wide-spectrum method for considering nature in the way we as humans relate to our environments. To put it in the founder, Janine Benyus' words it can be described as "innovation inspired by nature". *[Benyus 2002]*

The aim of this investigation is to see how this idea can benefit the making of a context sensitive architecture. Does nature hold any solutions to, and can it facilitate the making of, an architecture that has a real sense of place? The hope is that this report will prove that there is much to learn from the environment around us concerning the making of architecture, be it on a technical level or merely as a form of inspiration to building design in general.

Hence, the focus of this dissertation falls on the investigation of a Biomimetic approach to architecture. With the study that follows this technique will be examined as a means to not only theorize architectural thinking but to also explore new architectural forms, materials, connections and systems that would not have come to the fore with other traditional forms of architectural approaches.

THEORETICAL INVESTIGATION

Before we continue, it is necessary to first obtain a better understanding of what exactly Biomimicry involves. The following section serves as a summary to the theoretical outlines of this concept.

HISTORY AND BACKGROUND

After having written several books on wildlife habitats and behaviour, American biological sciences writer, Janine Benyus, started to see for the first time that the answers to our design problems can lie in the way organisms in nature are adapted to their environments and to each other. She believes that after 3.8 billion years of research and development, the failures of this world are the fossils we dig up, and what surrounds us today is the real secret to survival. [BENYUS, 2002] After having found a group of likeminded people she established the Biomimicry Guild in 1998 and thereafter the Biomimicry Institute in 2005. In 2002 she also wrote the book, *Biomimicry: Innovation Inspired by Nature.* [BIOMIMICRY INSTITUTE, 2011]

The term Biomimicry comes from the Greek words *bio* - meaning life, and *mimesis* - meaning to imitate.

To put it in Benyus' words: *"Biomimicry is the conscious emulation of life's genius."* [BENYUS, 2002]

Biomimetics is the technical term often used in biology, biochemistry and pharmaceuticals and is also commonly used by material scientists in their quest to find properties in living organisms and natural systems that can be analysed in order to recreate those properties for industrial, medical, and biological products. In other words, it is when someone uses nature as a source of inspiration for everyday design.

Material scientist Michael Rubner of MIT explains that the real benefit in using biomimetics is that it brings in a whole different set of tools and ideas you wouldn't otherwise have. [MUELLER, 2008]

Like mentioned before, for designers to find inspiration in nature is not at all a new concept, yet for biotechnology, biochemistry, genetics, and material science it is a newly invigorated approach. The reason why these fields only seem to be catching on with this trend now is not because the idea was never considered, but simply because we now have the technology to look further and in greater detail at the organisms around us which allows for a greater understanding of how they work.

LIFE'S OPERATING CONDITIONS

One of the basic requirements for being a good biomimic is to have a thorough understanding of life's operating conditions. So what does this mean? Well, it is general knowledge that human beings live and function within the same operating conditions as all the other creatures living on this planet, although we as designers tend to forget this sometimes and we don't see the value of knowing what those conditions are.

The four metaphysical conditions within which life on Earth operates are:

- ***Sunlight, Water, Gravity*** - these are the main conditions that make life of Earth unique

- ***Dynamic Non-equilibrium*** - everything around us is constantly changing and aims to restore equilibrium; consequently life is always in a state of non-equilibrium

- ***Limits and Boundaries*** - we live in a closed global system with limited resources, nothing new can be added and nothing can be taken away

- ***and Cyclic Processes*** - life operates in continuous closed-loops, e.g. recycling
[BIOMIMICRY INSTITUTE 2011]

LIFE'S PRINCIPLES

By unravelling life's mysteries we can unlock the secrets to survival. When we read through the many scientific papers and reports being published today, it seems that every organism has its unique way of surviving in its own habitat. Yet when one examines a bit closer, patterns start emerging. Patterns here refer to not only physical concepts, but also more abstract patterns of how living organisms actually relate to each other and to their environments.

In Biomimicry, these patterns are referred to as **Deep Principles or Life's Principles** and can be summarized as follows:

- *Life on earth is interconnected and interdependent*

- *Life's principles represent the overarching patterns found amongst species surviving and thriving on earth*

- *and Life integrates and optimizes these strategies to create conditions conducive to life*

Biomimics use these principles to both drive and evaluate the sustainability and appropriateness of their designs. They represent the overarching patterns found in nature; how life forms integrate them in ways to *create conditions conducive to life*. In other words, the way they impact their surrounding environment ensures a beneficial outcome for their future survival – a lesson the built environment is yet to learn and practice.

PATTERNS OF NATURE

Despite nature's sophistication, many of its intelligent devices are actually made from simple materials like keratin, calcium carbonate, and silica. Nature has the ability to manipulate these materials into structures of fantastic complexity, strength, and toughness. Take the abalone for example; it composes its shell out of calcium carbonate, the same substance as soft chalk. However, by merely manipulating this material into walls of staggered, nano-scale sized bricks, it creates armour as tough as Kevlar - 3,000 times harder than chalk. [MUELLER 2008]

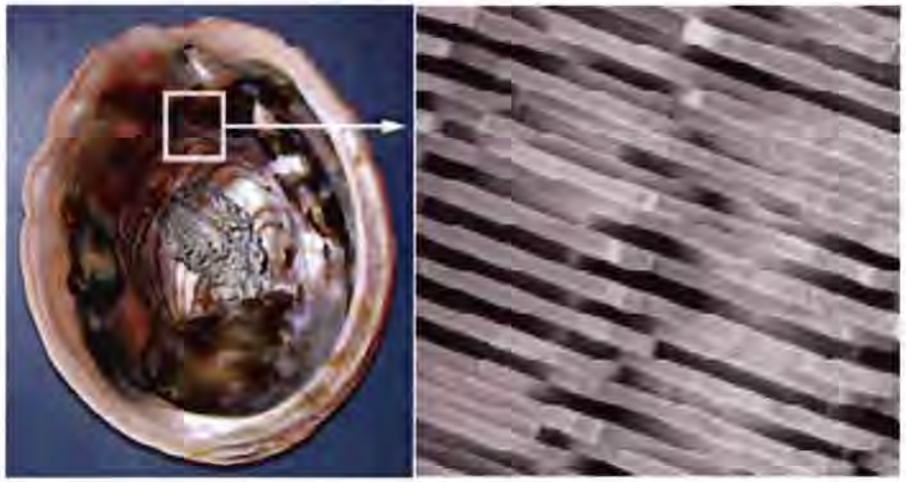


Figure 1: an abalone shell on the left with a microscopic image of its staggered nano-scale sized bricks of calcium carbonate in the right.

This is just one example of how researches have to keep digging deeper and deeper in order to find out what the underlining patterns are that nature utilizes so effortlessly. Luckily for us, some of these amazing patterns have already been identified and translated from biological terms into the general language of engineering/design.

Nature's patterns are:

- ***Evolve to survive***
  - Replicate strategies that work
  - Integrate the unexpected
  - Reshuffle information

- ***Be resource efficient***
  - Use multi-functional design
  - Use low-energy processes
  - Recycle all materials
  - Fit form to function

- ***Adapt to changing conditions***
  - Incorporate diversity
  - Embody resilience through variation, redundancy and decentralization
  - Maintain integrity through self-renewal

- ***Integrate development with growth***
  - Self-organize
  - Build from the bottom-up
  - Combine modular and nested components

- ***Be locally attuned and responsive***
  - Use feedback loops
  - Leverage cyclic processes
  - Cultivate cooperative relationships
  - Use readily available materials and energy

- ***Use life-friendly chemistry***
  - Build selectively with a small subset of elements
  - Break down products into benign constituents
  - Do chemistry in water

[Biomimicry Institute, 2011]

The patterns most useful for the generation of architectural form are the three mentioned first: evolve to survive, be resource efficient, and adapt to changing conditions.

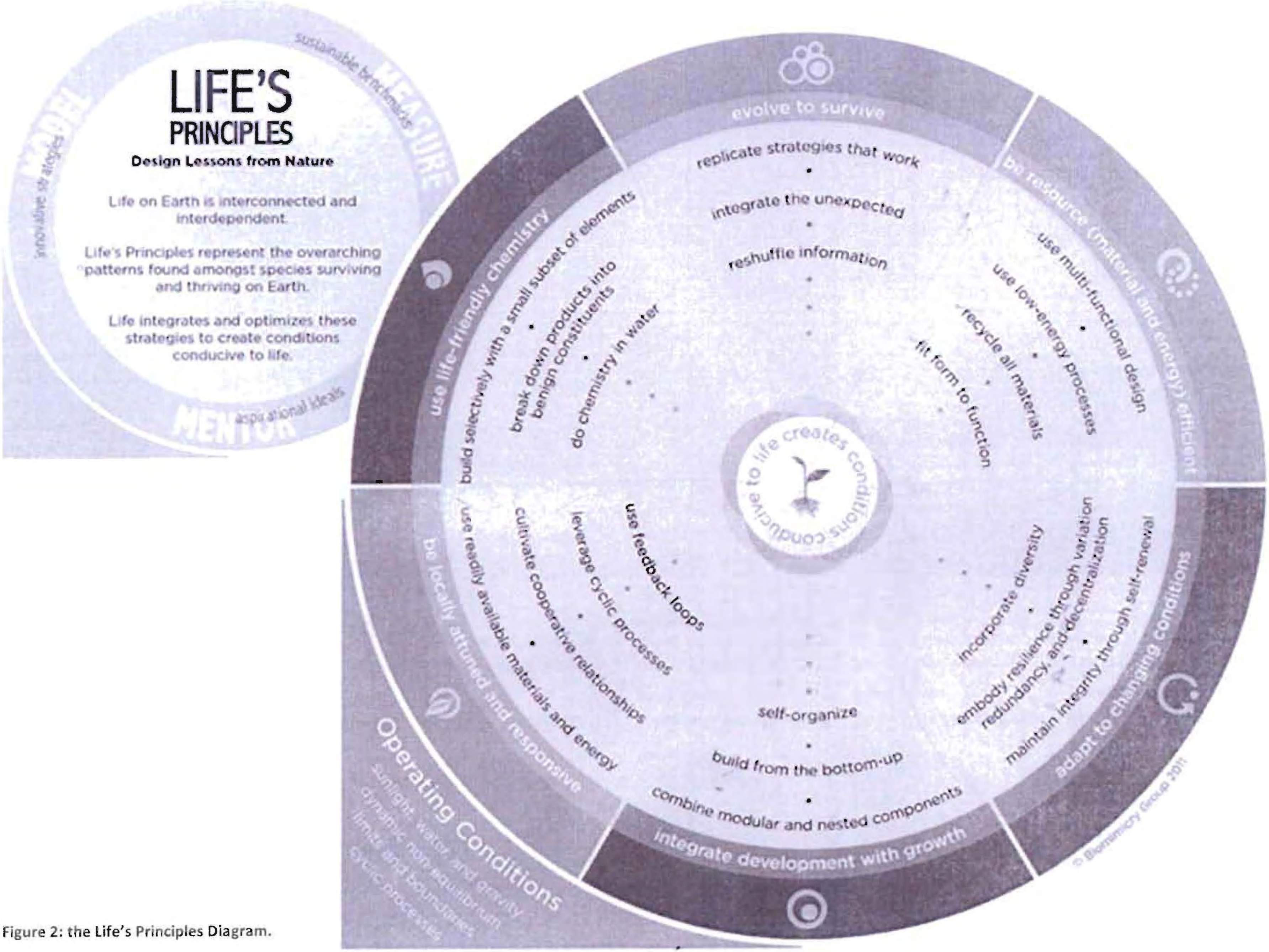


Figure 2: the Life's Principles Diagram.

BIOMIMETIC METHODOLOGY

Seeing Biomimicry can be described as mimicking life, it is necessary to identify what exactly it is in life that one mimics. Commonly there exist three levels of life-mimicking, namely the mimicking of natural **form**; natural **process** (or how things operate); and lastly the mimicking of natural **systems** (like eco-systems). Some of these levels are used in certain design fields exclusively, but in terms of architecture all three can be used either on their own or in combination. *[Kemp 2009: 2]*

To introduce life's systemic wisdom to everyday-design, biomimetics use *Life's Principles* as an overarching, scoping and general evaluation tool. Yet, the question remains: how does one apply this practically to the design process? To answer this, we need to know how the Biomimicry methodology works.

First it is necessary to know that nature-inspired innovation can come from two directions:

1. ***biology to design*** - inspiration from nature applied to an existing area of interest
2. ***challenge to biology*** - an existing design problem looks to nature for solutions/inspiration

This approach seeks nature's advice in all stages of design, from scoping, creation, to evaluation. The *Biomimicry Design Spiral is often used by designers as a tool to guide the reiterative process of design.* Innovators explore the true functions they want their design to accomplish, and then ask: what organisms in nature depend on those functions for survival?

Now understandably, this task seems almost impossible for designers from fields other than biology to even begin to have any knowledge of how organisms work. However, herein lies the crux of the matter: Biomimicry does not seek to make everyone into a biologist, but rather suggests that engineers, architects, designers, scientists and biologists (who all possess a wealth of knowledge of their own respective fields) should share their knowledge with others through means of interdisciplinary learning. The pooling of biological insight and engineering pragmatism is vital to success in biomimetics. *[Mueller 2008]*

In addition to this, there now exists a *Biomimicry Taxonomy* (classification) that can be used as a guide to indentify the functions of a design challenge or a natural organism in a language that can be interpreted to both fields. This diagram shows the classification divided in three groups/sections. The first group lists the main functions that both man-made objects and living organisms have. From the second group to the third group these functions are described in more detail and get more and more specific. What the taxonomy allows the "non-designer" or the "non-biologist" to do is to translate engineering and design language into biological language or vice versa. And once they know what function in nature they want to mimic for their specific design, it gets easier to find an organism that does exactly that.

For all the power of the biomimetics paradigm, and the brilliant people who practice it, bio-inspiration has led to surprisingly few mass-produced products so far. Arguably only one household name does this successfully, namely Velcro. It was invented in 1948 by Swiss chemist George de Mestral, by copying the way cockleburs clung to his dog's coat. Nevertheless, technology, bioengineering, computation, and fabrication industries are in the process of fundamentally changing the design professions - in the next few years construction of what is now impossible will be standard. *[Mueller 2008]*

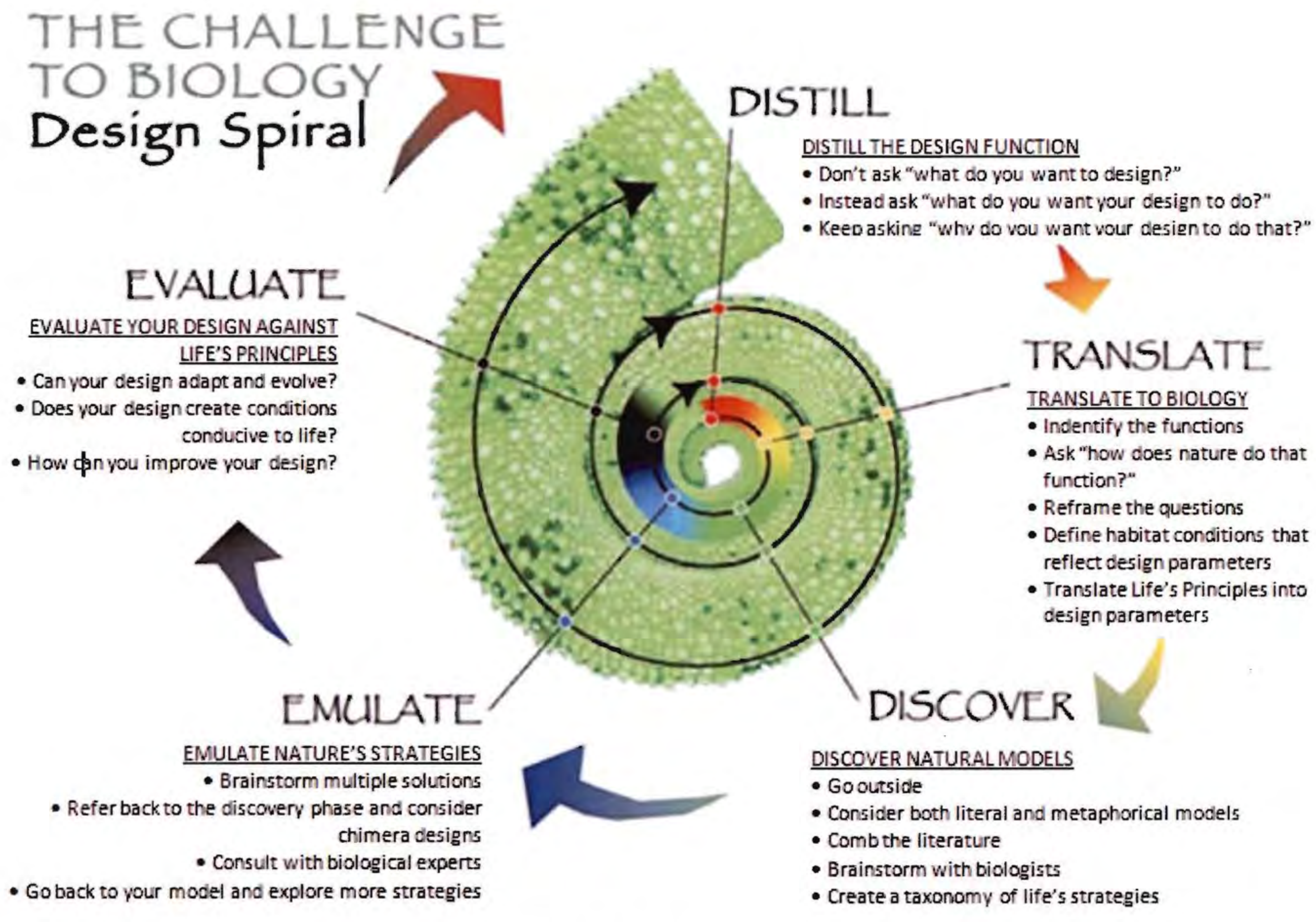


Figure 4: the Biomimicry Design Spiral showing the different steps in all stages of design.

BIOMIMICRY TAXONOMY

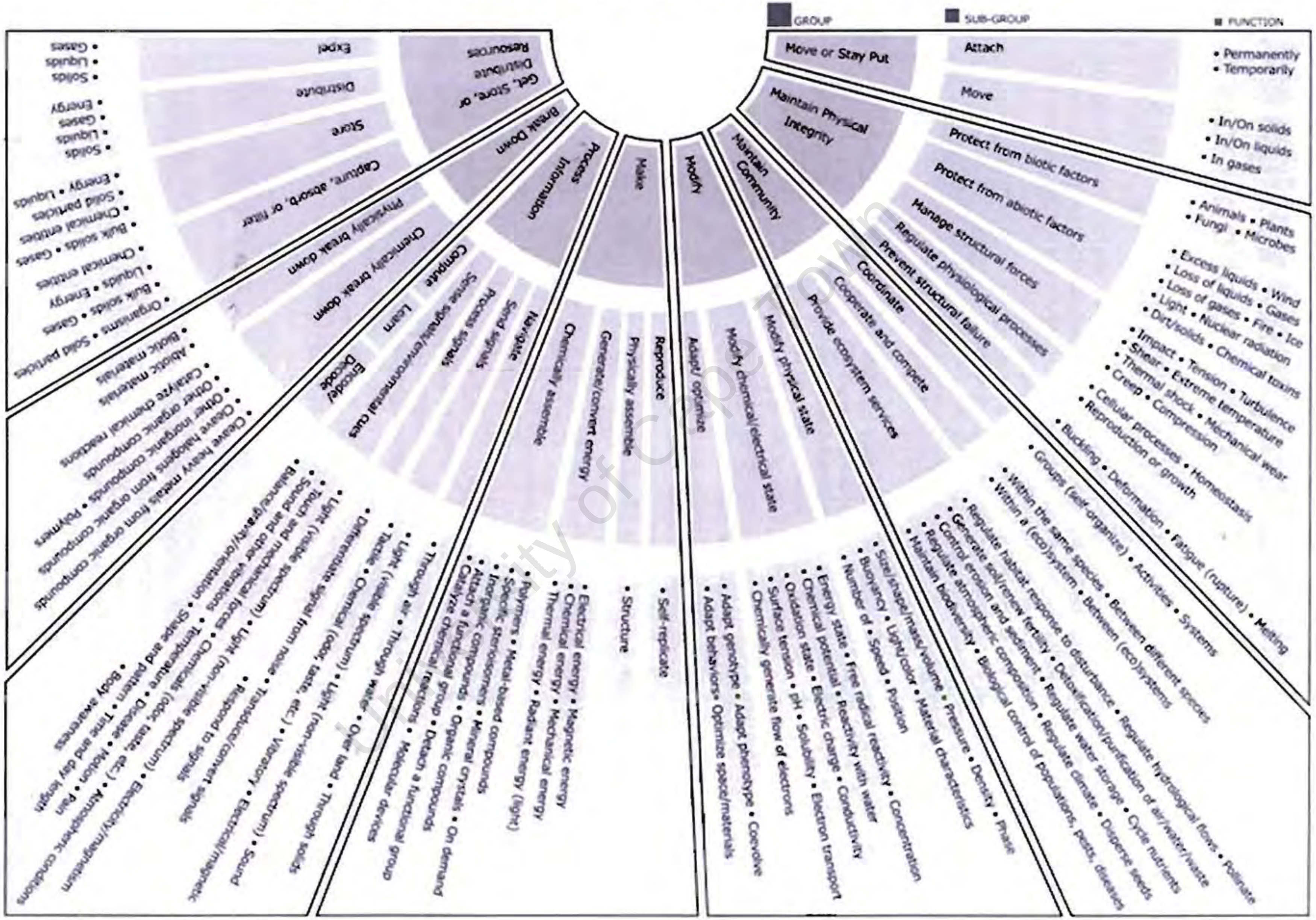


Figure 5: the Biomimicry Taxonomy.

TECHNICAL INVESTIGATION

Currently a whole host of biomimetic technologies are being developed for all areas of building construction including insulation, windows, electric lighting, controls and mechanical systems. One of the main aims of these technologies is to be designed in such a way that it can be integrated with other systems for greater efficiency and comfort; just like nature would. However, my interest in architectural biomimicry is not just limited to the incorporation of nature-inspired materials, but also in other fundamental aspects of architecture like geometry, composition and performance systems. This section will elaborate on just some of these aspects.

THE POWER OF SHAPE

The fractal, the Fibonacci Spiral and the gridshell are geometries which are particularly helpful when it comes to understanding the way natural organisms around us are structured, and the way they live, grow, reproduce and attach to other objects. These construction methods can also be a stimulating tool for the making of contemporary architectural form.

The Fractal

As architects, we often describe the making of shapes in terms of geometry. The word geometry comes from the Ancient Greek: γεωμετρία - *geo*, meaning "earth", and *-metri*, meaning "measurement". So if directly translated it means "Earth-measuring". *[Mlodinow: 1992]*

It is the division of mathematics concerned with questions of shape, size, relative position of figures, and the properties of space. Although there are many branches of Geometry, I think two in particular have relevance to architecture, namely Euclidean Geometry and Fractal Geometry. Whilst Euclidean geometry is concerned with objects which exist in numeral dimensions, Fractal geometry, on the other hand, deals with objects in non-numeral dimensions. In other words, Euclidean geometry is a description of lines, ellipses, circles, etc. while Fractal geometry is described in algorithms which are a set of instructions on how to create a fractal thread. *[ThinkQuest: 2011]*

Contrary to popular belief, Fractal geometry has never been a man-made construct, but can be found all over nature. Clouds, mountains, coastlines and bark are all in contrast to Euclidean figures; not smooth but rugged and they offer the same irregularity in smaller scales (which are important characteristics of fractals). *[Mandelbrot: 1982]*

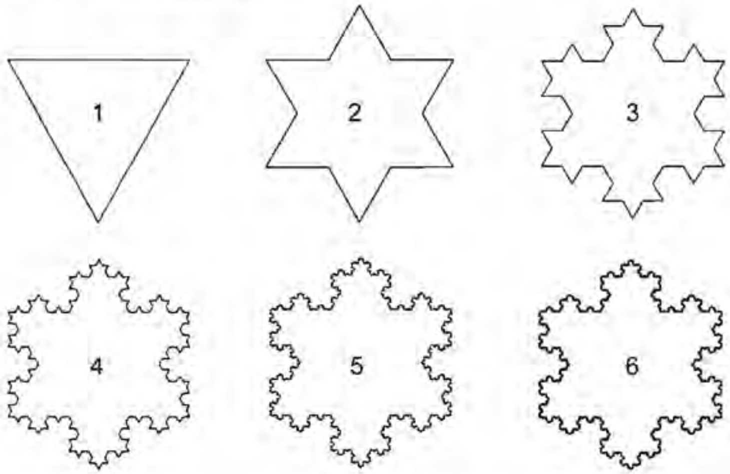


Figure 6: the fractal breakdown of a typical Koch snowflake.

The Koch snowflake is an example of a typical fractal. The above geometrical breakdown shows how it begins with an equilateral triangle and then replaces the middle third of every line segment with an equilateral "bump", equal in shape to the original triangle.

Since fractals appear similar at all levels of magnification, they are often considered to be infinitely complex. A typical fractal often has the following features: fine structure at arbitrarily small scales, too irregular to be easily described in traditional geometric language, self-similar, and it has a simple and recursive definition. *[FALCONER. 2003]*

Trees and ferns, for example, are also fractal in nature and can also be modelled on a computer by using a recursive algorithm. The recursive logic is obvious - a branch from a tree or a frond from a fern is a smaller replica of the whole: not identical, but similar in character. Other fractals found in nature are: frost crystals, clouds, lightning bolts, snowflakes and various vegetables like cauliflower and broccoli. It can also often be seen in various art forms like African textiles, camouflage designs and sculpture. Other areas in which they are useful is medicine, soil mechanics, seismology, and technical analysis as well as computer and video game design, especially in computer graphics used for the modelling of organic and complex shapes. *[FALCONER. 2003]*

Within architecture it is most commonly seen in only decorative form, although there has been some attempts from architects like Aldo van Eyck, for instance, to use this idea at a bigger, more structural or spatial scale. However, this concept can sometimes prove to be very challenging.

Figure 7: (left) the fractal crystallisation of frost on a glass pane. (right) A coral broccoli as example of an organically formed fractal.

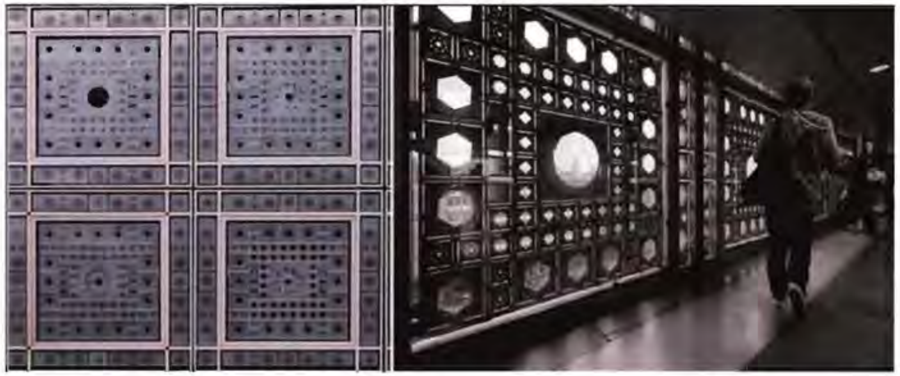


Figure 8: (left) close-up of the fractal pattern on one of the mechanical louver panels in the Arab World Institute in Paris. (right) internal view of the passage with the fractal louvers on the left.

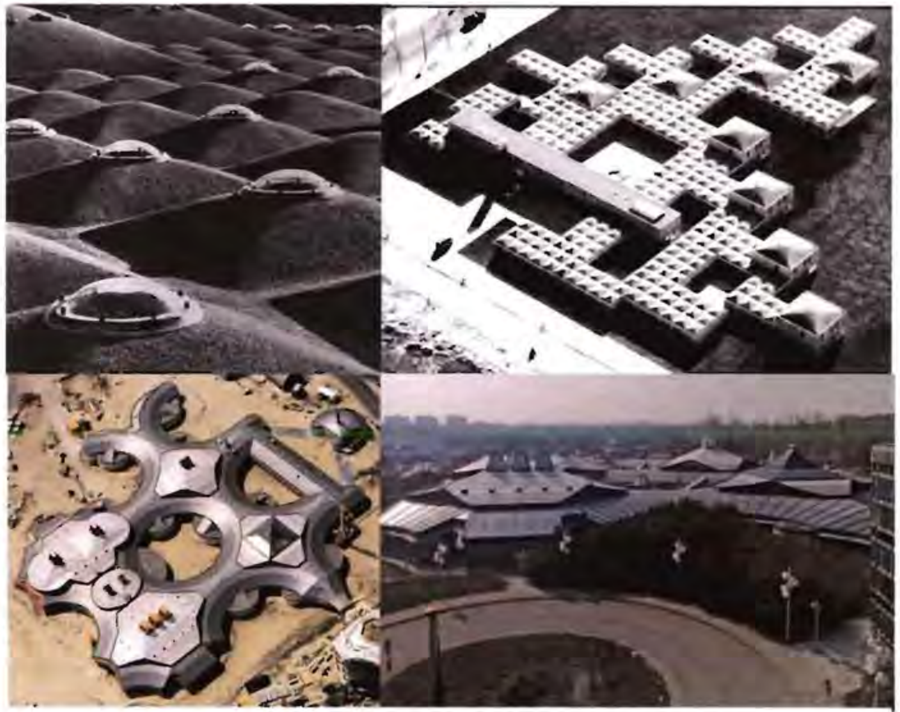


Figure 9: (above) Aldo van Eyck's Amsterdam Orphanage, (below) ESTEC building showing the use of fractal architecture at a bigger scale.

The Fibonacci Spiral

Another fascinating natural geometric concept is the Fibonacci Spiral which is also closely related to the Golden Ratio, famously illustrated by Leonardo Da Vinci's Vitruvian Man. *[PROTO. 2009: 14]*

A Fibonacci spiral, in turn, is a mathematical construct that generates a series of significant numbers also often used in algorithms, financial markets and other mathematical applications. It is created by drawing arcs connecting the opposite corners of squares in the Fibonacci tiling (see image below). The length of the side of one square divided by that of the next smaller square is the golden ratio. *[GOONATILAKE. 1998]*

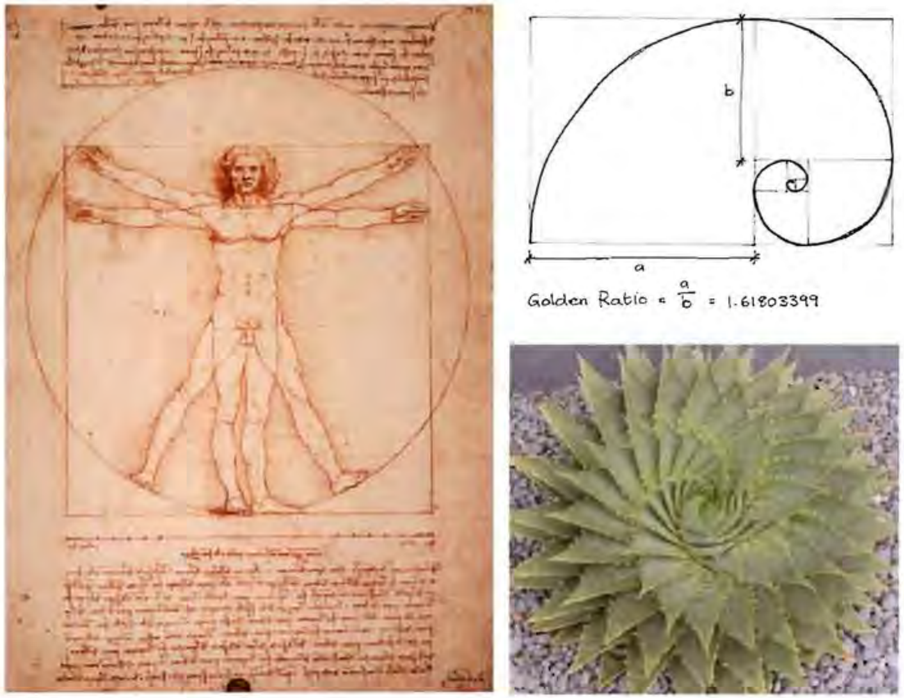


Figure 10: (left) Da Vinci's Vitruvian man drawing, (top right) a constructed Fibonacci Spiral, and (bottom right) an aloe plant is an example of Fibonacci spirals found in nature.

It is amazing that once you know what you're looking for, you can find this ratio in almost everything in nature from shells to flowers, e.g. in the leaf structure of the aloe plant.

Even so, it would be interesting to see how this type of geometry has been used in architecture. One example which is particularly inspiring is the Education Centre, known as The Core forming part of the Eden Project in Cornwall, GB (see below). It goes without saying then that this concept is not at all new to the field of architecture, but has been used by architects throughout centuries; clearly seen for example in the designs of Gothic and Baroque style cathedrals. Although recently, with more and more architects looking to nature as a source of inspiration, these techniques have been rediscovered once more.

Figure 11: (left) bird's eye view of the Eden Project with the biomes at the top right and the Core building in front.

The Gridshell

A gridshell, in architectural terms, is a constructed grid or lattice roof structure deriving its strength from a double curvature. It is mostly constructed of wood or steel, but can actually be made of any material. It can be said that gridshells were pioneered by Russian engineer Vladimir Shukhov in 1896 through his constructions of exhibition pavilions of the All-Russia Industrial and Art Exhibition in Nizhny Novgorod. But it was only used on a large scale in 1975 in the Multihalle Mannheim gridshell designed by Frei Otto. (See picture below) *[KURRER. 2008]*

Figure 12: pictures of the wavy timber gridshell of the Multihalle Mannhein by Frei Otto.

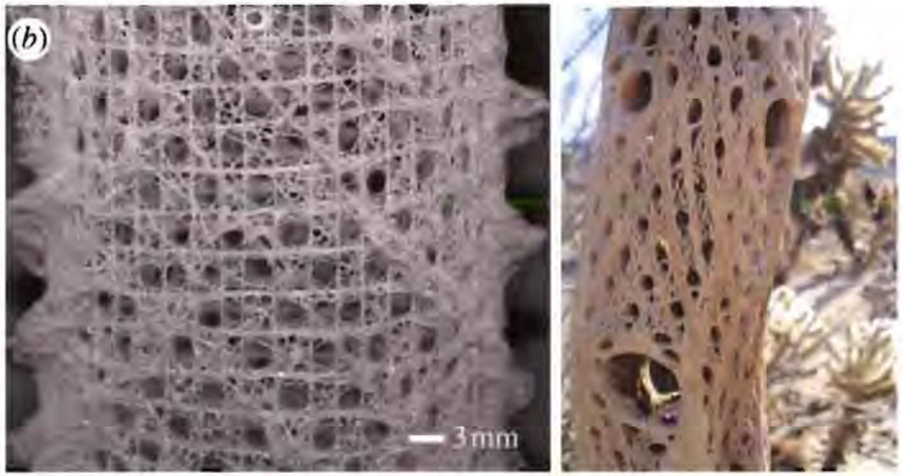
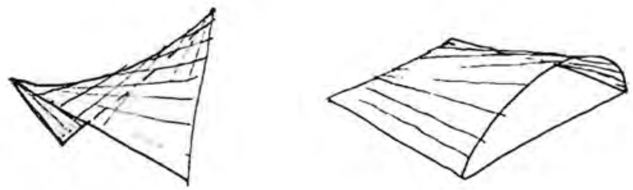


Figure 13: , (left) details of the structure of a glass sea sponge, (right) image of the grid-like patterns on an old dried up cactus.

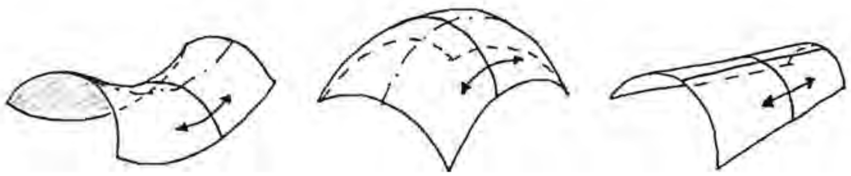
Like with the fractal, gridshells are also not entirely man-made constructs, but can be found in the make-up of certain types of plants, sea sponges and many other natural organisms. Often one can see similar patterns specifically in the dried up carcasses of cacti as indicated above. *[KURRER. 2008]*

A gridshell can be defined as a certain type of shell structure and in order for us to understand them; we need to first know what shell structures are. Any structural surface which is curved in one or more directions can be seen as a shell surface. By character a shell uses a very efficient way of carrying forces to its support structure - known as shell action. The benefit of shell action makes it possible to create large spans with very little material. Examples of natural shell surfaces are soap bubbles, sea shells and bird eggs. *[TOUSSAINT. 2007]*

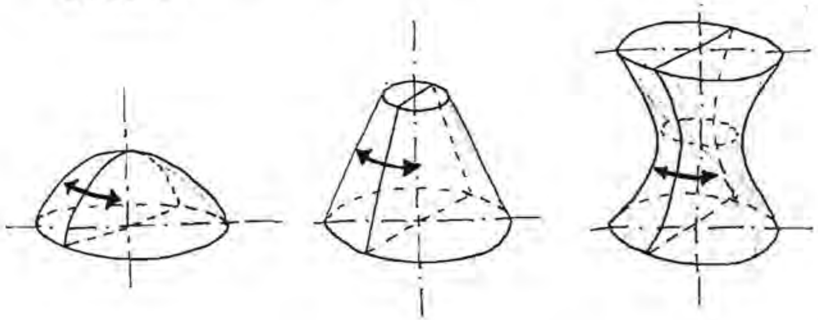
There are several ways in which each surface can be generated or created. Some of the different possibilities to do this are through means of the following:



1. Ruled surfaces: a ruled surface is generated by sliding the ends of a straight line along their own generating curve, keeping the straight line parallel to a prescribed direction. (see images above)



2. Surface of translation: created by translating one plane curve along another, while keeping the sliding curve's orientation constant.



3. Surface of revolution: generated by revolving a curve around the axis of revolution. Examples are the cone, the dome and the hyperboloid and also a basic cylinder.

Large-spanning gridshells (e.g. timber) are usually constructed by initially laying out the main lath members in a flat rectangular lattice, and subsequently deforming this into the desired doubly curved form by pushing the members up from the ground. Once the required shape is reached, the laths are fixed to the edge boundaries and the nodes are tightened. An alternative method would be to construct it by laying the laths on top of a sizeable temporary scaffolding structure which is removed in phases to let the laths settle into the desired curvature. [TOUSSAINT 2007]

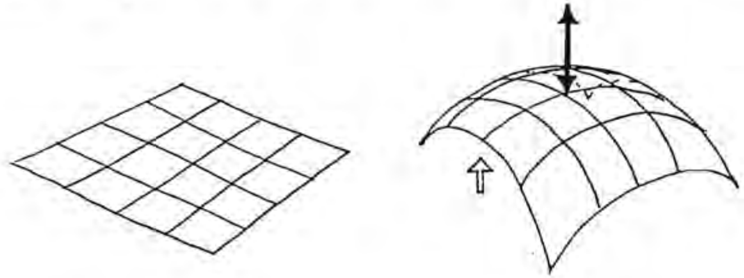


Figure 14: (left) A flat mat of laths is deformed to a spherical structure (right), by bending the laths and deforming the quadrangles of the mat to rhombic shapes.

In order for a gridshell to act like a normal continuous shell structure, the structure needs to be braced to achieve rigid diagonal stiffness. Triangulation of the grid, either by applying cross ties or corner bracings is realized quite easily. It is also possible to create diagonal stiffness by applying a continuous layer on top of the laths of the structure. [KUPFER 2008]

The main benefit of this kind of structure is that use of material is minimized as opposed to solid continuous surfaces or multi-layered structures. Timber is often regarded as the most efficient material for this, because during construction complex forms can be shaped relatively easy considering the material's strength-and-flexibility ratio.

Despite the advantages in appearance and sustainability, the gridshell is not used very often. The fact that the design process is quite complicated probably is an important factor in this. The iterative process to find a smooth surface to create the flat mat of laths has been a major logistical and practical issue in the past. However, major design and construction developments have taken place in the past few decades. With the help of computer aided design methods, this process has been improved dramatically. The Weald and Downland open air Museum in Sussex, UK is a good example of where computer technology was utilized to develop this complex construction technique more efficiently, 25 years after the completion of the Mannheim gridshell. Other new interpretations include the Japan Pavilion at the Expo 2000, designed by Frei Otto and Shigeru Ban which is constructed of circular paper tubes.

Figure 15: rendered image of the Japan Pavilion at the Expo 2000.

Figure 16: (left) scale model of the design, (right) close-up of the paper tube connection details.

SMART MATERIALS

In a perfect biomimetic world, we as humans would manufacture the way animals and plants do, using sun and simple compounds to produce totally biodegradable fibres, ceramics, plastics, and chemicals. In order to know how to do this we need to find those properties in living organisms and natural systems that can be analysed and translated to a language we can understand and utilize for the purpose of man-made designs.

Therefore, in agreement with Janine Benyus, the real lessons lie in the subtle ways organisms are adapted to their environments and to each other and the following organisms discussed in this section are the ones useful as sources of inspiration for rethinking the use of materials in design.

Learning from Bones

An interesting concept is the way our bones (and those of animals) can be so strong, and at the same time incredibly light and relatively flexible. There is also a lot to learn from the bone material composition in the skeletons of animals and humans.

The skeletal structures of birds, for instance, are well known for minimizing the energy required for flight by having incredibly lightweight bone structures. This is a very important factor, because from a functional perspective, the mass of an animal relative to its lift-generating surfaces is a key ratio if optimum efficiency of flight is to be achieved. *[Dumant. 2010]*

Biologists conclude that the material properties of bone tissue can largely contribute to its strength and stiffness, meaning as bone density increases, so does bone stiffness and strength. Although these types of studies have not often been conducted on birds, biologist Elizabeth Dumont has calculated the density of the cranium, humerus and femur bones in passerine birds, rodents and bats. By measuring bone mass and volume using a process called helium displacement, she found that these bones are most dense in birds, followed closely by bats. Dumont's studies suggest that both bone shape and the material properties of bone tissue have played important roles in achieving efficiency in flight. It also explains how bird skeletons can appear so delicate, yet contribute just as much to total body mass as that of walking mammals. *[DUMANT. 2010]*

Dumont is not the only one to have noticed the amazing make-up of bird's skeletons. Andres Harris in his article *Biomimetic 1.0* explains how he also looked to birds as inspiration for his design of a biomimetically optimized surface material. The main aim of his thesis was to generate a responsive structure that could carry different loads and external pressures while using as little material as possible. Through his studies he found that bone tissues, especially in the skulls of large song birds like the magpie, are extraordinary impact-resistant, incredibly light-weight and at the same time made up from a single material. *[HARRIS. 2010]*

Another thing that he found was that the skulls of birds are cleverly differentiated across its width: denser in the areas that undergo high external loads, and less dense in the areas that are less affected by these pressures. Similar to the way constructed gridshells conserve material while achieving lightness through its unique grid, so the skulls of these birds are also made up of a type of grid. The bone tissues consist of non-directional spongiosa cells, which in essence are pneumatised cells that allow for air "bubbles" in the material. The morphological configuration not only provides an acoustic function distributing air at the inner layer but also results in reduced overall weight of the structure without affecting its strength. The main benefit of this is that the forces acting on the shell is not focalized just on the outer layer, but relies on different cell components integrated into a major pneumatised system, each contributing to carrying the loads. *[HARRIS. 2010]*

As his curiosity grew, Harris started asking important questions like: what can we learn from the natural make-up of animal bone structures for the making of man-made structures? It is all good and well to say that we can manipulate our structures (which are mostly made of concrete, steel or timber) to perform like natural bone, but it is important to then find a material that also shares similar properties to bone. Harris concluded that bone's tensile strain (0.011 N/m2) and compression strain (0.015 N/m2) is quite similar to a wide range of synthetic readily available resins, and has since set out to find the full potential of this material. Below shows Harris' proposal for a bone-like, resin shell that in theory would perform very similarly to the skull structure of the magpie. *[HARRIS. 2011]*

Figure 18: (left) picture of a magpie, (right) Skeleton of a Turdus merula (Blackbird).

Figure 17: several levels of hierarchy in the skull of a magpie showing various densities.

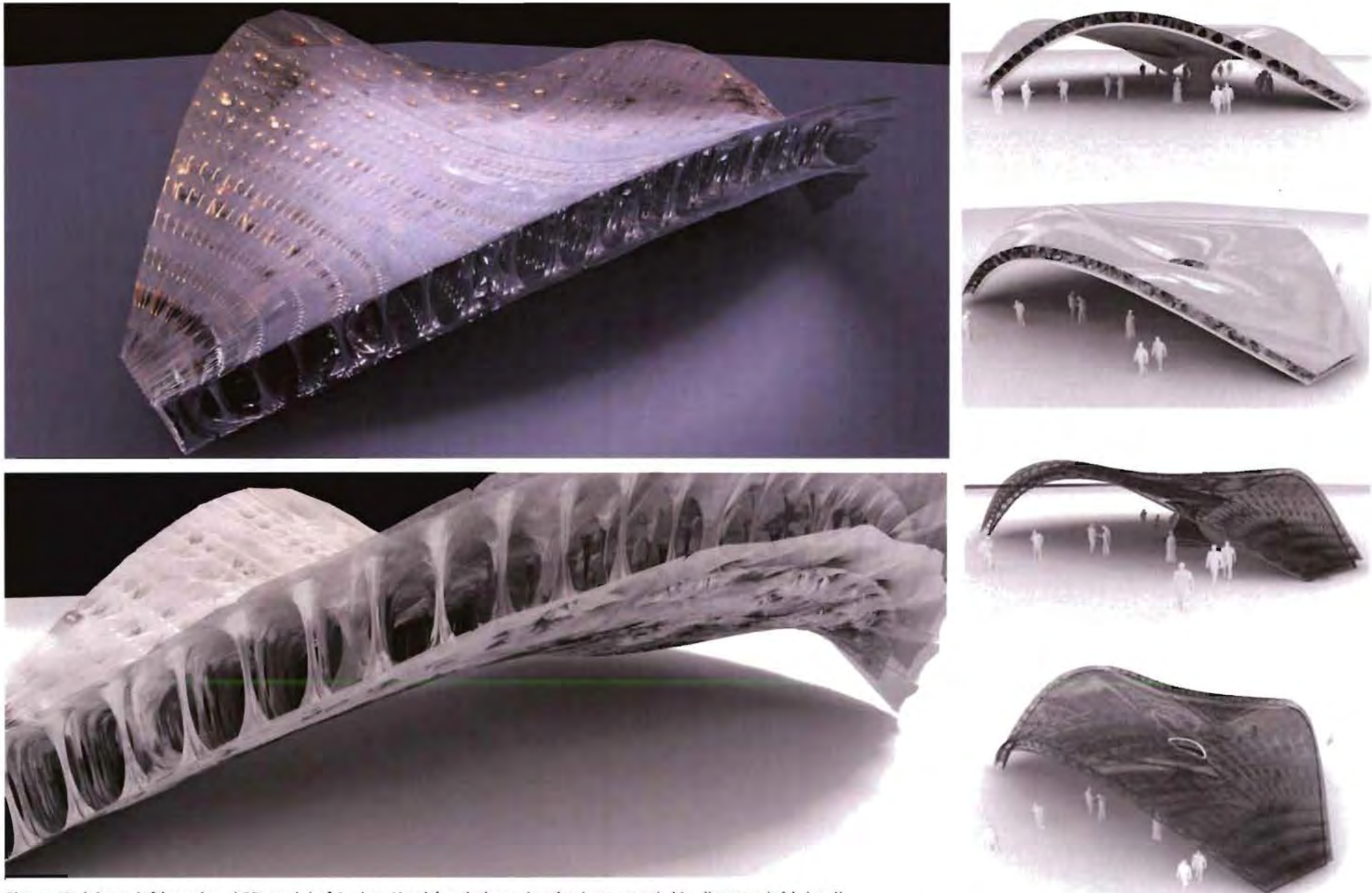


Figure 19: (above left) rendered 3D model of Andres Harris' resin bone-inspired structural skin, (bottom left) detail representation of the inner structure of Harris' structural skin, (right) a series of experiments with different types of cladding.

Learning from Enzymes

Modern photovoltaic panels found on the market are great for capturing the sun's energy, but in terms of flexibility and adaptability they have their limits. How bright would the future of architecture be if it were possible to create large tensile surfaces and building façades that could capture solar energy using flexible photovoltaics modularly woven into architectural structures? A company called, Metabolic Media have worked to achieve exactly this. They presented their idea as an exhibition piece at the London Design Festival in 2008 entitled Nobel Textiles. *[EHSAAN, 2020]*

The aim of the festival was to design energy producing textiles that can be applied to large or small architectural structures in an efficient and aesthetically pleasing way. Sir John E. Walker, one of the scientists on the design team, is known for being instrumental in improving our understanding of biological energy conversion in living cells. He was awarded a Nobel Prize in 1997 for his work describing how enzymes make ATP (adenosine triphosphate). ATP is used for many cell functions including transport of substances across cell membranes – hence one of the most important biological systems known to man. Inspired by his work, the design team set out to mimic the principles of the ATP enzyme. *[METABOLICMEDIA, 2011]*

So how do these enzymes work? Well, the ATP enzyme itself has often been described as a machine, because in essence that is exactly what it is. In short, it can be described in the following way: Through photosynthesis, living organisms can yield high-energy compounds like carbohydrates, fats and food proteins derived from crop plants and animals. The captured energy gets released inside every cell by mini organs called mitochondria. The mitochondria molecule has a rotary motor that spins at 50-100 times every second which in turn drives the synthesis of ATP. Almost all the oxygen we breathe is consumed by this controlled burning of carbohydrate and fats. Since *[METABOLICMEDIA, 2011]*

Figure 20: abstract diagram of the mitochondria molecule. The dark blue part is the rotary motor that drives the top synthesis mechanism (in green) which forms and releases the ATP.

Metabolic Media's proposal is for a lightweight solution to Urban Agriculture. The design comprises of a geo-textile structure with printed, organic solar cells (that functions like the enzyme) designed to charge the batteries of a fuelling pump system which feeds a network of plants by misting the roots with a nutrient rich solution. These modular architectural structures can provide a lightweight solution for growing food plants in small spaces without using soil. *[EHSAAN, 2020]*

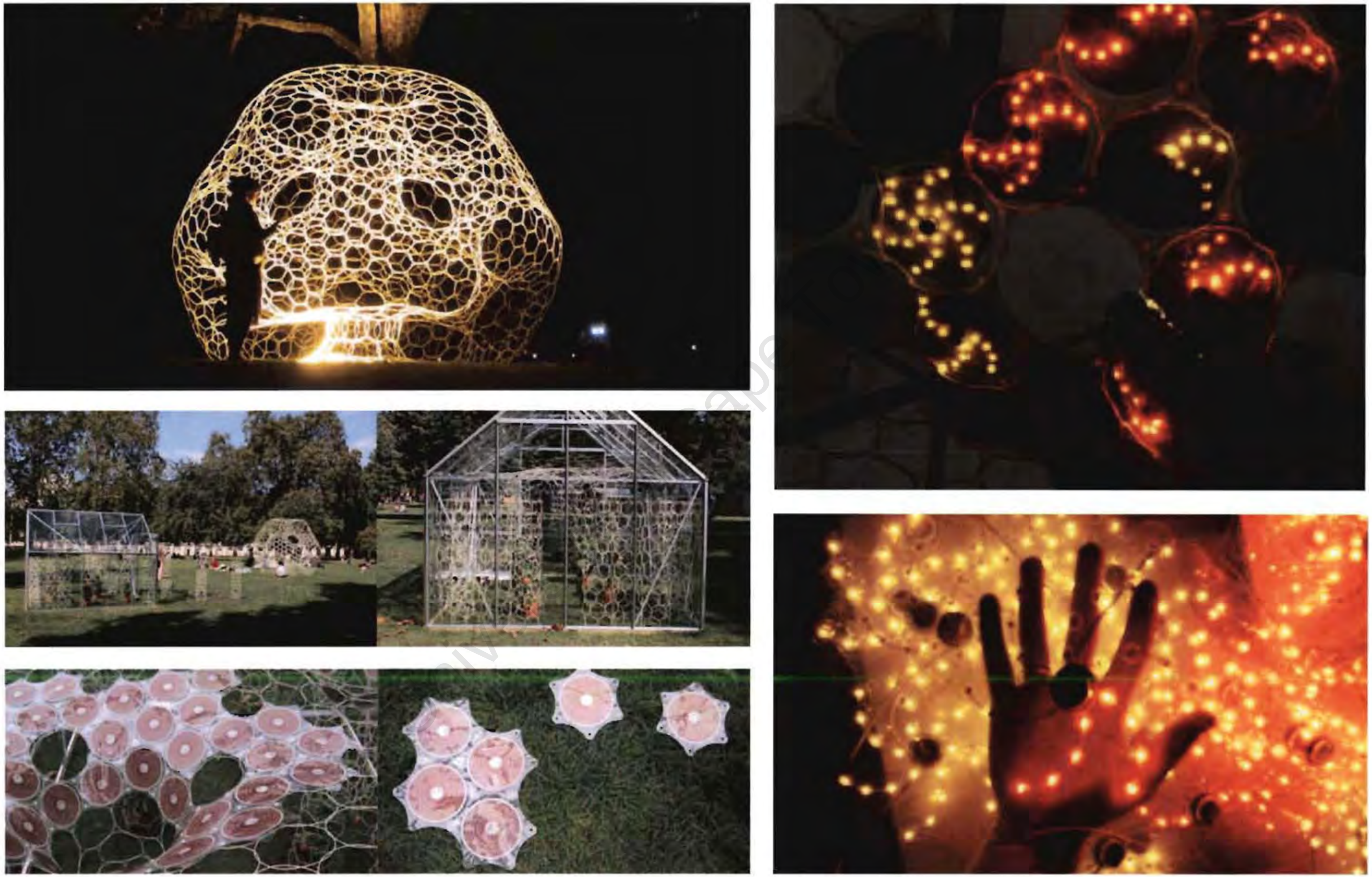


Figure 21: (top left) : night shot of the Nobel Textiles exhibition at the London Design Festival in 2008, (middle left) images of the modular agricultural structures that house the plants, (bottom left) close-ups of the geo-textile structure with the printed, organic solar cells, (top & bottom right) photos showing the lighting from energy generated from the solar cells.

THERMAL PERFORMANCE

One other aspect of architectural design in which we can learn a lot from our fellow living organisms is the optimizing of living conditions or thermal performance of spaces. What this means is achieving good internal air quality through proper ventilation and gas exchange, and also maintaining satisfactory temperatures suitable for human occupation within our buildings. In this regard, there are many animal species that do this efficiently, but the termites can be classified as the masters of ventilation and gas exchange. The following section is an elaboration into the principles they use to attain this.

Learning from Termites

In order for us to mimic the principles of termites use we need to know how they build their famous clay mounds. The *macrotermitine* termites (amongst many other termite species) construct mounds that maintain a constant internal temperature achieved only through its structure as opposed to using expensive, external energy sources. It is believed that each nest can house up to two million termites; all living, working and breathing within the same closed volume of the nest. And on top of this, the queen of the termites living in what is known as the Royal Chamber, requests a constant temperature of 30° C (suitable for the laying of her eggs), whilst outside temperatures can range from 2-40° C. Consequently, the workers have several strategies to make sure that this goal is maintained. [GOULD ET AL. 2007]

First of all, the mounds' thermal mass alone has sufficient heat capacity to buffer the internal environment from heat gain during the day with cold accumulated over night. A second strategy involves an automated air-conditioning system. The first step in this system is the fermenting of fungus to build up heat gain (see image below). Because hot air rises, the heat accumulated here travels up through a central chimney and due to the continuous flow in the chimney; the hot air is forced into the horizontal ridge ducts. These ducts are porous, enabling gas exchange to take place by allowing CO_2 to seep out and oxygen to come in through openings at the base of the mound which in turn ensures the constant air flow in the chimney as it pushes the hot air out. [PALLASMAA, 1995]

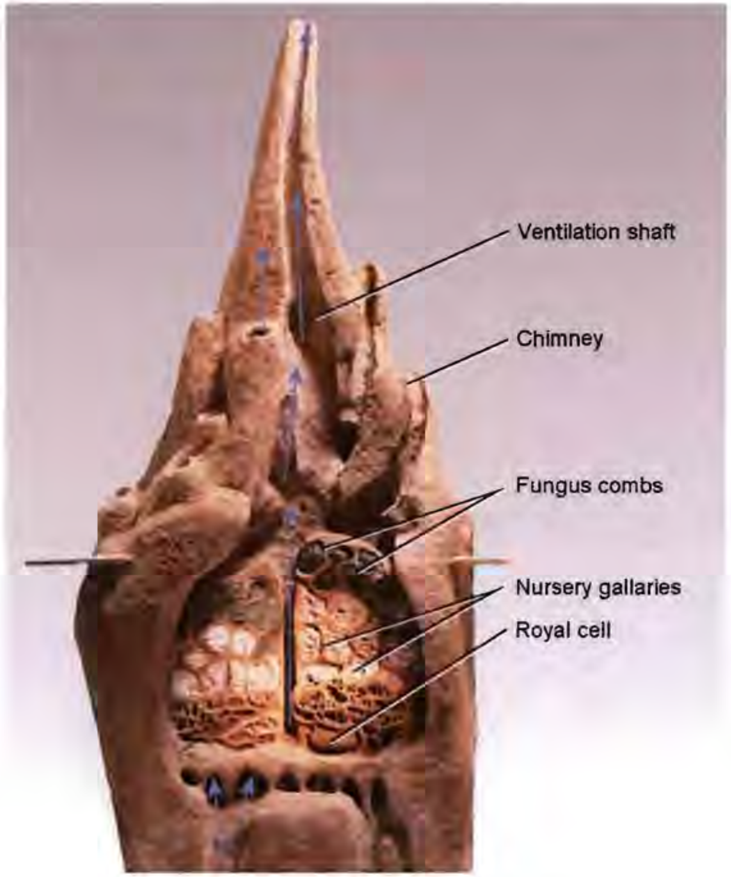


Figure 23: scale model of the inside of the mound.

Contrary to popular belief, very few termites are actually found in the mound itself, but rather they are located about a meter or two below the surface. What we can conclude from this is that functionally speaking, these remarkable mounds are not actually the residence for the colony, but rather serve as devices for capturing wind energy to power active ventilation of the nest. *[Pallasmaa. 1995]*

As can be concluded, these principles are highly informative to the making of buildings. One of the first architects to have incorporated these principles in his buildings is Mick Pearce in his design for the Eastgate Centre in Harare Zimbabwe in 1995. The building uses about 35% of the energy required for temperature regulation of similar conventional office buildings and has since inspired many other architects to follow its lead. *[Gould et al. 2007]*

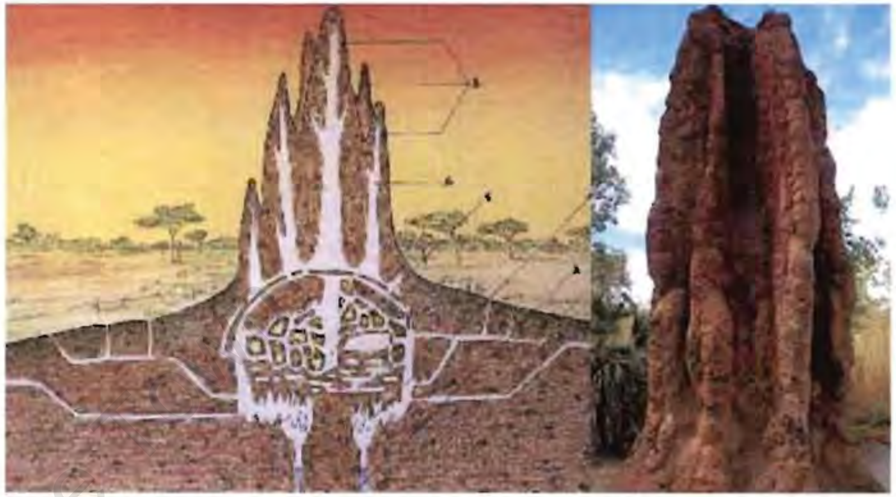


Figure 24: (left) cross-section through a typical termite mound, (right) image of the external structure.

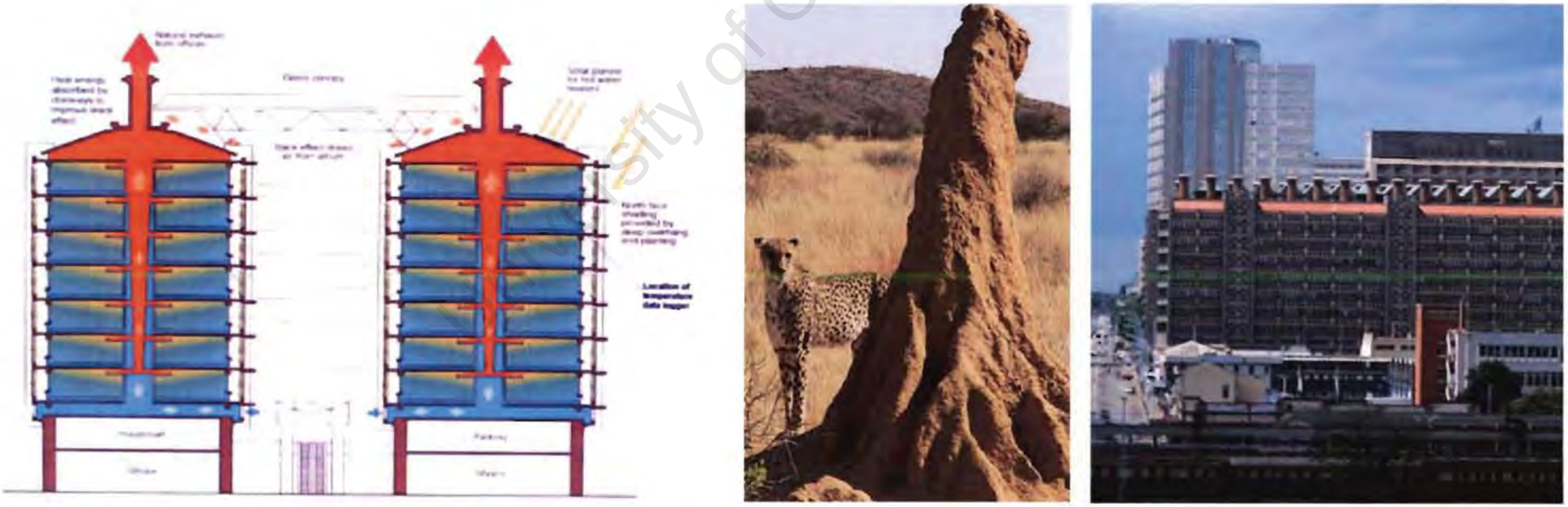


Figure 25: (left) diagrammatic section of the ventilation strategy in the Eastgate Centre in Harare, (middle) photograph of the mound of the African termite, (right) image of the building.

ARCHITECTURAL PROPOSITION

Certainly the inspiration of nature has lead to many different approaches, each with its own method. The focus of this report is not just in exclusive theories of digital and computer aided designs, but specifically traditional, passive means of design processes which have clear biomimetic intentions. This section will hence be a more thorough study of the design proposition itself, serving as an explanation of the design inquiry through exploring the relevant architectural interests.

AN ARCHITECTURAL APPROACH

To come back to the point made under the Methodology section, when it comes to architecture, *Life's Principles* can be applied in three ways: literally as a biomorphic approach, metaphorically as mimicking natural processes, or it can be applied to an approach that is more directed towards systems. *[VINCENT. 2009: 76]* At this point we have to ask ourselves whether the biomimetic methodology discussed earlier is applicable to all fields of human design. In the case of architecture, it is necessary to change our point of departure slightly.

First of all, it is important to make a clear distinction between *sources of inspiration* and *sources of explanation*. When the principles of nature are used for explanation or illustration, it is essential that the science is correct and that the analogy is applicable. But when it is used for inspiration or as a take-off point for thought experiments (like in the case of architecture) it matters less and can in fact provide much imaginative stimulus. *[FRAZER. 1995: 12]* Donald Watson provides us with insight from Schön's definition of "design as inquiry". He compares design in engineering with design in architecture, distinguishing engineering education as tending toward problem solving, characterized by the question "how to." This he contrasts with architectural education, in which the design problem is open ended and ill-defined, explored in a process of "solution finding" characterized by the question "what if." *[WATSON. 1997: 123]*

From the description of the principles of Biomimicry we are tempted to conclude that traditional Biomimicry tends toward the engineer's approach to design which focuses on problem solving. The reason for this is that it seems that the methodology of Biomimicry forces one in this direction; to first know exactly what your design should do and then to find an organism in nature to "solve the problem" of how to do that. And it is at this point that Watson claims that architecture is not problem solving, but rather a process of discovery of what might be possible. Therefore, when Biomimicry is used in architecture it should rather serve as a source of inspiration for what could be possible than a source of answers to life's so called "problems" – architecture does not solve problems but rather creates opportunities. During the course of this thesis investigation it has been my desire to explore a biomimetic approach more suitable to the design of architecture.

Space, structure and form are the traditional outward expressions of an architectural concept which has developed in the mind of the architect. In John Frazer's *An Evolutionary Architecture,* architectural design is regarded as a special kind of problem-solving process. When Biomimicry is considered in terms of problem solving, this approach has its limitations. For one, it assumes we can construct different kinds of representation which can vary from the "correct" answer as it may. However, it is extremely difficult to describe architecture in these terms, except of course in the very limited sense of an architectural brief to which there are endless potential solutions. The other problem is that any serious system will generate an almost unmanageable quantity of variations, making it extremely difficult to find that one "correct answer". Nevertheless, some recent architects are known to have used this "problem-solving" approach and have designed good buildings as a result. *[FRAZER. 1995: 15]*

Julian Vincent's article Biomimetic Patterns in Architectural Design recognises these three distinct levels at which patterns can be translated from biology to architecture and describes it in the terms below. [VINCENT 2009: 76]

THREE LEVELS OF TRANSLATION

The lowest level is the direct mimicking of the shape and form of biological objects. Unfortunately, this level of translation can often be regarded as simple copying and can be difficult to justify. Sometimes it merely becomes urban myth, such as the idea that the Eiffel Tower's structural design was based on the head of the human thigh bone. Due to the fact that there is no evidence for this, it remains pure speculation. Still, there exists a need for deeper analysis into biological materials and structures if one is to find where their success lies. [GREEN, 2005: 1]

The second level of translation is the recognition of patterns/principles in the basic functioning of organisms and to apply those to how we design building materials, forms, spatial layouts and systems. Often we learn different lessons from a certain organism by simply looking at it in more detail, like under the lens of a microscope. At the nanometres to millimetres scale, the observations are usually associated with the production and processing of materials (e.g. product design); the millimetres to metres scale is mostly concerned with structures and mechanisms (most commonly used in architectural and engineering designs); and from the metres to kilometres scale and beyond the concern is more with populations and ecosystems (often used for example to improve business models.) [VINCENT 2009: 77]

The third level of translation learns from the way organisms relate to things around them like in the case of eco-systems. At this level the patterns are more abstract, and enables access to 'unknown knowns' – things which are not recognised at first because they seemed irrelevant to the challenge at hand. Unlike natural ecosystems, the built environment is an incomplete and simple structure that generally does not recycle materials, are not adaptable, and instead of saving it wastes energy. The difference in the two causes the ecological approach to architecture not necessarily to imply the direct replicating of natural ecosystems, but rather applies its general principles of interaction with its various role playing factors. [FRAZER 1995: 16]

So understanding the micro-scale and nano-scale of structures responsible for a living material's exceptional properties is crucial to recreating it synthetically. [MUELLER 2008]

THESIS INQUIRY

Since this thesis inquiry is to investigate a biomitetic approach suitable for the generation of architecture specifically, an approach has been adopted that would test all three of the above levels of translation. It was also needed that both directions of innovation; a *biology to design* approach as well as a *challenge to biology approach* be tested. The pros and cons of these means will hopefully become more apparent under the Design Explorations section of this report.

PROGRAMME AND PARAMETERS

Given that this type of proposition is very site specific, one of the first steps in the design process was to decide on a site and programme. These constraints were helpful in terms of decision making and only once this was established could a more thorough analysis be done to determine which principles from nature would have to be translate to the design.

PROGRAMME

What was essential was a programme that would complement the type of investigation. Biomimicry is considered a research and education tool; hence it would be suitable for the building to be programmed as a tertiary education and research facility. True to the nature of Biomimicry, it was the vision right from the start to design a space/facility where students from different programmes (e.g. biology, engineering and architecture) can learn from one another, and in addition be exposed to professionals within their respective fields who can aid them in their learning process.

The following are some of the initial investigations and programme precedents that served as inspiration for further developing of the spatial requirements.

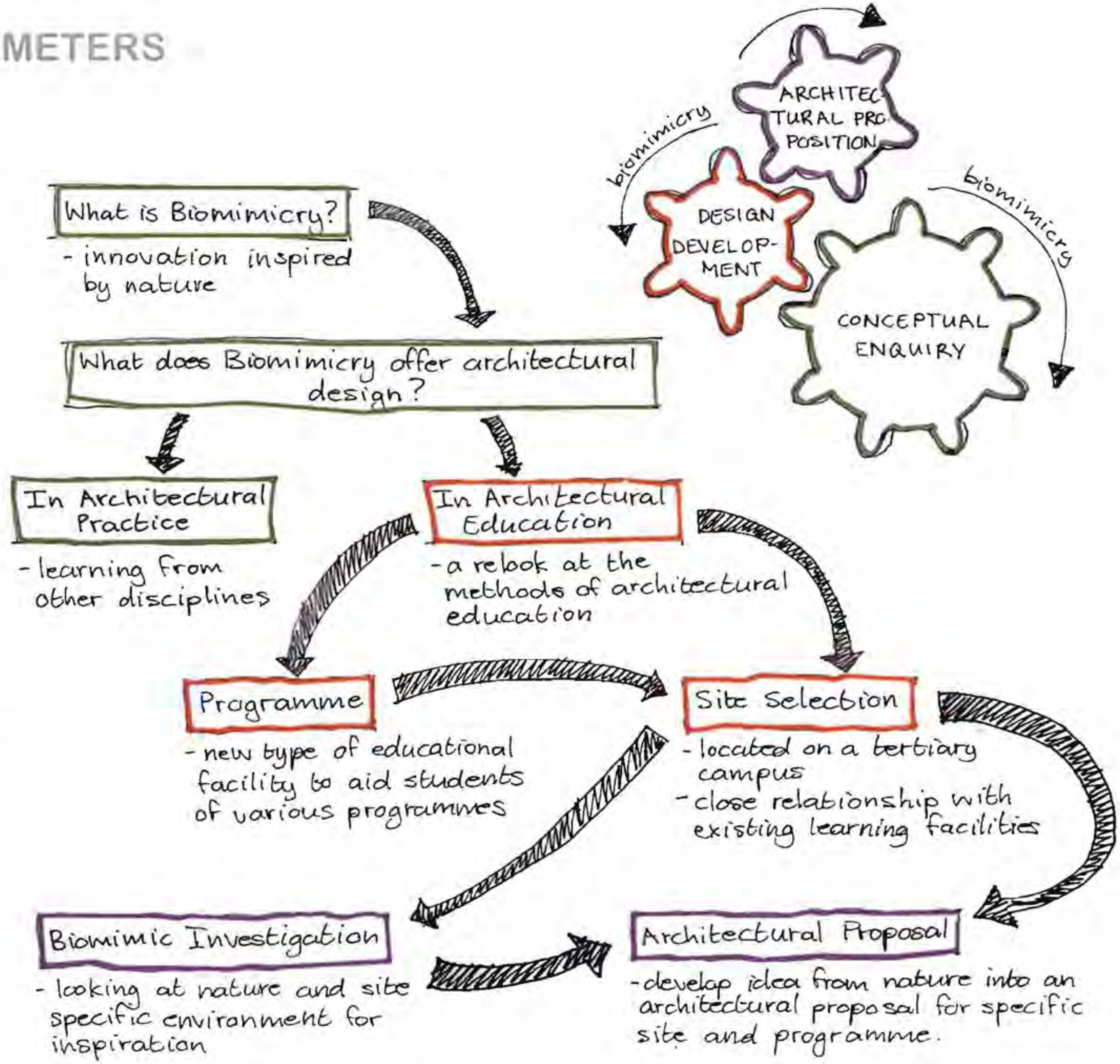


Figure 28: ideas for student workshops and laboratory spaces where students can be free to build prototypes for their various projects.

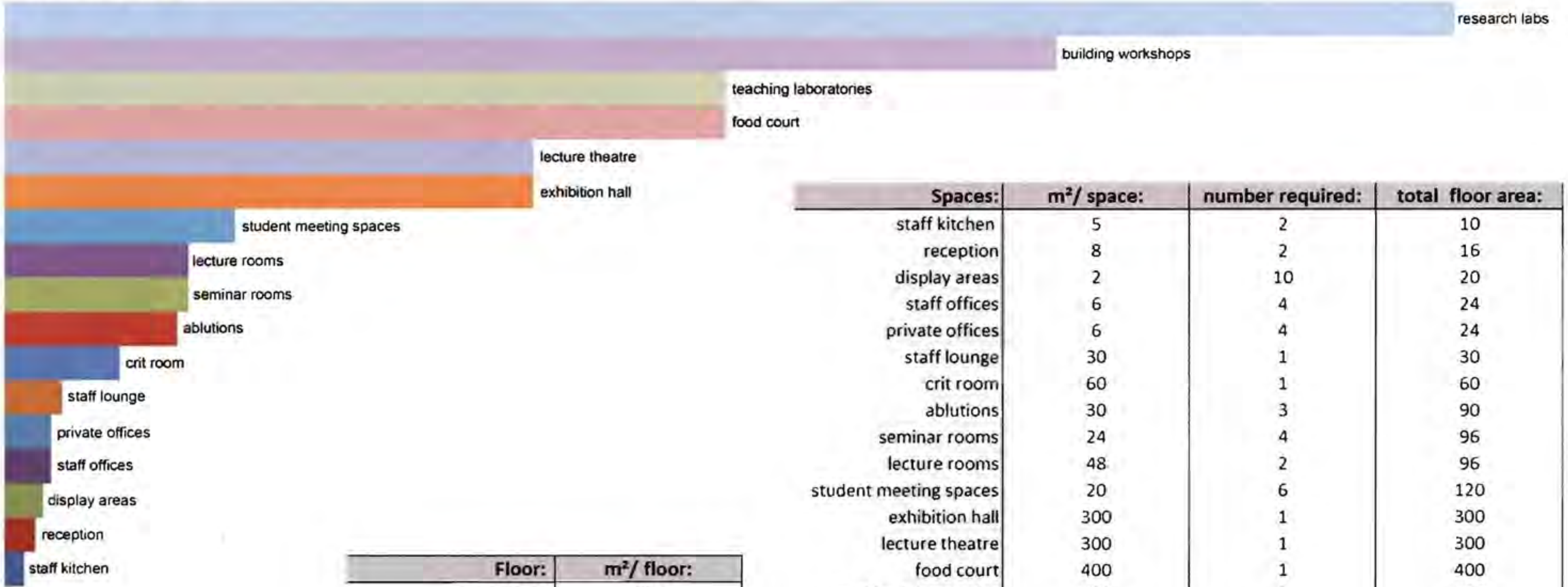
Figure 29: the above projects, the Parade by the London University of Arts (left) and the Boxel Pavilion by the University of Applied Sciences in Detmold (right) serve as precedent for spaces that allow for the building of larger, innovative student projects.

Figure 27: The School of Medicine at The University of Western Sydney was designed by Lyons Architects. It is a good case study for a tertiary building designed as an integrated teaching and research environment based on the contemporary educational principles of student centered learning and collaborative interdisciplinary research.

In order to make an informed decision which site to choose, a rough idea of the required square meters needed to be established. The graph below was a preliminary and quick study of which kind of spaces a facility of this sort might need. Based on various precedent studies above, an initial rough idea of sizes could also be included. Although, understandably, these would change according to site, location and other design parameters that will come into play later.

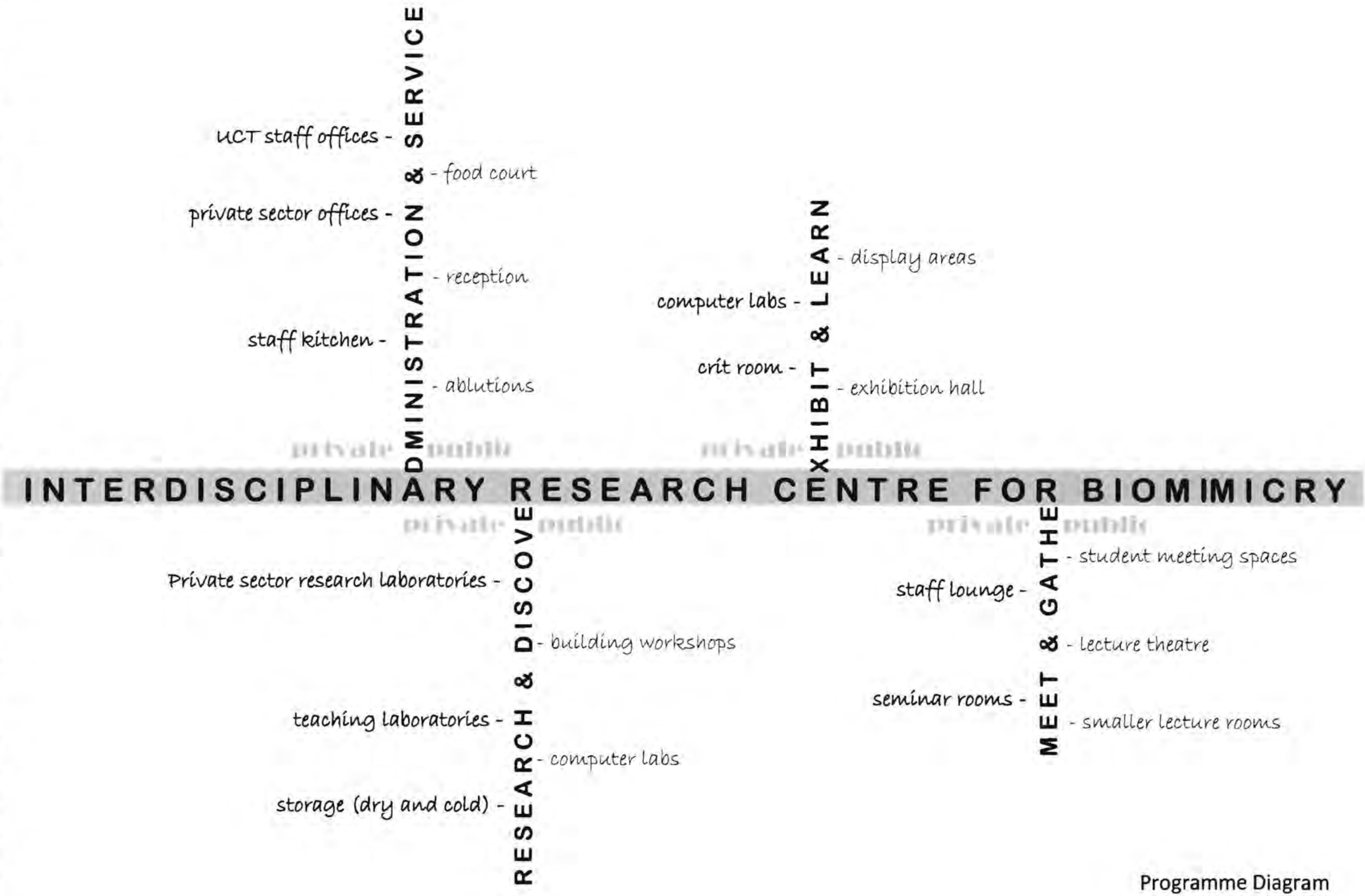
The diagram to the right serves as a layout of the different spaces categorized into four different types, namely: administration and service, research and discover, exhibit and learn, and meet and gather. Each of these types has a public (left) and a private (right) division. The aim would be for these spaces to be designed in such a way that they can facilitate interdisciplinary learning between students and professionals alike.

Diagramatic Spatial Sizes



Floor:	m²/ floor:
second floor	990
first floor	990
basement	1524
total floor area	**3504**

Spaces:	m²/ space:	number required:	total floor area:
staff kitchen	5	2	10
reception	8	2	16
display areas	2	10	20
staff offices	6	4	24
private offices	6	4	24
staff lounge	30	1	30
crit room	60	1	60
ablutions	30	3	90
seminar rooms	24	4	96
lecture rooms	48	2	96
student meeting spaces	20	6	120
exhibition hall	300	1	300
lecture theatre	300	1	300
food court	400	1	400
teaching laboratories	200	2	400
building workshops	300	2	600
research laboratories	280	3	840
total floor area required			**3426**



Programme Diagram

SITE ANALYSIS

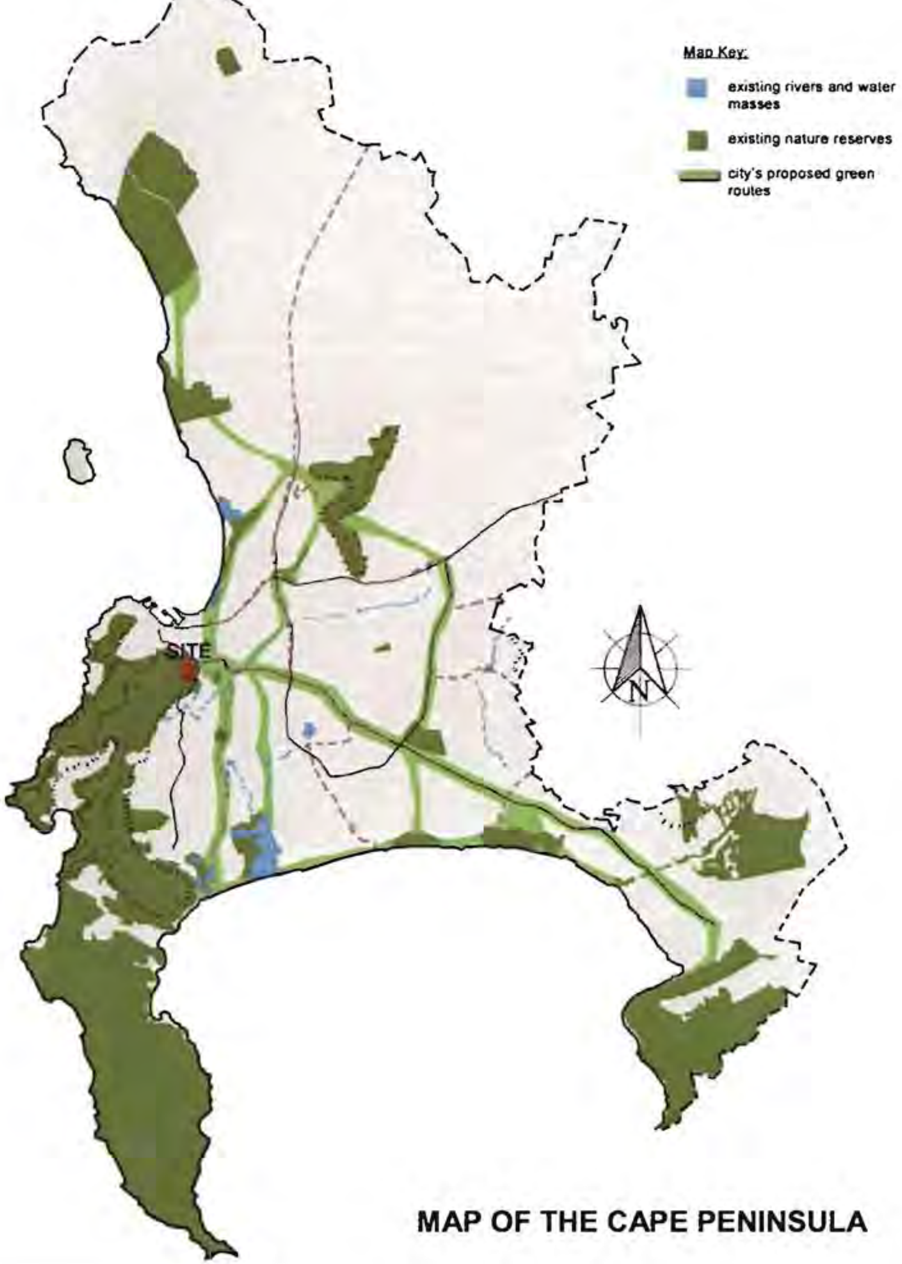
Having a clearer idea of the programmatic and spatial requirements was helpful in guiding the next step of the design, which was to decide on a suitable site for the building. This section includes the reasoning behind choosing the specific location as well as an analysis of the physical properties and its constraints.

Locality:

Due to the nature of the programme, certain requirements of the site location were already a given:

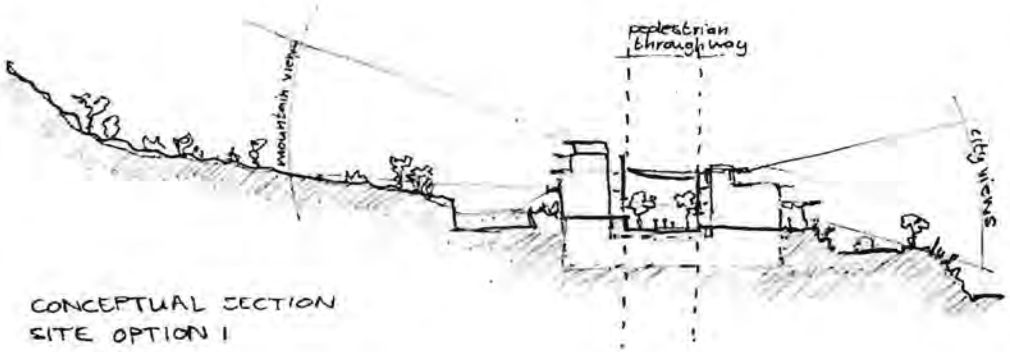
- For one, it needed to be within a tertiary environment.
- Students from different programmes like architecture, engineering and biology should be able to share the facilities offered within the building.
- Private research institutions like the Biomimicry Institute need to be able to use it as office and research space.
- It should also be in an area where the public would have easy access to it.
- And lastly, it needed to be in an area that would provide enough surrounding inspiration from nature for the making of an interesting biomimetic investigation.

The one place which could fulfil all of the above criteria was a location that would fall within the boundaries of the Upper Campus of the University of Cape Town. Once this general location was established, further investigation needed to be done to find a specific site suited for this investigation. Initially three possible sites were identified. Reasons for choosing these three will be analysed in more detail below.



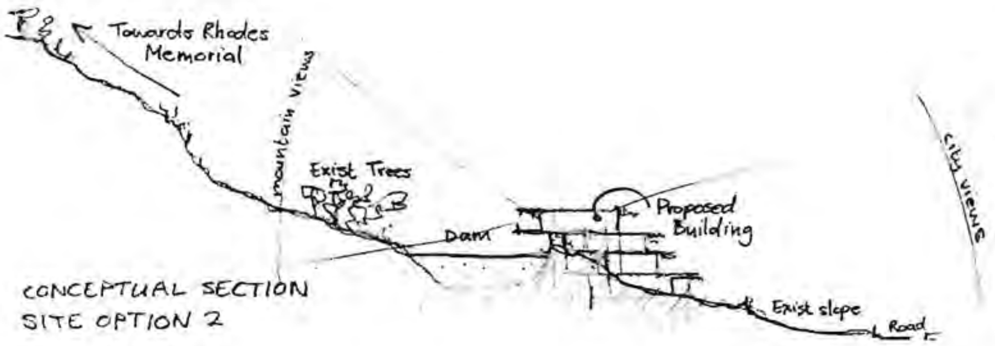
MAP OF THE CAPE PENINSULA

UCT UPPER CAMPUS_SITE OPTIONS



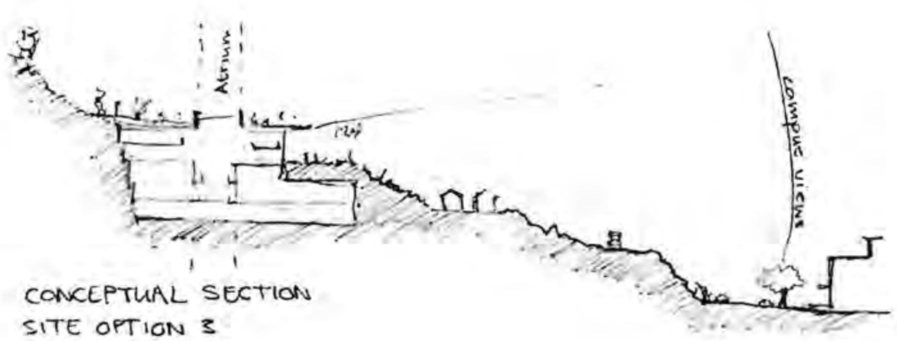
Site Option 1:

The first option as possible site is located on the south end of the campus. Initially the marked off area included a portion of land on either side of the very busy South Exit Road. The main reasons for choosing this location was because of its potential as gateway to that end of campus (as this is currently ill-defined) and also as metaphorical link between the Old Zoo (forming part of the Table Mountain National Park) to UCT itself. The overarching idea would be to revitalise the Old Zoo as a place where both the public and students alike may learn more about the fauna and flora of the area. Although, it could prove difficult to design for a facility that crosses over a road with two legs, per say, on either side.



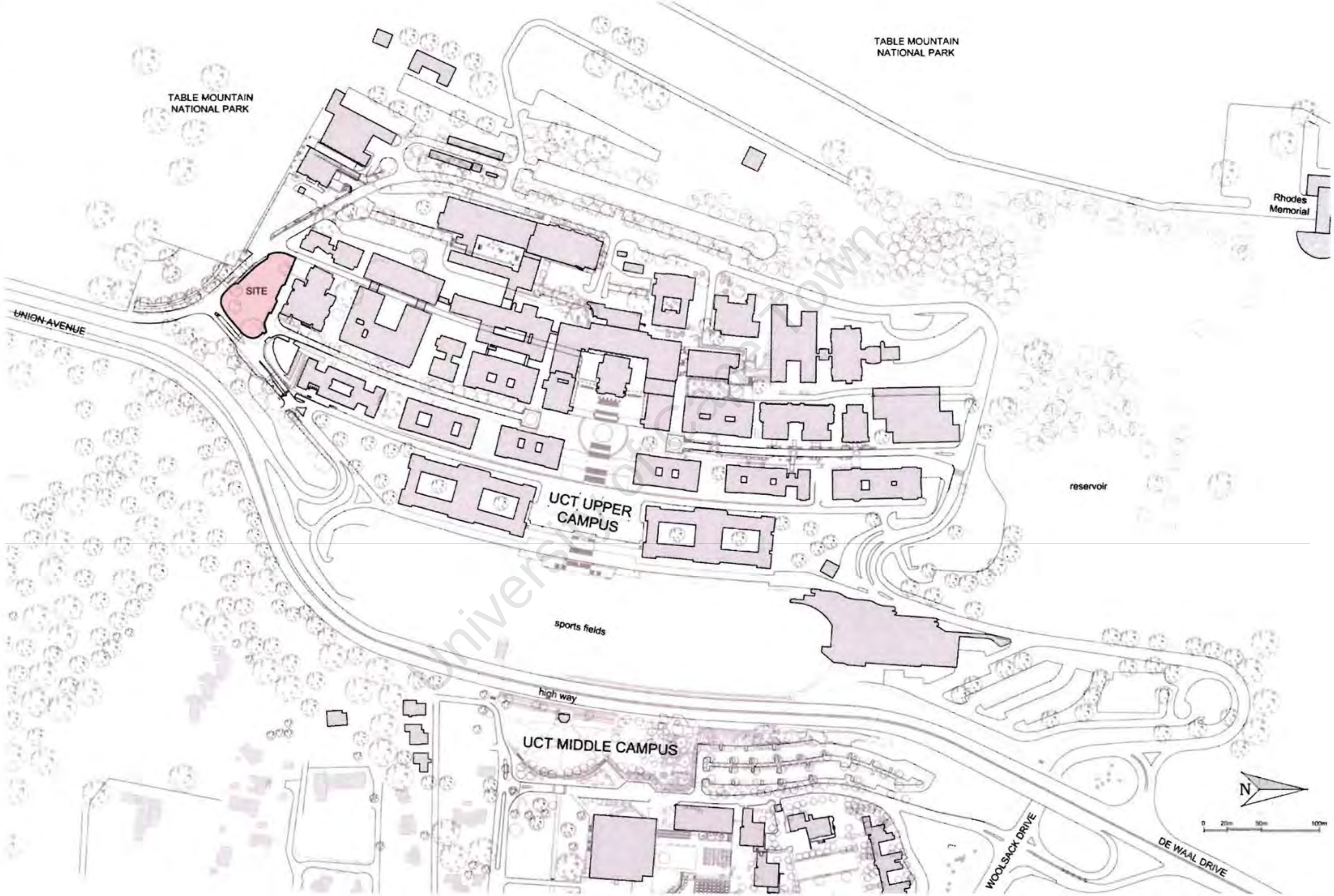
Site Option 2:

The second option is located on the north end of campus. This location would potentially serve as an area with ample open-air space for students to learn and examine nature. It also has the potential to utilize the reservoir for research purposes to cultivate water plants and possibly fish. The site also has beautiful views out onto the city as well as towards the mountain. Unfortunately, it is not within close walking distance to existing UCT academic buildings such as the Architecture School and engineering buildings located on the south side.



Site Option 3:

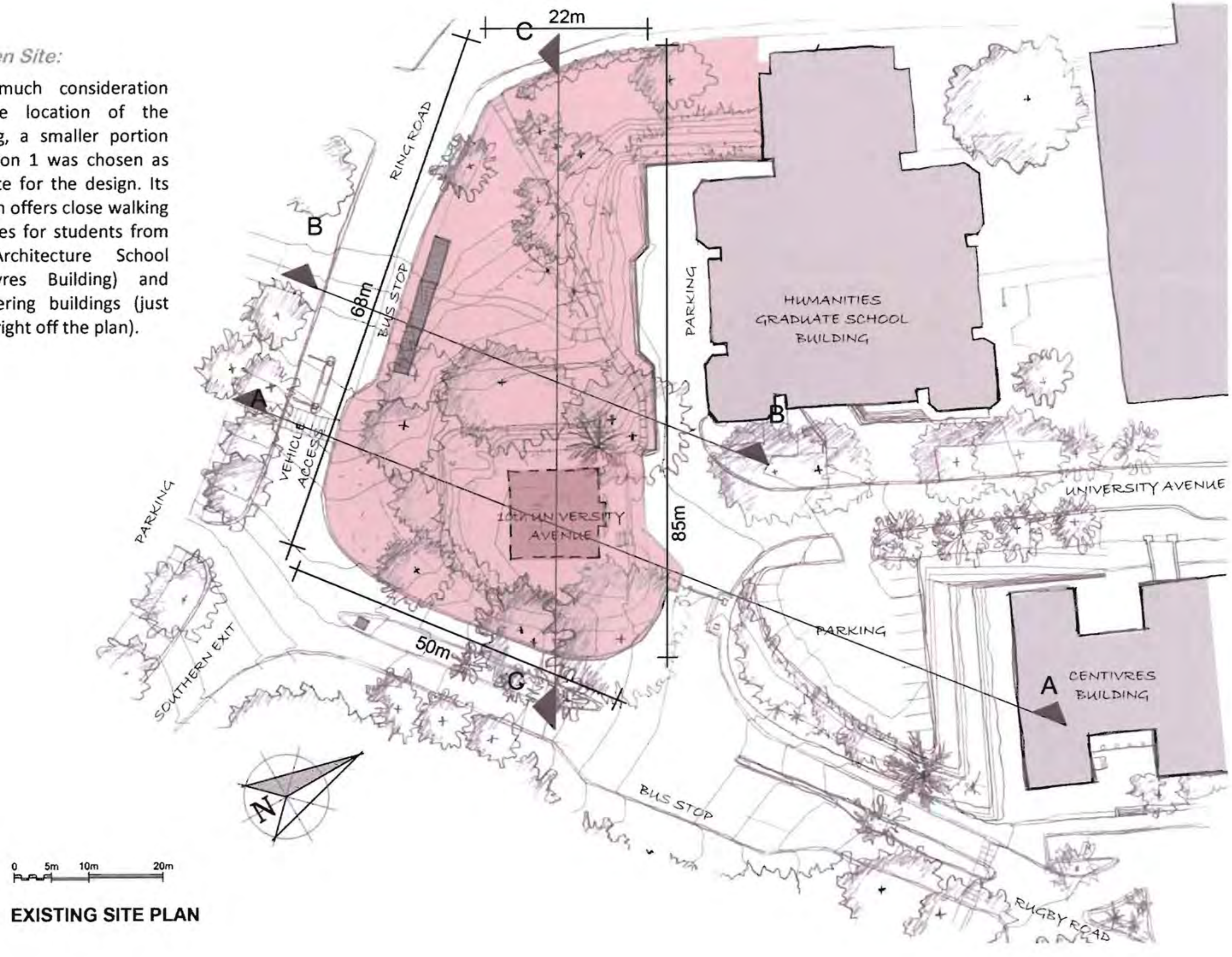
The third option is at the western edge of the campus, south of the existing tennis courts. It is a good location for a type of building that would require being in touch with nature with a 'building in the landscape' concept. It has a really nice slope that could provide for interesting biomimetic design solutions. Access would prove difficult though as the intention would be to have a facility that would allow for use by the private research sector, students, and additionally the public through exhibition spaces. As it stands at the moment, the whole western end of campus is considered private allowing access only to UCT staff.



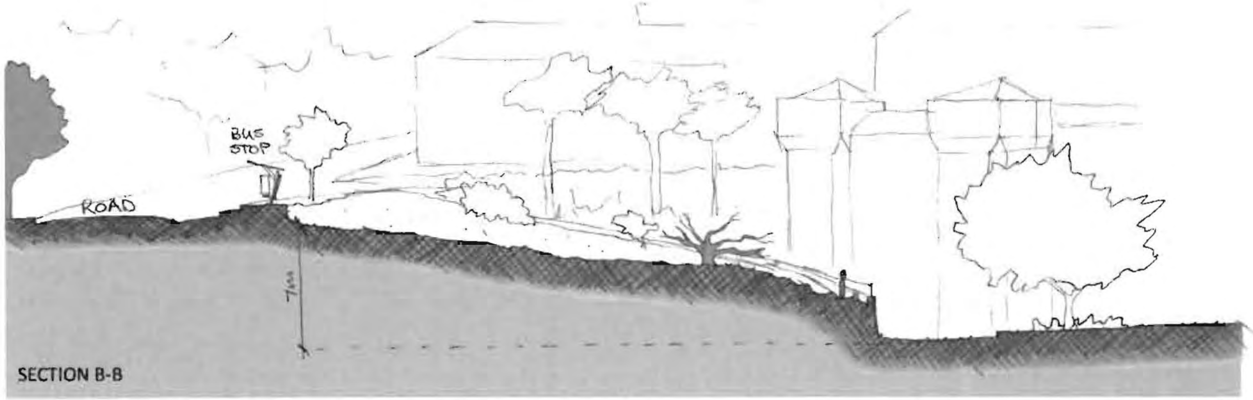
LOCALITY PLAN OF THE CHOSEN SITE

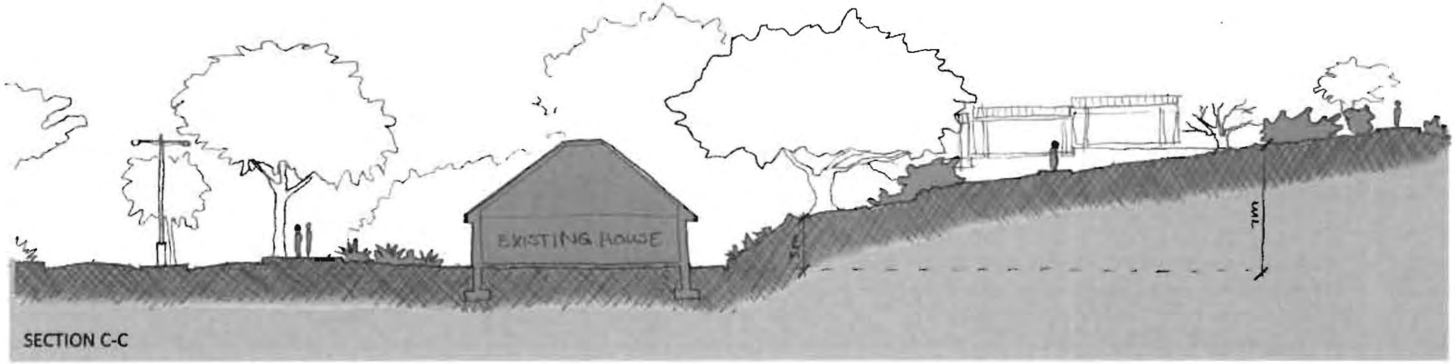
Chosen Site:

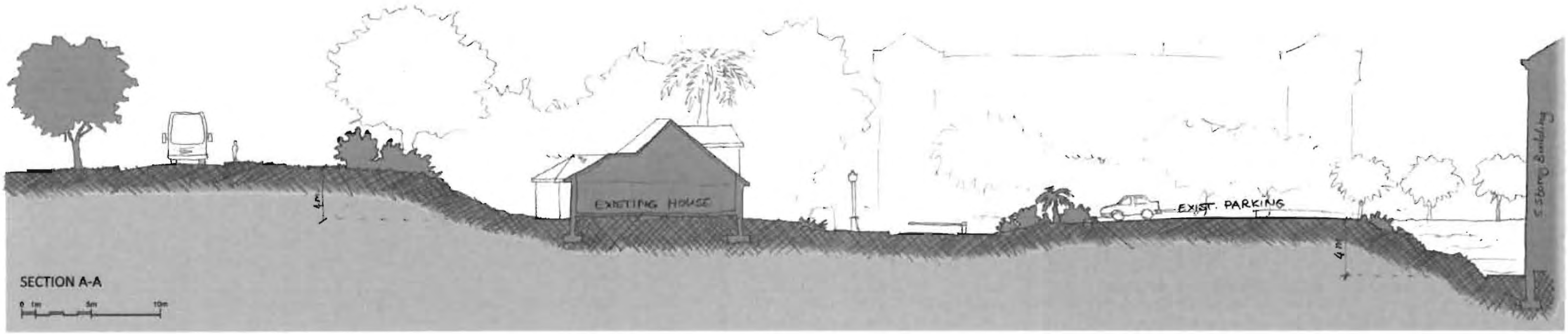
After much consideration for the location of the building, a smaller portion of Option 1 was chosen as final site for the design. Its location offers close walking distances for students from the Architecture School (Centlivres Building) and engineering buildings (just to the right off the plan).



EXISTING SITE PLAN


BUS STOP
ROAD
7m
SECTION B-B


EXISTING HOUSE
7m
SECTION C-C

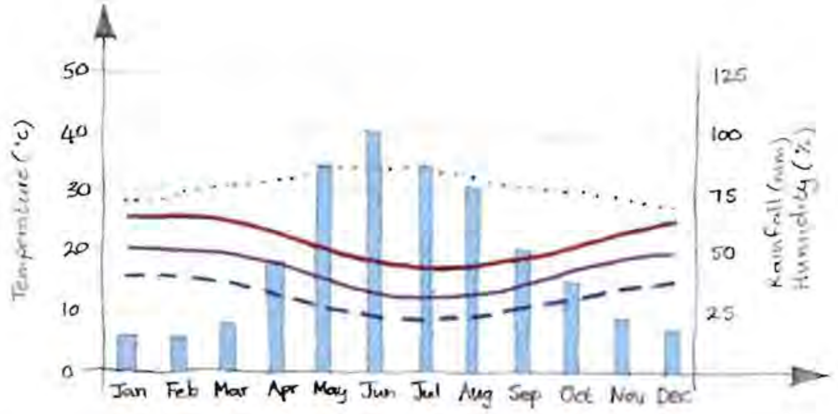

EXISTING HOUSE
EXIST. PARKING
4m
5 Storey Building
SECTION A-A
0 1m 5m 10m

Climate & Weather:

The chosen site falls under the greater Cape Peninsula area which has a Mediterranean climate with dry summers and wet winters. Winter (characterised by heavy rain on the mountain slopes, strong north-westerly winds, and low temperatures) occurs between May and August, whilst the larger part of the rest of the year is considered summer (characterized by warm and dry weather, with occasional strong south easterly winds). With rainfall peaking from May to August, this building would have potential to harvest large volumes of rainwater for at least six months of the year if so needed. *[WorldTravels, 2011]*

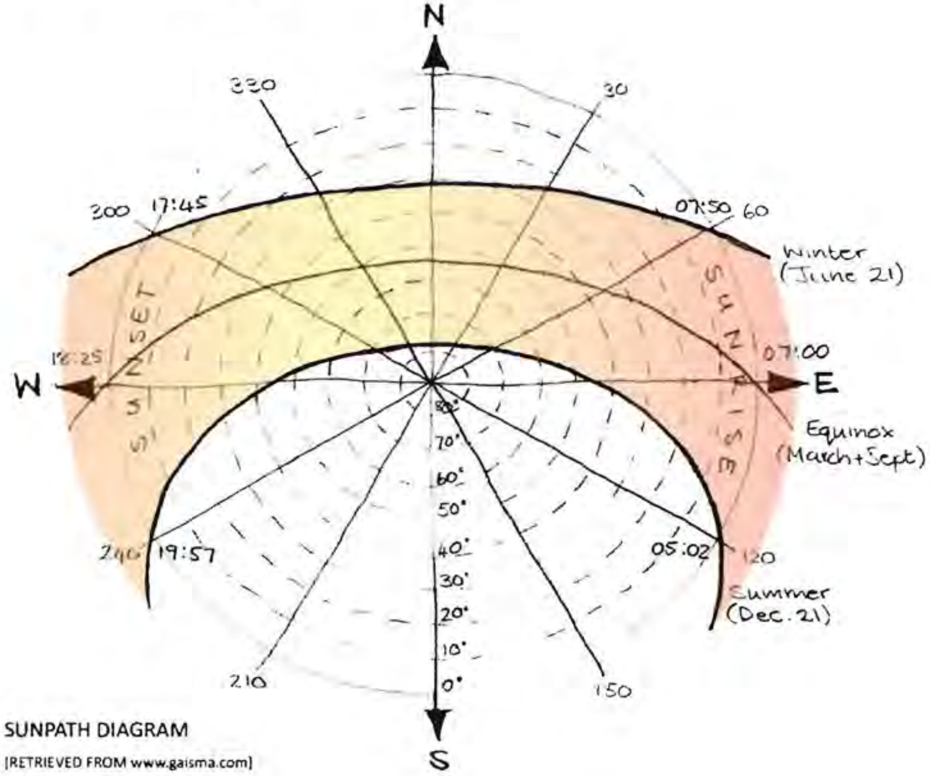
The mean daily maximum temperature of this area is 25°C in February, and the mean daily minimum is 7°C in July. In summer, the famous south-easterly cloud known as the "Table Cloth", brings substantial mist precipitation to the southern and eastern slopes, exactly where the site is situated. As no part of the Peninsula is more than 7 km from the sea, snow is very rare, and when it does fall, it never lasts. Frost also occurs on fewer than three days per year. *[SANBI 2011.]*

The diagrams on the right show the average rainfall and temperature for the area as well a sunpath diagram indicating typical sunrise and sunset hours. These factors will bare consideration in the spatial layout and façade treatment of the building.



AVERAGE RAINFALL AND TEMPERATURE

[RETRIEVED FROM www.capetown.gov.za]



SUNPATH DIAGRAM

[RETRIEVED FROM www.gaisma.com]

Fauna and Flora:

The type of plant life in the area surrounding the site falls under the Peninsula Sandstone Fynbos (PSF), or just commonly referred to as "Mountain Fynbos." Due to the poor soil quality as well and its steep slopes in some places, it is both the least destroyed and the best conserved veld type in the city. It also has the most number of plant species including endemic plants unique to Table Mountain. *[SANBI, 2011]*

The soil types are known to be acidic, rocky soils varying from deep or shallow coarse sands, to solid rock, to deep, black, peaty soils. Often these leave very few crevices for plants to grow, allowing only a few types of the toughest plants to be able to survive in it. *[SANBI. 2011]*

Fynbos varies from succulents on the dry northern cliffs, to dense, moist, tall Proteoid Fynbos in the wetter areas, whilst Ericaceous Fynbos (with many rare species) is found on well-drained, higher slopes. Threats to these endemic plants include frequent fires as well as aliens like the Port Jackson, Rooikrans wattles, Hakea, and Cluster Pine. *[SANBI. 2011]*

Large portions surrounding the site have actually been covered with Pines for many years, proving how well they have adapted to the area. Hence, they would be worthwhile organisms to look at from a biomimetic point of view. Along with this, the following plants and animals have all been considered as amazing biomimetic stimuli for the design.





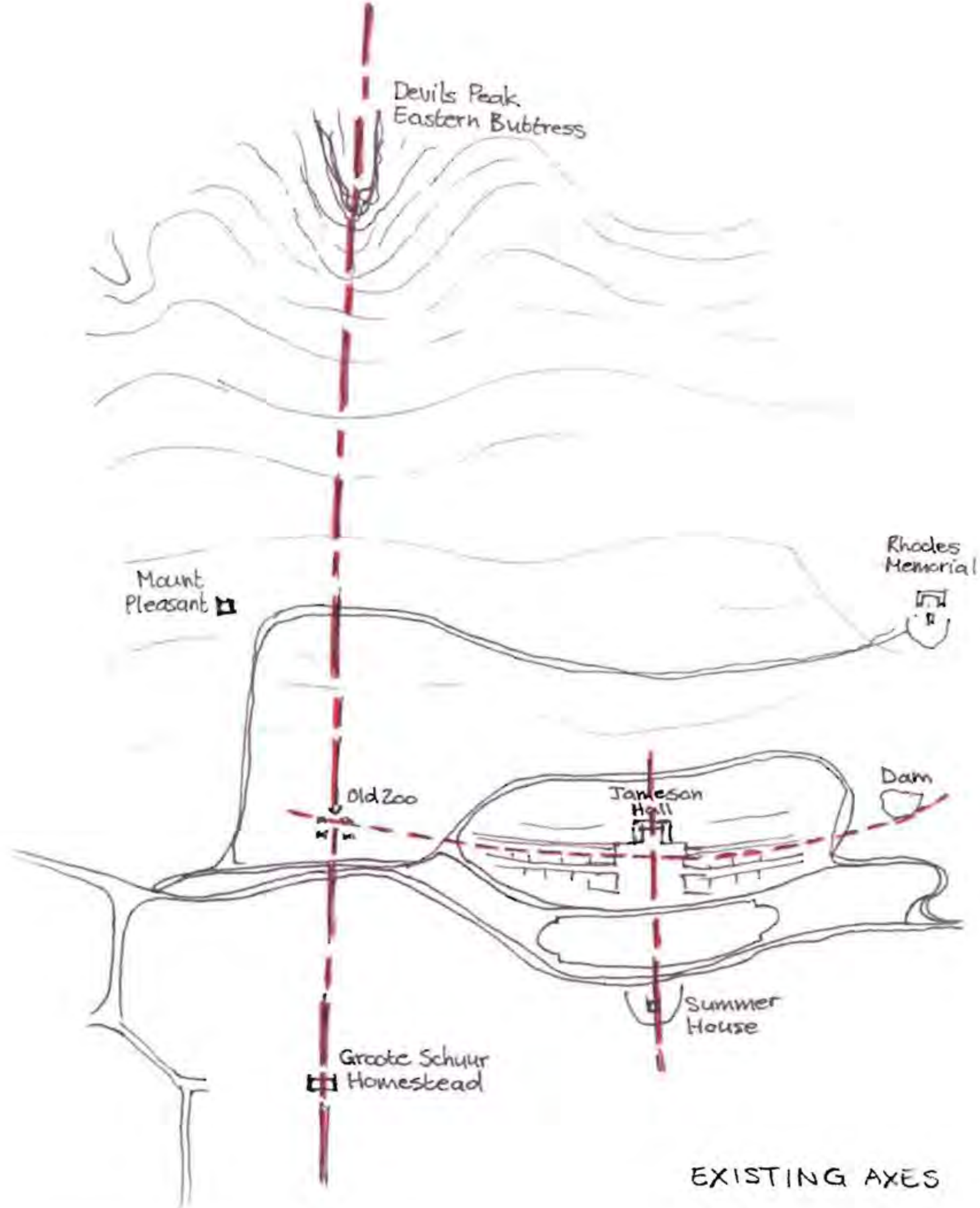


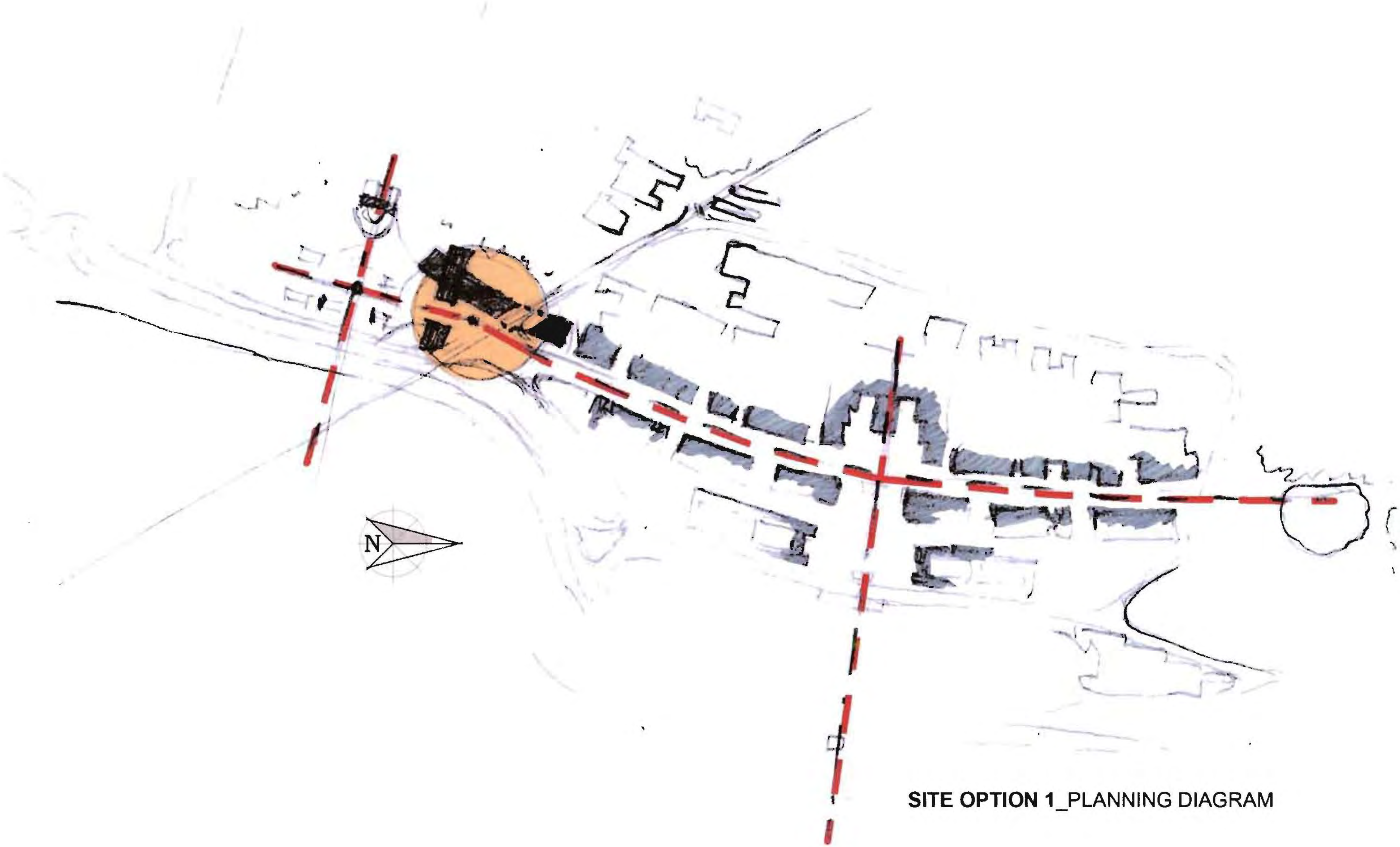
DESIGN EXPLORATIONS

This section serves as a series of smaller design explorations each testing a different aspect or approach to biomimetic architecture. The aim of these studies was to find the most appropriate design solution for the specific site, programme and thesis enquiry. The different explorations have been, as far as possible, kept in chronological order as this is the best indication of how certain design decisions have come about.

EXPLORATION 1 | existing fabric

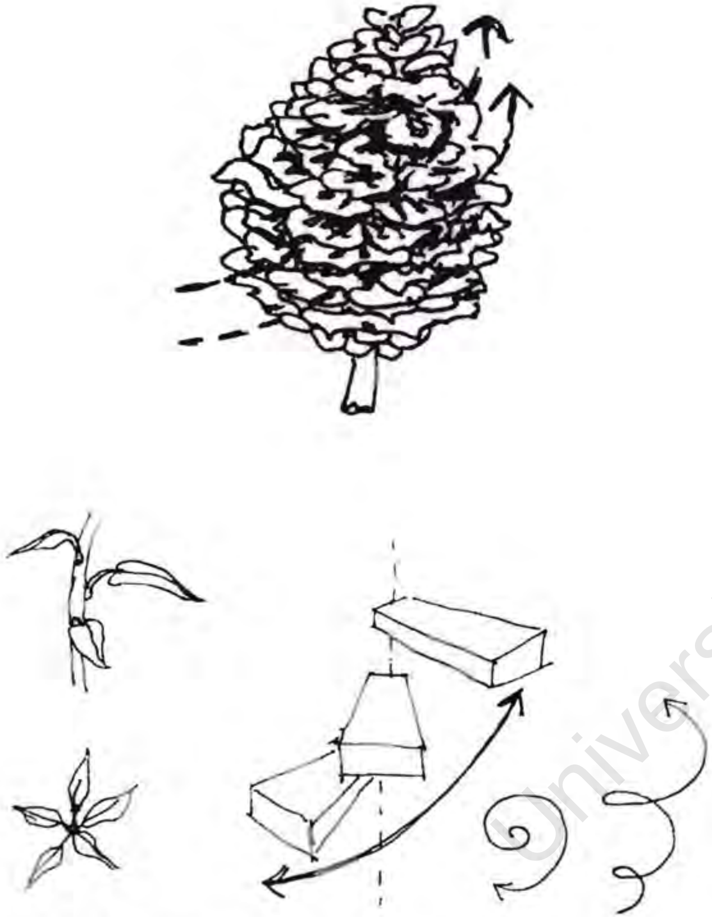
One of the first explorations done was a study of the existing fabric of the site. Most of this first phase in the design process has already been discussed in the previous section. Other exercises included a study of the existing formal axes, initial design explorations, as well as a short study of the existing architecture of the UCT buildings.



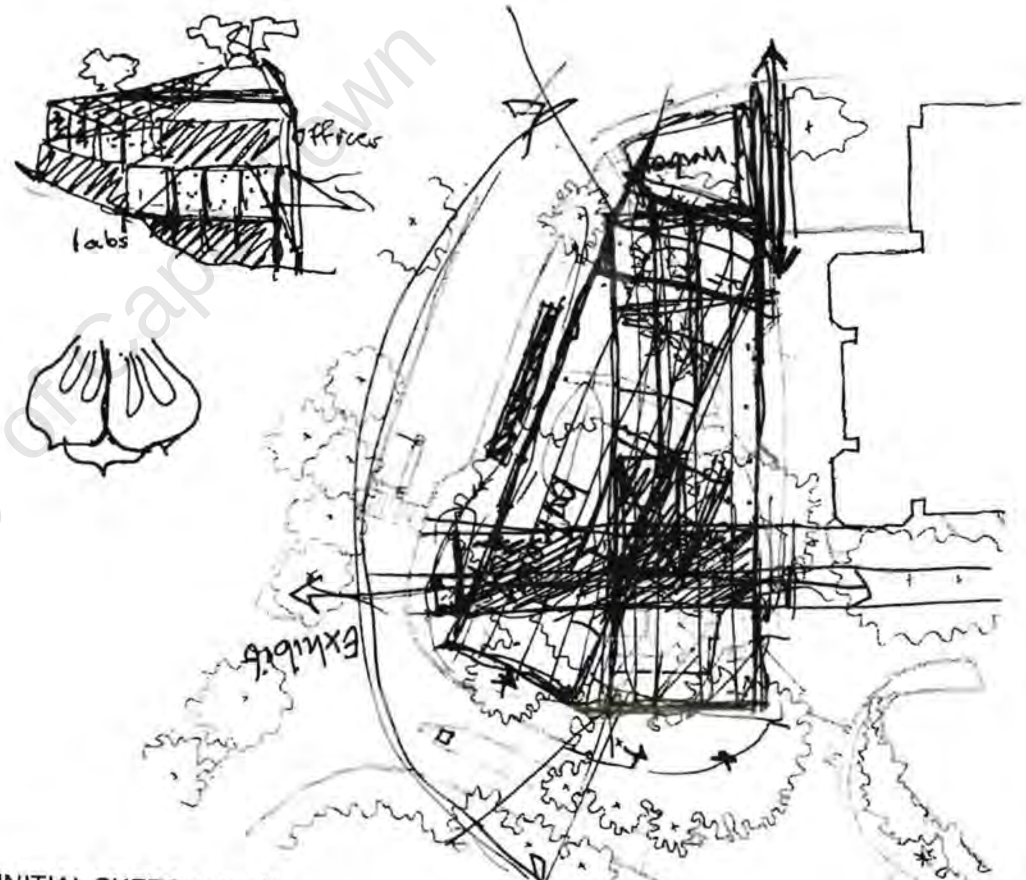


SITE OPTION 1_PLANNING DIAGRAM

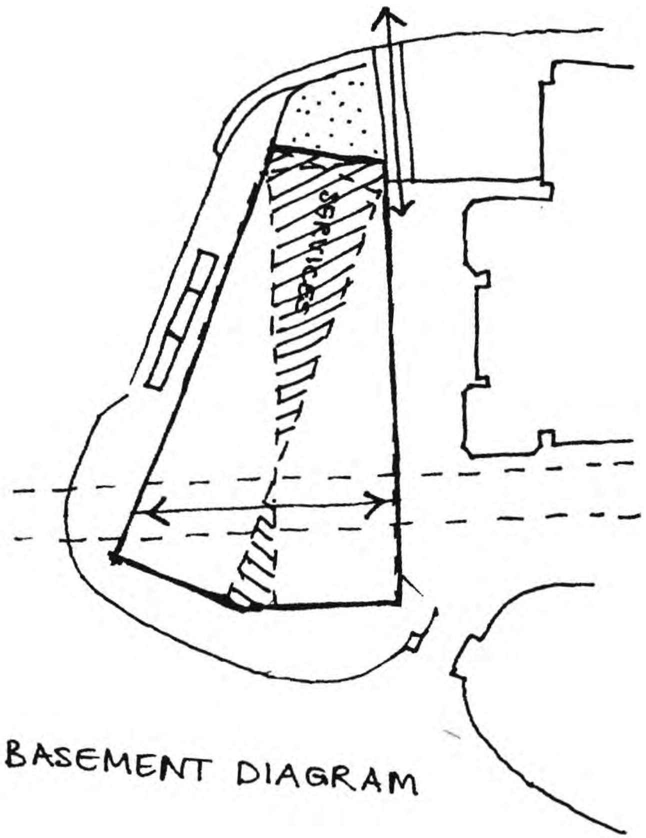
EXISTING UCT ARCHITECTURE



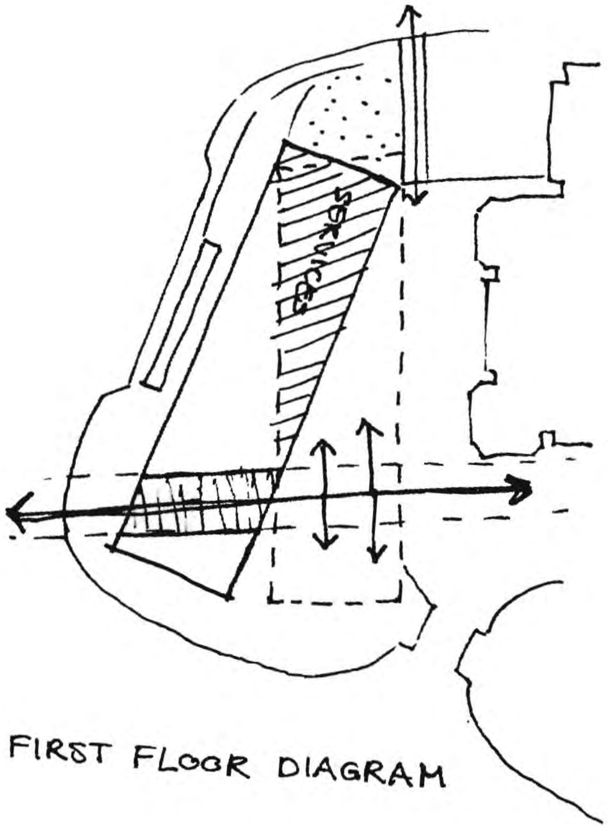
INITIAL CONCEPTUAL DIAGRAMS



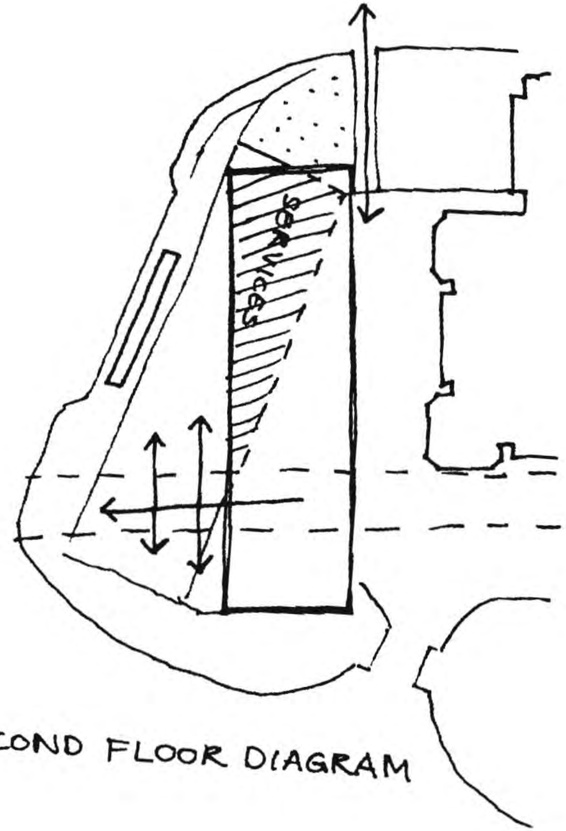
INITIAL SKETCH PLAN



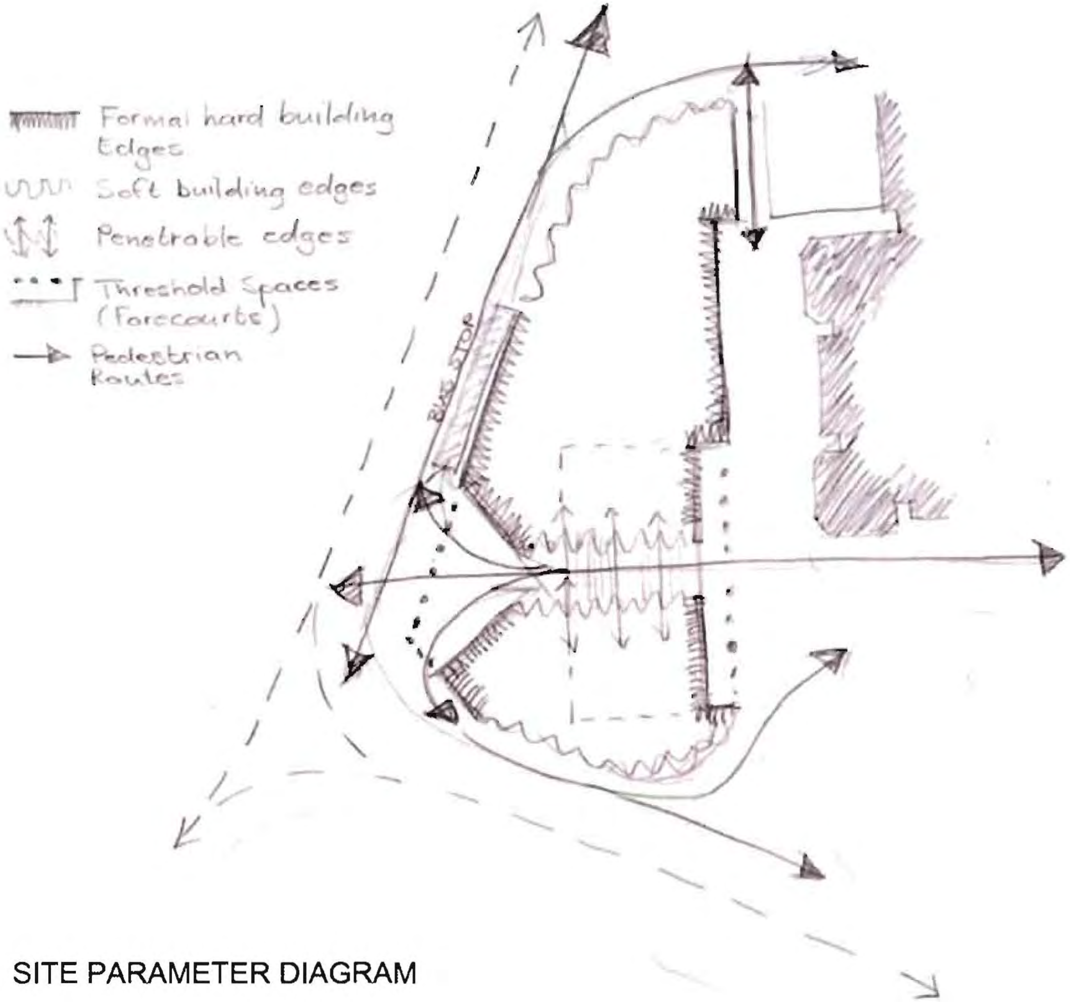
BASEMENT DIAGRAM



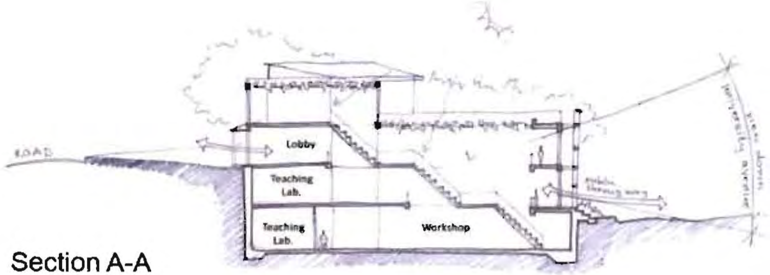
FIRST FLOOR DIAGRAM



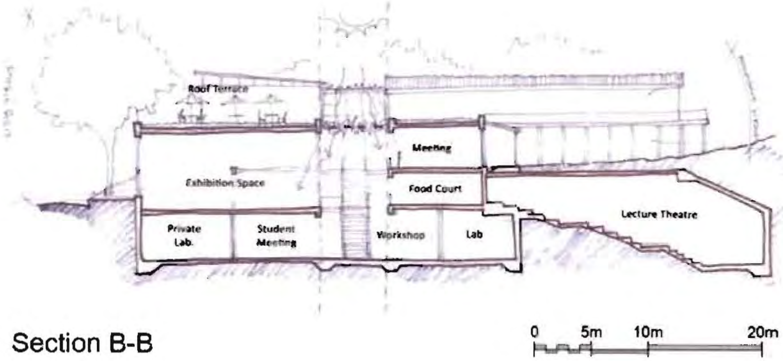
SECOND FLOOR DIAGRAM



SITE PARAMETER DIAGRAM



Section A-A



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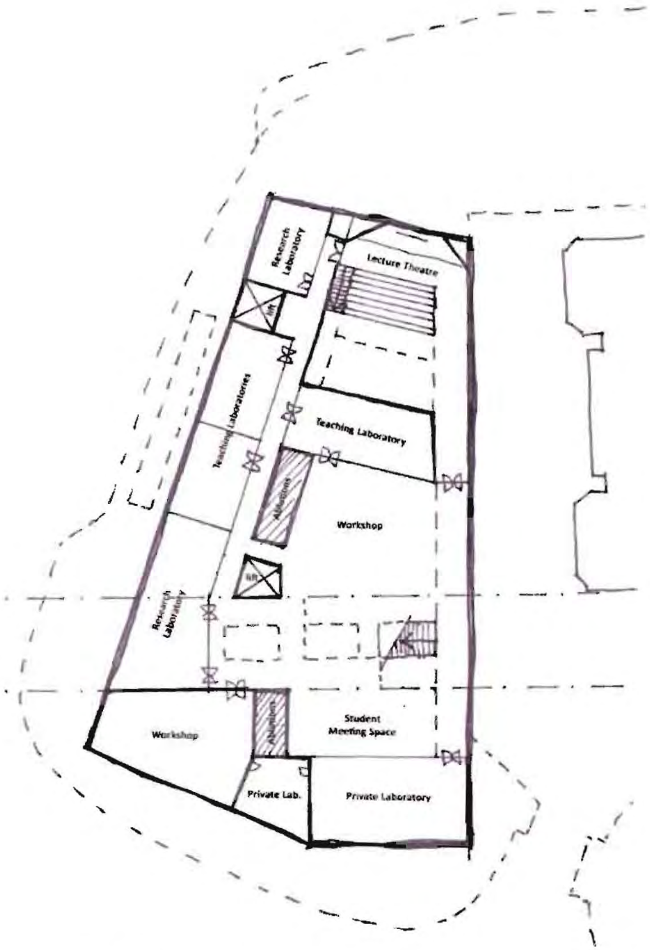
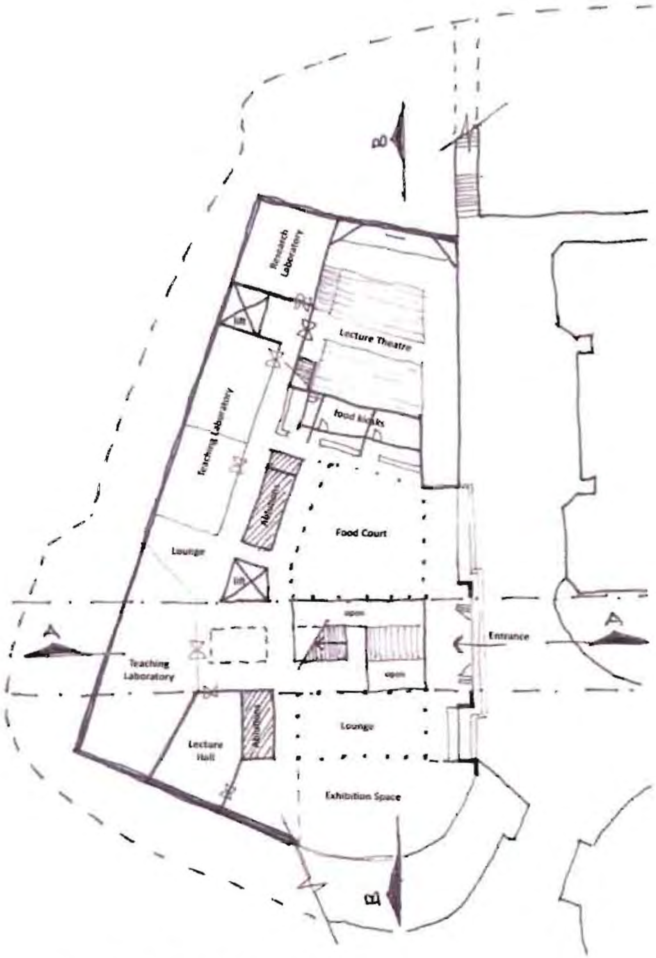
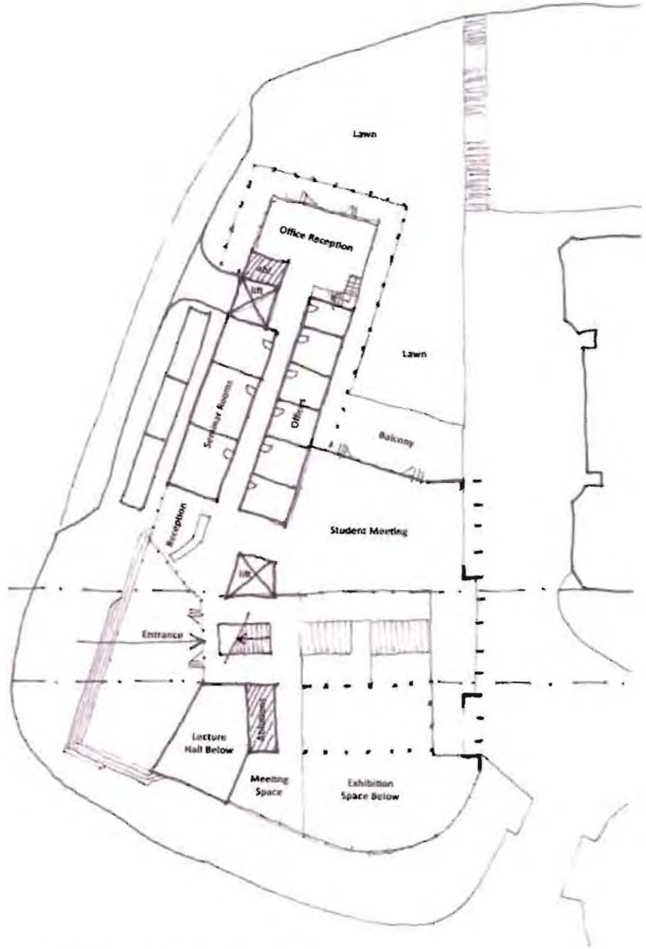


BASEMENT LAYOUT

0 5m 10m 20m



GROUND FLOOR LAYOUT



FIRST FLOOR LAYOUT

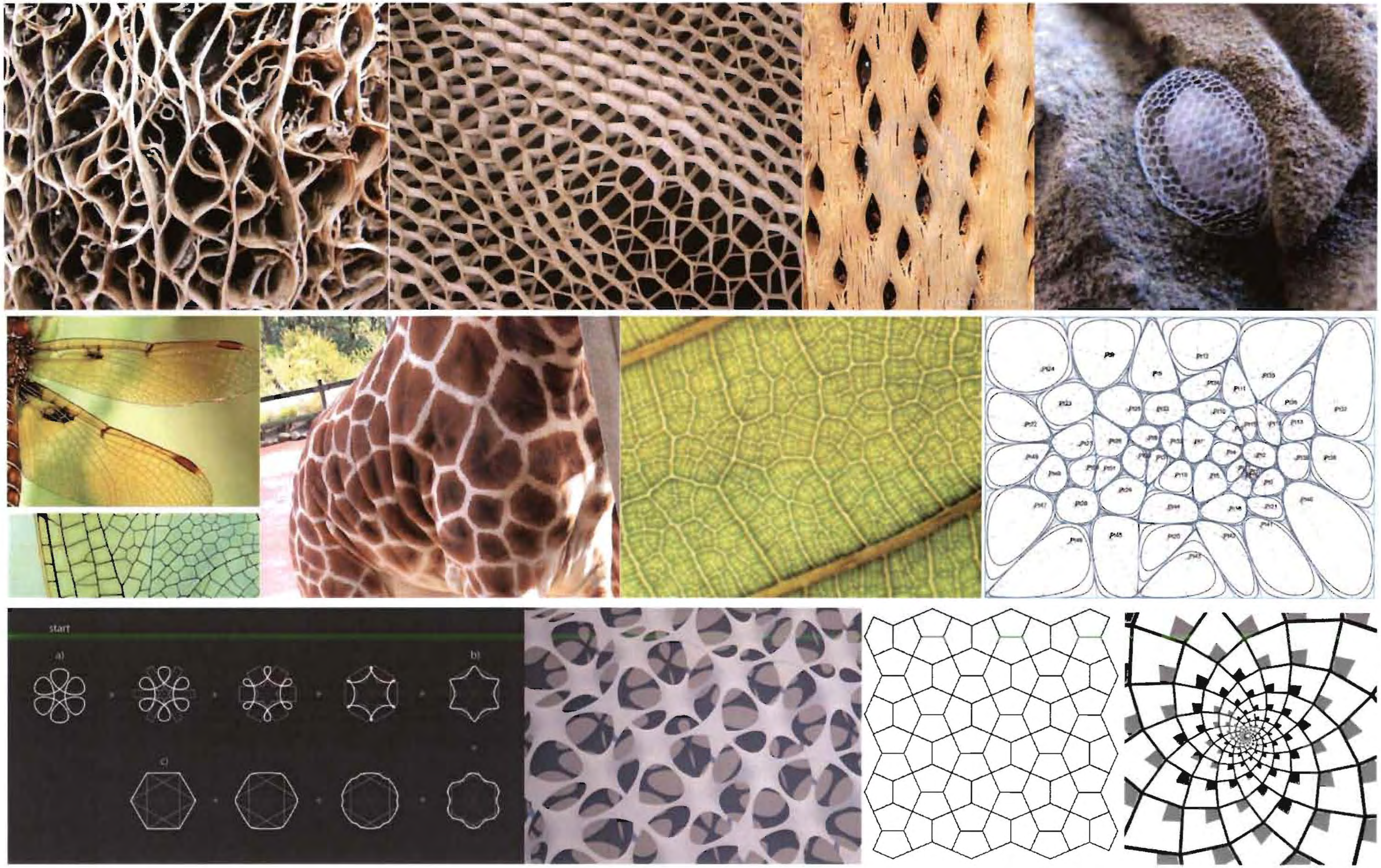
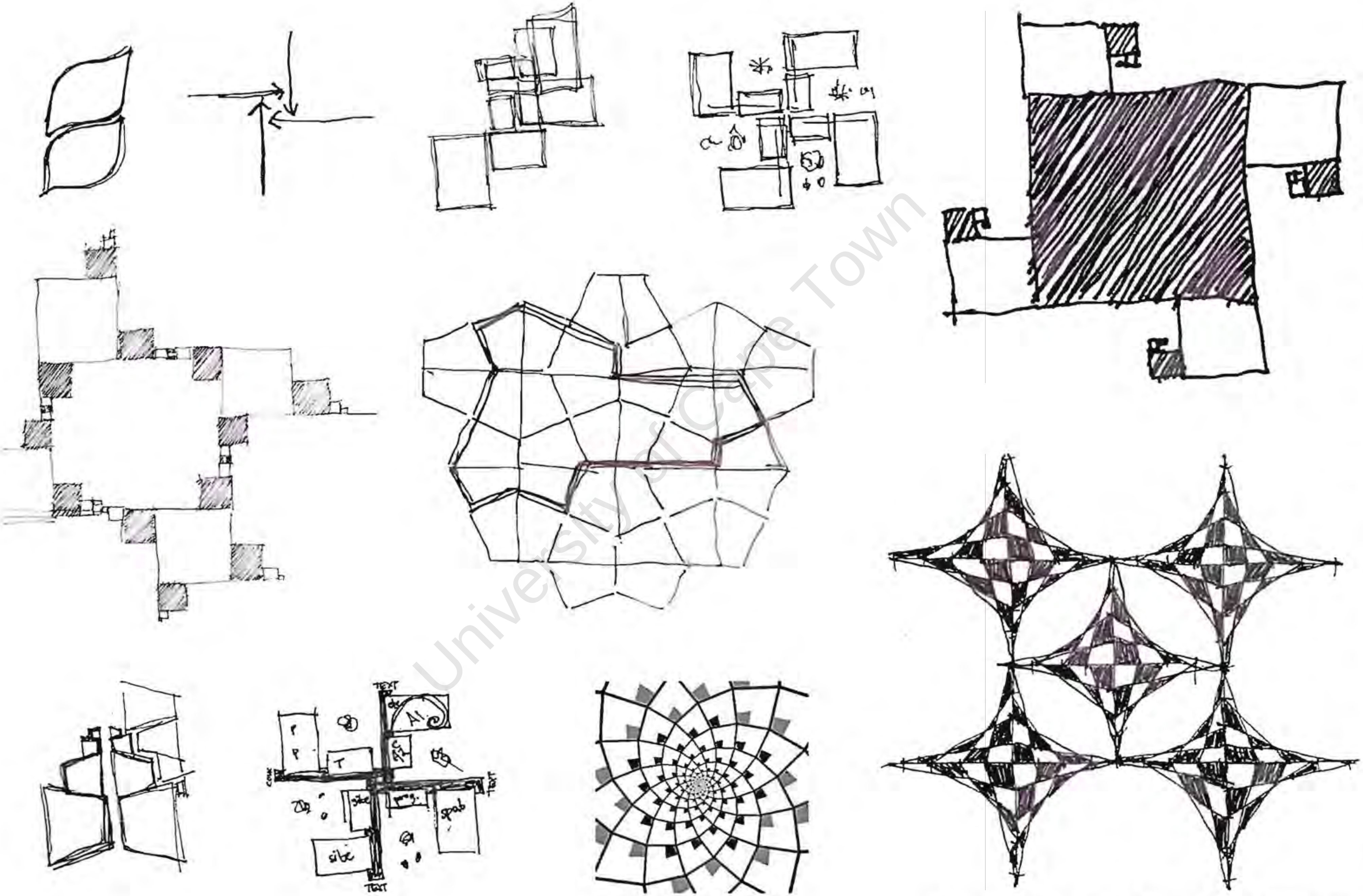
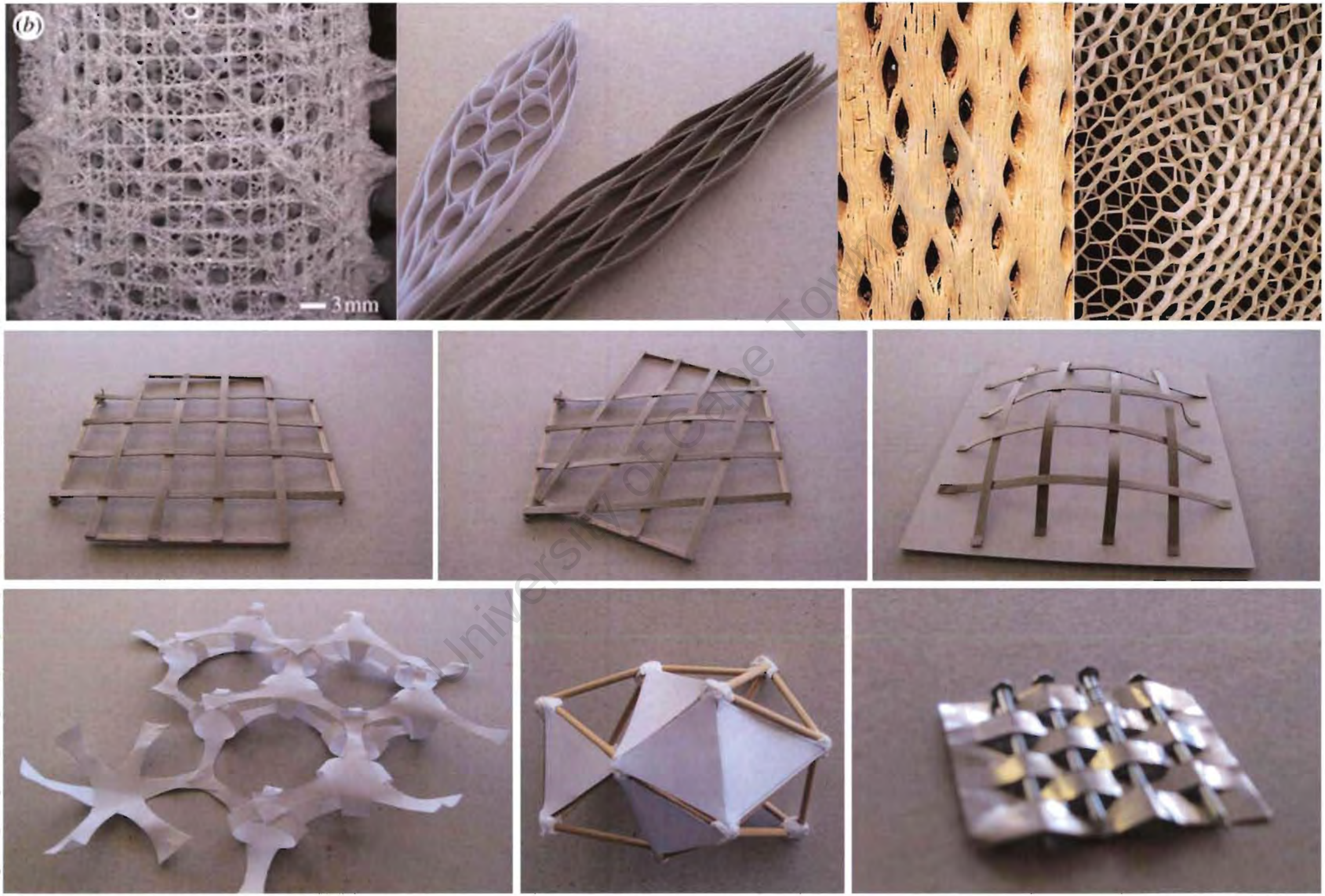


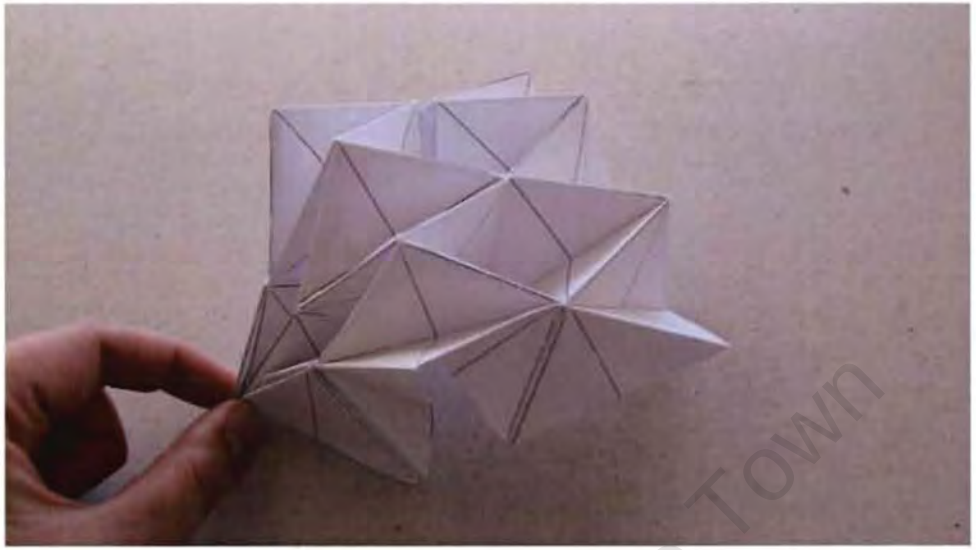
Figure 30: pattern inspirations from nature.

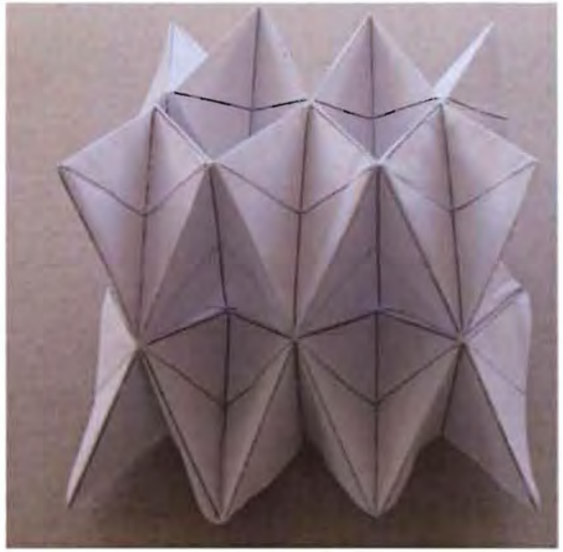


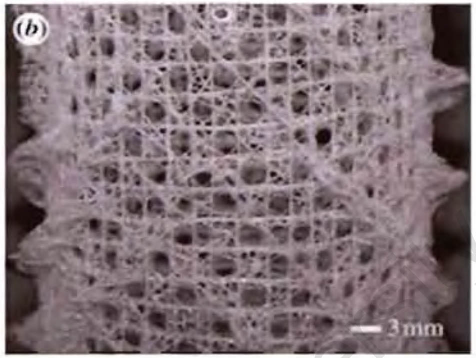
EXPLORING WITH FRACTAL PATTERNS



EXPLORATION MODELS







EXPLORATION MODELS

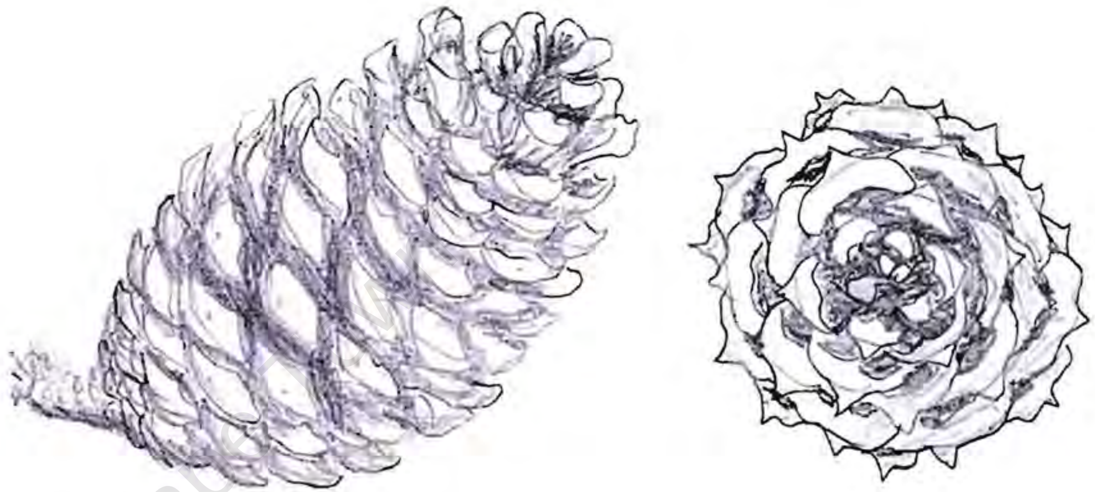
EXPLORATION 5 | conceptual study

Pine trees are fascinating organisms, especially when one studies the way their pollination process works. The trees depend on sexual reproduction to survive, meaning they have both male and female flowers (in this case: cones) that cross-pollinate in order to fertilize the seeds.

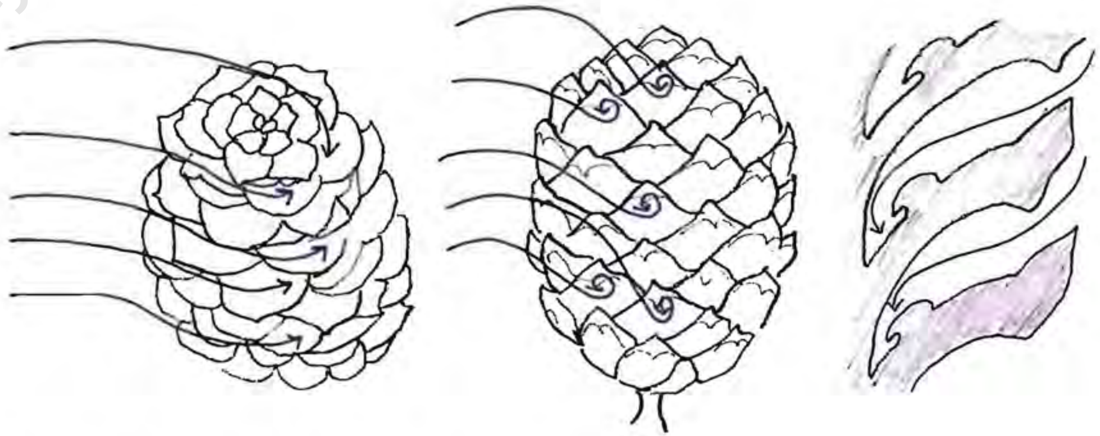
Because the pollination process is wind dependent, the seeds have to follow a very specific path in order to get to the well hidden ovules within the female cone. One aspect that successfully deals with this problem is the aerodynamically structured cones. In a sense, it can be said that the cone itself alters the wind currents around it through means of its specific structure, making it easier for the pollen to reach the reproductive areas. *[Dawson et al. 1997]*

It does this in mainly three ways. First, the wind is turned towards the centre by means of the needle-like leaves. The wind in this region is then twisted and pulled into the area where the eggs are formed. Secondly, the wind, which spins like a whirlpool around the spiral grooves of the cone, is then directed towards the region which opens to the centre. Thirdly, the bumps which give rise to small currents turn the wind downwards and direct it towards the casings. *[Dawson et al. 1997]*

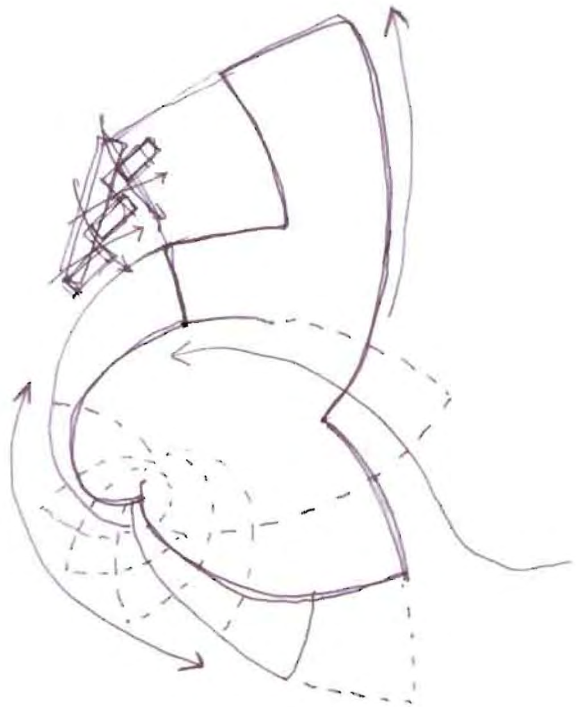
The sketch design below aims to find the specific principles these cones use in order to translate them to an architectural geometric proposal.

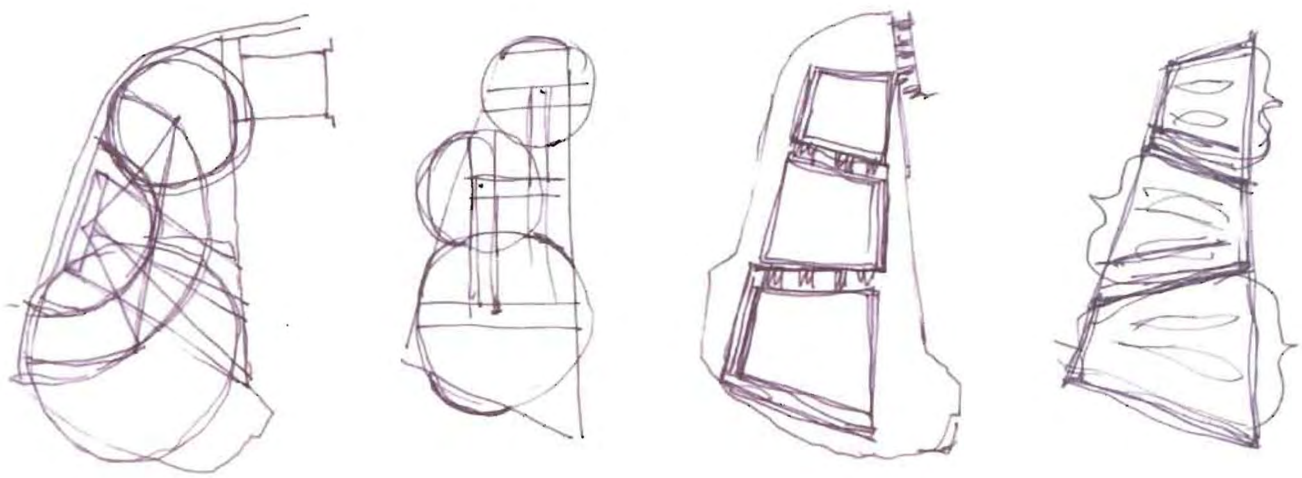


SKETCH OF SIDE AND TOP VIEWS OF A TYPICAL PINE CONE



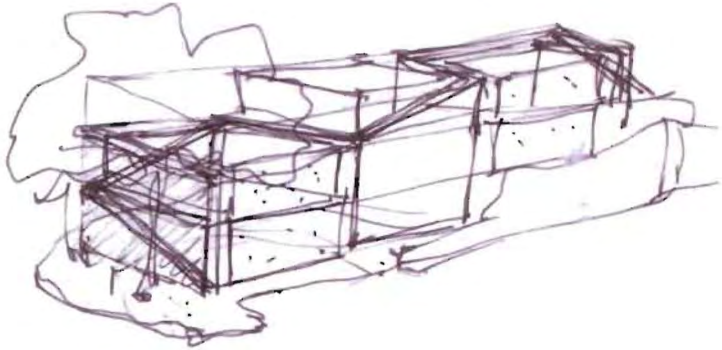
WIND MOVEMENT DURING POLLINATION

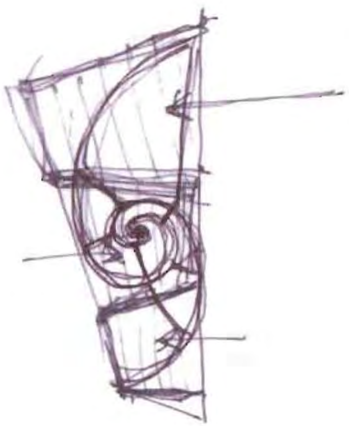


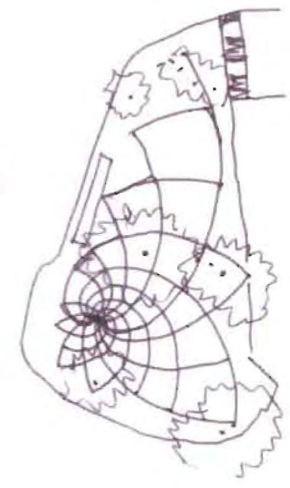


building like a pine cone

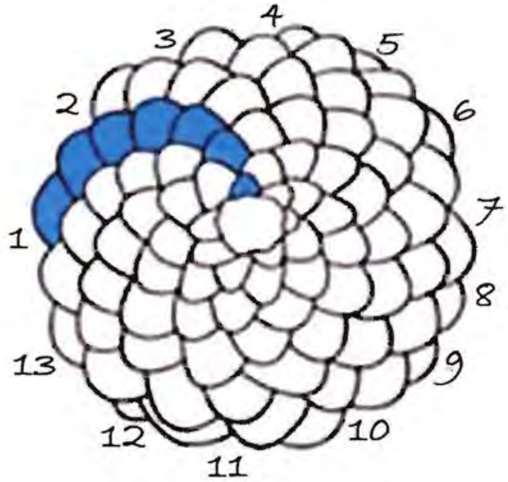
pine cone principles:
- ~~make use of wind~~ manipulate wind direction
- fibonacci spiral
- fractal geometry
- adaptive materials (locally atuned.)
- allow for future growth



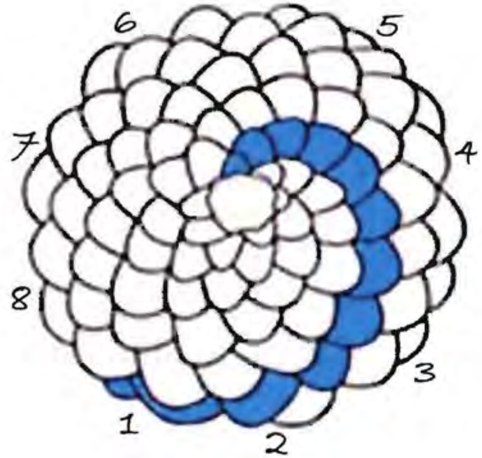




CONCEPTUAL SKETCHES



13/8 Spirals clockwise



8/5 Spirals clockwise

1

1+1=2

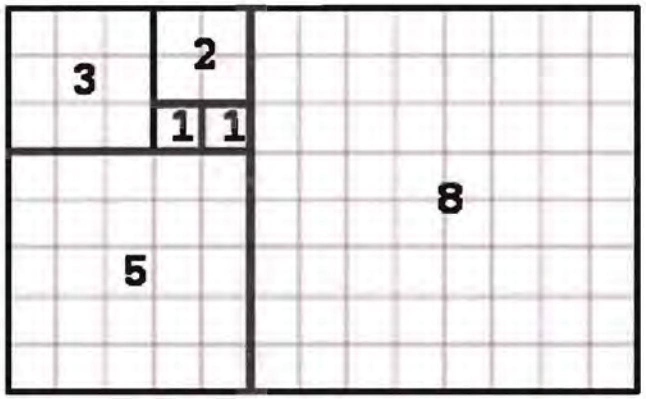
1+2=3

2+3=5

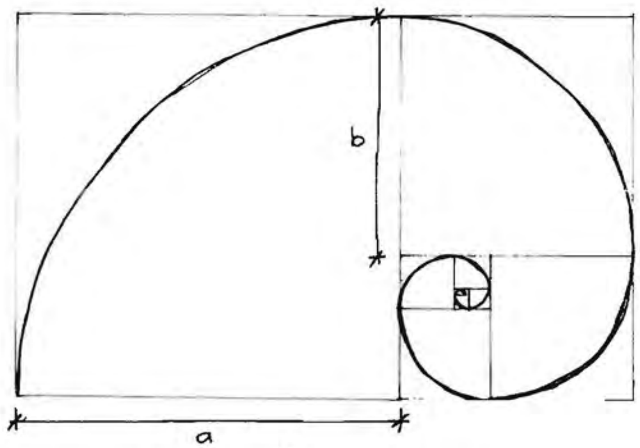
5+8=13

8+13=21

FIBONACCI NUMBERING SYSTEM

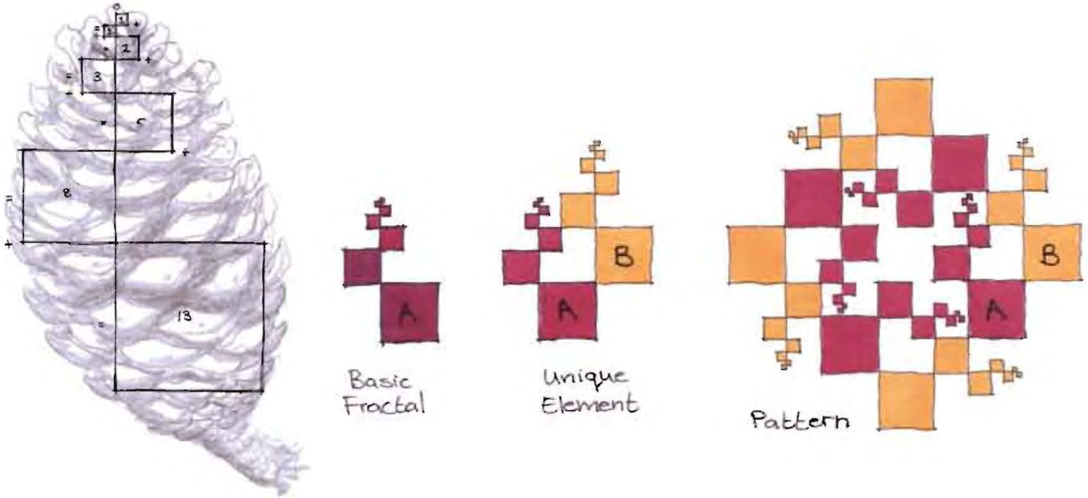


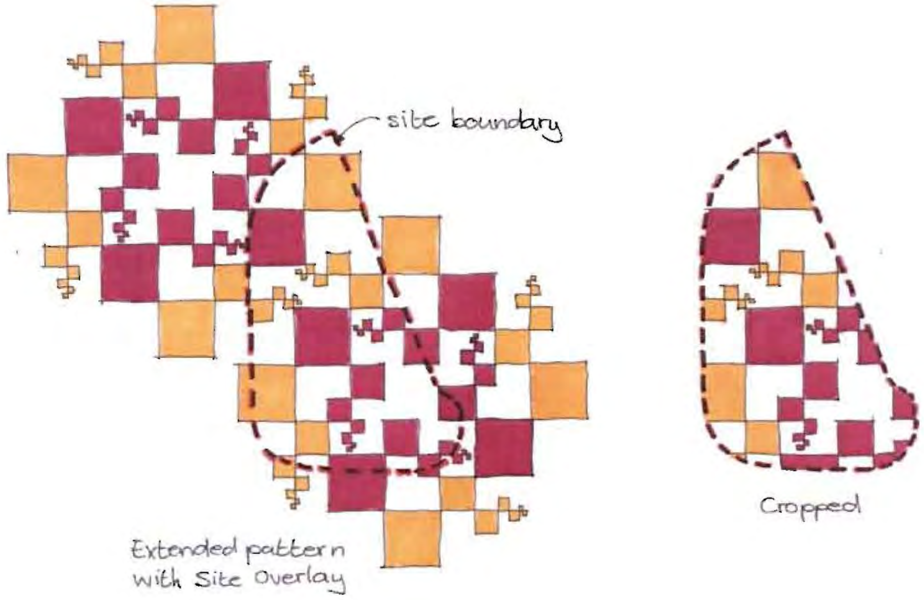
FIBONACCI TILING
(SET UP FOR FIBONACCI SPIRAL)

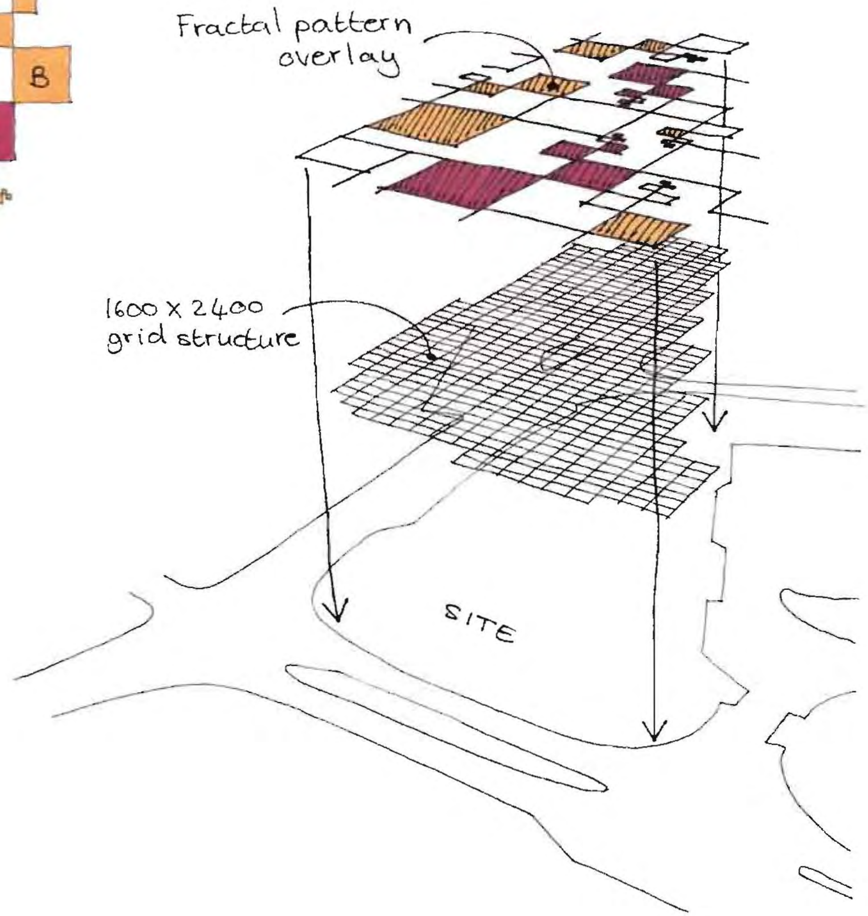


Golden Ratio = $\frac{a}{b}$ = 1.61803399

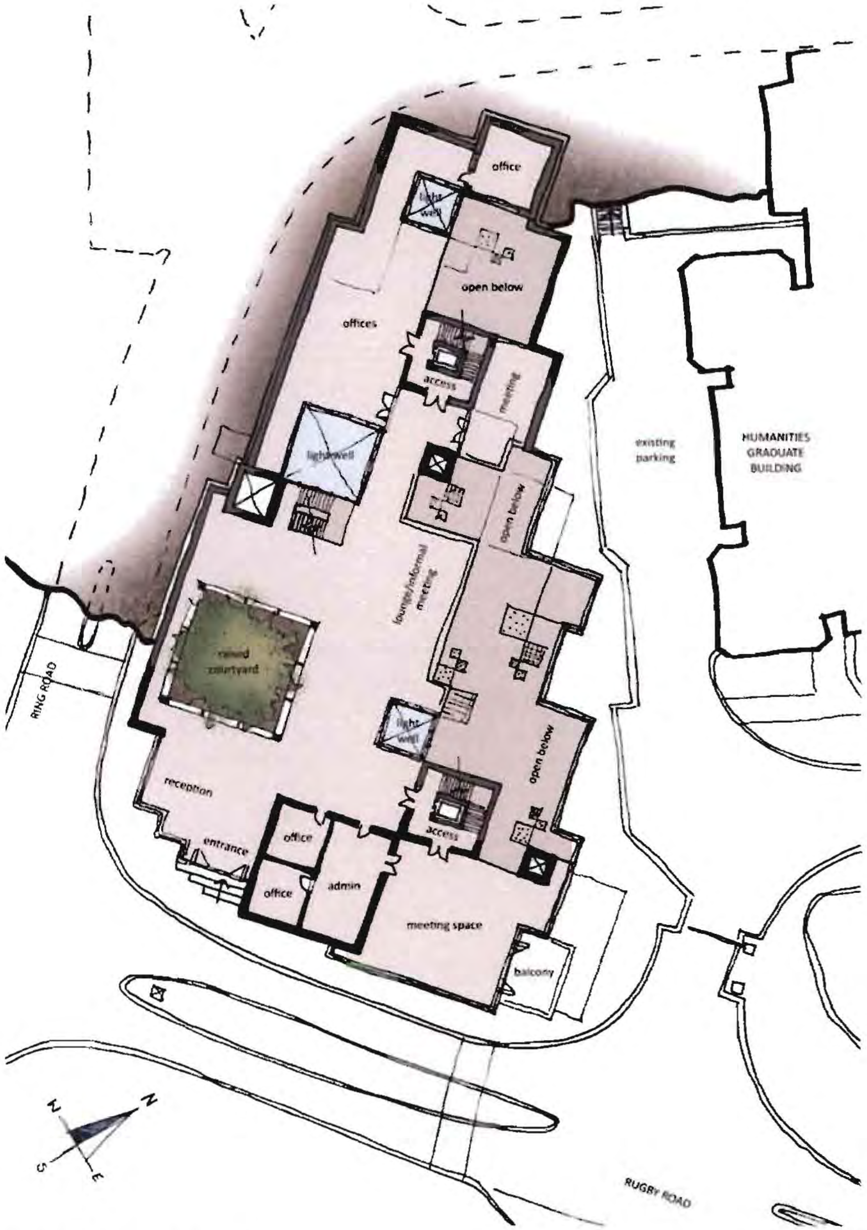
EXPLORATION 6 | initial proposal



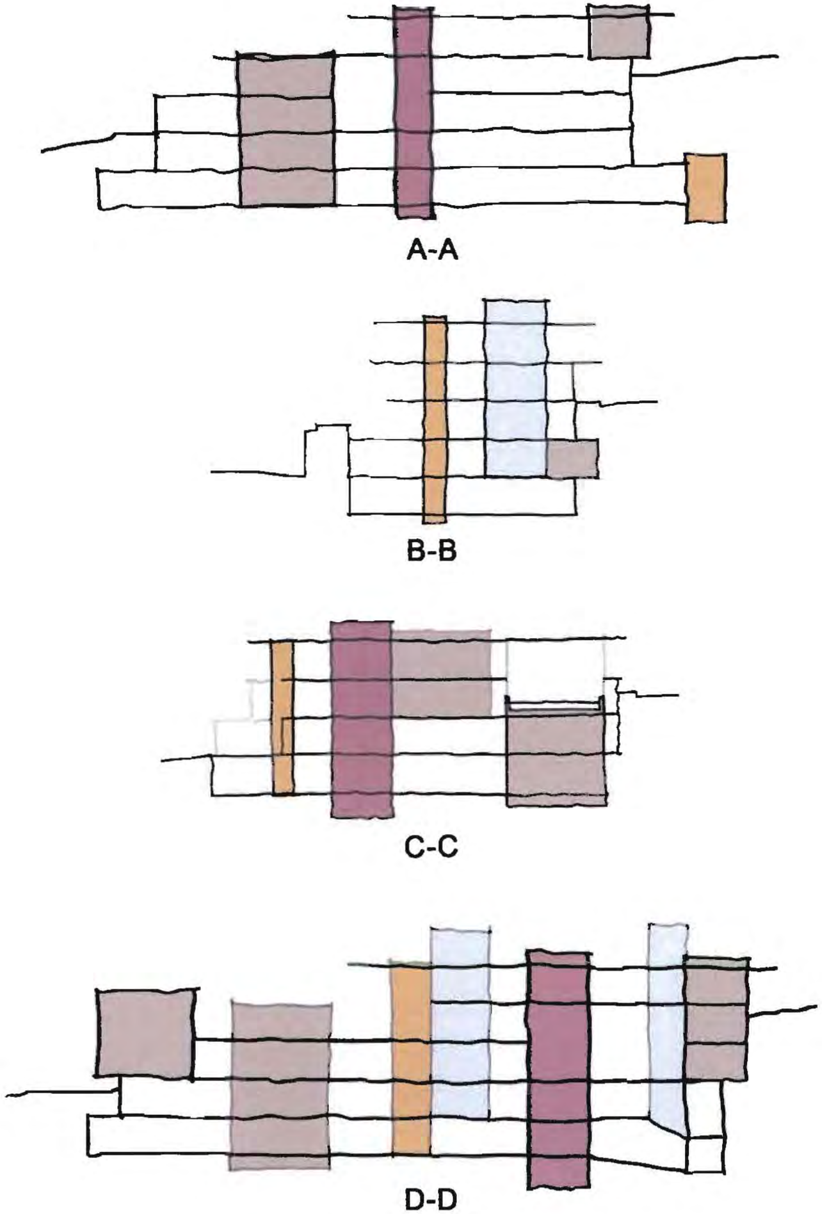




CONCEPTUAL DIAGRAMS

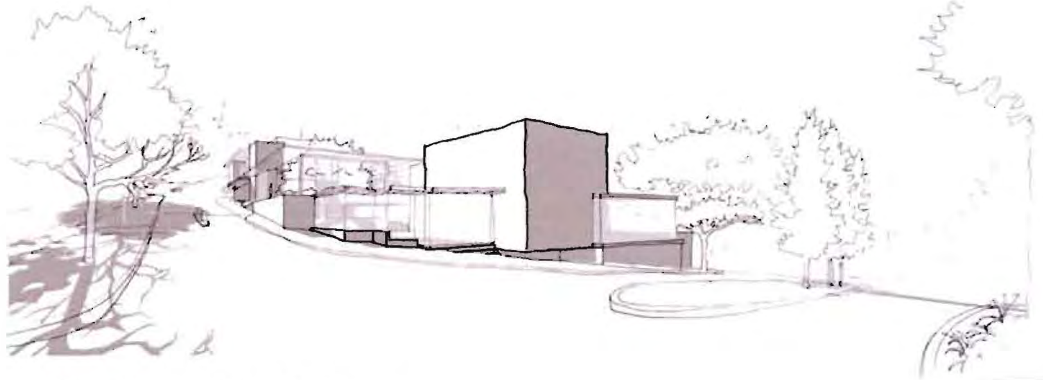


FIRST FLOOR PLAN



DIAGRAMMATIC SECTIONS

CONCEPTUAL PERSPECTIVE PLAN



PANORAMIC VIEW FROM SOUTH EXIT

BIRD'S EYE VIEW FROM NORTH-EAST

EXPLORATION 7 | concept redevelopment

However, like mentioned before, it is very tricky to design with fractal patterns at such a big spatial scale. After having looked at the design more critically, it could be concluded that a scheme of this nature would not be entirely appropriate for a site like this. The main reason for this is that fractal buildings, like the one proposed, are best prescribed for relatively flat and vast sites (as seen in Van Eyck's architecture earlier). Open sites, like the ones he worked on, highlight the suggestive nature of a fractal that has endless potential to expand in any direction. This specific site, however, is not of that nature.

More inspiration should be drawn from the uniqueness of the site's environment, e.g. the steep slope, the indigenous plant life as well as its location within the UCT campus. The next phase in the design can hence be seen as a search to find a more suitable concept/metaphor for the building, one that would immediately draw attention as a place of innovative learning and research.

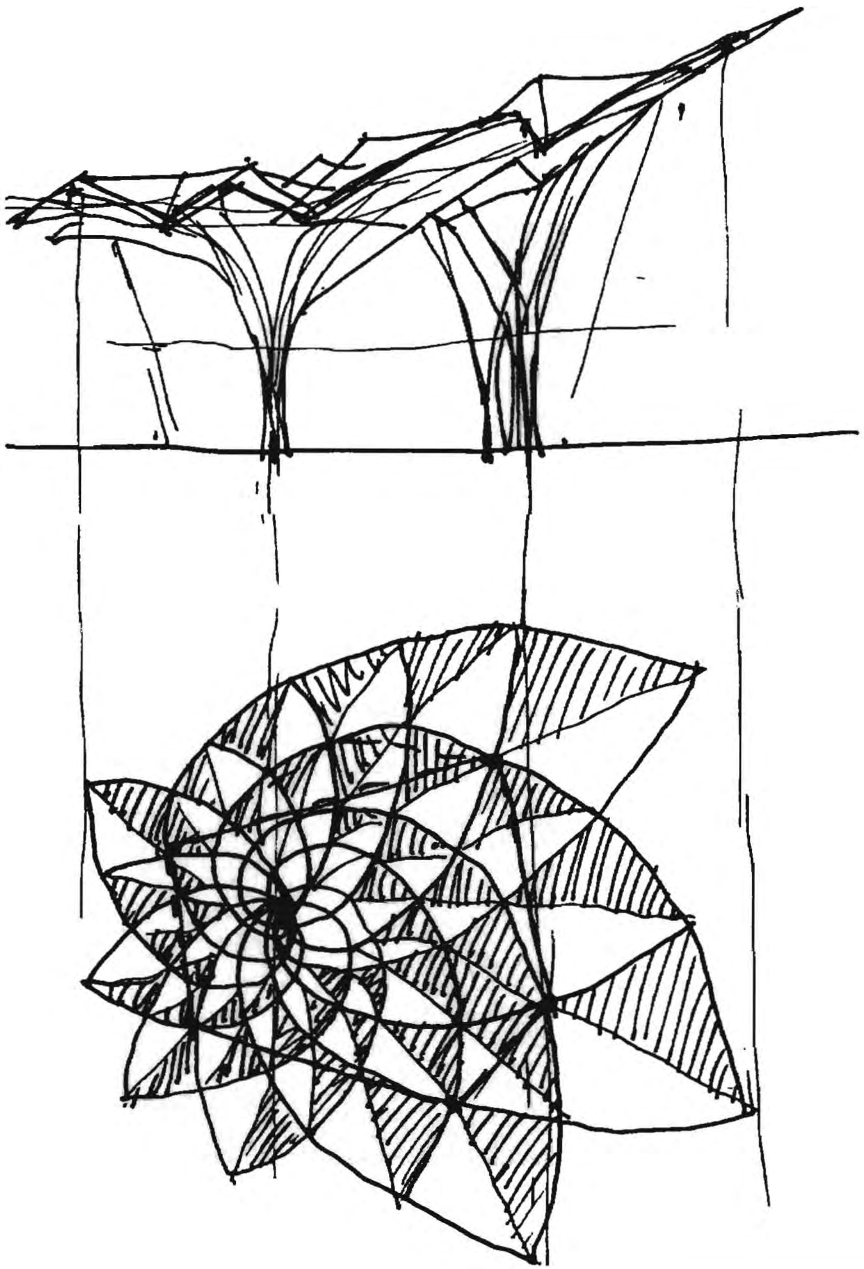
Silver Leaf as Metaphor:

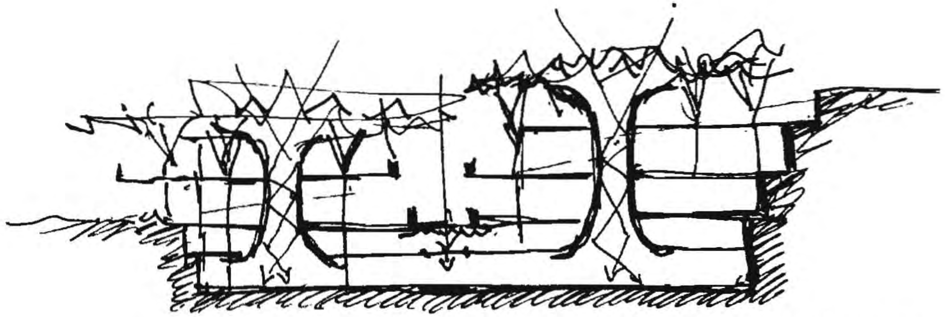
One of the most intriguing indigenous plants in this area is the *Leucadendron argenteum*, or commonly known as the Silver Leaf Tree. This is a very rare and endangered species endemic to the slopes of Table Mountain. It derives its name from the soft, silky leaves with their distinct silvery sheen produced by dense velvety hairs on the leaf surface. [NOTTEN ET AL, 2008]

Like the pine tree, the Silver Leaf is also dioecious, which means it has separate male and female flowers. The woody cones contain numerous seeds that each consist of a small nut with a silky-helicopter parachute which enables it to be dispersed by the wind to pollinate the female flower. [NOTTEN ET AL. 2008]

From the research done so far, we have seen that biomimetic architecture is not just limited to mimicking natural principles to that of functional design, but can also be freely used as inspiration for metaphorical concepts. Thus, the two parts or "pods" of the building in the revised concept below is based on a metaphor for the communication between the male and female flowers of these dioecious plants.

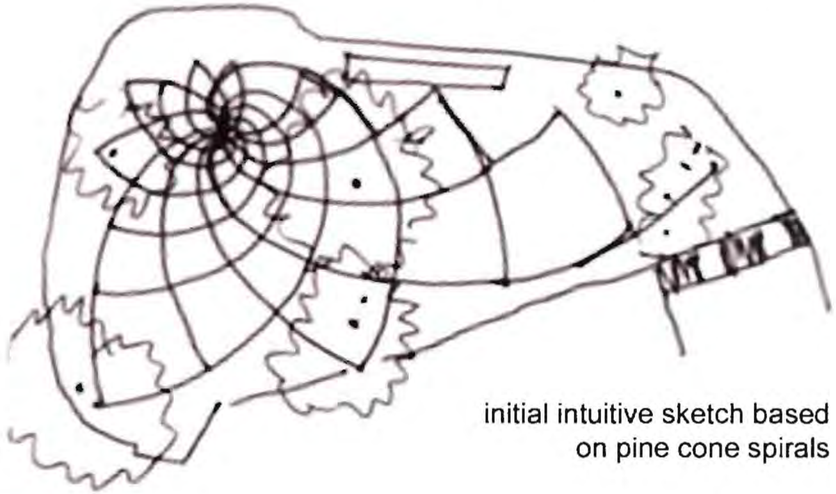
Figure 31: (above) the female and male flowers of the Silver Leaf Tree respectively. (below) Close-ups of the fruit with the parachute-like seeds.



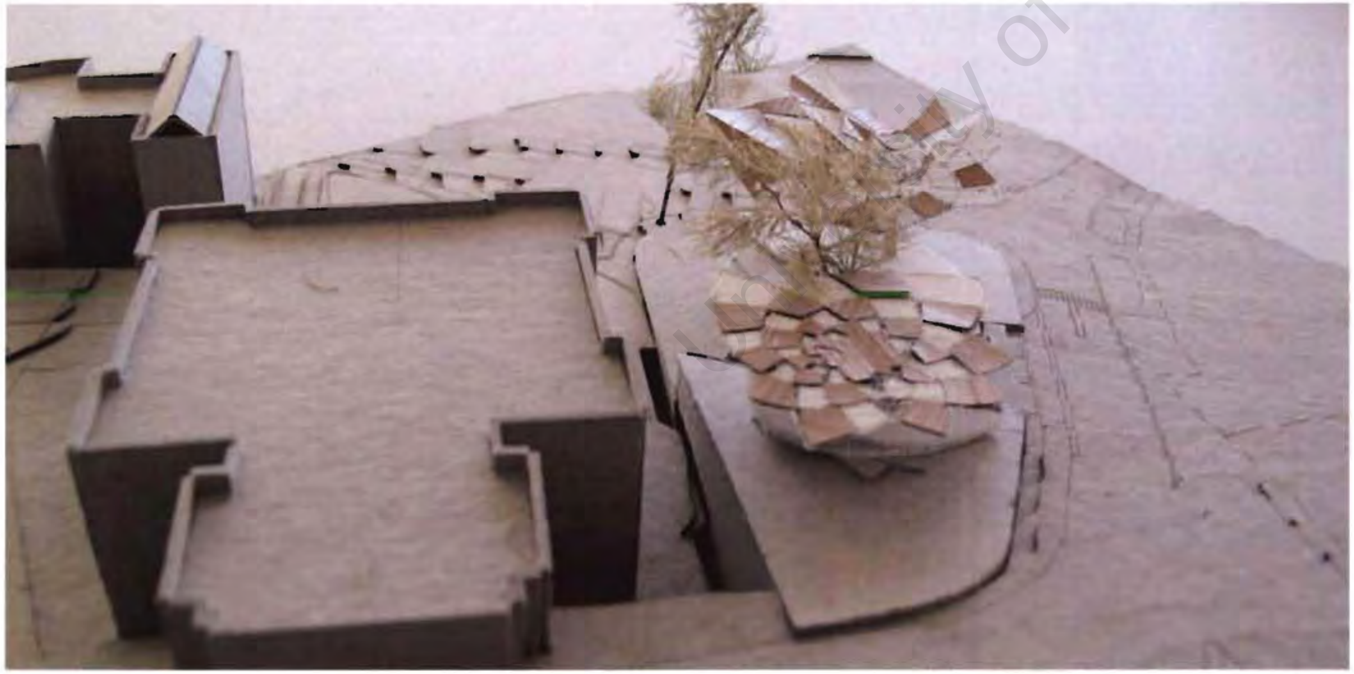


conceptual section

new layout with two sets of spirals



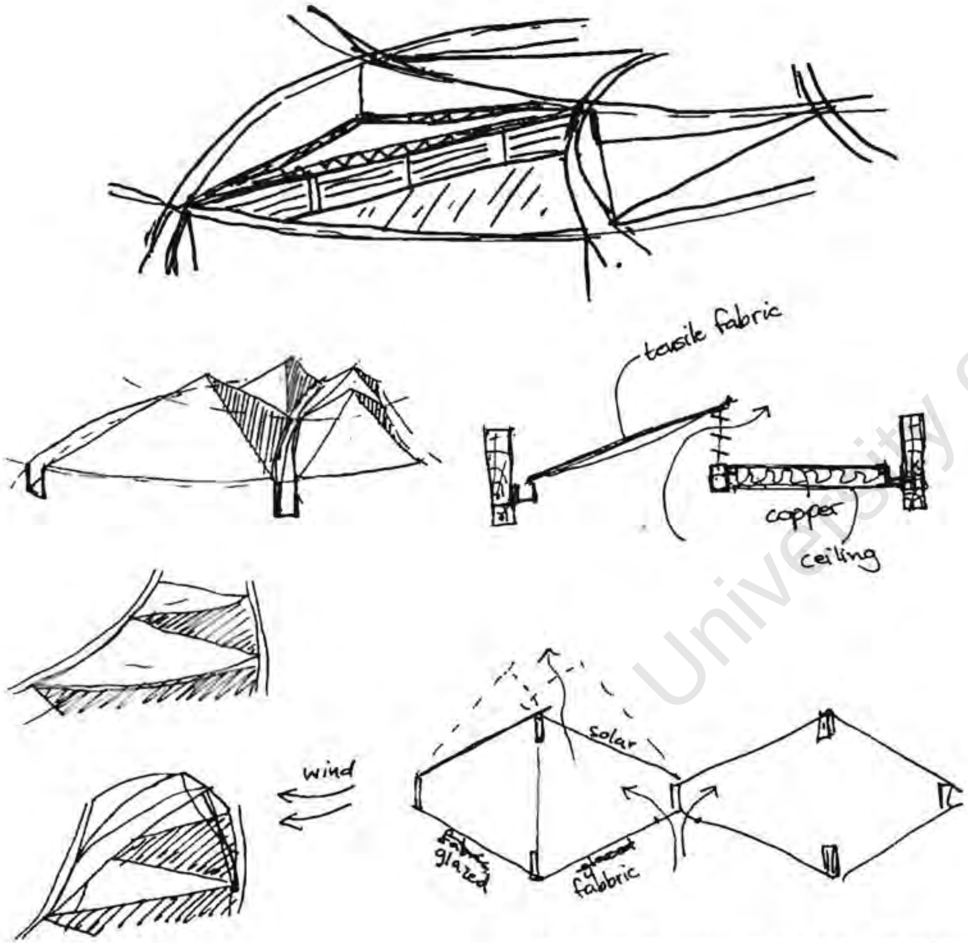
initial intuitive sketch based
on pine cone spirals



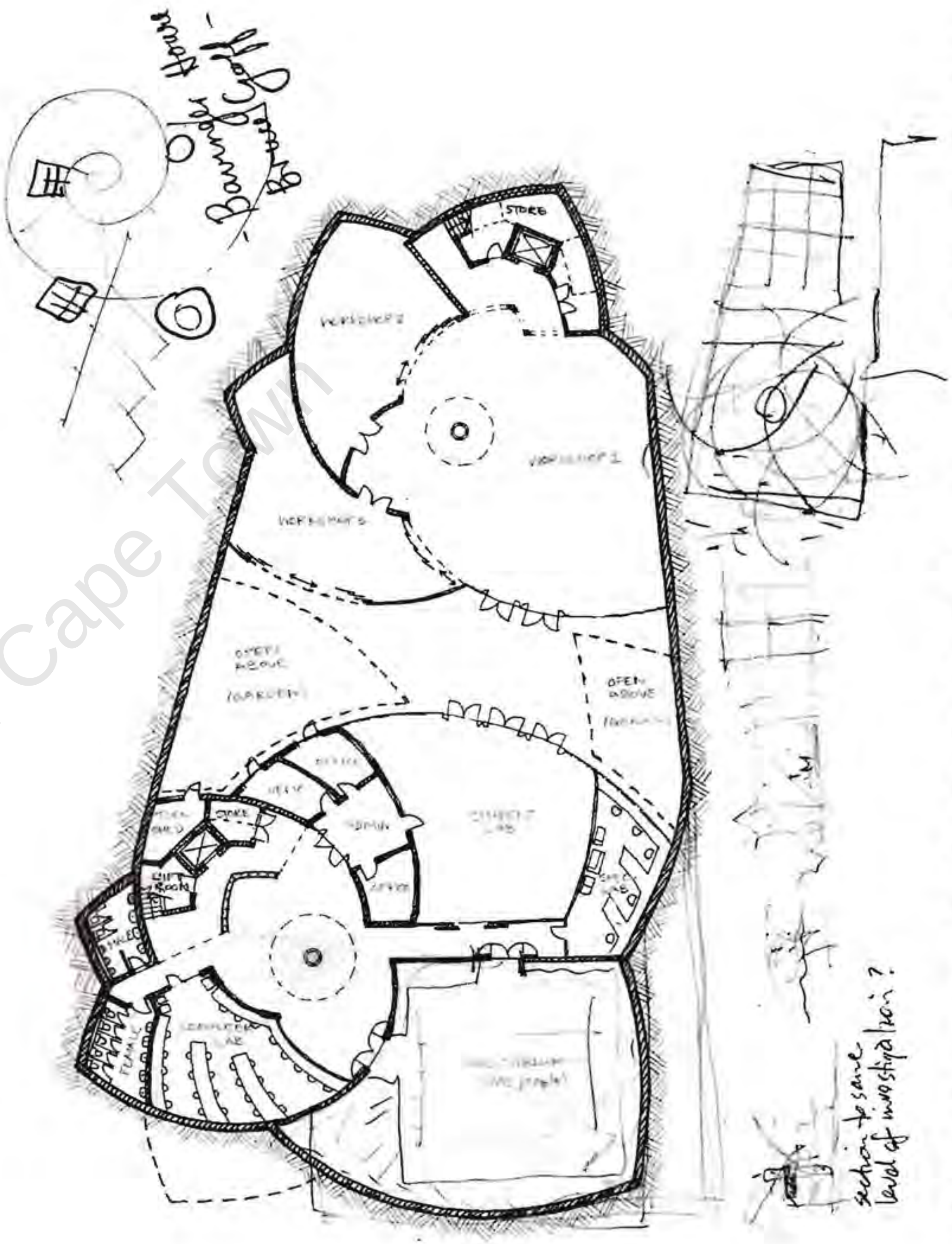
CONCEPT MODEL

EXPLORATION 8 | sketch proposal

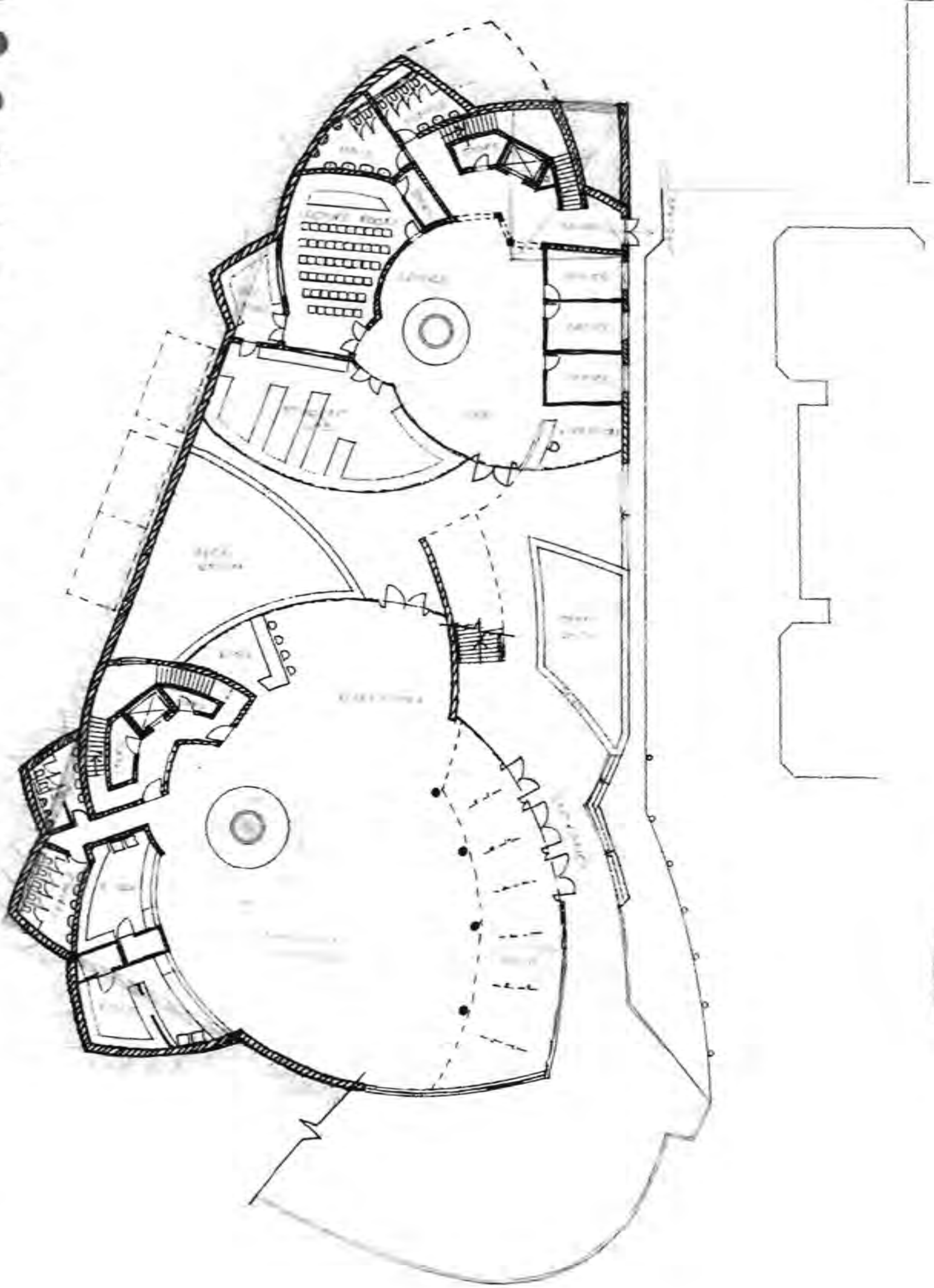
After having revised the concept of the scheme, the next step was to develop the planning of the building. The exercise that follows involved the configuring of the spatial layout and programmatic ordering of the building as well as initial conceptual sketches for the roof design.



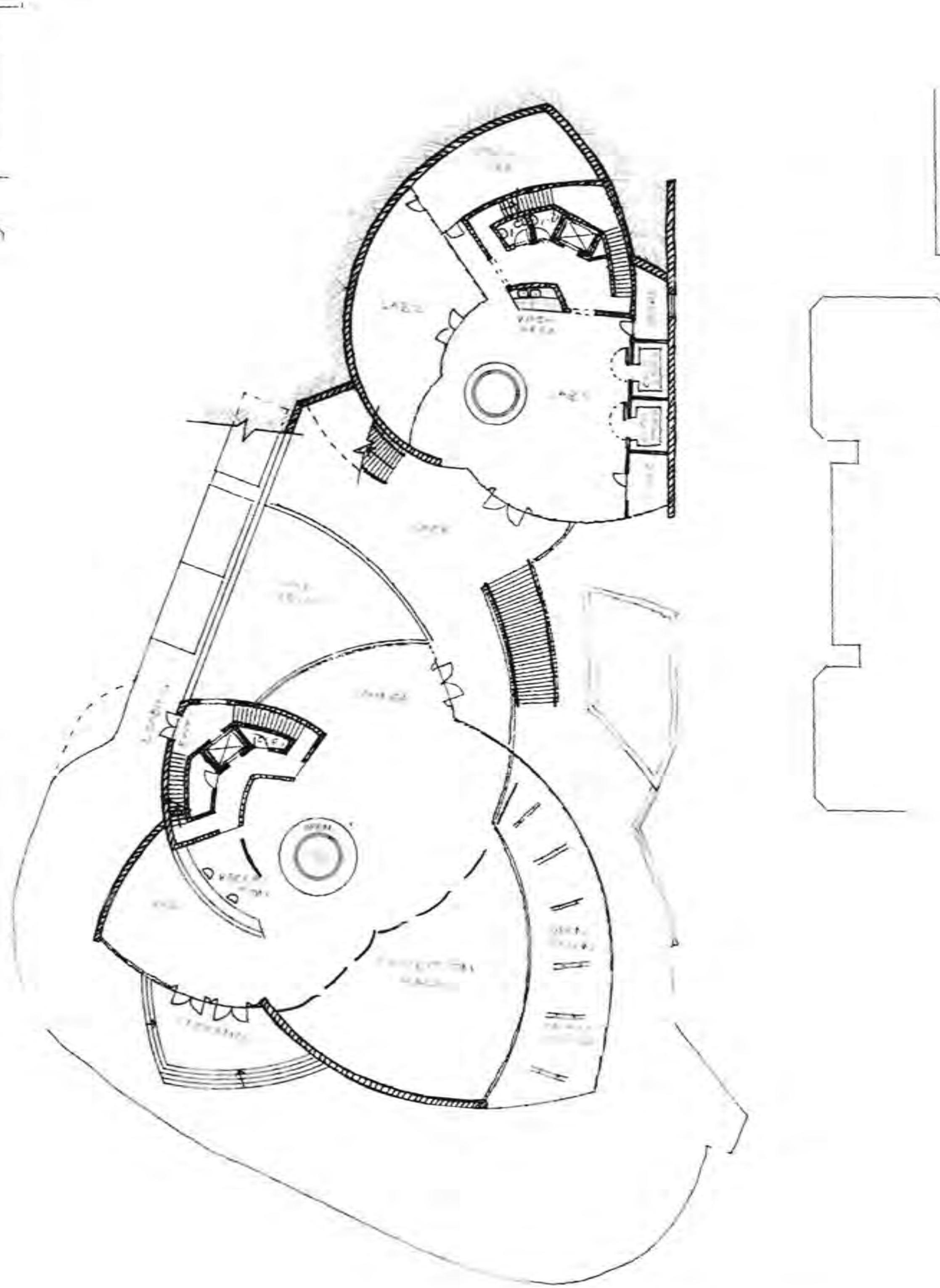
CONCEPTUAL ROOF DESIGN

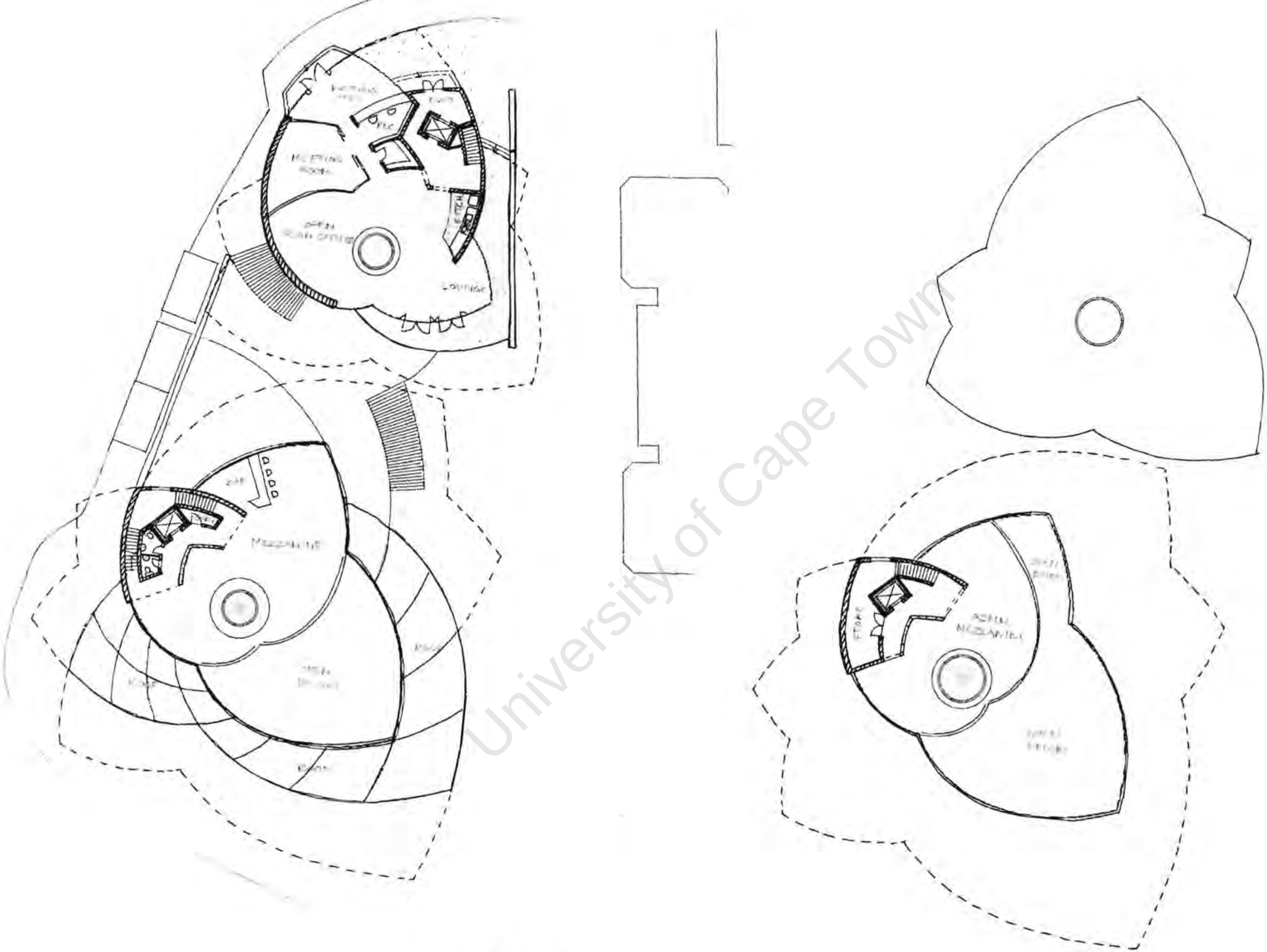


BASEMENT



GROUND FLOOR





SECOND FLOOR

DESIGN DEVELOPMENT

True to the iterative nature of a typical biomimetic investigation, the above scheme needed to be scrutinized once more in order to optimize the design. One aspect that proved problematic was the direct translation of the spiral grid. This strict view on the geometry proved limiting to the spatial planning, and hence a second layer (or set of rules) needed to be applied to allow for more freedom with the spatial configuration.

In order to do this it was necessary to go a few steps back to re-establish exactly which principles in nature needed to be translated to this specific design. This last phase in the conceptual design of the building served as a relook at how to make the design more biomimetic. Is there more to learn from the pine cone or the silver leaf? Do these organisms have anything within their make-up that can help with other areas of the design other than the metaphorical concept or architectural geometry?

This phase is an attempt to find the principles within these organisms which can aid with the designing of the environmental performance of the building with a specific focus of responsive architecture.

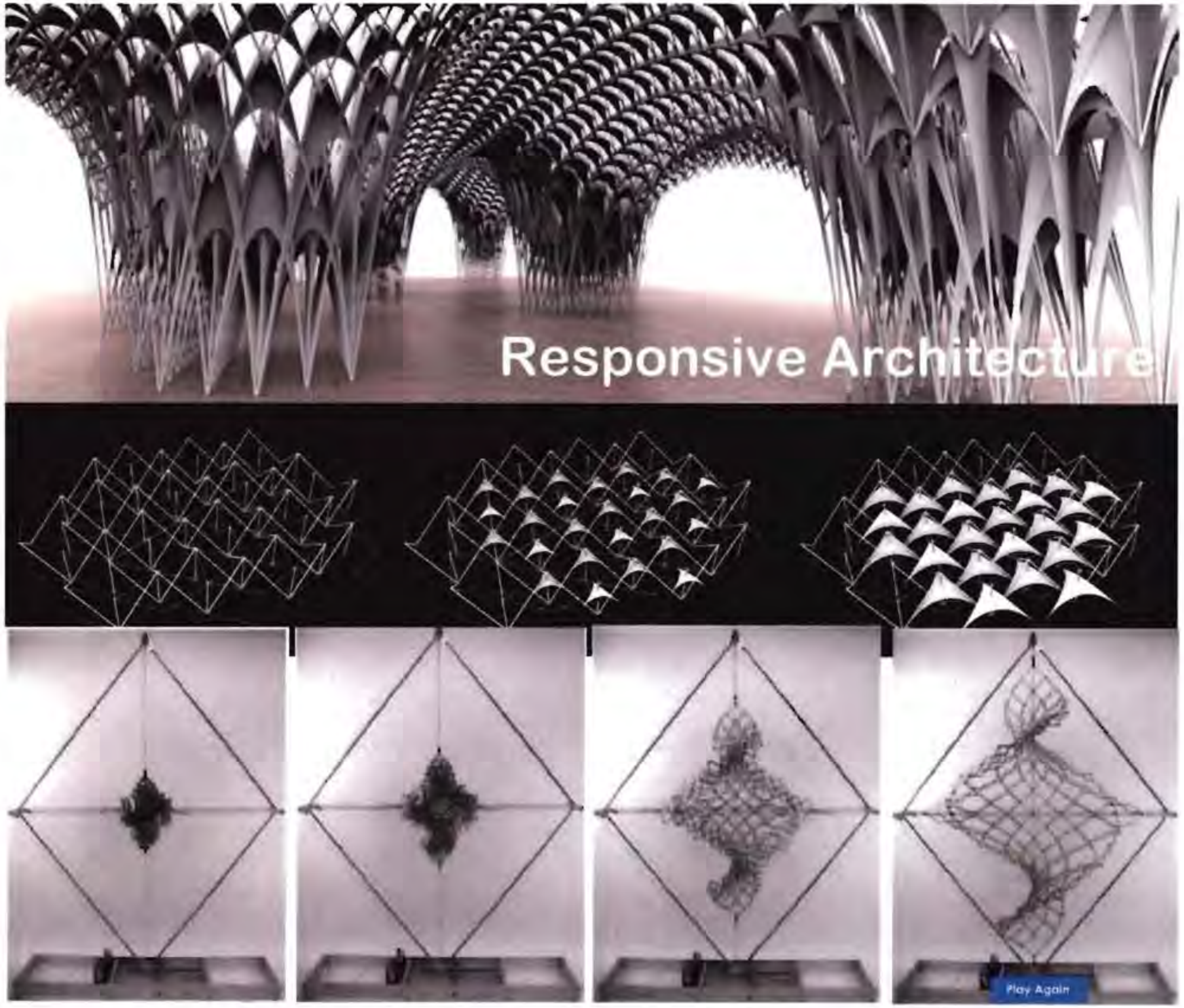
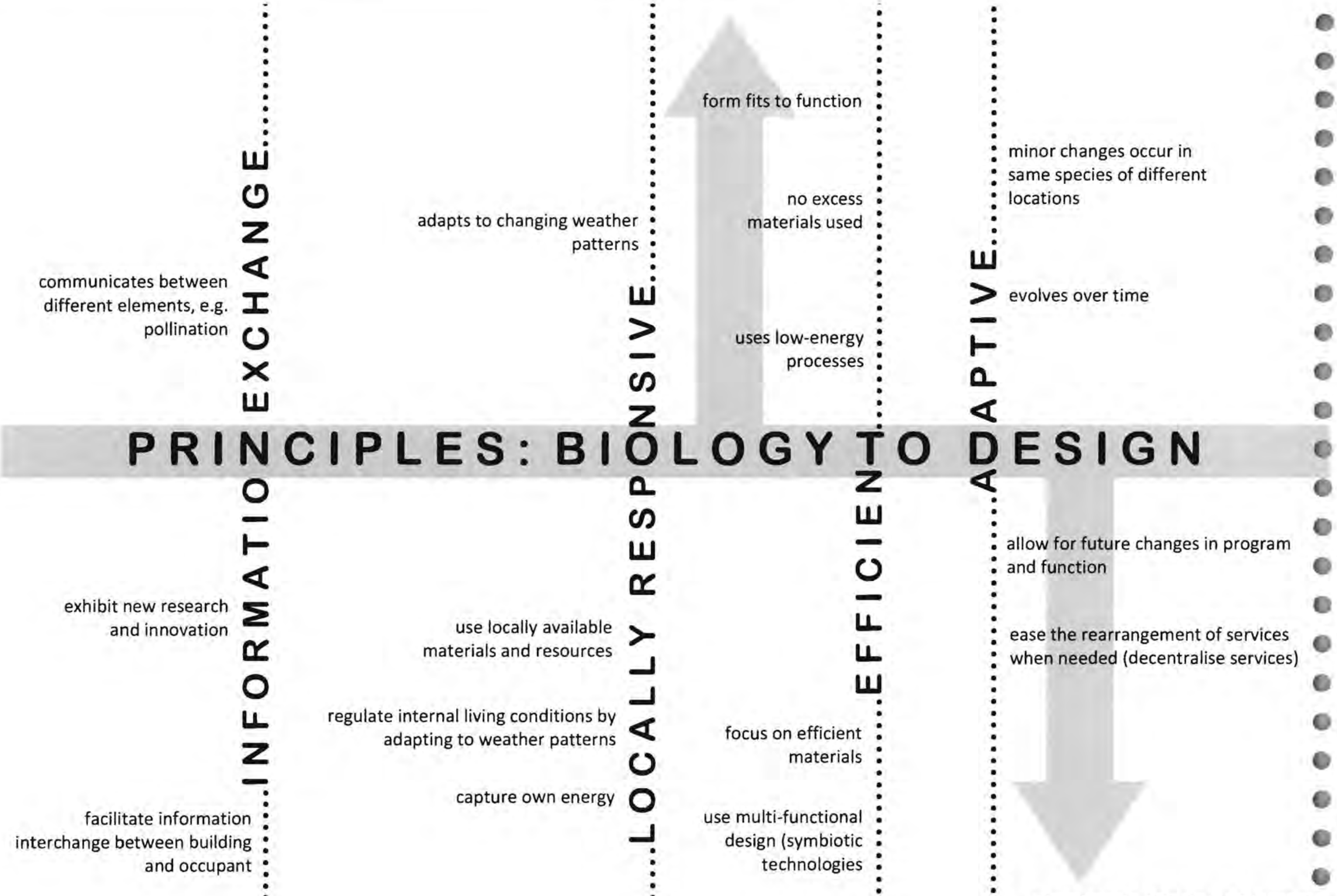


Figure 32: examples of responsive architecture.



Biomimetic Principles Diagram

RESPONSIVE SILVER LEAFS

Another interesting aspect of the Silver Leaf that could potentially be translated to a design principle is its ability to retain moisture in dry seasons.

When the air is too cold and wet, the tiny silver hairs pull away from the leaf surface in order to allow for more evaporation to take place. When it experiences hot and dry weather, the opposite happens, the hairs lie flat on the leaf surface reducing evaporation and retaining moister needed for the plant's survival. *[NOTTEN ET AL. 2008]*

If this technique could be incorporated within the design of the roof of this scheme, it could potentially provide for an interesting biomimetic solution to an environmentally responsive architecture.

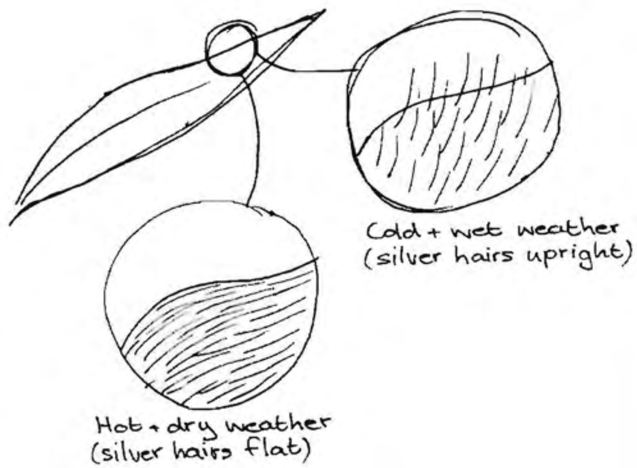


Figure 33: (left) close-up of the Silver Tree leafs. (right) collection of parts from the plant.

HYGROMORPHIC PINE CONES

Using the principle of the Silver Leaf hairs within an architectural system seems easy enough, but it doesn't really answer many of the questions concerning the actual materiality and making of such a system. At this point it is more helpful to turn to the pine cone for these answers.

Pine cones are hygromorphic in nature, which means they move in response to changes in relative humidity. This is a fascinating characteristic! When the cone drops from the tree and dries out the scales gape open in order to release the seeds within and when it is damp the dead scale will close up again. This means that this system is not dependent on living cells for its movement, but that this all happens purely through passive means. The thing that causes the actual movement is the response of the structure of the scale and the walls of its cells to changing relative humidity. *[Dawson et al, 1997]*

The success of this back and forth movement is based on the two different types of cell structures within the scale, the one distorting in one direction and the other in another direction. The translation of this system can be modelled as a simple bilayer structure. All that is required is to know three parameters: the stiffness of the two tissue types, the relative dimensions of each layer and their coefficient of hygroscopic expansion. *[Dawson et al, 1997]*

Bilayer materials like these already exist on the market and it should therefore be interesting to see how these can be used within the roof of the building as a passive ventilation system.

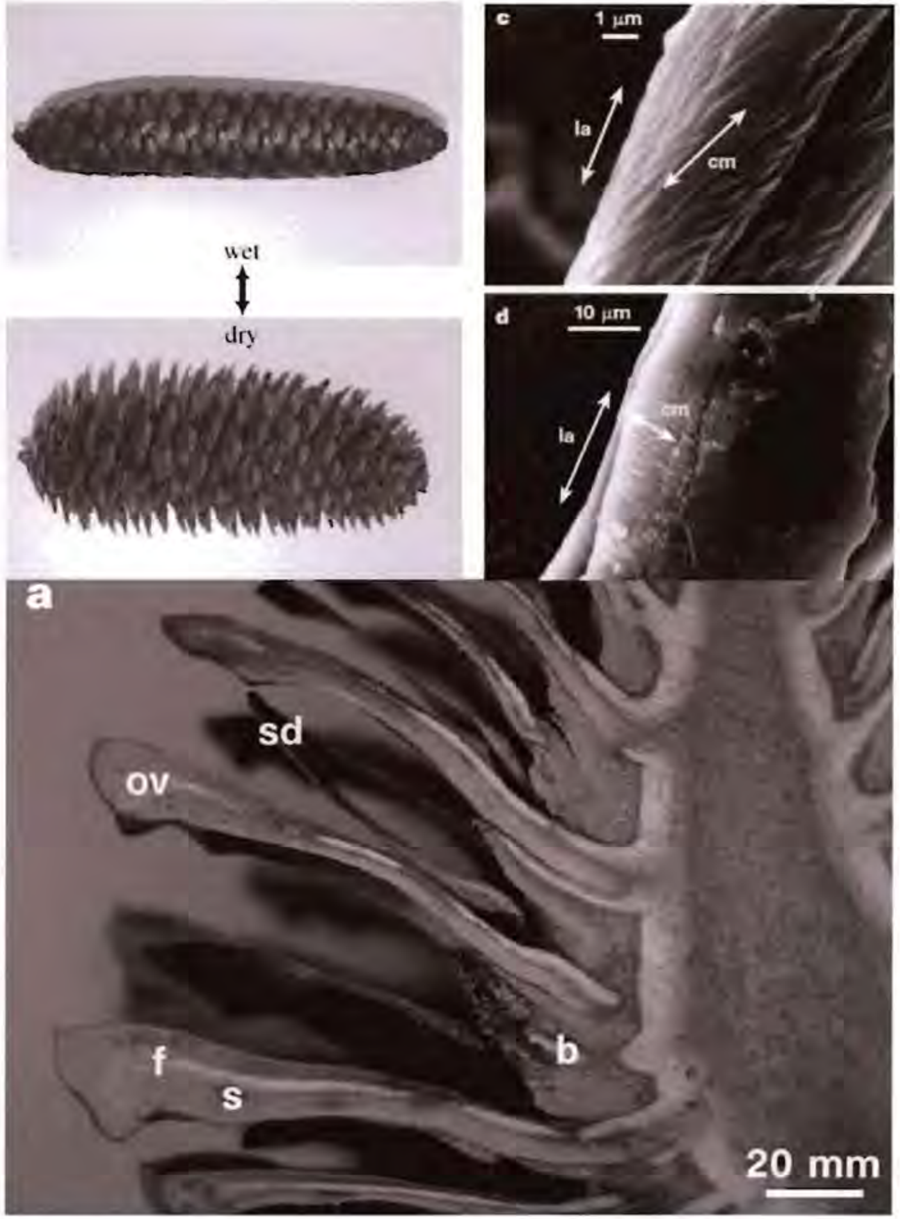
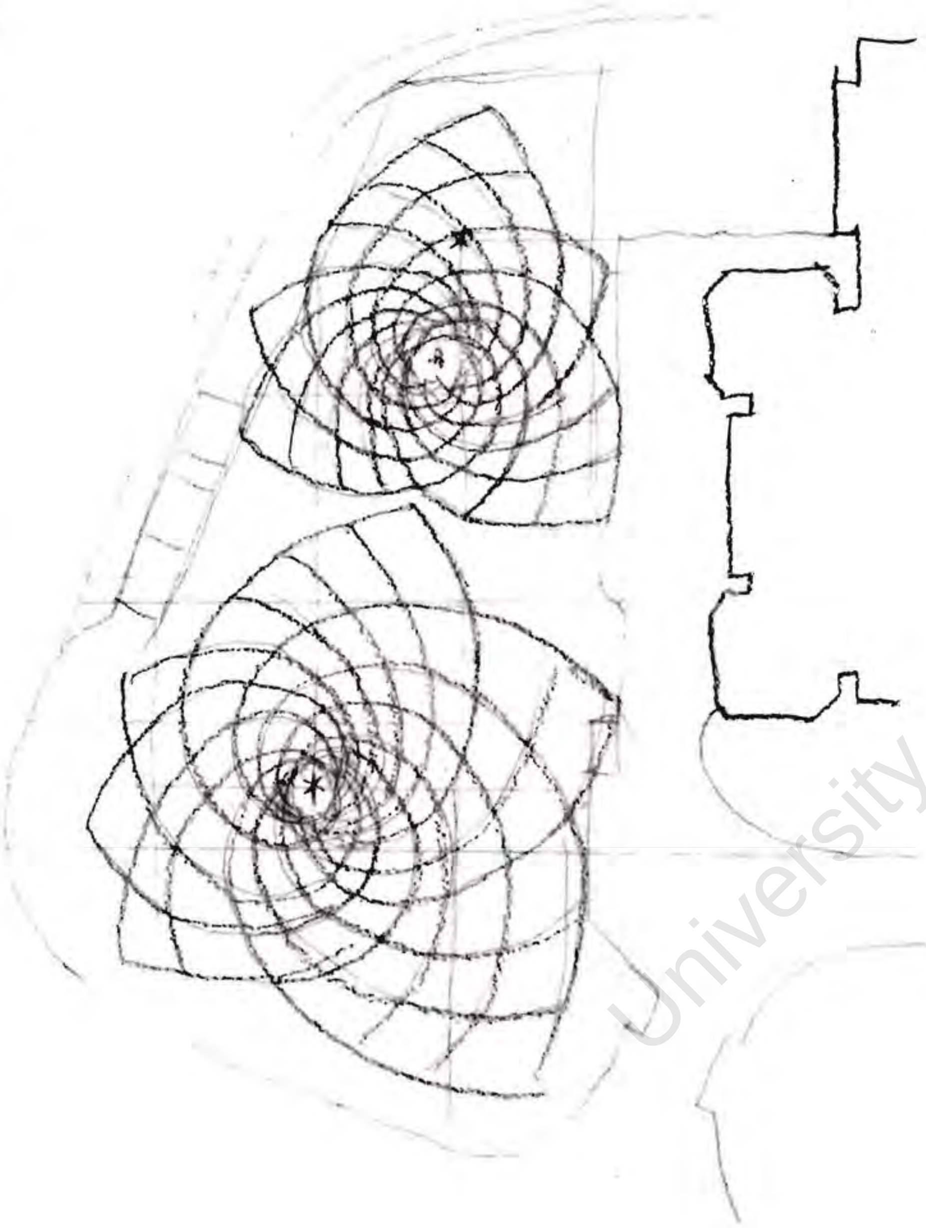
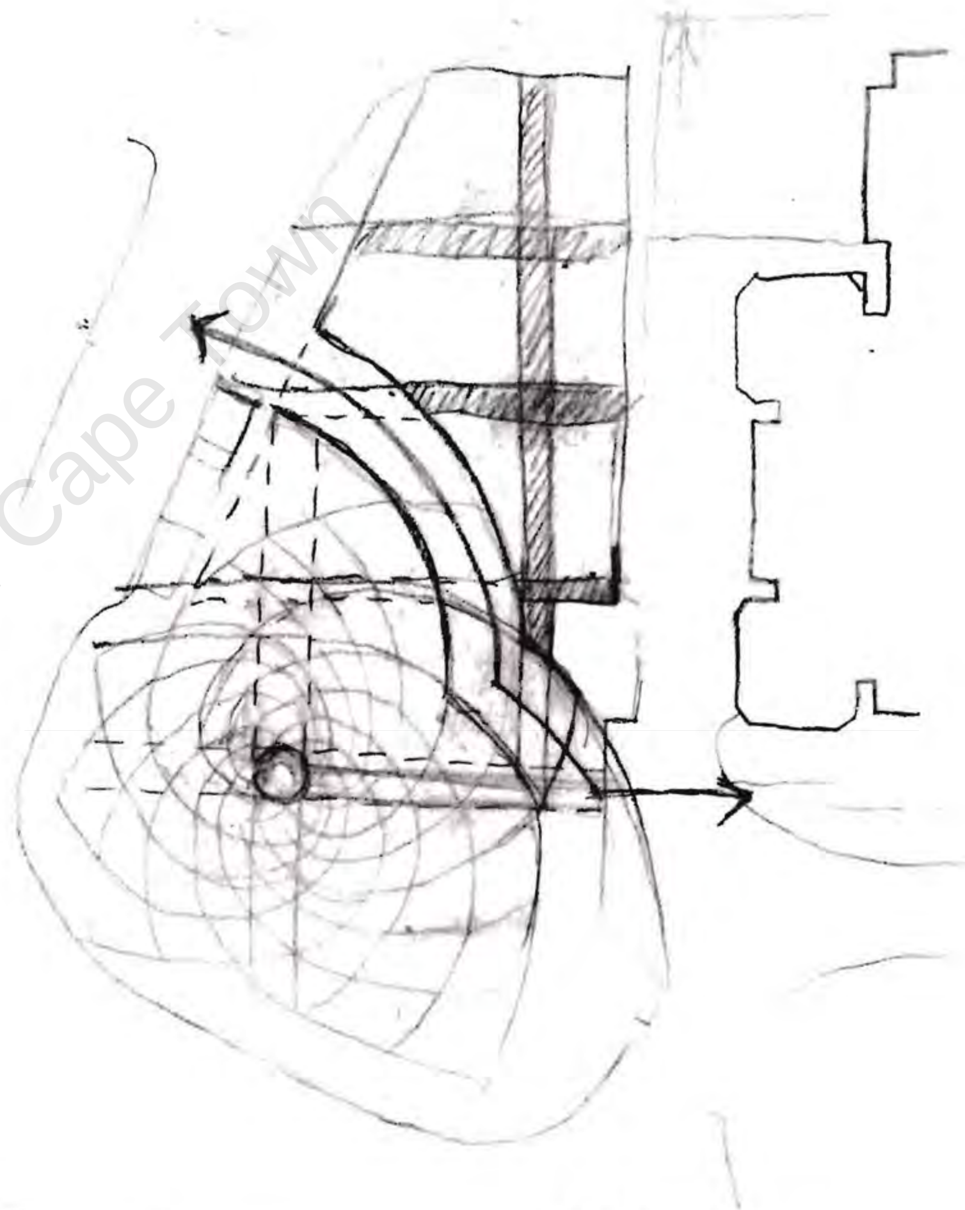
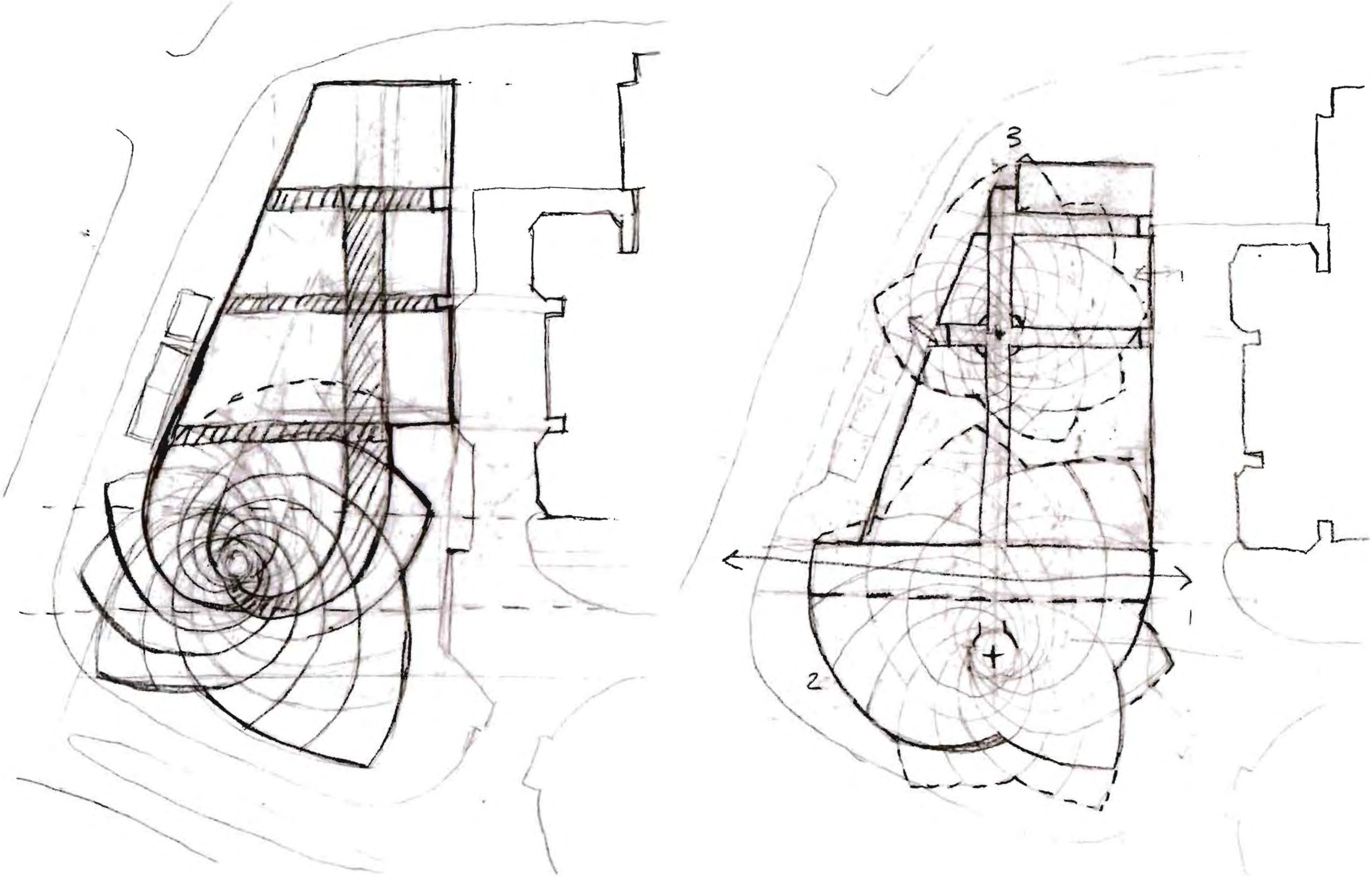


Figure 34: details of cut-opened pine cone.

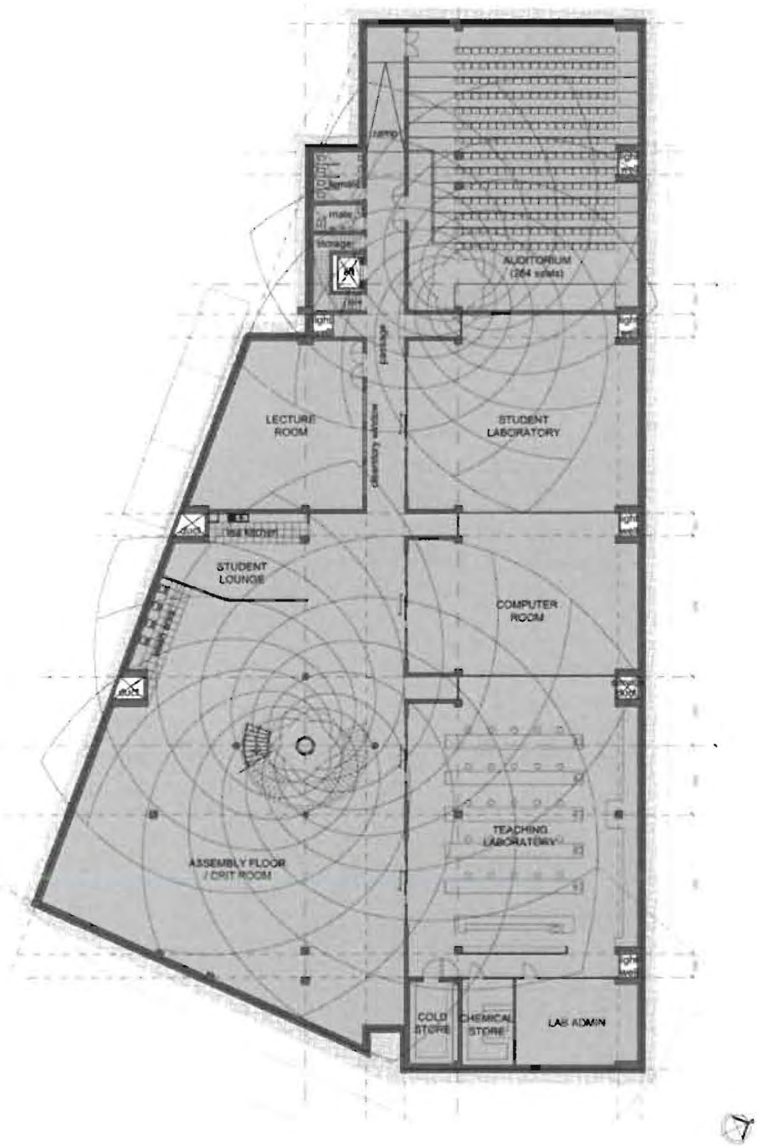




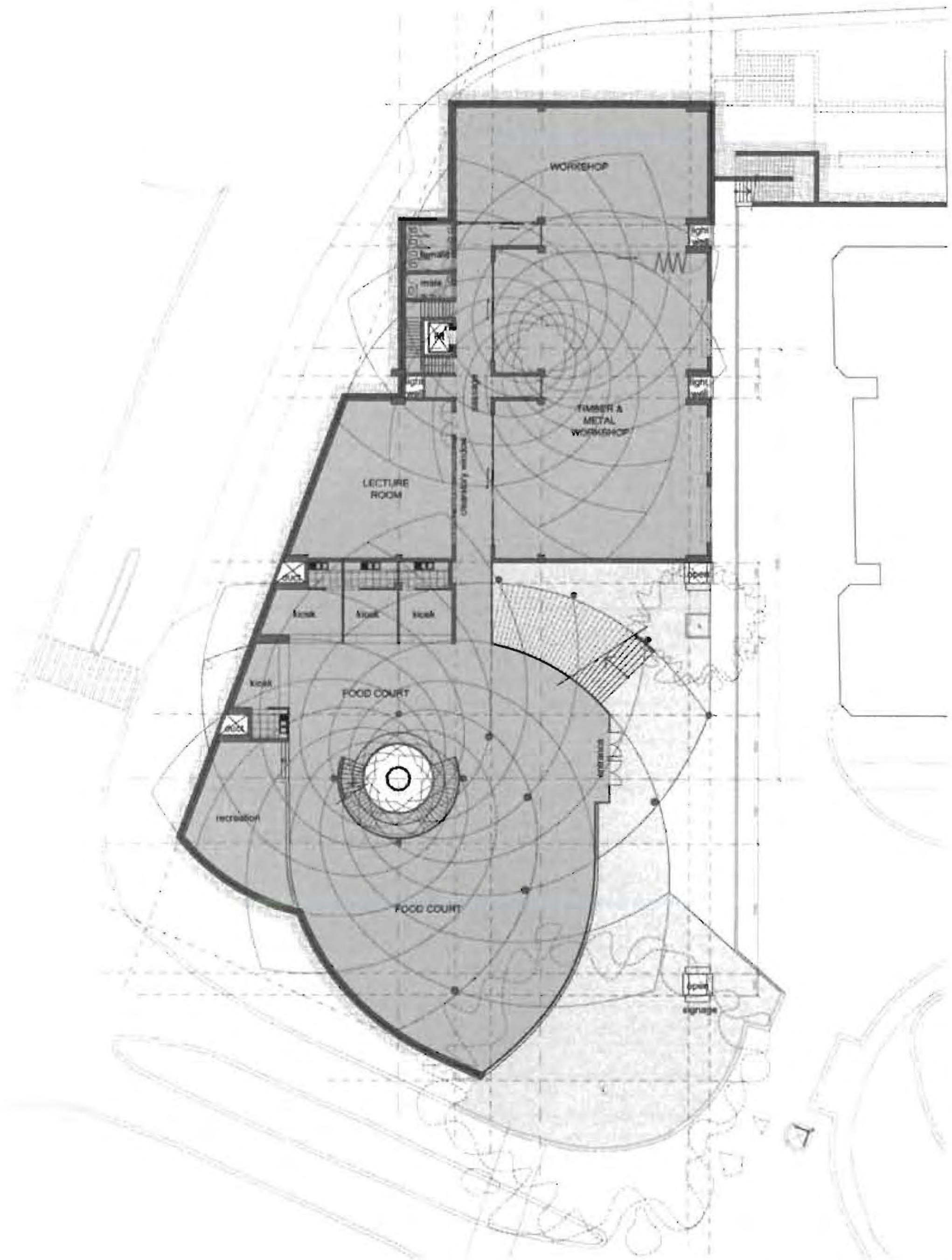
PROCESS SKETCHES



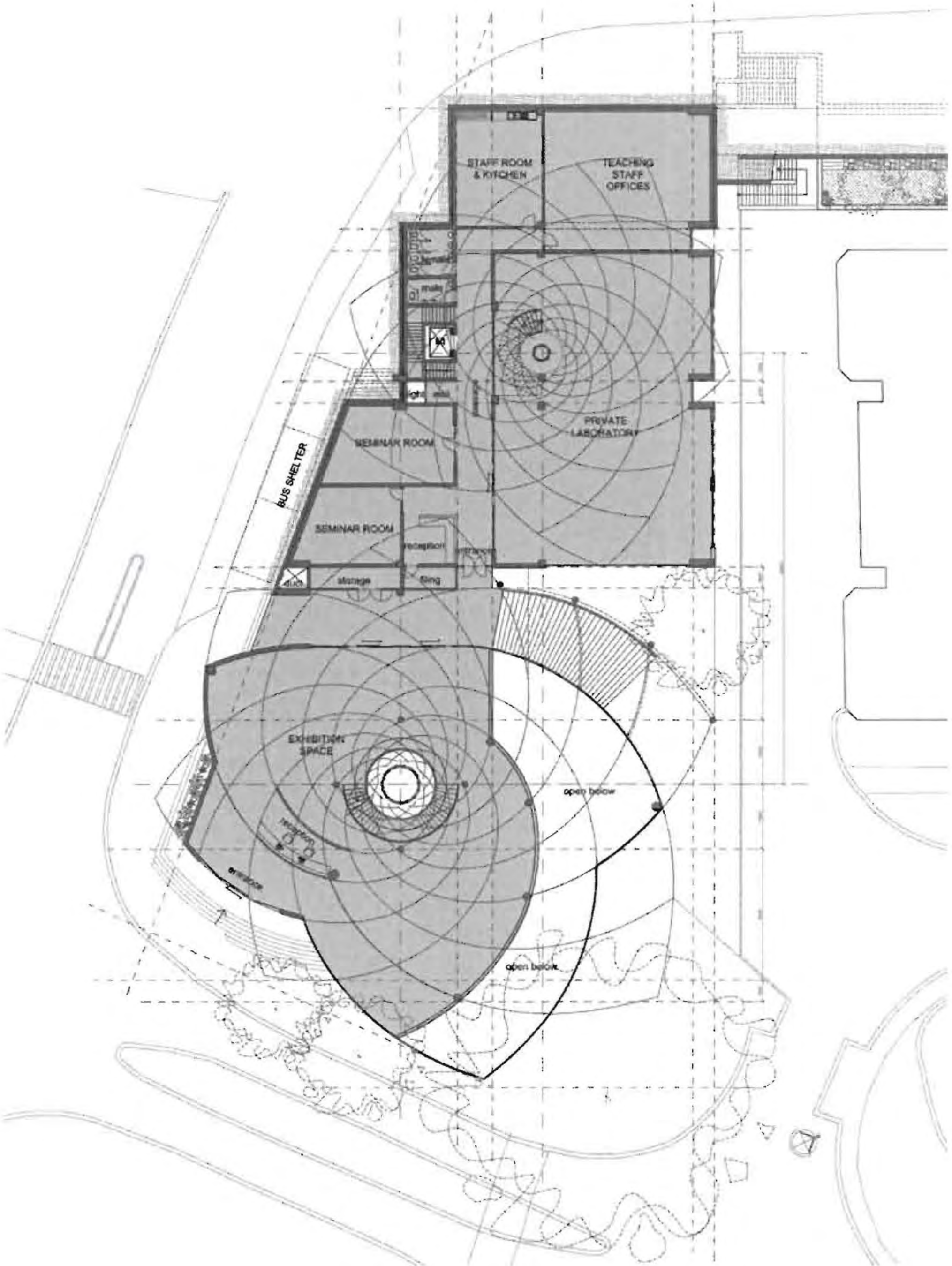
PROCESS SKETCHES



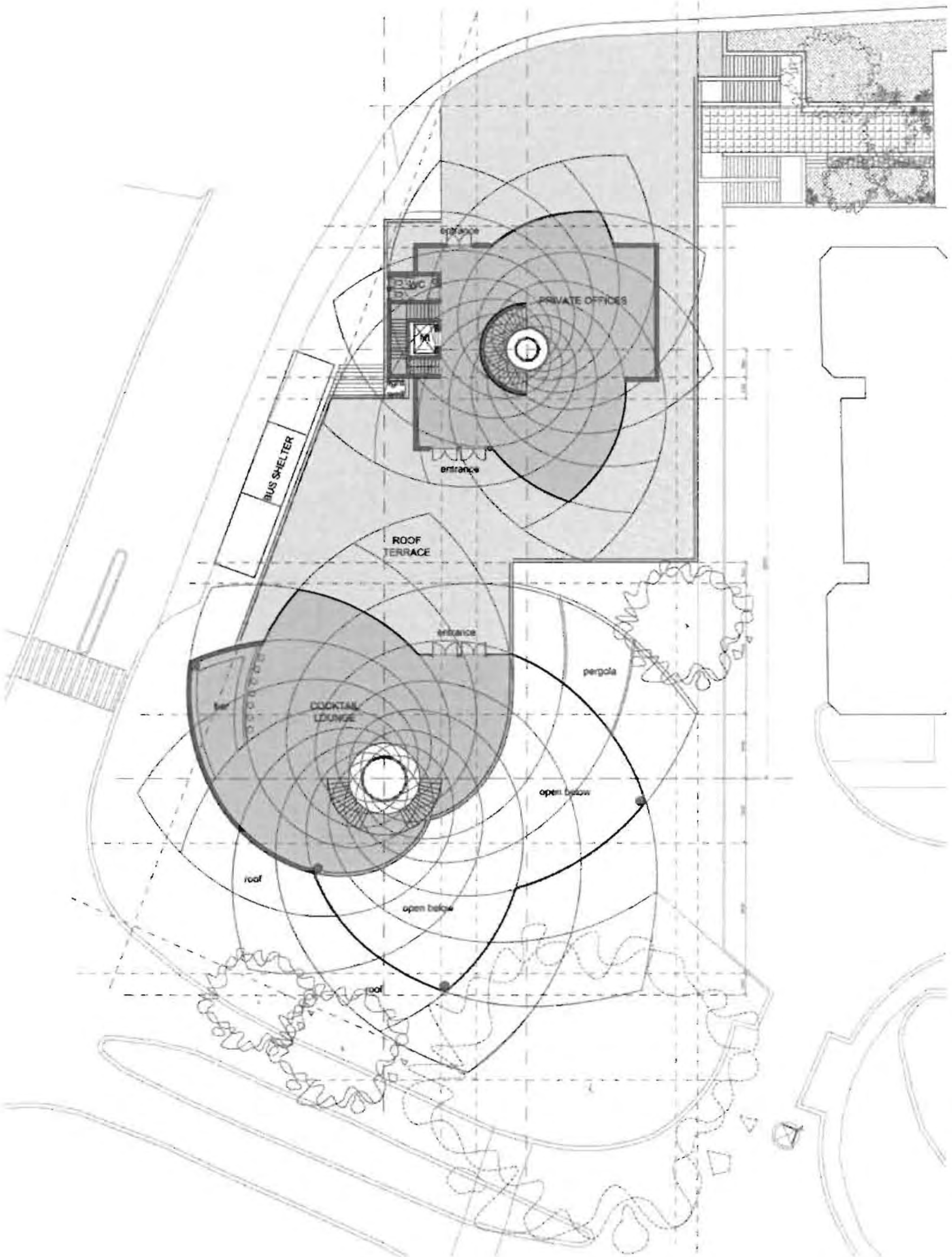
BASEMENT PLAN | 1:500



GROUND FLOOR PLAN | 1:500



FIRST FLOOR PLAN | 1:500



SECOND FLOOR PLAN | 1:500

CONCLUSION

Like mentioned before, technology, bioengineering, computation, and fabrication industries are in the process of fundamentally changing the design professions - in the next few years construction of what is now impossible will be standard. *[Mueller, 2008]*

In the spirit of this change, this thesis suggests a research method for architectural design based on observation and extrapolation of principles from nature - a biomimetics for design that also include the possibilities of designers not only to go back to the basics of design, but also to work together with scientist, engineers and biologists to redefine what potentials a collaboration between science and design could hold. It promotes an architecture that once again sees technology, design, as well as environmental knowledge as areas of study that are interdependent on one another, together forming part of the architectural design process as a whole.

Through the examples, organisms, and case studies discussed it can be clearly seen that Biomimicry is indeed a valid architectural design tool. By using nature as a metaphor for building, the architect's range in which to explore forms, materials, connections and systems just opens up to such a great extent. To reiterate: the technology we possess today can provide us with the tools needed to gain access to critical information not even known yet, and it can really help us to develop and analyse the world around us more efficiently and in greater depth than ever before.

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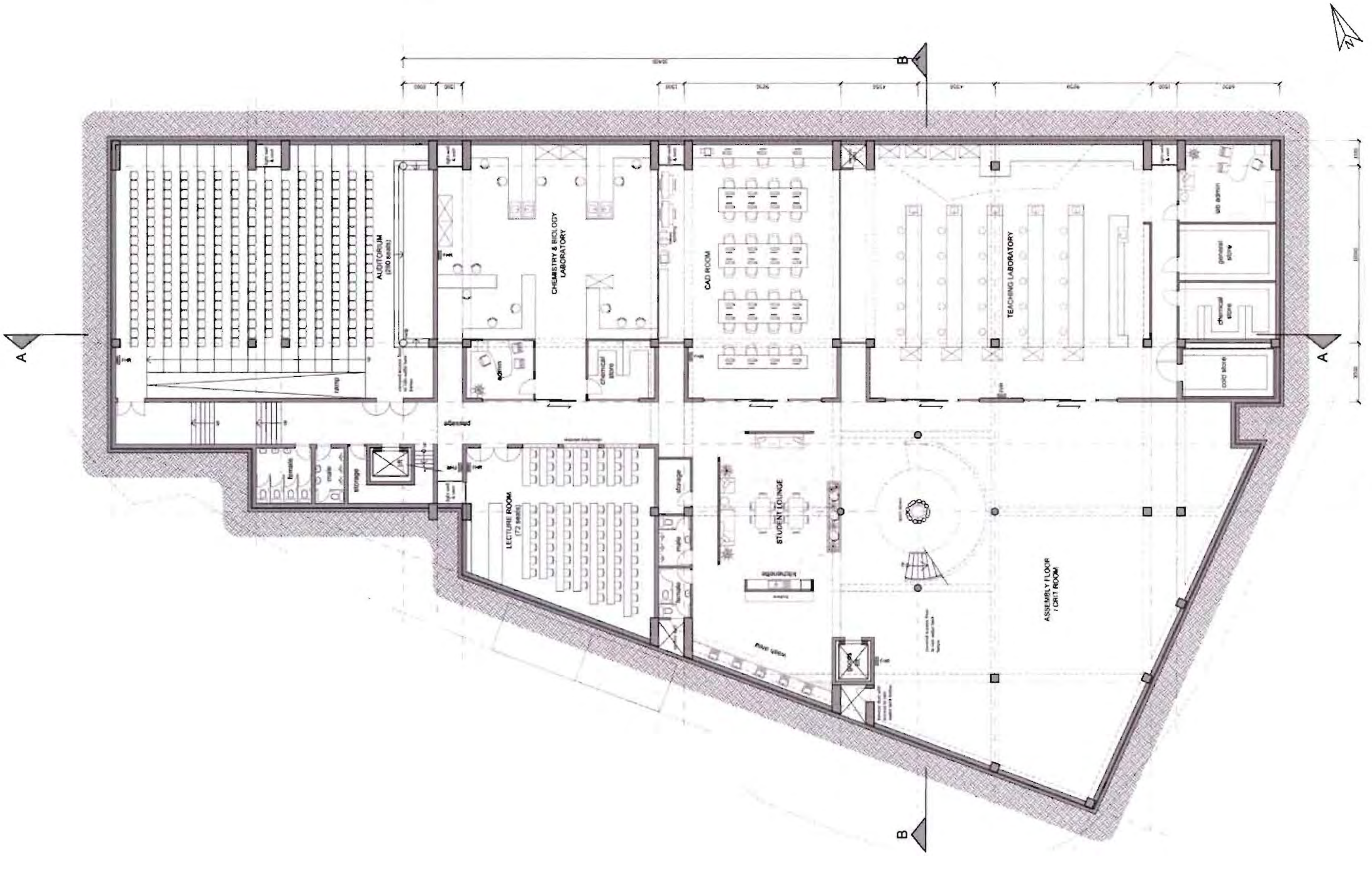
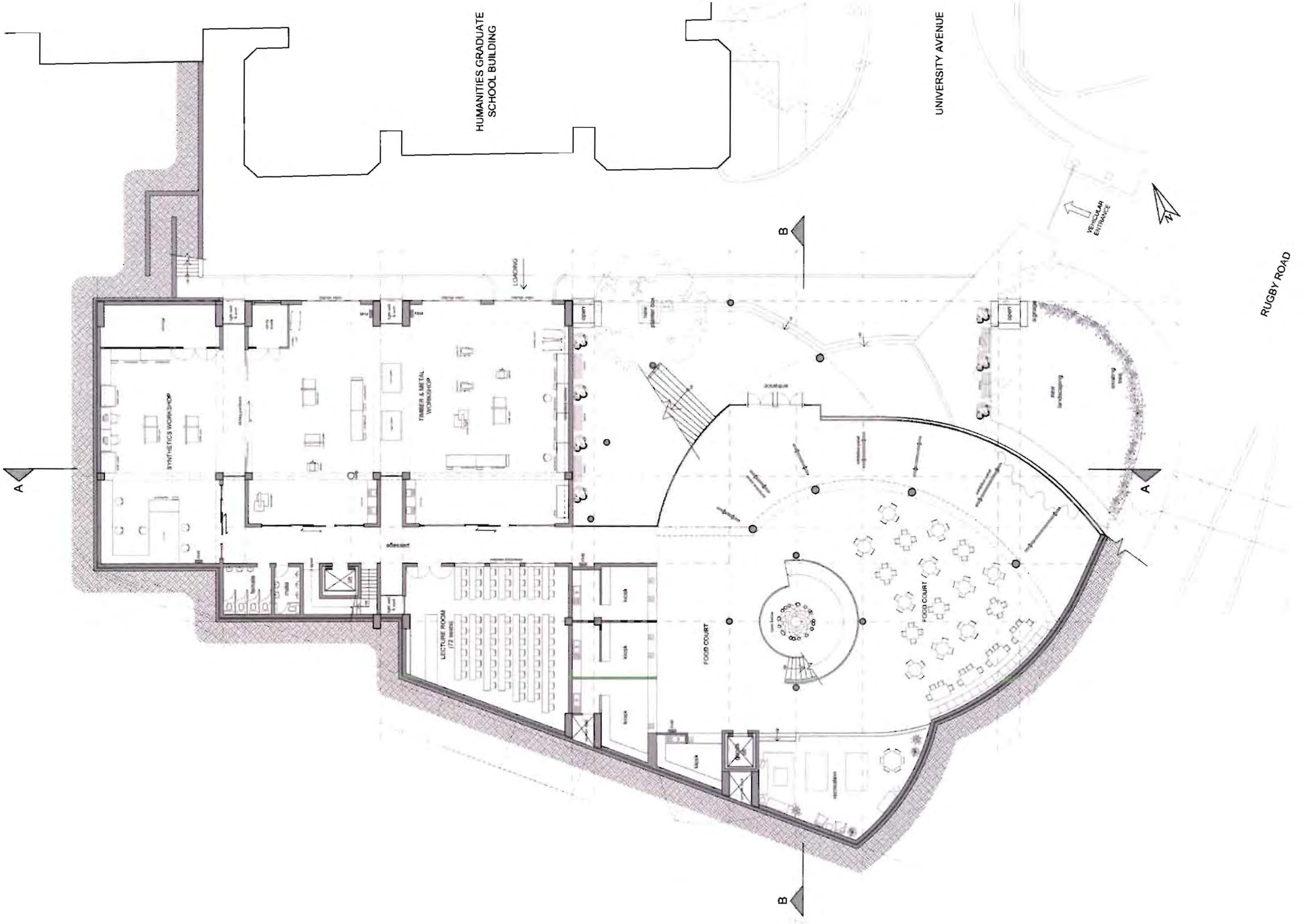
APPENDIX : FINAL PROPOSAL

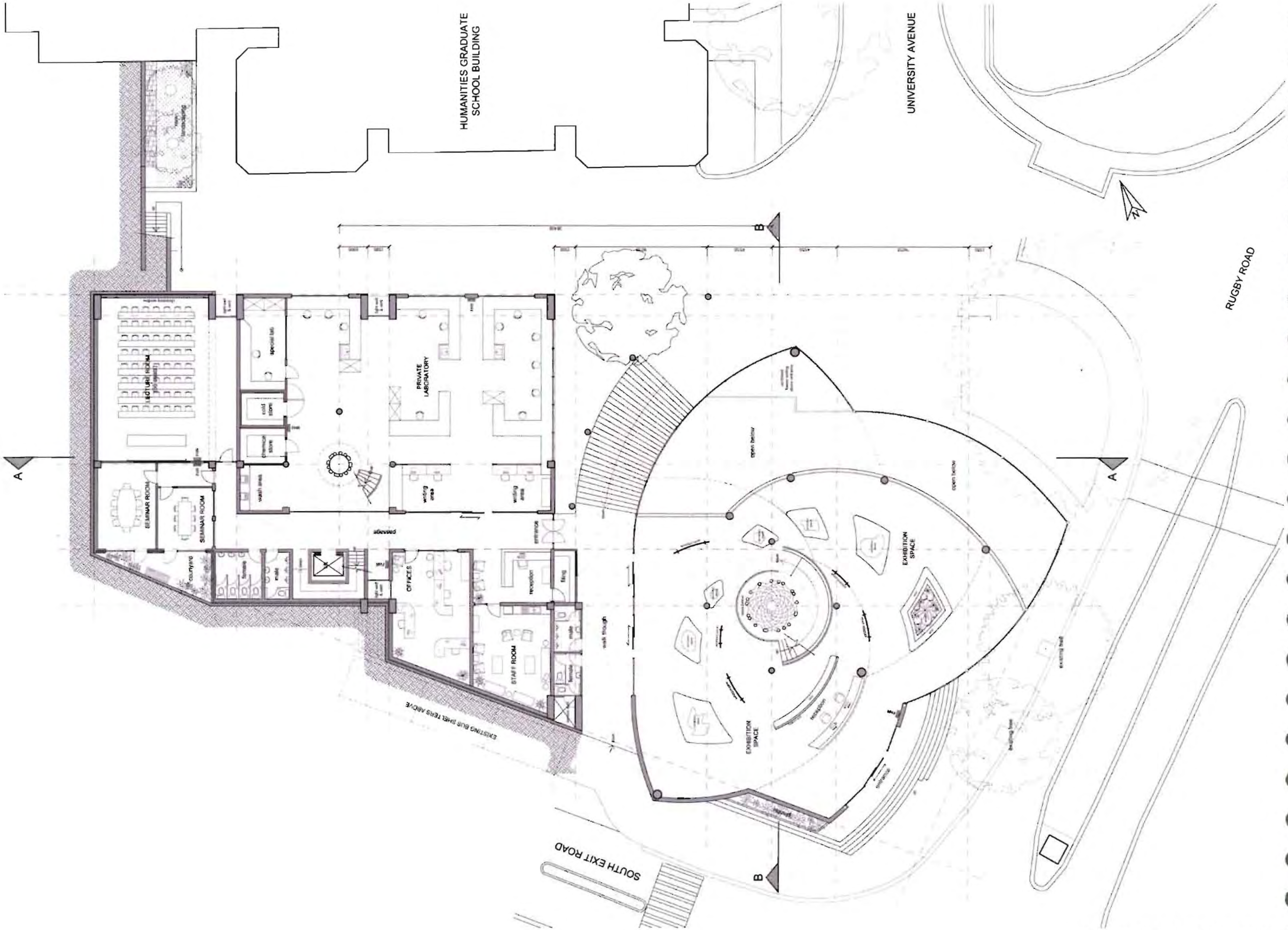
LOCALITY PLAN



BASEMENT PLAN



GROUND FLOOR PLAN



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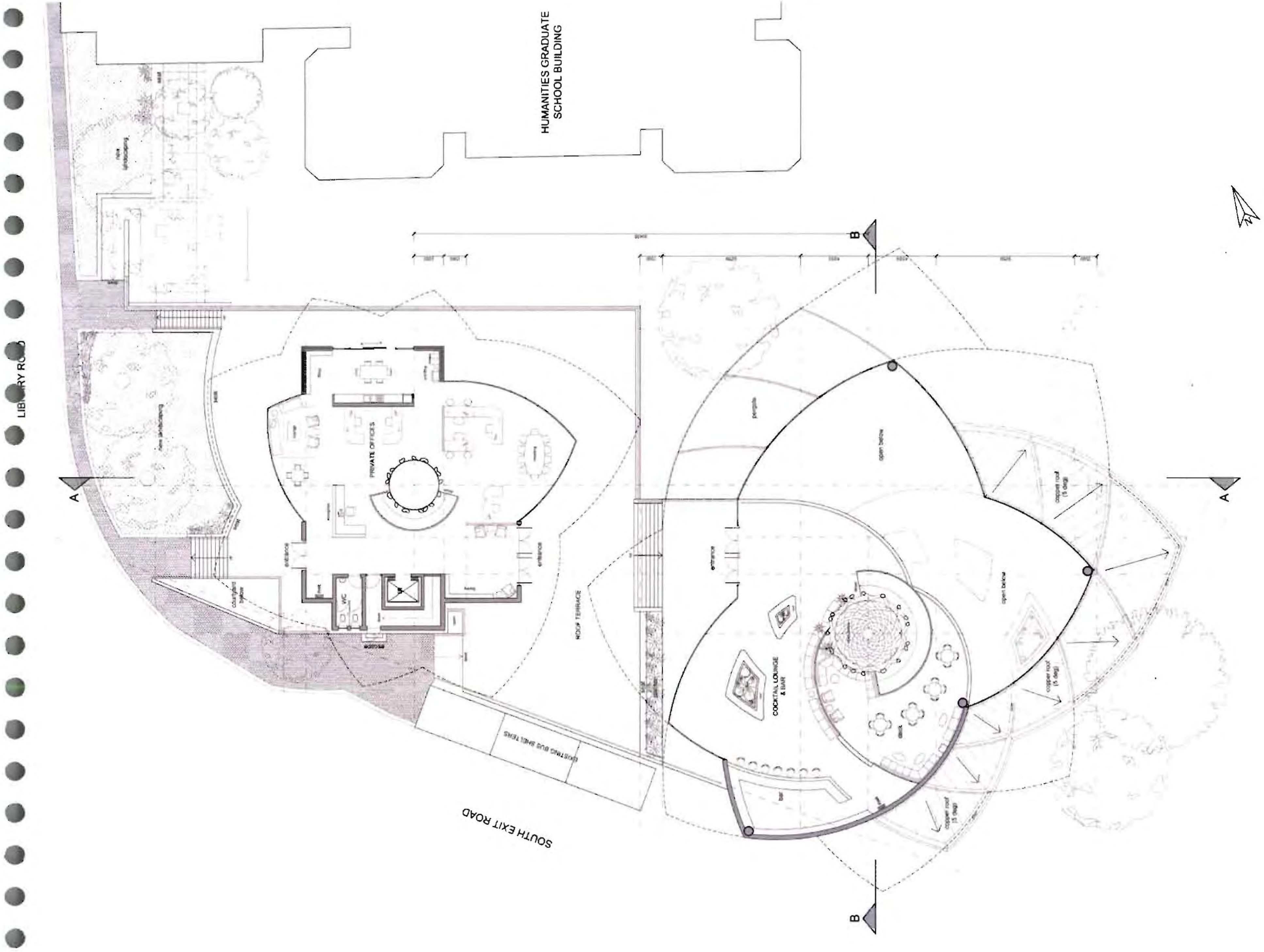
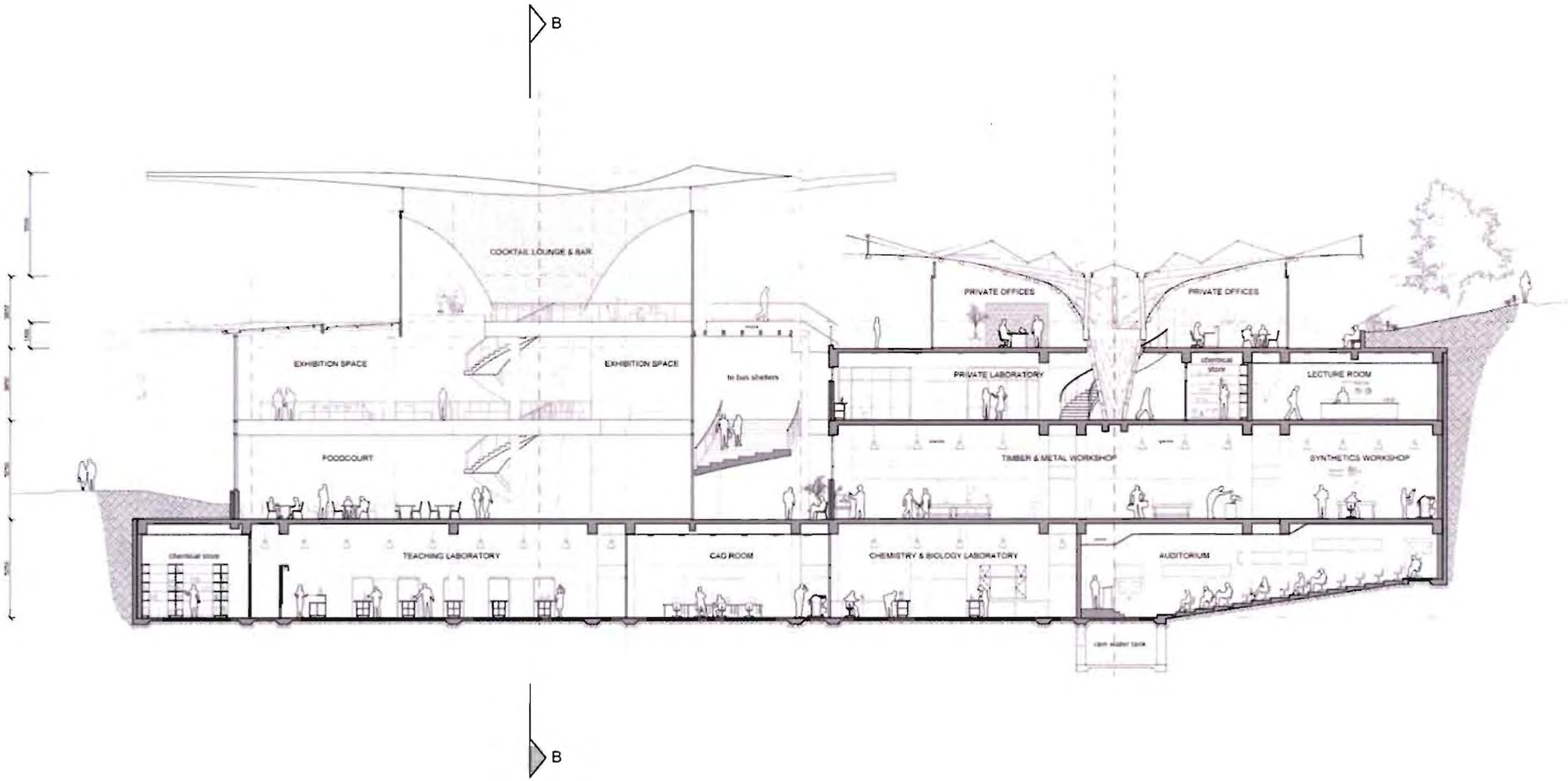
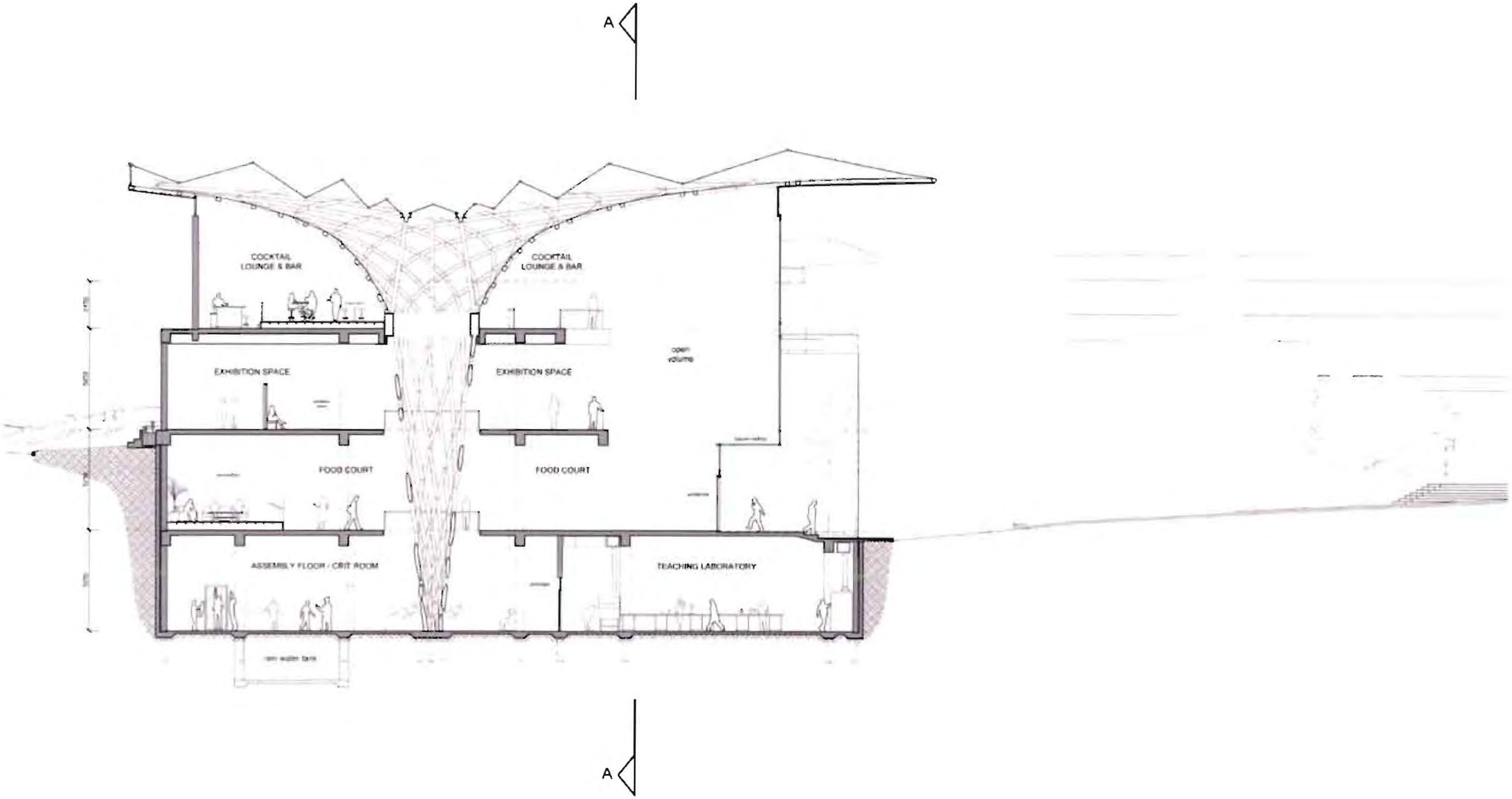


SECOND FLOOR PLAN

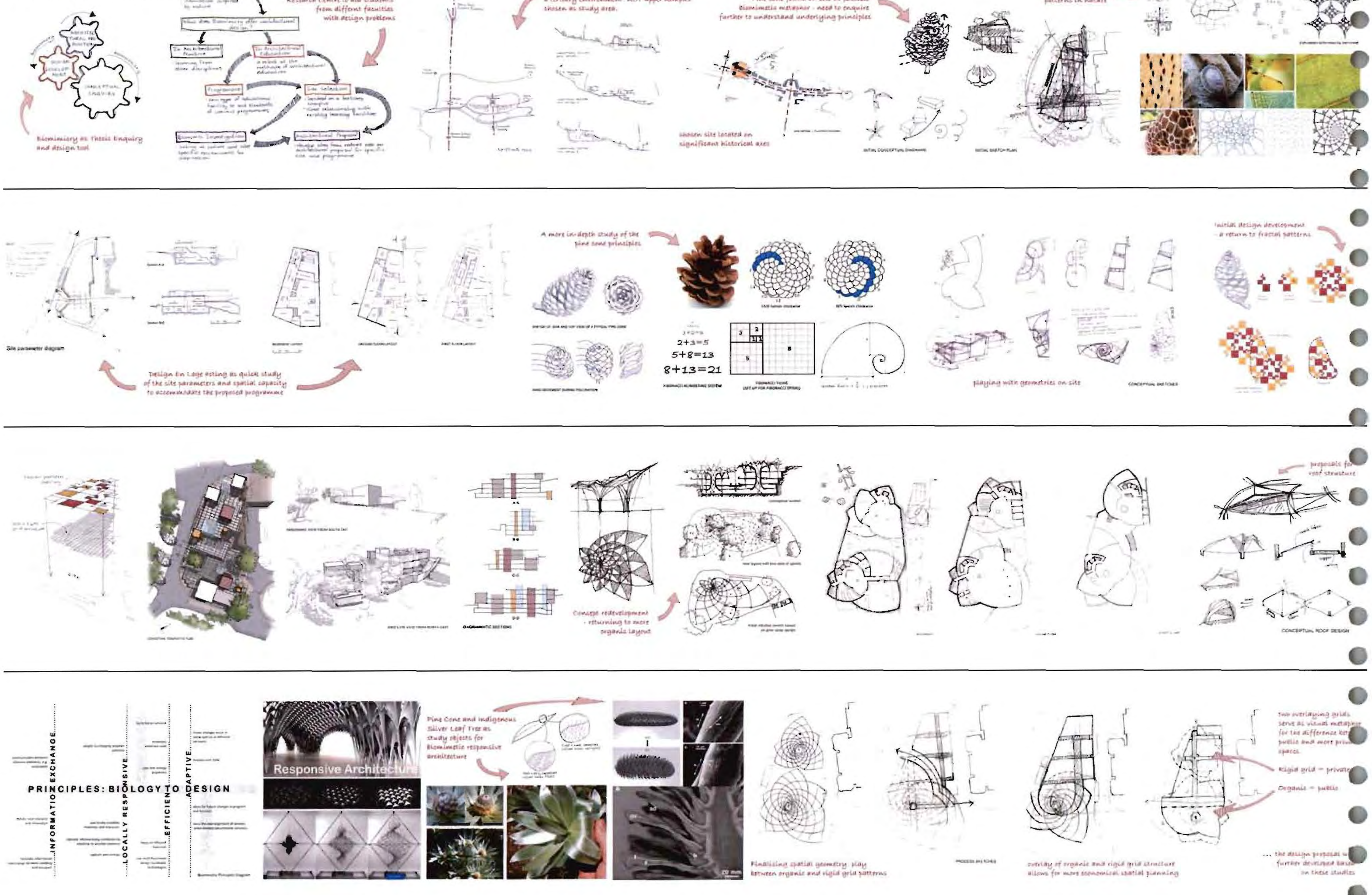

B
COCKTAIL LOUNGE & BAR
EXHIBITION SPACE
EXHIBITION SPACE
to bus shelters
FOODCOURT
chemical store
TEACHING LABORATORY
CAD ROOM
PRIVATE OFFICES
PRIVATE OFFICES
PRIVATE LABORATORY
chemical store
LECTURE ROOM
TIMBER & METAL WORKSHOP
SYNTHETICS WORKSHOP
CHEMISTRY & BIOLOGY LABORATORY
AUDITORIUM
rain water tank
B

SECTION A-A

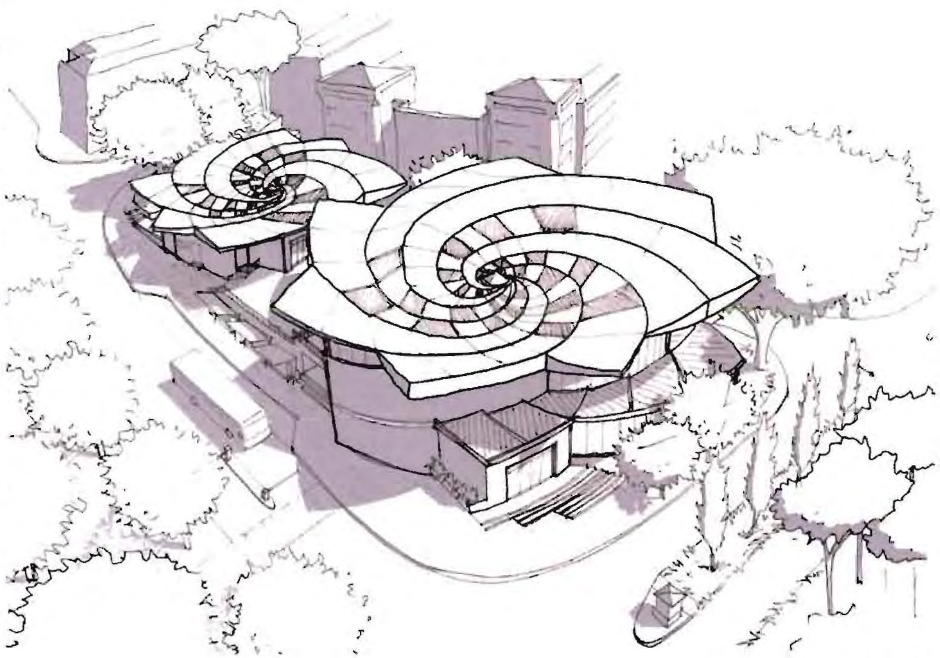

A
COCKTAIL LOUNGE & BAR
COCKTAIL LOUNGE & BAR
EXHIBITION SPACE
EXHIBITION SPACE
open volume
FOOD COURT
FOOD COURT
ASSEMBLY FLOOR / CRIT ROOM
TEACHING LABORATORY
A

SECTION B-B

CONCEPT DEVELOPMENT

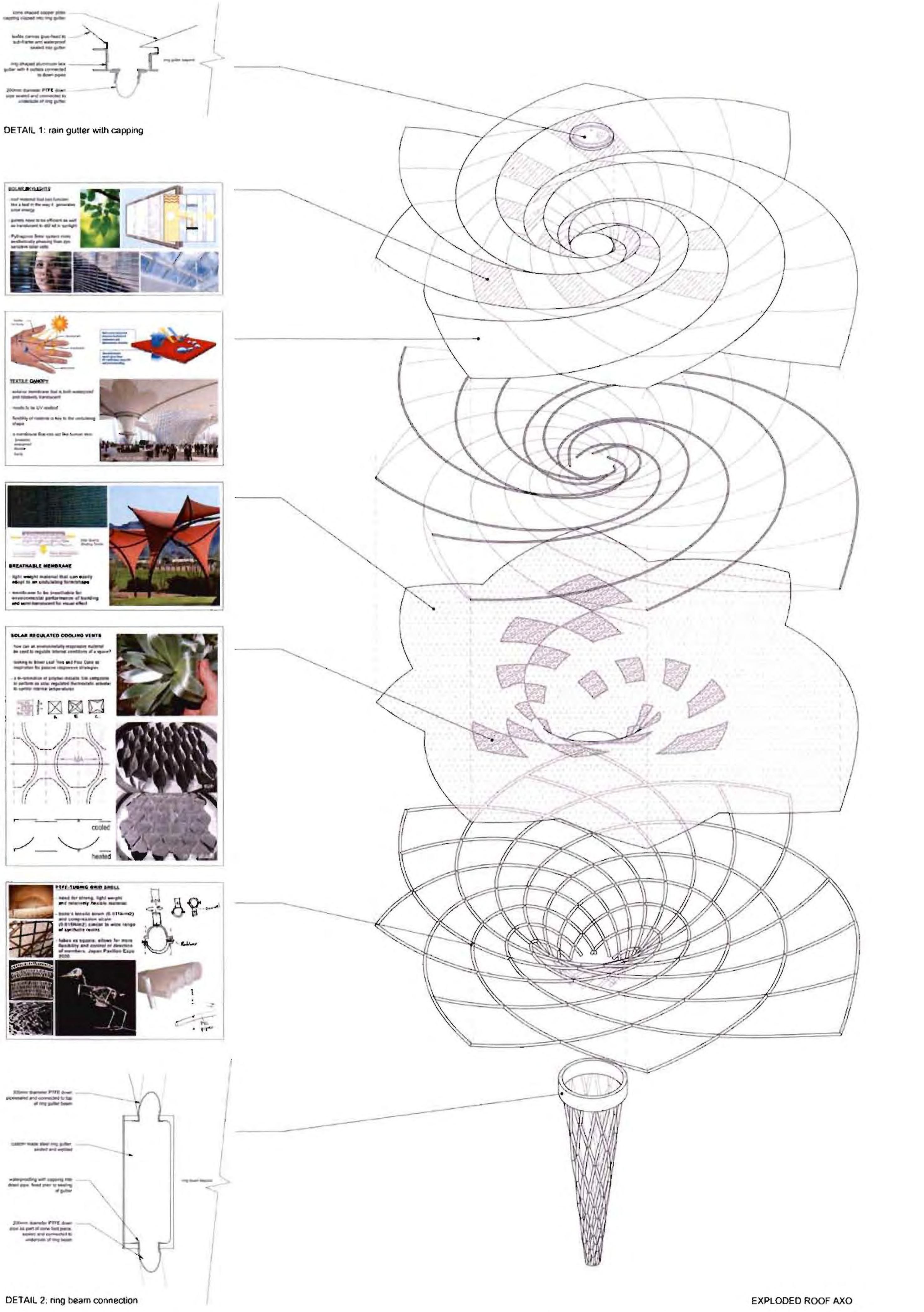


STREET PERSPECTIVE FROM SOUTH EXIT ROAD



BIRD'S EYE VIEW

STREET PERSPECTIVE FROM RUGBY ROAD



DETAIL 1: rain gutter with capping

DETAIL 2: ring beam connection

EXPLODED ROOF AXO

South-East Elevation

North-East Elevation

North-West Elevation

South-West Elevation


biomimicry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APPENDIX

The following pages represent the design resolution as presented at the final oral examination. Most of these panels were printed on 1000x700mm panels and are therefore not to scale in this document.