SPATIAL AGENCY

A New Frontier for South Africa's Space Program

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fig 1: Johannesburg Observatory

ABSTRACT

Although many people are unaware of its existence or purpose, South Africa has a space program. With the prevailing advancements in international space research and development, now is a convenient time for South Africa to cement itself in the eyes of the world as a contender in space research and exploration. For us to successfully evolve our space program, and therefore grow our technological advances for the future, we have to approach research and public involvement in a new way.

The aim of "Spatial Agency" is to provide a springboard to launch a new era in South Africa's space-related technology research, education and spread of information. This research report will aim to create a framework that can be used to design a research centre that can catalyse the country's satellite industry, as well as inform the design of a platform for public engagement. A new satellite research, development and visitor's centre will be designed to allow the astronomy and space research to be approachable, exciting and contemporary. It will also set a precedent for how the South African National Space Agency can approach public engagement and eduction.

This new space centre needs to be close to the city to facilitate public engagement. Because of the focus of technology research and development over astronomical observations, radio and light pollution from the city will not affect the work that researchers are doing on-site. Because of the focus on public engagement, the site should have a certain standing in the public eye as an available public site. Due to its historical value, the publicness as mentioned earlier and the amount of open space on the site, the Johannesburg Observatory in Observatory, Johannesburg is the ideal site for this scheme.

This scheme should frame space as an approachable subject to which all humans are instinctively drawn. This could be done by learning from humankind's history with merging architecture and astronomy and designing the building with such precedents in mind.

The new space centre and, ultimately, the redesign of the space program will allow South Africa to take steps towards becoming one of the world's contenders in the new space race and will ultimately bolster the country's economy and technological development.

Front cover: A section through the site of the Observatory Satellite Research, Development and Visitor Centre. As the centre is meant to be the springboard for South Africa's nanosatellite industry a nanosatellite is shown being launched from the site, representation of what the scheme aims to do. The night sky in the background is what one can see from Johannesburg, given the right conditions. Light constellations are drawn into the sky as the site with partially focus on educating people about the night sky.

SPATIAL AGENCY

A New Frontier for South Africa's Space Program

Agency refers to the capacity of an actor to act in a given environment; it also refers to an administrative division, for instance, the South African National Space Agency. The title of this research report, Spatial Agency, refers to South Africa's potential to participate in the international satellite creation industry - to act in the environment that is the space technology industry, with the assistance of academic institutions, private companies, and government agencies. This research report explores a spatial solution to this puzzle, a facility that enables the country to fulfil its potential as a player in the international contest of space exploration.


fig 3: Africa as seen from the International Space Station (NASA, 2016)

DECLARATION

I, Rory David 712458, am a student registered for Master of Architecture (Professional) in the year 2019. I hereby declare the following:

I am aware that plagiarism (the use of someone else's work without their permission and/or without acknowledging the original source) is wrong. I confirm that ALL the work submitted for assessment for the above course is my own unaided work except where I have explicitly indicated otherwise. I have followed the required conventions in referencing the thoughts and ideas of others. I understand that the University of the Witwatersrand may take disciplinary action against me if there is a belief that this in not my own unaided work or that I have failed to acknowledge the source of the ideas or words in my writing.

Signed Author: Rory David
Student Number: 712458
Date: 10 February 2020
Supervisor: Garret Gantner

This document is submitted in partial fulfillment of the degree Master of Architecture (Professional) at the University of the Witwatersrand


fig 4: Stonehenge's solstice stone, the Heel Stone, seen through the Great Trilithon (Banton, 2014)

ACKNOWLEDGEMENTS

I want to express my appreciation to Garret Gantner for his valuable and constructive suggestions during the development of this research report. His willingness to give his time has been very much appreciated.

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I would like in particular to thank my mother, Joanne David, for the support necessary to be able to continue my studies - it wouldn't have been possible without your sacrifices. Your support has been unwavering in spite of the tribulations you faced this year. I admire your strength, and I cherish you.

I would also like to thank Charlie and Fatima Farinha. Your unrelenting generosity of spirit never ceases to amaze and inspire me, and without it, I would not be where and who I am today. I cannot thank you enough for your continued support and for accepting me into your family as one of your own.

To my beloved Deandra, your presence during this leg of our journey has provided inexpressible comfort to me. I love you, and I cannot wait to see where our adventure will take us next.

Thank you all.

Spatial Agency

A New Frontier for South Africa's Space Program

"This is not merely about advancing human understanding of the origins of the universe – it is about responding to the challenges that face South Africans now and into the future. It is about developing the technology and the capabilities that will build a dynamic and competitive economy that creates decent, sustainable jobs. It is about enhanced food security, better disease management, and cheaper, cleaner and more efficient energy. It is about smart human settlements and social development solutions built around people's needs and preferences. It is about smarter, more responsive, more effective governance."

- Cyril Ramaphosa (State of the Nation Address, 2019)

fig 5: Image taken of the centre of the galaxy by the MeerKAT telescope array in the Karoo, Northern Cape (SARAO, 2018)

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1 / 7 Introduction

"This is not merely about advancing human understanding of the origins of the universe - it is about responding to the challenges that face South Africans now and into the future. "

- Cyril Ramaphosa (State of the Nation Address, 2019)

fig 6: Photo of the Milky Way Galaxy (Michael, 2018)

fig 7: Image of the night sky, taken from Johannesburg.

BACKGROUND

My interest in space started as a young boy. My father would travel to remote areas of Mozambique for outreach missions. When he was there, he would be able to see the night sky in ways that were not possible where we lived. He would return from his missions with stories of being able to see the entire Milky Way Galaxy spilt across the night sky. We would stand in the back garden with a pair of binoculars and try to identify what few constellations we could see, look at the patterns in the moon and try to spot the planets. My father's enthusiasm instilled in me a burning interest in outer space that continues to this day.

Growing up, my interest in space was limited to looking up at the night sky in existential awe. "What is out there?" My limitations and intrigue were representative of nearly the entirety of human civilisation up until that point. This pure, elemental relationship that humans have with the universe should be fostered and encouraged. The universe has always drawn humans outward, and recent years have proven that humankind is destined to be a space-faring race - a destiny that we can finally manifest.

In this year's state of the nation address, President Cyril Ramaphosa stated that embracing South Africa's space program is "a choice between being overtaken by technological change or harnessing it to serve our developmental aspirations". The world at large is taking great strides to push outward into the cosmos, many of them successful. South Africa has a history of space-related innovation, but that is hopefully only the beginning of where we will end up as a nation. We must embrace our future as a space-faring country, while there is still so much to explore. The frontier of space is relatively unexplored, and there is much to gain from being on the cutting edge.

This research report is an exploration of the path that South Africa can travel down. How does a country like South Africa cement itself as a worthy contender in the international space competition? How can a country with such an intrinsic connection to the earth explore the cosmos? How can one use architecture as a catalyst to facilitate the growth of a space program?

Fig 8: Engineer working on James Webb Telescope Satellite (Pixabay, 2010)

RESEARCH METHODOLOGY

Given the nature of architectural research, particularly with regards to the primary concept of the final design in this book, a more qualitative approach was conducted in terms of the research. This is especially true when considering the arguments made in favour of nanosatellite research. The research conducted in the "satellite theory" section focuses primary on quality of life improvements brought on by the pursuit of satellite research. A large amount of research was done regarding the dominant concept of the design: How does one find a way to marry architecture, the Earth and space? This primarily consisted of researching precedent studies, questioning humans' tendency toward this relationship and the history of this connection. Furthermore, research was done regarding the nature of academic research; while potentially quantitative, this research focused more on the human-research relationship and one can foster this relationship through architecture. Naturally, these are all examples of qualitative research. One of the reasons for such a deep review of the humanitarian aspect of the research report was because of the apparent lacking of such knowledge in other research reports found online or through the university library. Many such reports, either in terms of academic architecture or satellite development, focus a lot on the "science" or the "engineering" aspects of these subjects – not strictly the only aspect to research when it comes to designing academic spaces.

Although the primary type of research was qualitative, a certain amount of research was done in a quantitative capacity – this was primarily focused on the numbers regarding cost, time frames and financial benefits of launching nano-satellites. In the pursuit of legitimacy, research was done to justify the cost of building and running a satellite development centre: building costs, operational costs, funding options, etc. This is all regarded as quantitative research.

The broadness of a research report of this scale means that research will not be primarily qualitative or quantitative and often a combination of the two.

Much of, if not the majority of research, was done through the facilities provided by the university and research done online. The nature of the climate of contemporary satellite research means that the most current and informative research is found online, either as precedent studies, research papers or general discussions online. However the relationship between architecture, the Earth and the sky is a research topic that can be studied in the traditional sense – in brick and mortar libraries or online libraries that the university grants access to.

It was part of the original research plan to send out enough questionnaires to residents in the neighbourhood of the scheme to gain a considerable understanding of the impact that the current observatory and learning centre have had on the context – however not enough questionnaires were received in order to make a major impact on the design. What did have an impact on the design was interviews conducted with students who were enrolled at universities that offered satellite design courses; these universities were University of Texas, University of Illinois and University of Colorado. The interviews in question were casual discussions on an online platform, but provided enough understanding to make "quality of life" changes for the research spaces.

2 / 7 Theory

> “Just like some might ask ‘Why should we spend time exploring space when we have so many problems here on Earth?’, some of our ancestors probably asked ‘Why should we waste time trying to figure out agriculture when we have so much work to do hunting and gathering?’”
>
> - Mark Rober, (14 Feb 2018)

fig 9: Falcon 9: Starlink 1 launch from Cape Canaveral Air Force Station (John Kraus)

CHAPTER CONTENTS

CHAPTER INTRODUCTION

The theory chapter of this book will cover two main themes: satellite theory and architectural theory. Each will weigh into the design of the scheme in some capacity; the satellite theory section is focused on understanding why a satellite research centre is necessary and what the process of manufacturing satellites is. The architectural theory section will focus on research that can allow this scheme to function as intended and deliver the desired results in terms of program and design.

The satellite theory section will answer two question: How do satellites work? And how are they used? The aim of answering these questions is to justify the need for the satellite research and development centre. The creation of a scheme such as this can be expensive and requires a return on investment of some kind to justify its creation. As President Cyril Ramaphosa said in his state of the nation address, pursuing advancement in an industry such as space research is about more than merely researching space. What is learned through this research can be implemented into the lives of the people of South Africa; scientific knowledge has value beyond the measurement of cost. That in itself can be the return on investment needed to justify this scheme. This chapter will explore the factors of satellite research and development that can help the country, economically, socially and technologically. One of the most common arguments leveled against space research is that money could be better spent on issues down on Earth, fixing those problems before moving on into the rest of space. This chapter will explore that argument and prove that issues down on Earth can be solved by pushing out into the rest of space.

Architecturally, this chapter will explore one of the questions posited in the preface to this research report: How can a country with such an intrinsic connection to the earth explore the cosmos? The method proposed is to translate a seemingly unapproachable industry into something relatable and to frame the research and exhibition spaces on the site as something toward which humans are instinctually drawn. The design of the scheme itself will use this research as an informant. Furthermore, this chapter will outline the necessary design methods and styles for the program of the building; specifically, the exhibition spaces and the research laboratories.

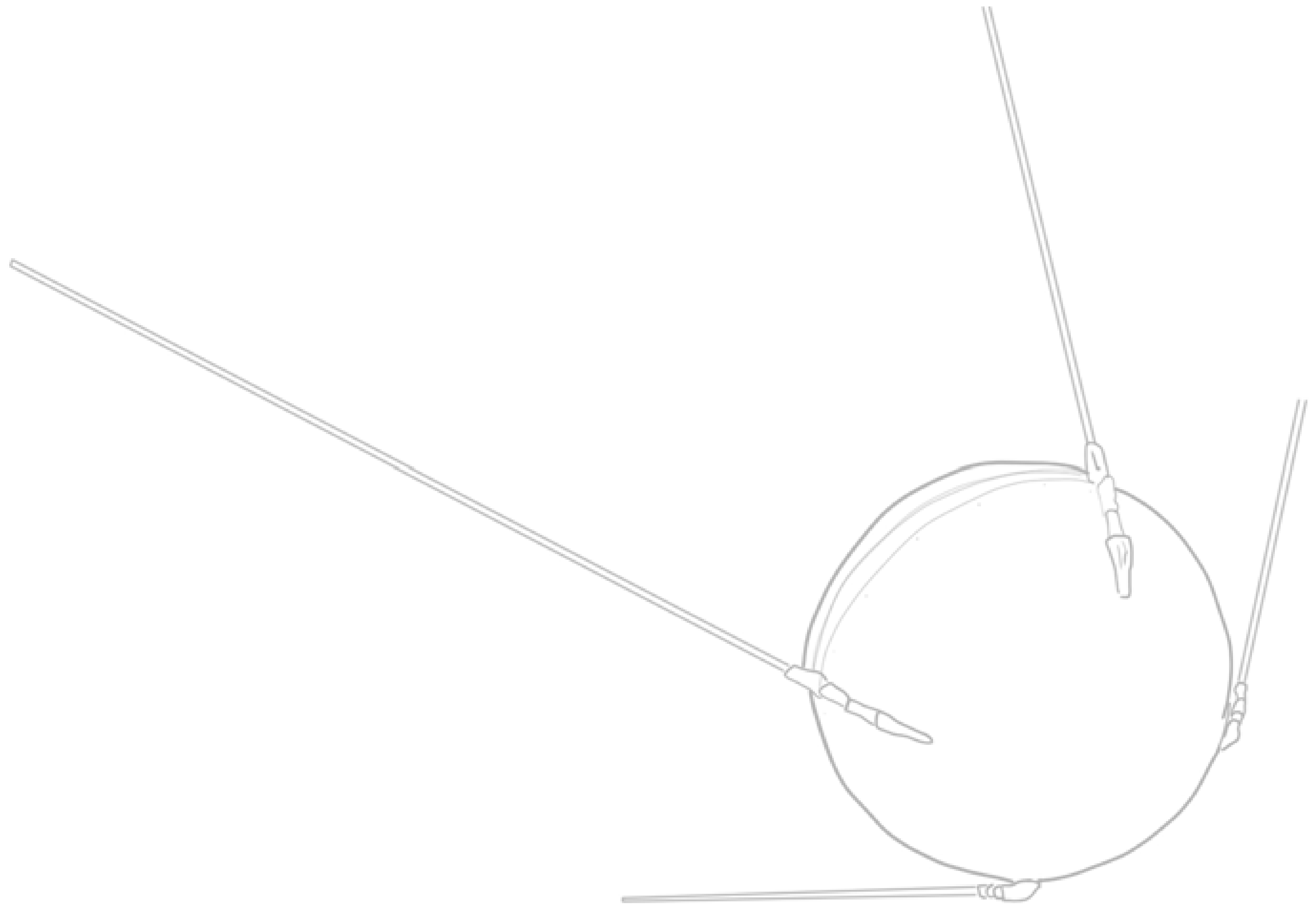


fig 10: Sputnik 1

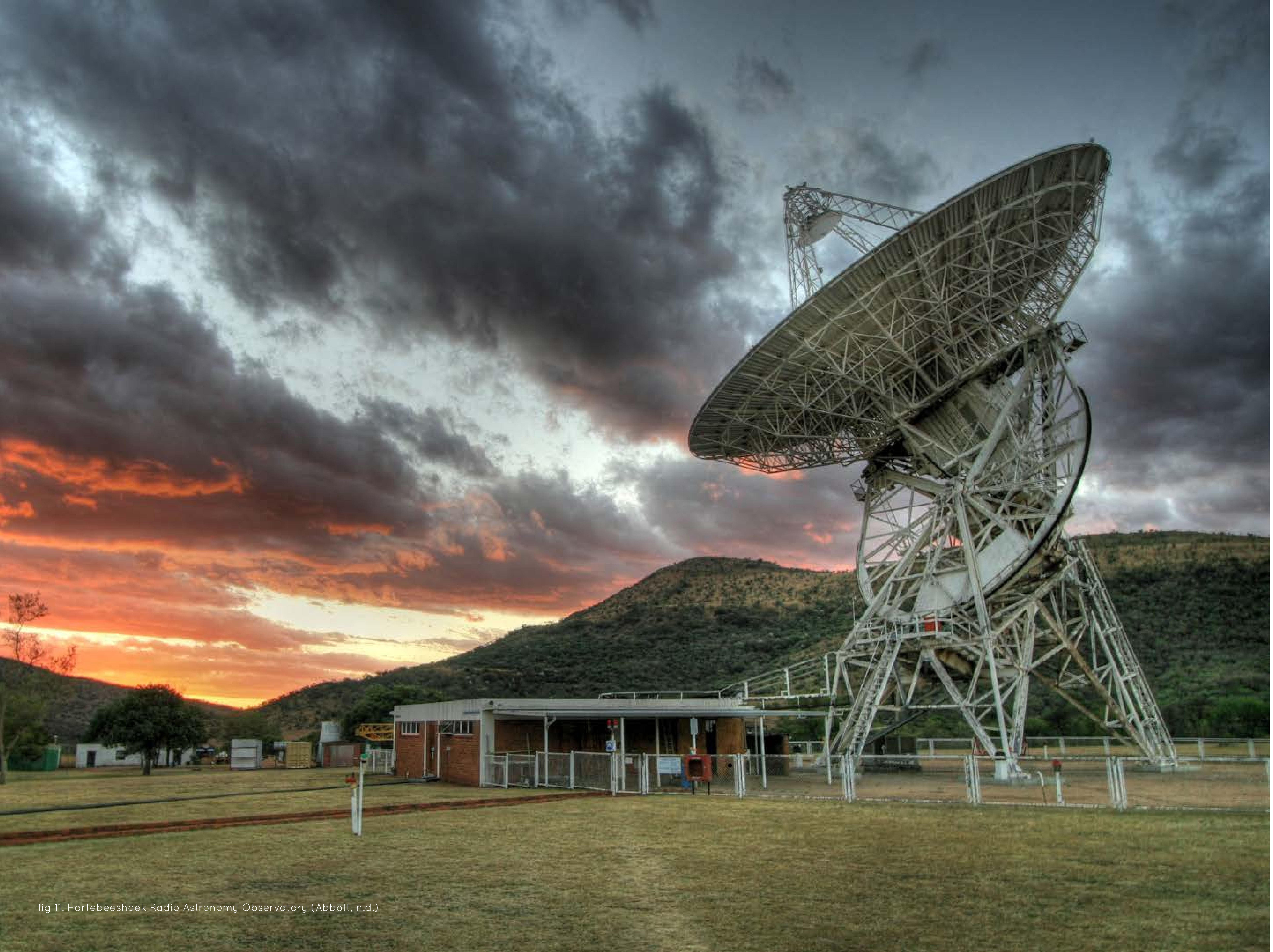


fig 11: Hartebeeshoek Radio Astronomy Observatory (Abbott, n.d.)

1 | satellite theory

To fully understand the impact that the Observatory Satellite Research, Development and Visitor's Centre can have on the community, the history and principles behind designing and using satellites need to be recognised.

This chapter will present the path that satellite research has taken from a concept in the late '50s to a ubiquitous technology today, how these satellites work and how they are used today.

One of the issues that South Africa's space program faces is the lack of awareness that the general public of the country has of the space agency and the associated applications. This lack of recognition is due in part to the disconnect between academia, industry and the general public. The Observatory Centre will act as a catalyst to attempt to address the lack of engagement between industry, academia and the general public. One of the most vital parts of fostering public engagement is showing people how the use of satellites can affect them directly as most people are not aware of what satellites are used for or they can change the lives of the public. The effect that satellites have on people will be covered in this chapter, which will eventually also form a part of the program of the scheme.

Furthermore, engagement of the public with the satellite industry can be taught and fostered by showing people the process of researching and fabricating satellites. This too will both form part of the program of the scheme and a portion of this chapter.

DIFFERENT TYPES OF SATELLITES

There are several different sizes of satellites; five broad categories, but countless subdivisions based on exact weight, size and proportions.

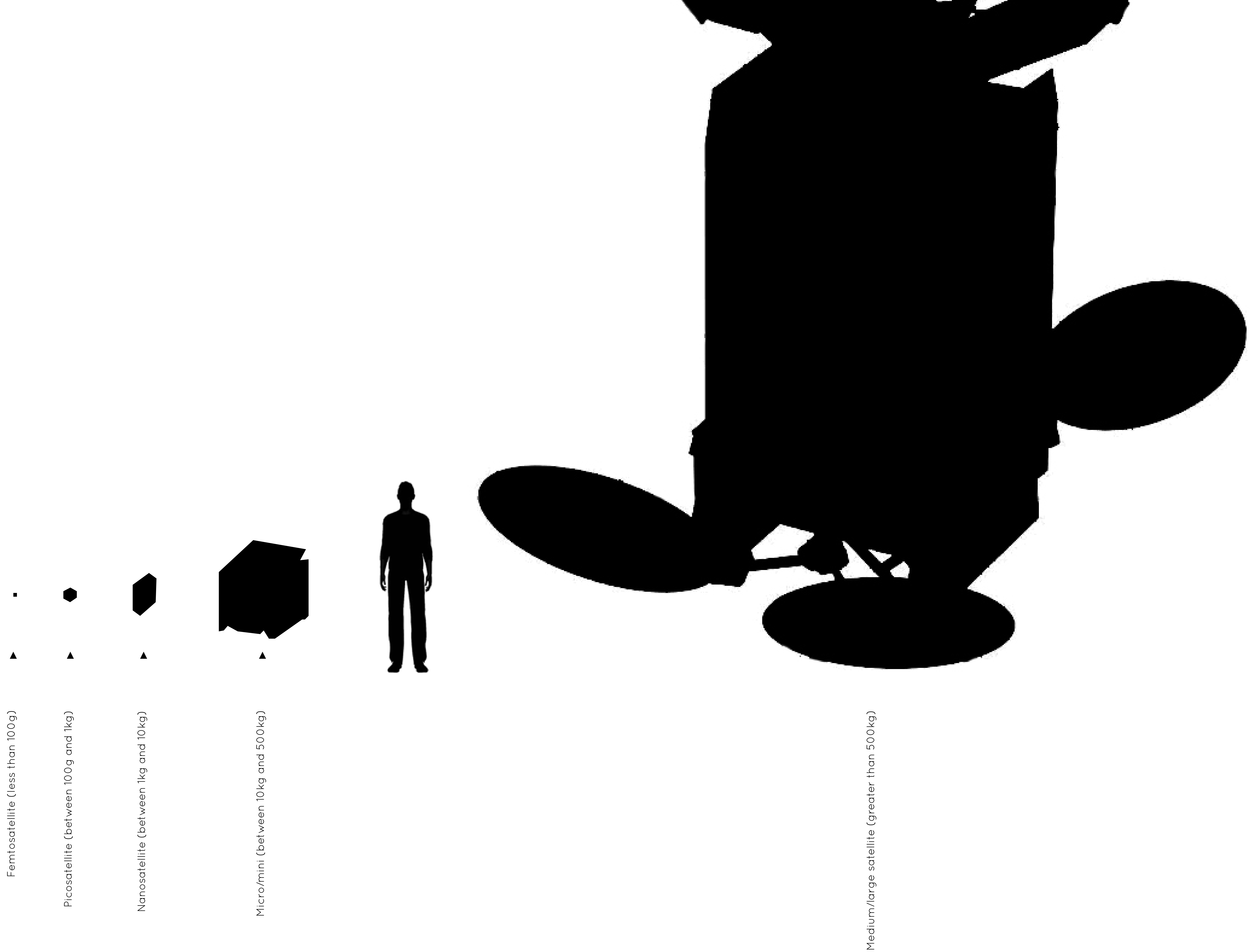
Femtosatellites weigh less than 100 grams and are, at most, 30mm cubed. Naturally, the applications of these satellites are limited and generally restricted to working in conjunction with a larger satellite, the mother satellite; in cases such as this, the femtosatellites are called sprites. Much like CubeSats, the usage of these satellites is generally as large constellations. There have been very few missions that have utilised these femtosatellites. Those that have launched and successfully operated from orbit have been testbeds to understand the limitations of the technology. The general understanding is that with enough sprites orbiting the planet, there will essentially be an antenna around the planet, allowing efficient communication between any two points on Earth.

Picosatellites weigh between 100 grams and 1 kilogram. Much like femtosatellies, the applications have not been fully explored. However, much like the other small satellites, the intended application is as a constellation. Picosatellites are the most common do-it-yourself kit-built satellite because the parts are easy to source from other technologies and the launches are relatively inexpensive. 1U CubeSats fit into the upper range of picosatellites.

Nanosatellites weigh between 1 and 10 kilograms. The most common type of nanosatellite is the CubeSat configuration; this is because of the framework that has been created to make it easily accessible, which is covered later in the chapter. The strength of nanosatellites is in the size: they're small enough to be launched as a constellation and built inexpensively, however they're large enough to carry effective payloads such as cameras, magnetorquers, et cetera. The majority of the satellite theory section will be dedicated to nanosatellites because of the focus on CubeSats. However, CubeSats can be big enough to fall into the next bracket of satellite size. Cubesats can be up to 12 modules, which could make them up to 12 kilograms or more.

Micro/minisatellites are a much broader range than the smaller satellite size classifications. They can weigh anywhere between 10 kilograms and half a ton. These operate as traditional satellites do and have longer mission times than smaller satellites. The benefit over traditional satellites is that they are cheaper to manufacture and launch. Naturally, they have limited functionality compared to large satellites, especially considering their lifespan. Large satellites are typically equipped with fuel to be able to change direction whereas micro/minisatellites may not have functionality like this.

Medium/large satellites weigh over 500 kilograms and operate in the traditional sense, staying in orbit for up to decades and are equipped with a large range of equipment.



HOW SATELLITES WORK

It is essential to note the difference between satellites and space debris. Although, technically, anything that orbits a planet is considered a satellite, for this thesis, "satellite" will refer specifically to artificial satellites that serve a useful function. Human activity over the years has placed millions of pieces of debris in Earth's orbital; according to NASA's Orbital Debris Program Office, there are over 100 000 000 pieces of debris in Earth's orbit (Modders, 2019). Most of this debris is from rocket launches, objects jettisoned from spacecraft and accidental litter from astronauts. There have been attempts at eliminating the debris and observing the long terms effects of operating spacecraft in this haze of junk. One of the most recent research projects aimed at removing space debris has been the OSCaR (Obsolete Spacecraft Capture and Removal) cube nano-satellite (CubeSat) constellation. The CubeSats will be equipped with nets and tethers and will autonomously seek out debris to deorbit it; once each CubeSat has destroyed enough debris, it will deorbit itself, burning up on re-entry.

Satellites are launched into orbit by being carried by rockets. The rocket will travel vertically at first, going through the thickest part of the atmosphere as quickly as possible. Once at a certain altitude, the rocket will begin to tip over, granting horizontal momentum. The type of satellite determines the height that the rocket will reach and the height to which the satellite will rise. The altitudes of satellites can be classified into three main classes: low-Earth orbit - anything below 2000km; geostationary orbit - 35,786km above the Earth. These satellites have an orbital period equal to one day, meaning they're always above the same point of the Earth; and medium-Earth orbits - anything between low and geostationary orbits.

There are eight different types of satellites, namely:
- **Weather satellites** allow for the monitoring of weather systems on the ground, generally by taking photographs of the Earth's weather for meteorologists to analyse.
- **Communications satellites** enable people to make phone calls by receiving and amplifying frequencies to and from Earth.
- **Broadcast satellites** work similarly to communications satellites, except that they are used for television broadcasts instead of phone calls.
- **Scientific satellites** are intended to perform scientific missions, such as searching for stars or measuring the ionosphere.
- **Navigational satellites** help navigation on Earth via GPS.
- **Rescue satellites** allow for distress signals to be broadcast.
- **Earth observation** satellites allow scientists to take measurements or in some way monitor the Earth, either via photographs or other scientific analysis, such as infrared readings.
- **Military satellites** are used for government projects, most of which are kept a secret from the public. These may be used for encrypted communication, nuclear monitoring, tracking missile launches, watching enemy movements, et cetera.

To keep a satellite in orbit, it needs to be going at a certain speed. This speed is determined by the height and nature of the orbit; the closer to Earth a satellite is, the faster it needs to go to stay in orbit. Satellites stay in orbit by balancing gravitational pull toward the planet and centrifugal force, which attempts to pull it away from the planet. Centrifugal force is imparted to the satellite by its horizontal momentum.

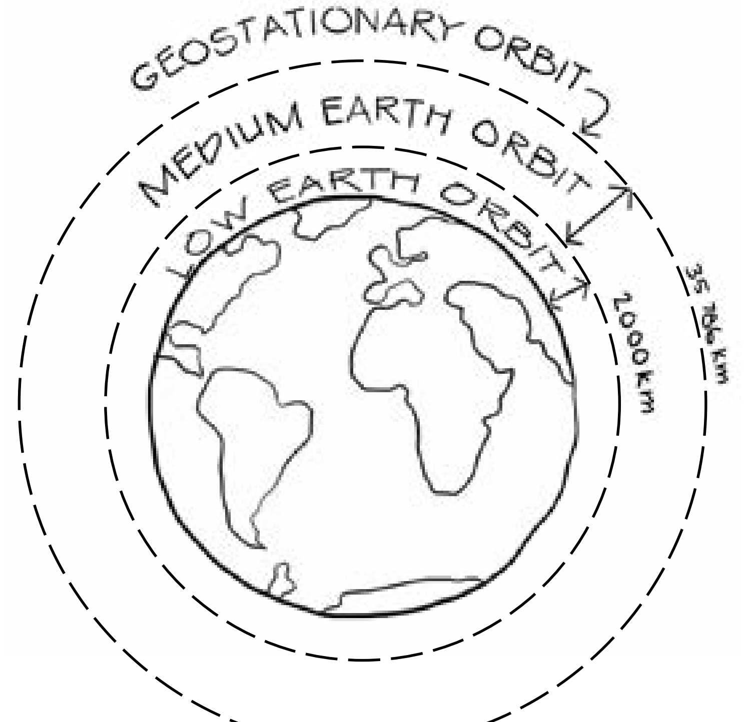


fig 15: Altitude designations

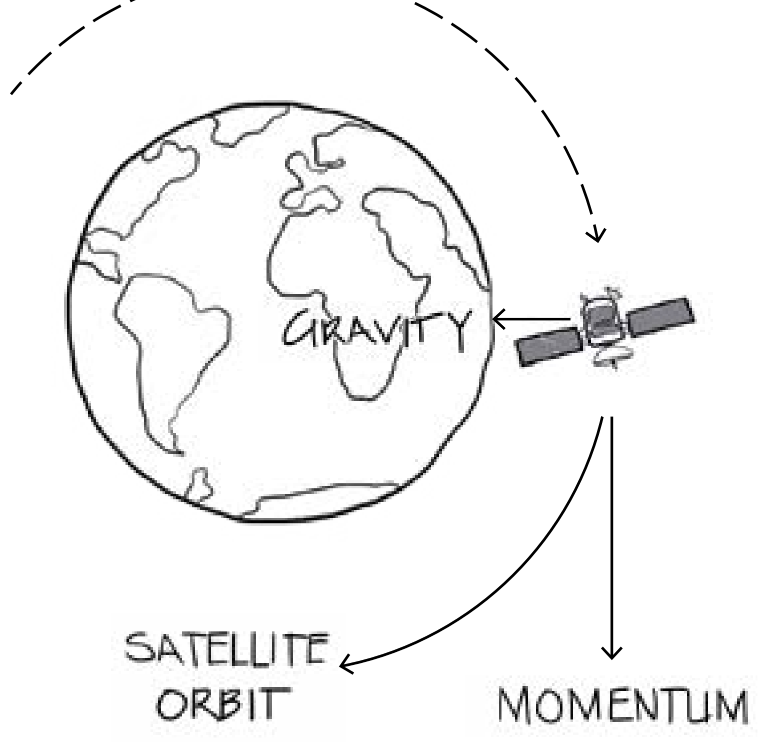


fig 16: How orbits work

This explanation is often described as satellites falling to Earth but travelling fast enough to miss the planet, continuously. If a satellite flies too slowly, it deorbits and falls back down to Earth. If it moves to fast, the centrifugal force exceeds the gravitational force, and it escapes from Earth's orbit.

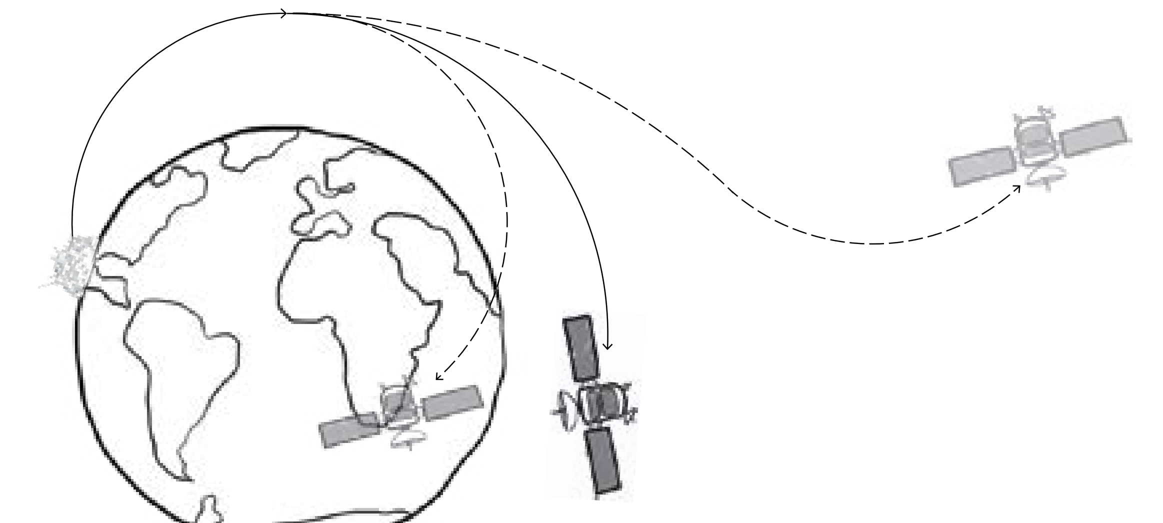


fig 17: How orbits work

Based on the application of the satellite, it will be equipped with the necessary components and technologies. However, all satellites have at least four base components: the chassis of the craft, meant to hold all the components; a source of power, usually a combination of solar cells and batteries; an altitude control system; an onboard computer; and communications systems, usually a radio and antennae but possibly something more advanced depending on the application.

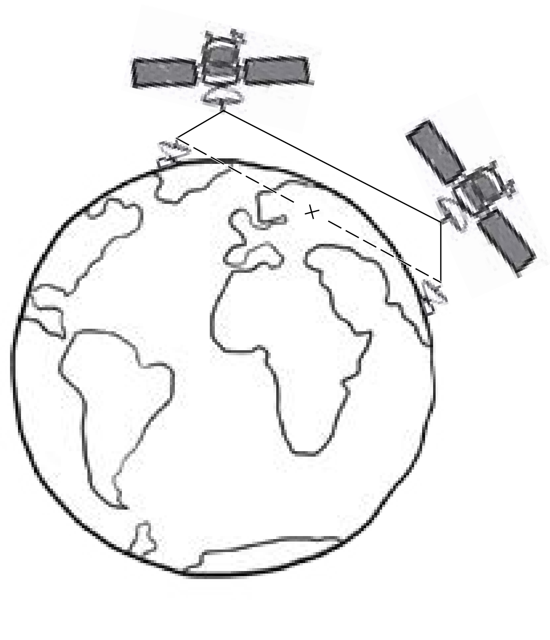


fig 18: How telecommunication works

Satellites use these radios and antennae to communicate with ground stations on the Earth and with each other in orbit. All satellites have to be equipped with communications capabilities, at least to be able to receive commands and transmit telemetry data. More advanced satellites, specifically communications satellites, have more advanced communications capabilities. Satellites use radio waves to communicate. Unfortunately, radio waves can only move in straight lines so communication over the horizon is impossible. However, with more than 5000 satellites orbiting the planet it is possible to use these satellites as relays to send radio waves over the horizon. Satellites will receive information on one frequency and relay that information on a new frequency; this is to help mitigate radio frequency interference.

Since scientists first started launching satellites into space, the technology for and uses of the satellites have become more and more complicated and therefore increasingly expensive to launch and maintain. As the satellites gain functionality, they naturally gain more equipment and thus, more mass; as space companies charge per kilogram that is launched into space, the more mass a satellite has, the more it costs to launch. With some satellites weighing up to several tons, it can begin to balloon the costs of launch. The specific cost per kilogram depends on the company and the size of the rocket - a rocket with more carry potential will cost less because it has less demand for space. Rocket launches can cost anywhere between R100 000 and R470 000 per kilogram depending on the space agency carrying the craft and the size of the rocket; this price means that a large satellite that weighs several tons can cost hundreds of millions to several billion rands for the launch alone.

The cost to produce the satellite itself depends on many factors: the use of the satellite, how advanced the technology is, the intended lifespan on the craft, et cetera. SumbandilaSat, a South African satellite launched in 1999, is an interesting example to put into perspective the relationship between the cost to launch and the cost of the craft. Roscosmos, the Russian space agency, carried the 81kg satellite to orbit aboard their Soyuz-2 rocket for R8.3 million - roughly R100 000 per kilogram. The craft itself cost R26 million to design and manufacture, roughly one-tenth of the cost that NASA would pay for the same craft (Martin, 2012). This massive price tag associated with building and launching satellites is a burden for many countries, hence the reason that so many private companies are beginning to compete in the satellite industry. The price is also part of the reason that so many governments and companies are turning to smaller, easier to manufacture CubeSats and why universities can contribute to the industry. The cost to manufacture CubeSats is a fraction of that to manufacture traditional satellites and they do not need a dedicated rocket - they can essentially "piggyback" on rockets used for other missions meaning that the launch cost is also less.

HISTORY OF SATELLITES

The history of artificial satellites starts in the late '50s. In an internationally shared interest for knowledge about outer space, the Soviet Union launched an artificial satellite, Sputnik 1, into space for the first time. The launch came as a surprise as the rest of the world was unaware that the USSR had the capabilities to launch satellites into space. The satellite's purpose was to demonstrate USSR's skills - a way to showcase their technology. The surprise of the launch and the technological capabilities of the USSR essentially started the space race, a competition which continued for more than a decade until the USA landed men on the moon in 1969.

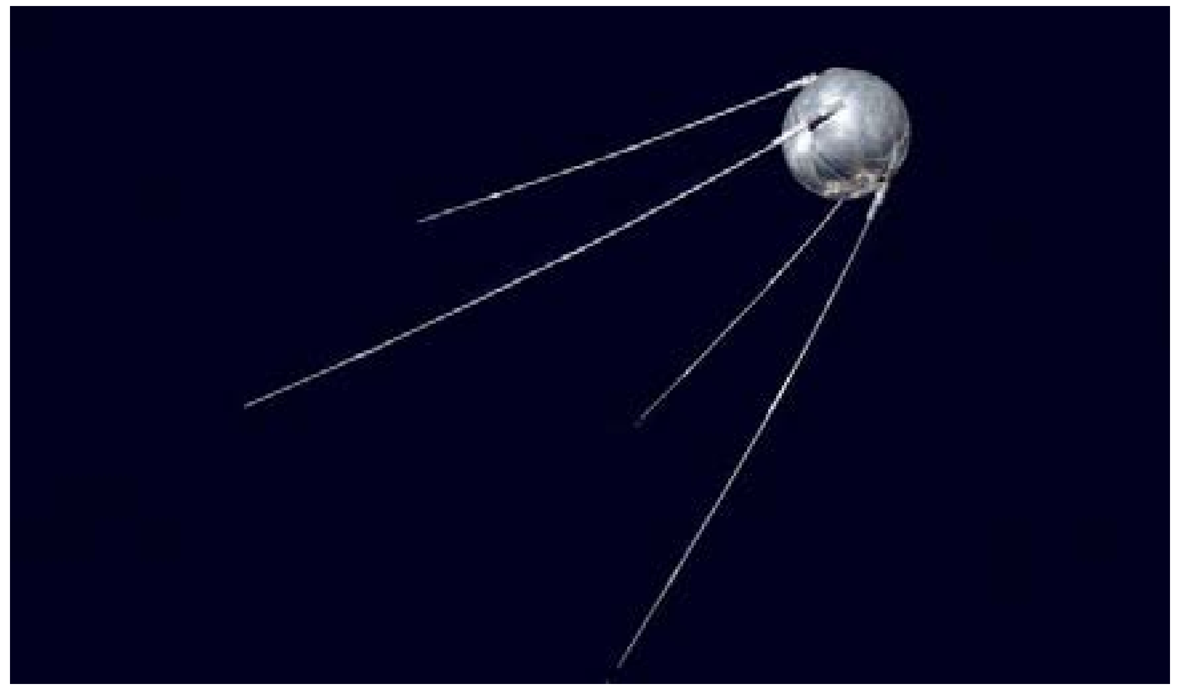


fig 19: Sputnik 1 Replica, owned by the National Air and Space Museum (Air and Space Magazine, 2017)

A month later after the launch of Sputnik 1, the USSR launched an even larger satellite into space named Sputnik 2. The second satellite housed the first terrestrial being to orbit the planet: a dog named Laika. Part of the reason for the second launch was to study the effects that weightlessness had on a living creature - clearly in preparation for launching a human into space. Regrettably, Laika died several hours after the launch of the satellite on the Sputnik 8K71PS rocket due to stress and overheating. However, this proved that weightlessness did not necessarily have an immediate negative effect on living creatures. The satellite had many functions, including measuring pressure, temperature, being able to pick up and transmit telemetry information. This multi-use satellite was the beginning of a long line of large satellites that had multiple uses once in orbit.

A few months later, the USA launched its first artificial satellite - Explorer 1. Considerably smaller than the 80kg Sputnik, the Explorer 1 weighed only 13kg. Much like Sputnik 2, the Explorer 1 had various uses once in orbit. Besides solely a technological demonstration by the USA, the satellite was also designed to detect cosmic rays, temperature, and had several devices to measure micrometeorite impacts.

fig 20: JPL Director William Pickering, James Van Allen and Wernher von Braun at a Washington, D.C., news conference holding a model of Explorer 1 after its successful launch. (NASA, 1958)

Over the course of the next several decades, the benefits of artificial satellites began to ripple through society with several other countries launching their satellites, many of which had a direct impact on the lives of the people down on Earth. These included satellites that were beneficial for weather forecasts, land-observing satellites used to track changes on the Earth, telecommunications satellites which normalised international television broadcasts and phone-calls and finally Internet connections. However, like many of the first satellites, these satellites tended to be very large and have a range of uses to justify the weight and price-tag of the satellites themselves.

The next stage in satellite development was the miniaturisation of satellites, possible due to the miniaturisation of relevant technologies. Although nanosatellites come in various configurations, CubeSats are the most common form because of the configuration created to make them accessible to a broader range of creators. Researchers created the CubeSat specifications at California Polytechnic State University in 1999 as a way to promote the development of the skills to design, test and fabricate nanosatellites with a specific set of research functions. The CubeSat specification was designed for graduate students to be able to build, test and operate satellites. Jodi Puig-Suari, one of the inventors of the CubeSat, said in an interview with Space News that he never imagined the CubeSat would become as popular as it did and to be adopted by universities all over the world and "that the National Reconnaissance Office (NRO), the Department of Defense, the National Science Foundation (NSF) and NASA would be interested in it was not on the radar screen". (Werner, 2012) The success of the CubeSat is partially thanks to the technological revolution. As Puid-Suari says, "the ability to do a lot in a small package with a very low power consumption has changed dramatically" and has allowed the development of a powerful research tool in a small package.

The CubeSat configuration has a simple definition: A satellite made up of modules of 100mm x 100mm x 100mm, with each module weighing no more than 1.33kg. The syntax for CubeSats is simple: one module is a 1U CubeSat, two modules is a 2U CubeSat, et cetera. The examples and extent of these CubeSats will be explored in the next section. Typically, researchers build CubeSats with off the shelf parts or parts taken from other technology, such as phones or cameras.

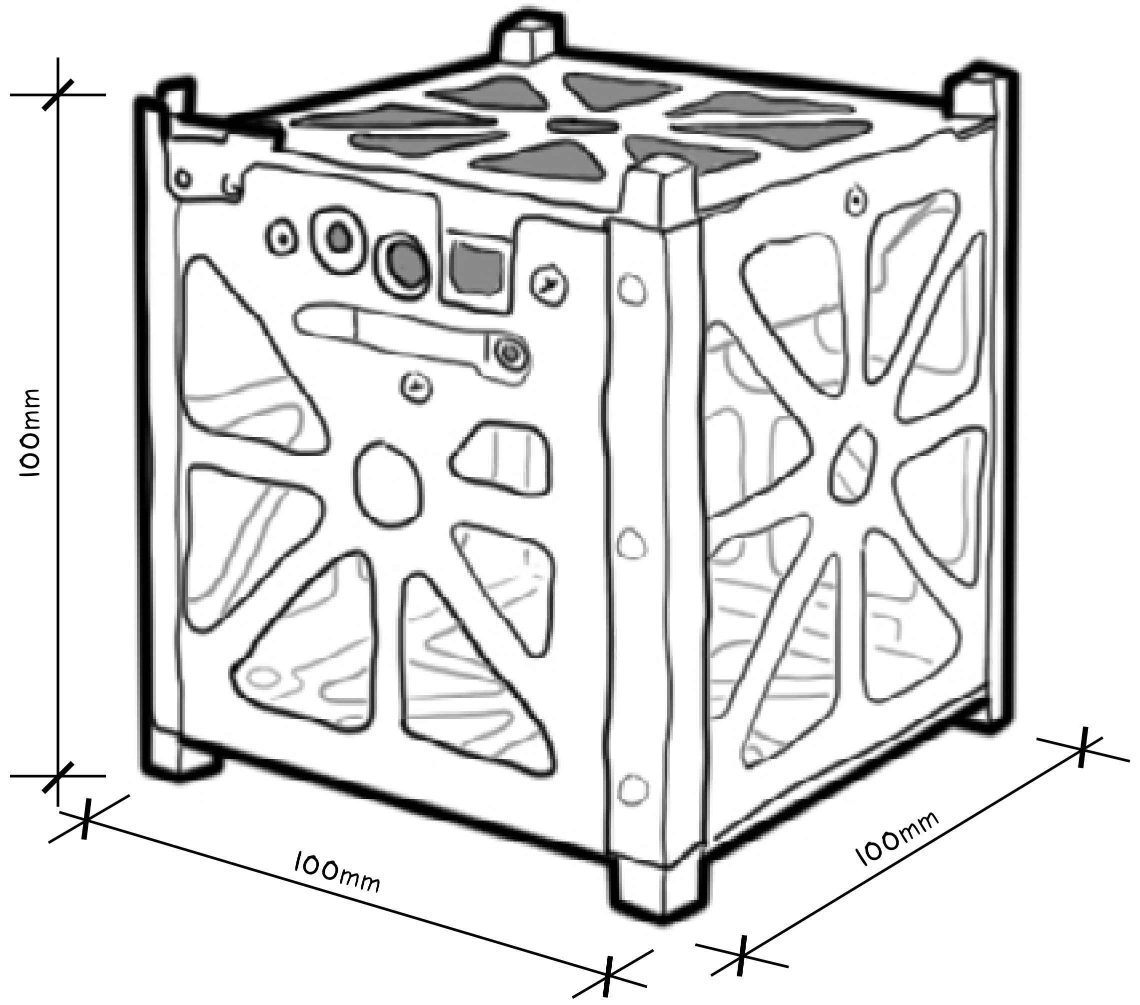


fig 21: CubeSat module frame

The miniaturisation of satellites has solved many of the problems with which manufacturers of full-sized satellites struggle. For instance:

• **They are cheaper to manufacture and are more convenient to make.** Traditional satellites often cost hundreds of millions of dollars to research and build, and the cost of launching these satellites to space can often be up to $1 billion. Nanosatellites can be created for as much as $100 000 dollars or even as little as $7 500 for an "at home" kit. Nanosatellites can also be built quicker than traditional satellites. Nanosatellites generally don't have as long a life as traditional satellites and as such the regulations for their creation are not as strict; this, combined with the cheaper manufacturing cost, means that they can be built in a fraction of the time as a full-sized satellite.

• **They can help space programs in developing countries.** Because of the low bar of entry for researching and developing a nanosatellite, it allows many smaller or less developed countries join in the international space industry. Often, less developed countries have to weigh the importance of developing a space industry against the cost of other more immediate needs. However, with such a low cost for research and development, not only are developing countries able to participate, it encourages the more youth to enter into STEM careers. Typically traditional satellites are researched and developed by experienced professionals, and large companies produce the technology. With the low cost and more relaxed regulations, nanosatellite research and training can be integrated into university curricula, allowing young people more exposure to the technology and more interest in joining the industry.

• **They are more technologically advanced than traditional satellites.** Traditional satellites have lifespans of sometimes up to several decades. The long lifespan of these satellites, and the continually improving technology of the modern-day, means that satellites quickly become outmoded. Earth observation satellites equipped with state of the art imaging equipment are frequently swiftly outdated, not least of all because the technology used in the space industry is often quickly adapted and improved for consumer technology. The shorter lifespan of nanosatellites, and the quick development period means that these satellites are equipped with the latest iteration of specific technologies. When the next iteration of a nanosatellite is developed, it will receive the most current version of the technology available.

• **They offer a unique configuration.** Traditional satellites can take anywhere between 1.5 and 24 hours to orbit the planet, which means that information gained by the satellite can only be refreshed once per that orbit. The benefit of nanosatellites is that, if they are arranged in a constellation (a network of satellites orbiting the planet) they can offer a real-time feed of any place in the world. This new configuration has opened opportunities for companies to maximise off of this new-found configuration. For instance, companies like SpaceX or SkyFi have formulated plans to offer a worldwide Internet connection by creating a constellation that broadcasts to the entire planet, leaving no place without communication contact - even the most remote areas. Until recently, this option was not available because of the drawbacks of having single satellite systems orbiting the planet. These constellations have further potential in being able to monitor things like forest fires, weather phenomena, marine life or ocean-faring vessels.

CUBESATS AND YOU

One of the most commonly levelled arguments against space exploration is that governments and companies have poured so much money into the industry with no direct benefit to the people on Earth; and while it is true that there are more pressing issues than space research, the advantages of space research is quantifiable in many ways. Many projects that have used the CubeSat framework have directly benefited people's lives without their knowledge. These benefits will be covered further in the next section.

South Africa's first in-orbit nano-satellite, ZACube-1, was a 1U CubeSat was launched on 21 November 2013 from Yasny, Russia aboard a Dnepr rocket as part of the ISLAUNCH03 mission. The mission's objective was to study the ionosphere. Traditionally, studies of the atmosphere were done via aeroplane and would require that the plane be flown to an extreme height at an extreme angle. At the top of the flight, readings would be taken for a few moments and then the plane would return. This would be repeated over the course of several hours until sufficient readings had been taken. The benefit of using CubeSats to do this research is that the mission can last between several months and several years - meaning that months of atmospheric data can be collected, not just several minutes worth of data.

While the objective of the mission, an international collaboration, was to take ionospheric readings, South Africa had its own secondary objectives: to demonstrate that South African institutions were capable of designing technology of this level and as a way to develop human capacity in the form of student training. These two objectives, having successfully been fulfilled, set a precedent for the country and proved that South Africa was capable of contributing to the international space exploration program.

ZA-AeroSat was South Africa's second CubeSat and fourth artificial satellite ever. The 2U satellite was one of 36 launched as part of the QB50 CubeSat constellation, being built by students at Stellenbosch University. Much like the ZACube-1, one of the objectives for the project was to demonstrate the capabilities of university students to conduct research, design and build a satellite of this complexity. This formed one of the mandates of the QB50 project, a project in which 20 different countries participated. The main tenets of the project were to facilitate access to space, conduct scientific research in the lower thermosphere, conduct an in-orbit demonstration of the technology used in the satellites and educate young scientists, engineers and researchers. The satellite was launched from the International Space Station on 18 May 2017 along with four other CubeSats from other countries. The planned lifespan of the project was three months after the launch date, with the expectation that the QB50 mission would collect a constant stream of data of the lower thermosphere during that time. The purpose of the project was to study the thermosphere during this period as it is the least understood layer of our atmosphere.

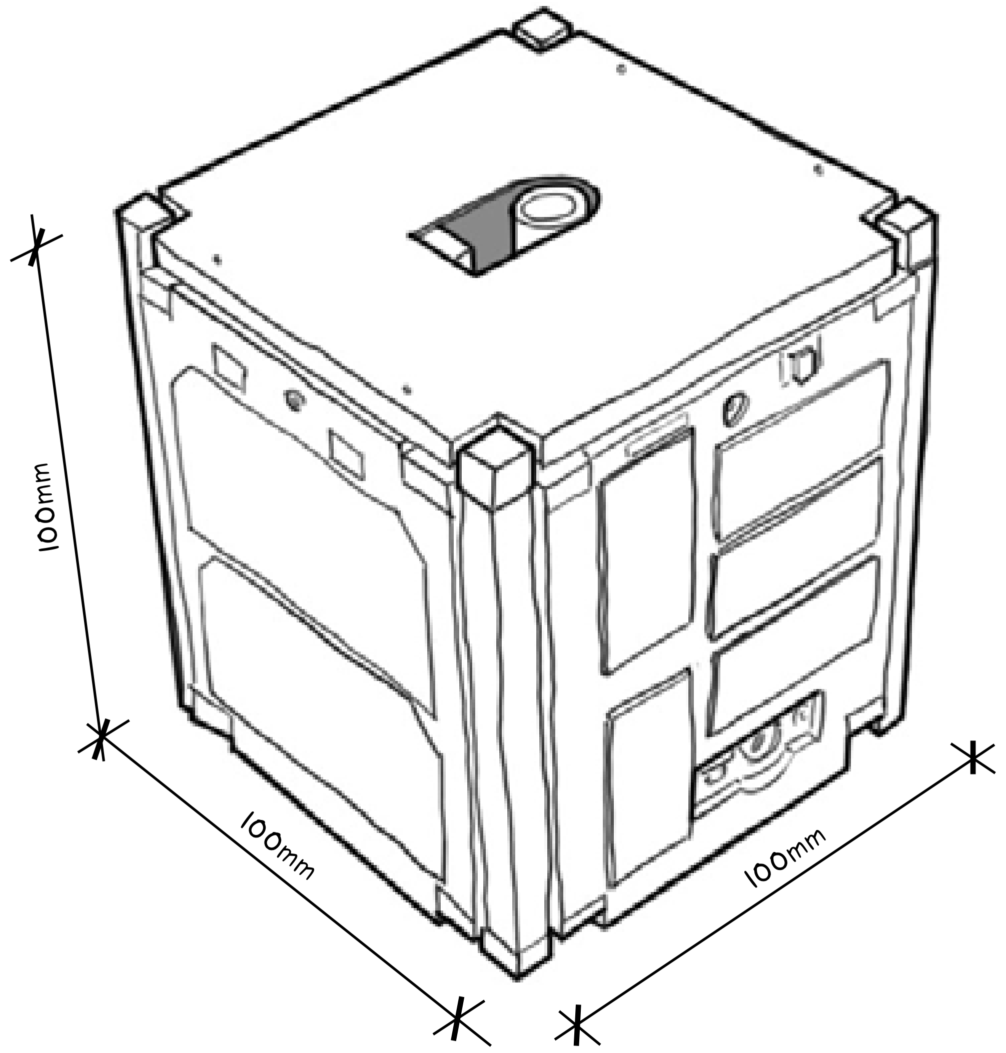


fig 23: ZACube-1, South Africa's first CubeSat, built by F'SATI/CPUT

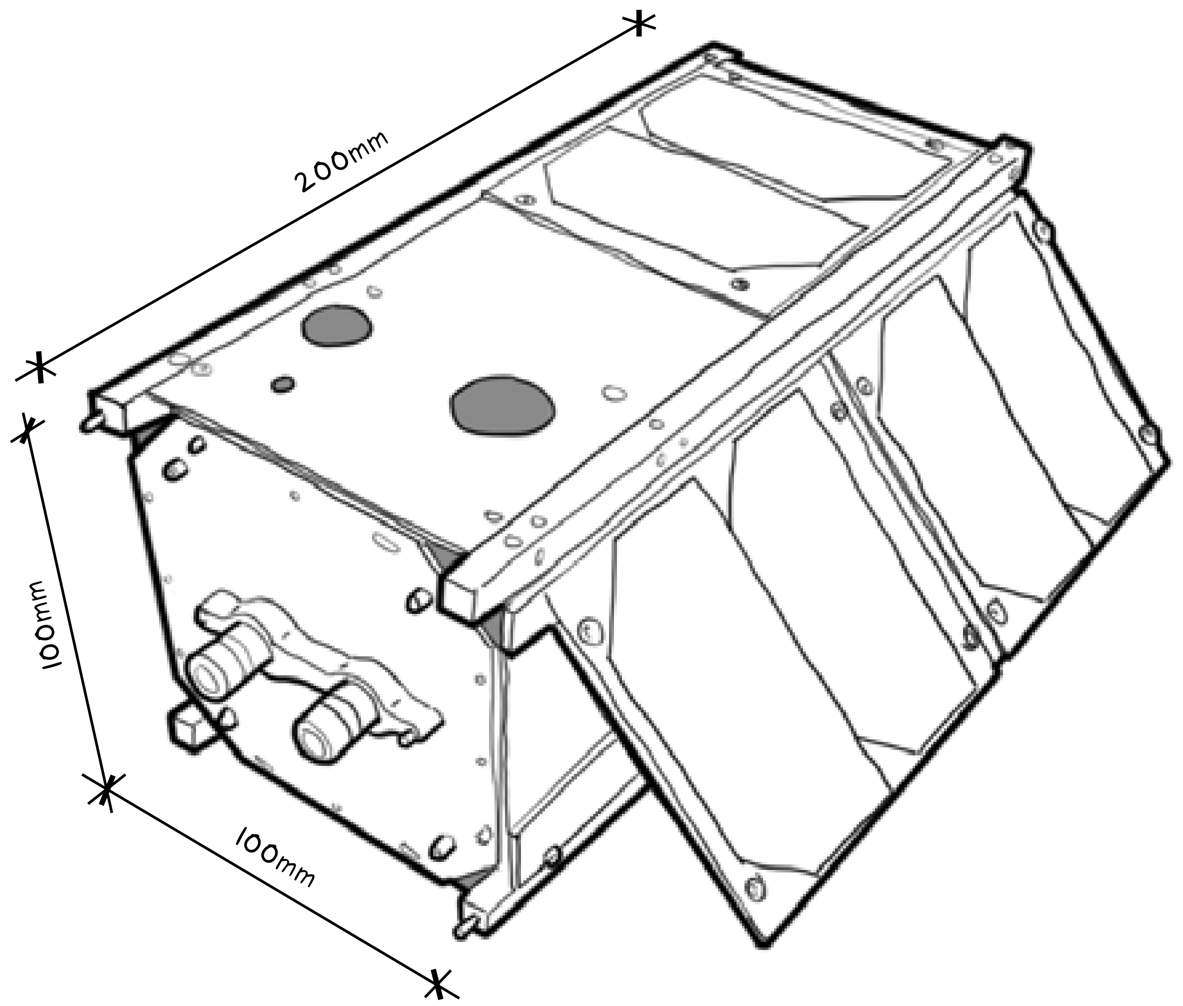


fig 22: ZA-AeroSat built by Stellenbosch University

The nSight CubeSat was South Africa's first foray into the private sector of South Africa experimenting with designing and building a nano-satellite. The Cape Town based company, SCS Space, built the satellite as South Africa's second satellite for the QB50 constellation and it was launched 25 May 2017. The satellite houses three payloads for three different mission objectives. Firstly, it houses instrumentation for thermospheric analysis, one of the primary goals for the QB50 constellation.

The second payload, which has significance for SCS Space, is their proprietary imaging camera - the SCS Gecko Imager. The inclusion of this imaging camera will explore the possibility of making it a commercial product which can be used for future projects, specifically ones for Earth observation. This Earth observation is useful for projects such as those used to monitor oceans, track ships or monitor natural disasters. While this is a fairly new industry for South Africa, and most of the technology is currently experimental, the expansion of this technology has a lot of potential for the future of the country. The third payload was provided by the Nelson Mandela Metropolitan University as a demonstration of the private satellite industry and universities around the country and the world. The payload was a patented Radiation Mitigation VHDL Coding Technique.

ZACube-2 is South Africa's most recent exploration into CubeSats, launched 27 December 2018.

ZACube-2 is a 3U CubeSat with several mission objectives: firstly, it is a platform to test the feasibility of tracking ocean vessels and monitoring ocean colour. For this task it has been supplied with medium resolution cameras. As an additional task, these cameras can be used to track large fires. For instance ZACube-2 was utilised in the monitoring of the Western Cape during the fires in late 2018 (Philander, 2019) and was used to monitor the pollution in the air following the fires.

Much like ZACube-1, the CubeSat also focuses on education and training and flight heritage for CPUT. It also served as a demonstration of communications hardware for further CubeSat projects.

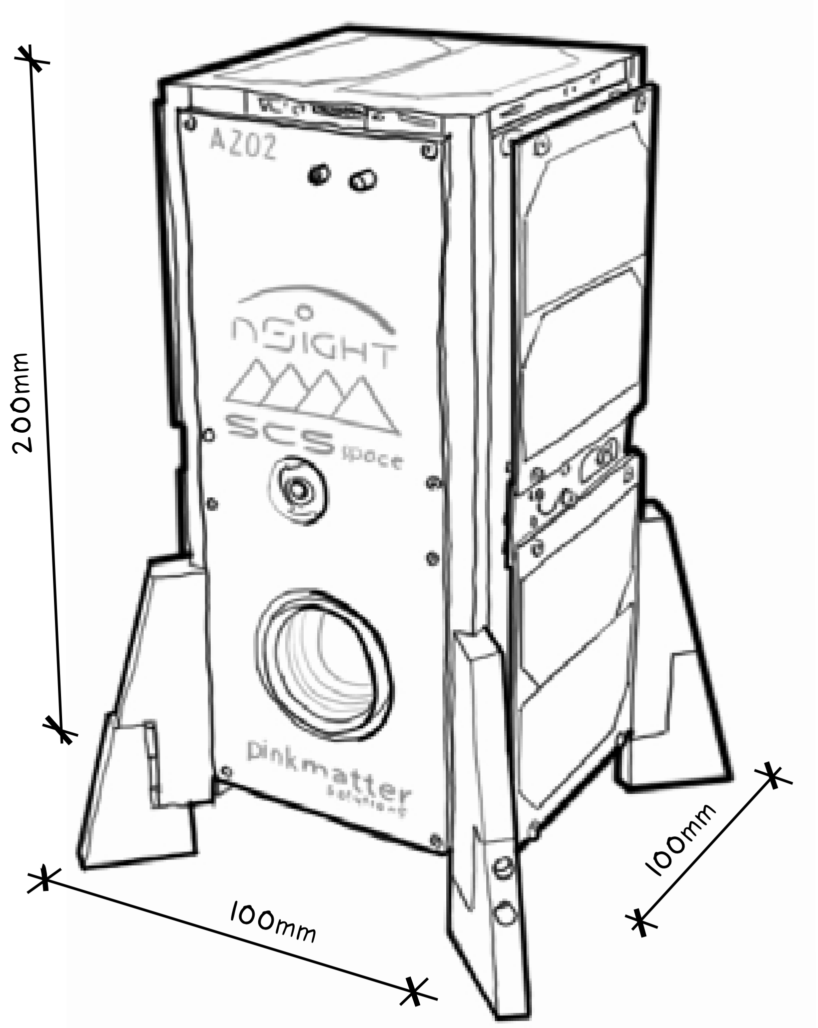


fig 24: nSight-1 built by SCSSpace

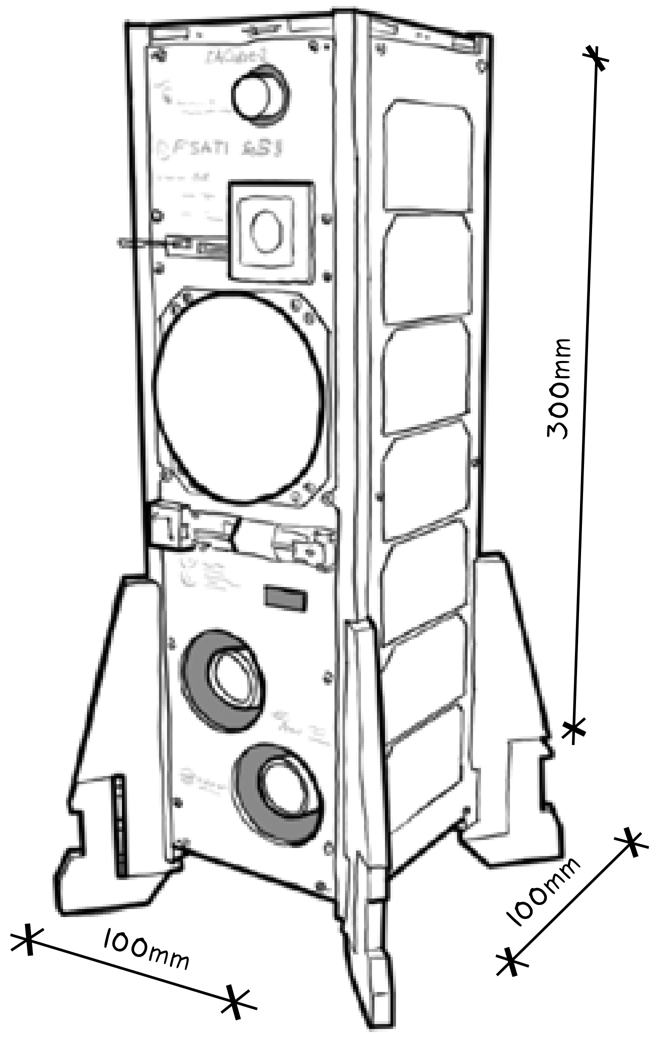


fig 25: ZACube-2, South Africa's second CubeSat, built by F'SATI/CPUT

HOW SATELLITES CAN BE USED

fig 26: Image of Tigris-Euphrates basin, taken in 2006 by Landsat 5 to track water loss (NASA, 2013)

fig 27: Image of Tigris-Euphrates basin, taken in 2009 by Landsat 5 to track water loss (NASA, 2013)

In the case of Earth observation for parts of the world that are hard to reach or are too large to simply observe from the ground, satellite images are used to track progress over time. This is one of the main uses for the images taken with the nSight-1 CubeSat.

One example of research conducted with these Earth observation satellites is the Tigris–Euphrates river system's water loss between 2003 and 2009. The loss of water was first noticed by GRACE (Gravity Recovery and Climate Experiment), a joint mission by NASA and the German Aerospace Center. The satellite works by periodically measuring the gravity of any given area; the rising and falling gravity of the area is an indication of a loss of mass, normally water. When GRACE reported that the Tigris-Euhprates river systems were losing mass, NASA used the Landsat 5 satellite to take images of the river.

Researchers then used a combination of satellite images taken of the area and the data captured by GRACE to determine that 144 cubic kilometers of fresh water was lost between 2003 and 2009, with a particularly striking loss of water during the drought of 2007.

The method of comparing multiple satellite images in order to monitor changes to the Earth is done for many different applications. For instance, the South African National Space Agency monitors several different topics including fires, food security, vegetation growth, human settlements and water resources.

South Africa's space agency, SANSA, has its own Earth observation department. Researchers collect data with international satellites and use the information to map out different layers of information. SANSA maps out 11 subjects, namely: geology, mining, agriculture, tree cover, urban planning, urban development, water quality, fire damage, flood analysis, snow cover and climate change. Each of these has sub-categories; for instance, tree cover as a broad topic covers crop anomalies, vegetation boundaries, food security, vegetation density and forest analysis; urban development includes formal and informal settlement, currently and historically, et cetera.

This information is available to the public, chiefly through their interactive website where one can apply layers of data over an interactive map, a la Google Earth, to gather information regarding their mapped topics.

The process of gathering information for each of the topics is different, relying on different satellites and different methods of processing data. The two maps shown are a good example of different approaches. The urban development map uses images of the same area over time to keep track of changes to the urban fabric. This is critical to advance and support governmental programs related to developing urban fabric and service delivery projects such as low-cost housing. The agriculture map uses "near-infrared and visible spectrum bands" and a set of algorithms to track the health of vegetation of a given area. This can be used to assist farmers in when, how or where to grow their produce.

fig 28: Image of Rustenburg in 2007 (left) versus 2012 (right) showing spatial urban growth (SANSA, 2015)

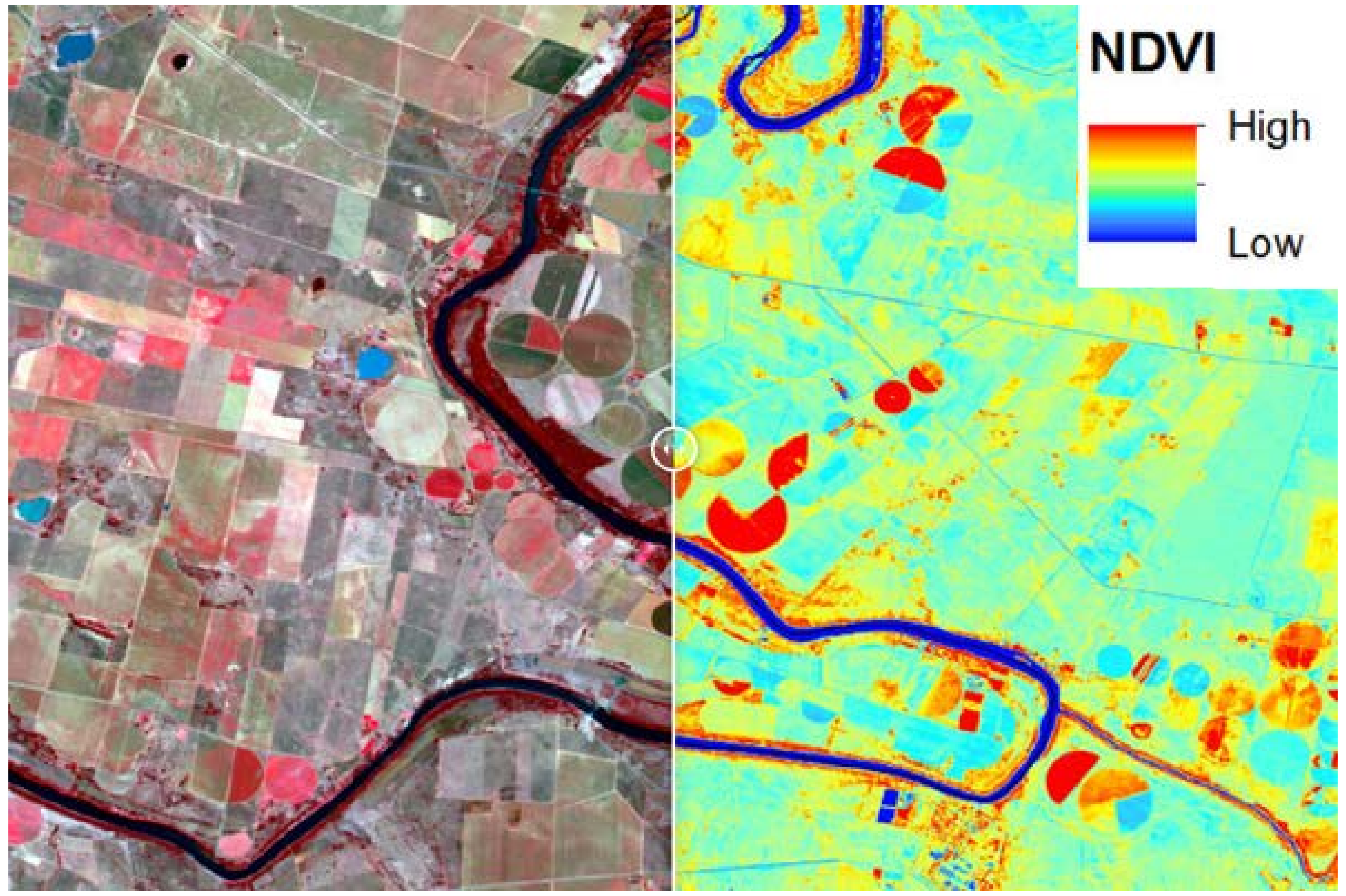


fig 29: Image of Bothaville farmlands in false colour (left) versus near infrared (right) to show soil health (SANSA, 2015)

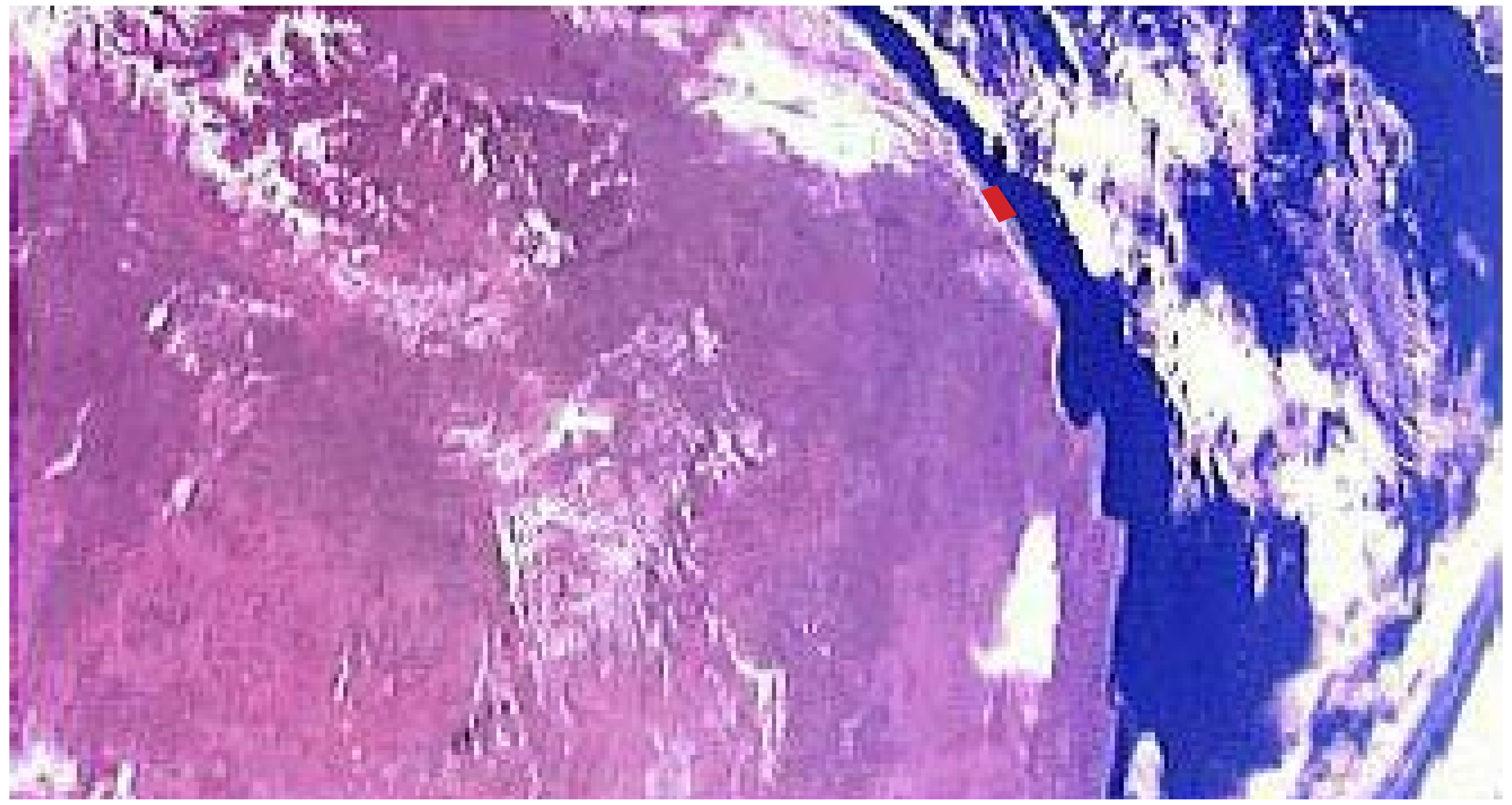


fig 30: An image of the Eastern Cape taken by ZACube-1 (F'SATI/CPUT, 2016). The red rectangle is the area captured in nSight-1's image of the Wild Coast.

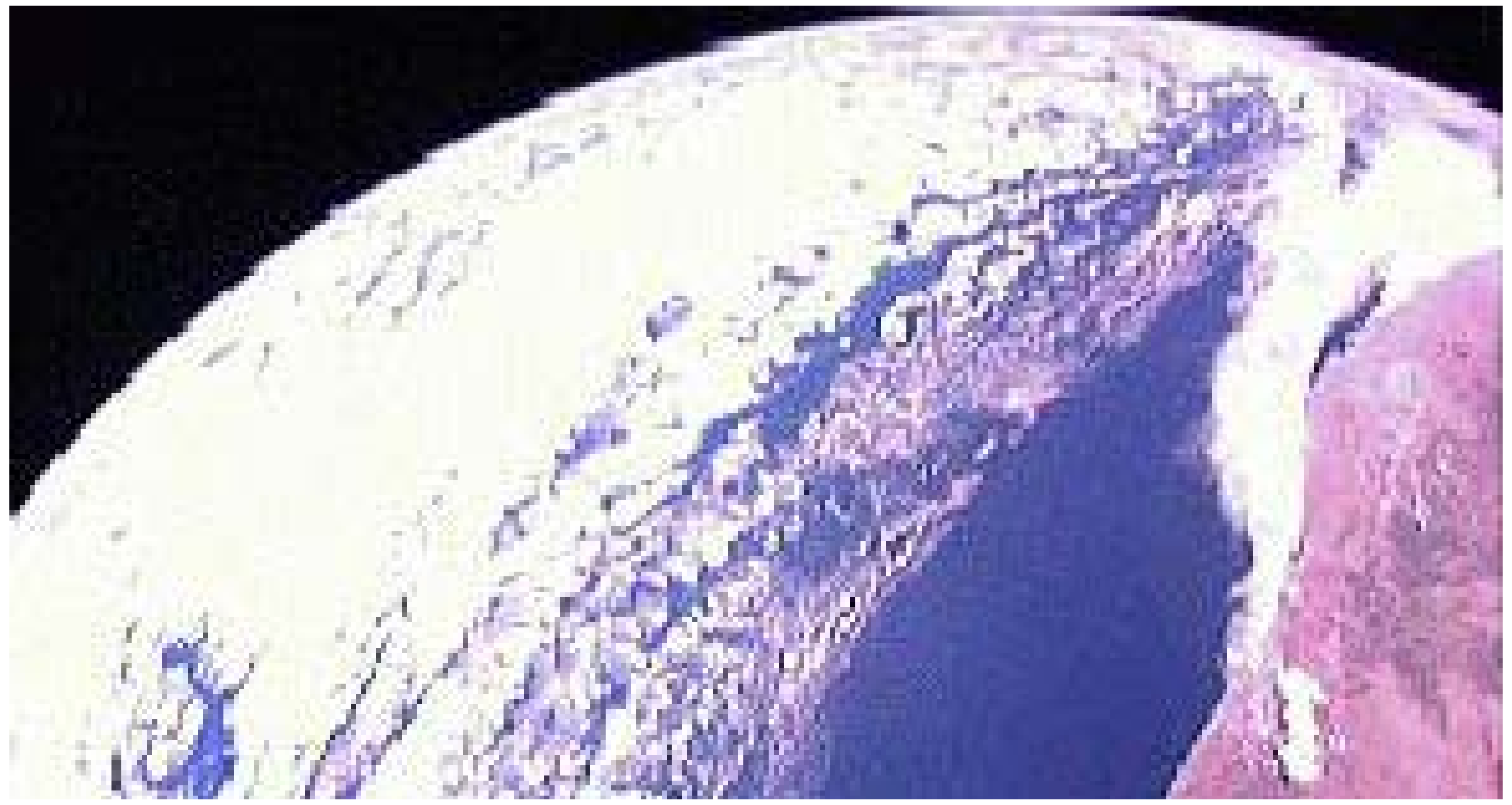


fig 31: An image of the Indian Ocean taken by ZACube-1 (F'SATI/CPUT, 2016).

To be able to capture images from orbit, satellites need to be engineered to fulfil that purpose; i.e., tasks that are not adequately engineered or planned for cannot reliably be undertaken. One such example is the imaging done by ZACube-1. If the satellite was intended to take high-resolution images of the Earth, it would need to be equipped with a high-resolution imager and the capability to stabilise itself; while it was equipped with a magnetorquer (a device that uses the Earth's magnetic field to stabilise the craft) the images reveal that the satellite may not have been able to stabilise itself sufficiently. The telemetry data transmitted from the craft showed that it entered a tumble after it reached orbit. The tumbling, as well as the fact that the imager was a low resolution, meant that images taken could not be used for Earth observation, although the satellite was created for ionospheric analysis. These images are used to emphasise the engineering required to be able to capture images used for Earth observation.

nSight-1 was developed by SCS Space, partially to fulfill a mandate by the QB50 mission in order to conduct thermospheric readings from orbit and partially to provide flight heritage to SCS Space and their proprietary imager, the Gecko Imager. The imager is designed to be used for CubeSats and the nSight-1 mission was the testing bed for the imager. A significant purpose of including a high resolution imager such as this into a CubeSat would be for Earth observation purposes, such as is conducted by SANSA. A CubeSat constellation equipped with high resolution imagers would be able to provide near real time observation of any anomoly in the world, from forest fires to floods. nSight-1 orbits the Earth every hour and a half, meaning that a constellation could have near worldwide coverage.

Unlike ZACube-1, nSight-1 was able to stabalise itself and even point to specific locations. This, coupled with the fact that it had a much higher resolution imager, meant that it was able to take much higher quality images, demonstrating that the imager is usable for Earth observation.

fig 32: An image of Wild Coast, Eastern Cape taken by nSight-1 (SCSSpace, 2017).

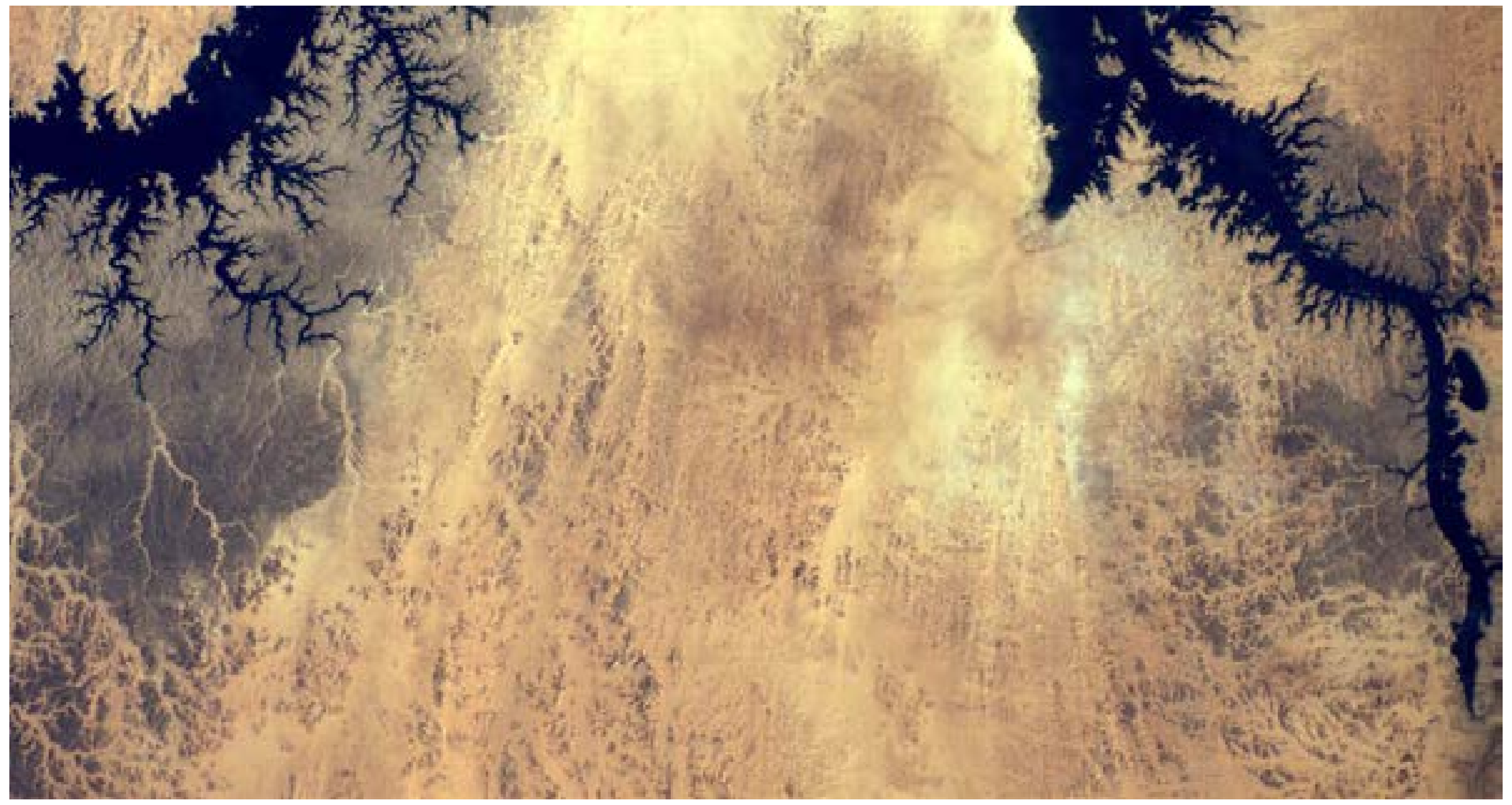


fig 33: An image of Aswan Dam, Egypt taken by nSight-1 (SCSSpace, 2017).

WHAT CUBESATS HAVE DONE FOR THE WORLD

It is pertinent to realise that the applications of CubeSats are universal. In the age of increasing globalisation, the nature of the satellites is that they are rarely used for one specific country - unless they are military or for a purpose for one particular country. So while CubeSats are launched by only a few countries or companies, generally their intended use is beneficial for all countries. The relative novelty of the CubeSat framework means that the heritage of the spacecraft involved has been mostly experimental. The number of planned satellite launches this year alone demonstrates the newness of the CubeSat framework: between 1998 and 2013 there were a total of 211 CubeSat launches (an average of 14 per year), less than half of the 438 planned to be launched this year alone (Kulu, 2019). A graph of this data is shown on the next page; note that while this number has increased substantially over the last few years, it will continue to rise. Nanosats has stated that they estimate this number will rise to 3000 satellites launched within the next 6 years. This also demonstrates the importance of South Africa choosing to back this industry now - the new market has a lot of potential for growth and making progress towards capitalising on that market is important to bolstering South Africa's space industry.

During this period (1998 to 2013), universities developed the majority of nanosatellites although some companies, militaries and other institutions were also involved in a small portion of the launches. This essentially means that the majority of missions during that time were purely experimental; finding ways to optimise the technology, creating flight heritage for universities or companies, creating relationships between companies and universities, et cetera. Although, as seen in the graph, there has been an increase in the number of launches by universities, this is now heavily outweighed by the amount launched by companies. Essentially what this means is that the age of beneficial CubeSats is only dawning now, with the most useful applications still to come. Nevertheless, there have been several successful missions over the last few years that have started to take shape and have valuable uses. This year, and likely over the next few years, there will be more news regarding large CubeSat missions and constellations run by companies that aim to provide a service to the public at large. There will likely also be an increase in the amount of universities and other institutions that become involved with CubeSat development, partially because as the technology becomes more widely embraced it will also become easier to practice development of these nanosatellites because of the amount of research available, the expertise available and the development of the actual technology and components involved in the satellites.

Planet Labs is an American company with the largest CubeSat constellation project currently in existence, with 355 satellites orbiting the globe. The objective of the constellation is to have a series of satellites that can image the entire planet daily or twice a day to keep track of micro-changes over time. The satellites use a telescope to take extremely high-resolution photographs of different areas of the Earth and transmit that data down to Earth once they are close enough to a ground station. The company uses data collected to help several different markets: agriculture, civil government, defence and intelligence, education and research, emergency management, energy and infrastructure, finance and business, forestry and land use, insurance, maritime and mapping. Like SANSA, the company provides this information to the public to service the needs of the people in whatever capacity they need. The application of CubeSats in a scenario such as this is an example of a new satellite framework overcoming the limitations of an outdated system. A regularly updated feed of information like this would be impossible with traditional satellites. Planet Labs is a private company, however, and the information that is freely available to the public is limited. Very high resolution satellites are available (with a resolution equivalent of 75cm per pixel) One can get higher resolution images of a specific location, at a price. With a government-funded scheme that mainly performs in the same way, one would be able to provide the government or the public at large with free information and could support community development or service delivery projects. This application is something that SANSA currently aims to do, but the limitations of the technology available to the agency have limited the usefulness of the program since the maps provided are updated annually, rather than daily. Planet Labs was integral to monitoring damages caused by Hurricane Dorian in the Bahamas. Daily imaging allowed the company to keep track of areas that were subject to severe damage.

fig 34: Marsh Harbour, Bahamas 29th May (top) and 4th Sept. 2019 (bottom) (Planet Labs, 2016)

Another example of the benefit of daily location monitoring is Planet Labs monitoring of Dukono, Indonesia's active volcano. No major eruptions have happened since the 16th century but the number of minor eruptions has been increasing since 2014. Planet Labs uses their Earth observation satellites to image the volcano daily or twice daily, in order to monitor the volcano. The images below were taken on August 24th and 25th in 2016 when the volcano had a minor eruption. Although the constellations were constantly taking photos of the site, researchers at the company started taking careful note of the developments during that time. Like SANSA, one of the objectives of the company is to provide post-disaster assistance.

fig 35: Satellite image of Dukono, Indonesia taken 24th of August 2016 (Planet Labs, 2016)

fig 36: Satellite image of Dukono, Indonesia taken 25th of August 2016 (Planet Labs, 2016)

Spire Global has launched 103 satellites into orbit and aims to increase that number to 150 shortly. Spire Global's primary objective with their fleet is to "[collect] data from space to solve problems on Earth" (Spire, n.d.). Their primary goal is to solve issues regarding maritime vessels, aviation, and weather analysis. Their constellation tracks the locations and monitors the health of ships and uses a series of machine learning algorithms to predict the positions of boats when not being observed. An extrapolated application of this technology is to help ships move in safer ways - as the satellites are used for monitoring weather, the company can provide vessels with a safer passage. Much like ocean-faring vessels, Spire also provides the ability to track aeroplanes. As the company states, "in the wake of the disappearance of Malaysia Airlines 370, there is a renewed sense of urgency to establish new methods of aircraft surveillance". As many planes fly over parts of the globe that are largely remote, they are unable to be tracked - Spire allows any flight on the planet to be reliably tracked. Finally, Spire aims to provide a reliable weather data platform that can provide live weather reports, possibly saving lives. As their satellites orbit the planet every 90 minutes, they typically have hundreds of satellites flying over the same place every day which could provide very accurate weather or potential disaster reports. This type of system could potentially minimise damage to communities due to flooding or fires, providing communities with sufficient data to manage these disasters. This, coupled with a service such as Planet Labs that monitors ground changes over time, could relieve much of the loss that communities suffer after disasters such as forest fires or floods.

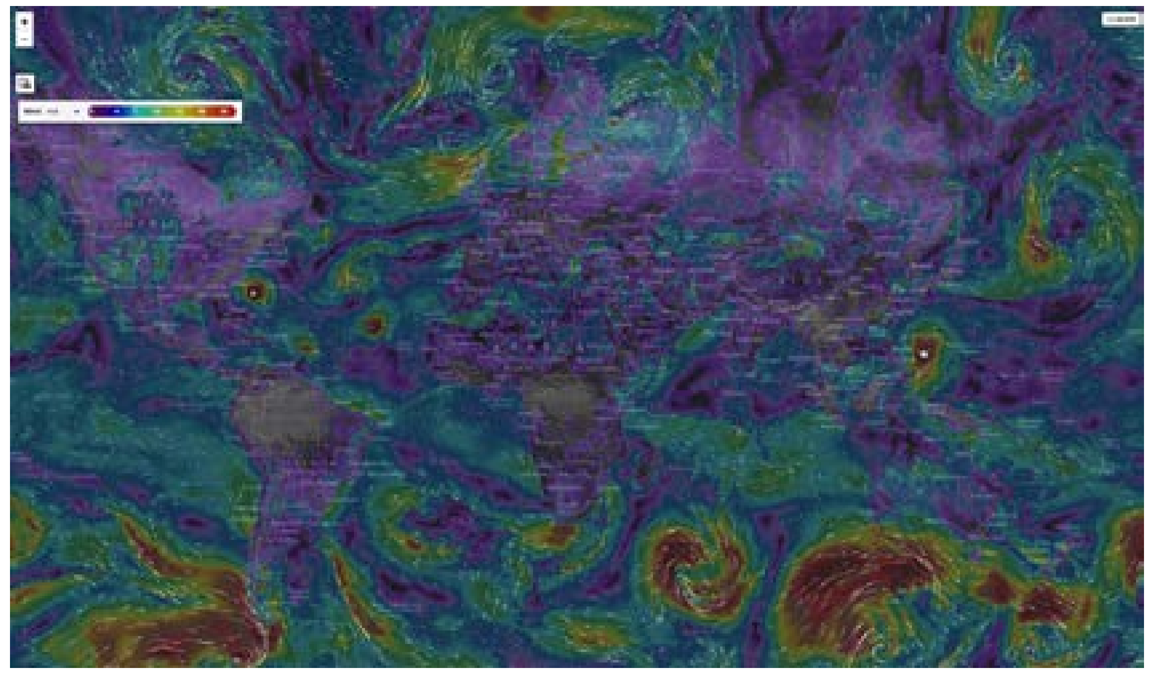


fig 38: A visualization of Spire Global's Weather Model (Gollier, 2019)

fig 37: A visualization of Spire Maritime's AIS archive over the Gulf of Oman (Gollier, 2019)

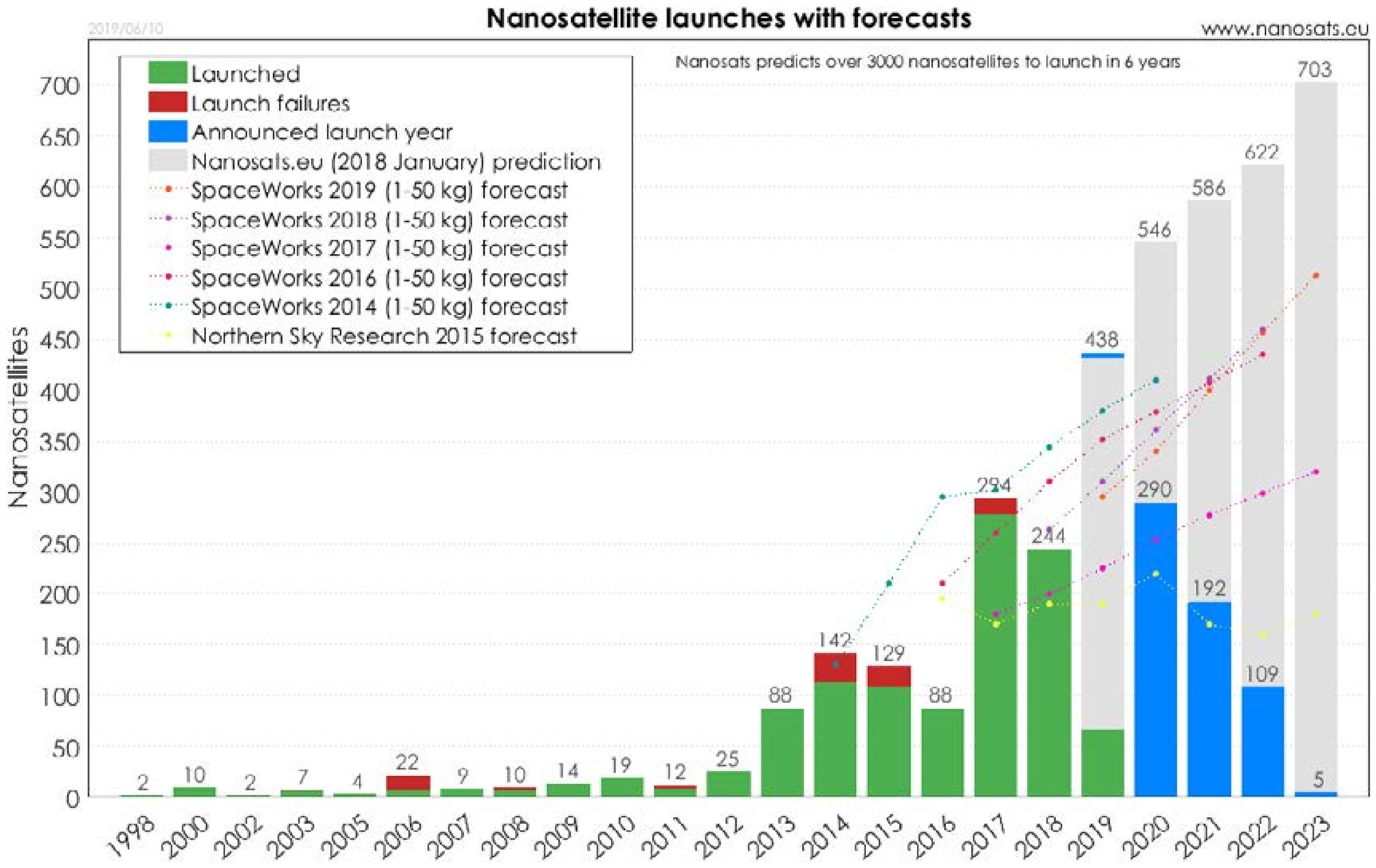


fig 39: Nanosatellite launches with forecasts (1998-2023) (Kulu, 2019)

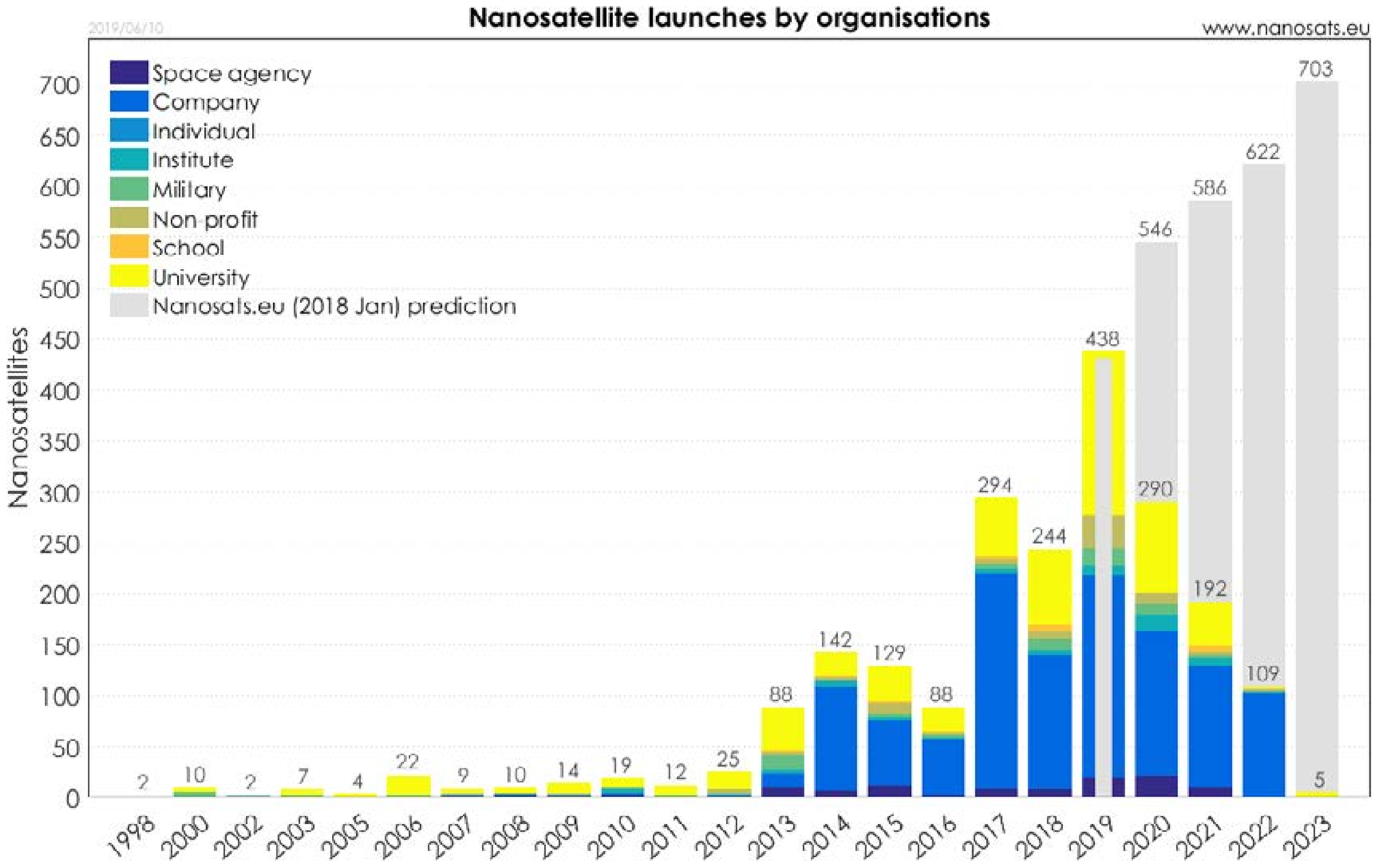


fig 40: Nanosatellite launches by organisations (1998-2023) (Kulu, 2019)

RESEARCH AND DEVELOPMENT OF NANO-SATELLITES

Broadly, the manufacturing of CubeSats can happen at three levels: individuals, educational institutions and the commercial market. Naturally, these three categories are broad and the approach to designing CubeSats in any of these categories will change, depending on the intended use of the satellite and the level of expertise of the creators.

As discussed previously, companies are currently the biggest manufacturers of CubeSats in the world. One of the most notable reasons for this is that historically, satellites have been massively expensive technologies to create. This alone would be fine, except that many satellite launches fail or the satellites themselves fail, thus leading to massive revenue loss. In recent years, with the wide adoption of CubeSats, companies have begun to realise that they can achieve the same, or higher, level of functionality with multiple CubeSats. This means that a failed launch essentially costs tens of thousands of dollars instead of hundreds of millions. The profitability of CubeSats is measurable and the impact that this adoption has had on the industry is also noticeable. However, it is important to note that profitability in the CubeSat industry is very one-sided. Money made from *manufacturing* CubeSats vastly outweighs money made from *using* CubeSats. The money in the industry is not in service delivery by itself. The market for selling satellite images has been saturated since the invention and wide adoption of Google Earth 15 years ago; money in the utilisation of CubeSats takes the form of data processing and form factors beside simple images or unprocessed information. Two examples of reinventing satellite service delivery are Planet and Spire, both companies take information, process it and sell their findings. In fact, this business model has been proven to be successful as Planet was the first CubeSat company to become a "unicorn" - a startup company worth more than a billion dollars.

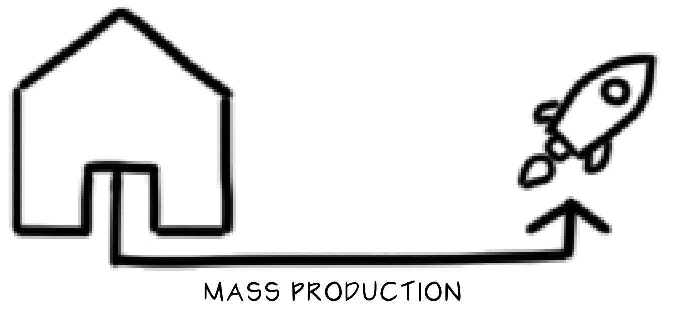


fig 41: "Internalised, fully vertically-integrated manufacturing and services" satellite production model

Large CubeSat companies use one of three methods to mass produce satellites. The first, and most common model, is the "internalised, fully vertically-integrated manufacturing and services" process. (Prasad, 2019) This means that the supply chain for the satellites is owned by the company, they have control over the ground stations that receive data, and the design and manufacturing process. This model allows adaptability in the CubeSat designs. Features are iterative and can be adapted to user requirements. Furthermore, it allows the company to have CubeSats that are updated with the latest technologies, maximising on one of the CubeSat framework's strengths. This is useful for a company such as Planet because they have several different types of satellites that are used for different services that they offer and as their client base grows, so too will the technology that they use. Owning the supply chain allows them to have state of the art CubeSats for relatively cheap. The drawback of this model is that it requires more capital. Large companies also tend to fall into a "routine" of sorts - in an ever adapting industry such as space technology, a company that operates in the same way for too long might be overtaken by smaller, more innovative companies.

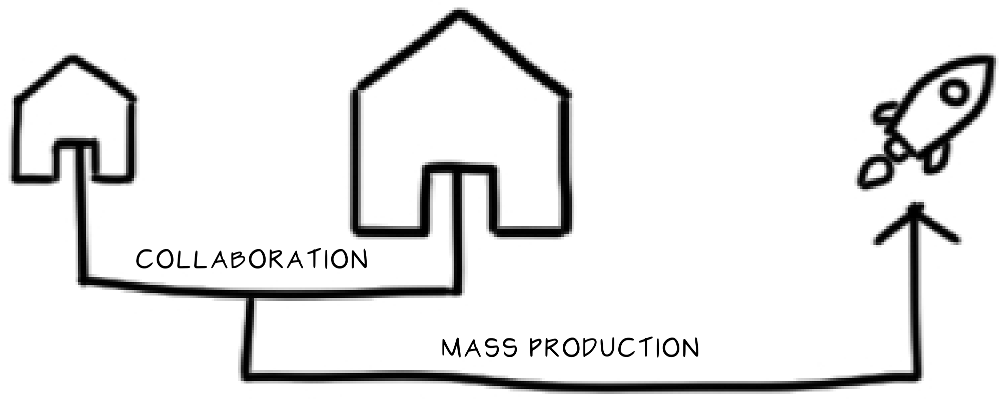


fig 42: "competence-based co-investment and partnership-based vertical integration for manufacturing and services" satellite production model

Some companies are choosing a second design model, "competence-based co-investment and partnership-based vertical integration for manufacturing plus services". (Prasad, 2019) This essentially functions in the same way that the first model does: a company owns a supply chain to manufacture satellites, but they collaborate with a smaller company to find innovative solutions for satellite fabrication and utilisation. This model has the benefit of using an established supply chain to minimise production costs, but using expertise from a possibly more innovative company in order to create a more reliable solution.

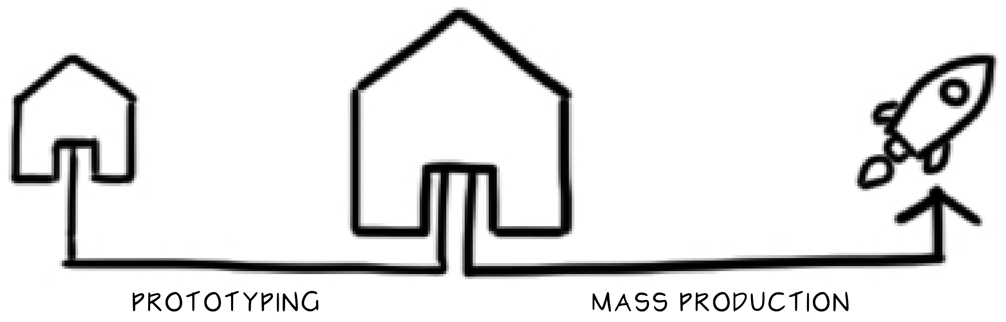


fig 43: "White label manufacturing service" satellite production model

The last solutions is the most likely to include research institutions such as the Observatory research centre. This model is called "white label manufacturing services" (Prasad, 2019) and essentially involves a large company giving a usecase for a satellite to a small institution. This could be a small company, a small team or a university class. The large company will give a mandate to the design team, who will create a prototype of a satellite that fulfils that purpose and it will be tested. If successful, this prototype will be adapted and mass produced for the company to use. This model allows more inclusion of students and researchers in the larger production of CubeSats and it takes advantage of the expertise that university students, professors and researchers can offer. The flexibility of smaller teams is also desirable as companies might change direction throughout the lifespan of a project; it is easier to make changes to a single satellite prototype than to change the entire output of a massive assembly-line like laboratory.

The creation for satellites at a commercial scale is similar to the process by which they are made at a smaller scale. The scale of the production and the design approach differs, but the fundamentals about the method of fabricating the satellites stays the same.

On an institutional level, satellites are often commissioned by the commercial market or by government agencies - the university class and the third party will then collaborate towards a common mission objective. This is the "white label manufacturing" model. However, not all institutions perform in this way. For instance, both ZACube-1 and ZACube-2 were funded by the French South African Institute of Technology (F'SATI) with a portion of R16mil of grant money given by the National Research Foundation (NRF) (Keating, 2014).

The design process for institutions is iterative; students will have a mission objective, either given by a third party or chosen by the class, and spend the duration of their year working toward that goal. Normally, the CubeSat components are divided amongst the class, each student getting a different component to design and fabricate with the class collectively building the satellite by the end of the year.

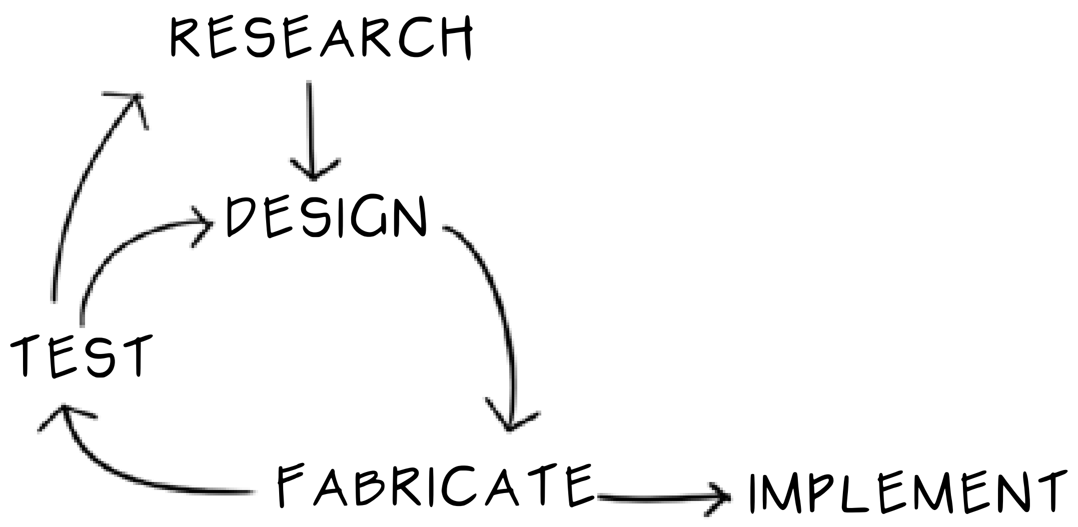


fig 44: Design cycle of satellites at an institutional level

Historically, satellite fabrication laboratories have been enormous warehouse-like buildings simply because of the size of the satellites in question, which would often have a deployed size of more than 10 meters across. Satellites require vacuum, heat and radio-interference tests as well and each of these testing facilities would need to be able to house the satellites. This meant that a satellite fabrication facility would be thousands or tens of thousands of square meters. Spatially, facilities required to fabricate CubeSats are much smaller. For instance, the F'SATI/CPUT satellite development facilities are $2500m^2$, and that number has been bloated by the inclusion of 48 research spaces for Master's and doctoral students. The facilities needed in CubeSat fabrication, however, are still very specific and often closely regulated. They are as follows:

Production areas where students can fabricate satellite components. These areas should be equipped with digital modeling and fabrication abilities - this would include 3D printers, 3-axis CNC machines, circuit board milling machines, microprocessor fabrication stations, workbenches and computers.

FM model areas allow students to program and encode the carrier waves of their satellites and would require computers and radio antennae. This space would also need to designed to mitigate radio interference.

A clean room for students to work on building the satellite or satellite components. The purpose of working in a clean room is to reduce the chance that alien particles (dust, hair, moisture, etc.) will come into contact and damage the satellite. These rooms have specific requirements, depending on the chosen rating. Satellite fabrication clean rooms can be as low as class 100 000, the lowest of six classes. This rating dictates certain requirements, such as number of air changes per hour, filter efficiency, ceiling type, light fixture type, wall system, floor cover, et cetera. This room should also be equipped with fabrication equipment and work stations.

Ground stations allow researchers to communicate with their satellites in orbit to collect data and send commands. These have certain requirements depending on the types of satellites being made, but are essentially satellite dishes and antennae.

Workspaces are simply computer labs with additional facilities such as microscopes, ham radios or large meeting tables.

Testing facilities are one of the most important and most used parts of satellite fabrication - researchers need to know that every aspect of the satellite is at peak performance before launch. For nanosatellites, most of the testing equipment can be housed in a single room as the spatial requirements are minimal. Testing facilities should include the following: radio frequency testing equipment that allows researchers to design the radio capabilities of their satellites. This is very closely regulated as almost all satellites communicate via radio, meaning room for error (which would lead to interference) is non-existent; a thermal cycle chamber to test if the satellites can survive in the cold vacuum of space; EMC reverberation chambers allow researchers to test the electromagnetic compatibility of satellites - satellites use the Earth's electromagnetic field for navigation and orientation; and magnetic characterisation equipment, which allows researchers to precisely calibrate satellites magnetometers and magnetorquers.

SATELLITE FABRICATION LABORATORY PRECEDENTS

The laboratories used for satellite fabrication are relatively small, normally smaller than 100m^2. This is primarily because all the construction and testing can simply be done on tables, it does not require large spaces or volumes as typical satellite construction does. For instance, Spire Labs' satellite assembly room is relatively small. The company hasn't been vocal about the size and specifications of their assembly labs, however based on images released, their laboratories do appear to be relatively small. This isn't to say that they're typical rooms, however. Regulation dictates that the construction meets very specific requirements, as discussed previously.

fig 45: Technicians work on the latest batch of Spire Global Lemur satellites (Gollier, 2017)

The company hired to design Spire's cleanrooms, Connect 2 Cleanrooms, equipped the cleanroom to meet a specific standard requested by the company. Spire required a cleanroom with classification 10 000, for electronic assembly. This rating implies several things: the room requires between 60 and 90 air changes per hour, meaning that a specific HVAC system needs to be installed. This HVAC also needs to be filtered air, as the room cannot have organisms smaller than 5 microns; the room filtration needs to be 99.99% efficient; these rooms can either have hardwall (solid panels) or softwall (plastic sheeting) envelopes, as long as the other requirements are met; these spaces require a locker room for changing and an airlock for removing loose particles; and lastly, the room needs to mitigate static buildup on surfaces and researchers, so it should be equipped with specialised floors. In the case of Spire's assembly rooms, the floor buildup is "conductive floor tiles, laid on copper earthing foil to the whole area, to dissipate dangerous charges" (Connect 2 Cleanrooms, 2017) that could damage the satellites. The cleanroom is 82m^2.

fig 46: Technicians work on the latest batch of Spire Global Lemur satellites (Connect 2 Cleanrooms, 2017)

CPUT/F'SATI's facilities are similar to Spire's in many ways. However, CPUT does not have the capital to fund as advanced a laboratory as Spire does. The general works spaces are equipped similarly, however CPUT has separate work stations to their cleanroom while Spire's cleanroom houses the necessary work stations. Separating work stations from cleanroom in an educational setting may be necessary because of the nature of students' work. They may be working throughout the night or eating or drinking while they are designing satellite components. Moreover, Spire's order of operations appears to be designing a CubeSat and then fabricating dozens of them whereas the iterative process that university research takes means that there is a lot more back and forth. The process for designing satellites differs and the design of the spaces reflects this difference.

fig 48: Master's class workspace (CPUT/F'SATI, n.d.)

As discussed previously, the cleanroom at CPUT/F'SATI has a rating of 100 000 which requires certain specifications for the equipment or construction of the room. The clean room requires between 5 and 48 air changes per hour, most likely on a separate HVAC system to avoid contaminates in the room. This rating also means that the room allows for larger particles than higher rated labs do, for instance Spire. Unfortunately, minimal information is published on CPUT/F'SATI's clean rooms - beside the rating, there is no other publically available information.

fig 47: Researchers gathered in CPUT/F"SATI cleanroom to discuss work on ZACube-1 (Steenkamp, 2012)

SATELLITE THEORY CONCLUSION

Ultimately, in order to effectively design a satellite research and fabrication centre, one needs to understand the principles behind the use and creation of these satellites and naturally this requires research into their application. This is true for the layout and design of the overall scheme, but also for individual research rooms or laboratories. For example, knowing what tests need to be run in order to fabricate a satellite is important for knowing what spaces to include in the building, or furthermore, how much space this equipment takes up and how other institutions deal with the lack off access to this equipment; or understanding the process of the satellite fabrication from conception to launch, one can understand what spaces play a role in the creation of this equipment, and therefore how one should design these spaces.

The scheme in general focuses on the overlap between academia and industry, particularly in the research laboratories. Understanding this particular relationship is crucial in designing an effective scheme and the spaces in which this interface happens. For some institutions, the directive from the third-party company is merely an end goal. The particulars of how this directive is given isn't something that a meeting or seminar room couldn't facilitate, and the spaces can be designed accordingly; in some cases, there is more interaction between industry and the creators of the satellite - in these cases, a more complex series of spaces would need to be designed to allow academics and professionals to work in the same laboratory. The understanding of the workings of the industry are therefore important to be able to choose how the scheme works, how the spaces facilitate this and then how the architecture revolves around the design of these spaces.

Programmatically, the public side of the scheme will focus on teaching people how satellites work, how they can be used and how they are created. Museum spaces should be designed in a way that displays the housed exhibitions appropriately - this cannot be done unless one knows what content these spaces will be exhibiting. For a class of students to understand how the CubeSats work in the atmosphere, they would need to understand how these satellites are able to orbit the planet or able to communicate with each other; naturally, the exhibition space should be designed in a way that can clearly communicate this information, and should not necessarily only be information boards that display this information. These spaces should be exciting and interactive and designed specifically to house the content of that exhibition. In theory, school children may have trouble understanding the complicated relationship between centrifugal force, gravity and momentum that allows satellites to orbit the earth. This relationship may be best described tactilely, possibly with a ball on a string or a water-based experiment; this may also best be described with a video exhibition. Each different approach to portraying information requires a different space and design approach and the specifics of how that information is displayed depends on the nature of that information. This is why it is necessary to include this information in the theory chapter, to effectively design these spaces rather than treating the exhibition spaces as a blank canvas for a hypothetical exhibition manager to design.

The nature of the scheme, and space research in general, is that it is often met with resistance. People struggle to understand the justification of spending millions of rands on space research or exploration that seemingly do not effect the people back on Earth. However, people also fail to realise that much of the research done for space exploration does effect them or other people on Earth, in more ways than they might understand. The resistance that the industry faces would also make it problematic to attempt to find funders or public approval for a scheme such as this. The research done on satellite applications and development would be used as a tool to convince investors or the public at large of the importance and need for a scheme such as this.

Similarly, one might find the choice of a scheme such as this to be problematic for a Master's student's architectural project, both in terms of the scale of the application of the satellites and relevance of the scheme to the country. The research done throughout this chapter provides precedence that this project is both achievable and necessary to the country.

fig 49: Image of Johannesburg taken from the International Space Station (NASA, 2011)

fig 50: Pyramids bordering El Giza, Egypt (Reding, 2019)

2 | architecture theory

One of the primary design intentions for the Observatory Centre is to make space an approachable concept again. The nature of space research, and therefore people's concept of space, is that it is marred by layers of politics, economics, governmental policy, business decisions, lack of public interest, et cetera. People have essentially been "disconnected" from space because of these barriers.

The Observatory Centre is meant to, in the public's eye, bypass these obstacles. The scheme is meant to ground outer space in the site and in the public's mind, therefore connecting people to space. This shouldn't be a foreign concept as for most of human history, people have had a personal connection to the sky - only in comparatively recent human history have people come to correlate space with these hurdles.

One of the primary informants for governing the orientation and configuration of the buildings on site is the scheme's response to the universe. Both the immediate universe in the form of the sun and moon, and the outer universe in the form of constellations. This chapter will explore architecture's relationship to both of these informants and ways to incorporate these elements into the scheme.

This chapter will also explore human's relationship with the stars, specifically in the form of these constellations. Part of this exploration will consist of examining what aspects of the human condition contributed to the determination of these constellations and how these aspects may translate to the design and interpretation of the scheme.

Architecturally, this chapter will detail the necessary approach to designing major aspects of scheme - namely, the research spaces and the exhibition spaces. This will be done partially through precedent studies and partially through research papers written by architects or professionals in academic fields related to the program of the Observatory Centre.

PAREIDOLIA

Pareidolia is the tendency to interpret vague stimulus as something familiar to the observer. Pareidolia explains the perception of objects in clouds, shapes on the moon, constellations, or dogs in rocks.

fig 51: Faithful as a rock (Anon, 2018)

Generally, the perception of faces is the most common - but the interpretation is always something familiar to the observer. Pareidolia is a result of the human brain and the pattern recognition important to our survival as a species. This evolutionary trait is normally argued to happen for two reasons:

• Babies tend to be looked after better if they can recognise faces more intuitively. As astronomer Carl Sagan says, “those infants who a million years ago were unable to recognise a face smiled back less, were less likely to win the hearts of their parents, and less likely to prosper”. (Sagan, 1997)

• Protection from predators. Our ancestors who could detect predators with minimal evidence were more likely to survive. Thus, natural selection has made us a species that more easily recognises faces.

Humankind’s survival relationship with pareidolia has largely ended, it is triggered in most people when looking at clouds or patterns on the Martian surface. In the modem age, pareidolia is, by and large, related to either psychology or superstitions. In psychology, the Rorschach test was used to supposedly reveal a patient’s innermost thoughts and desires by allowing the subconscious to express itself in the form of pattern recognition. The Rorschach test’s use in psychology is now largely disputed because of it’s lack of empirical evidence or apparent usefulness.

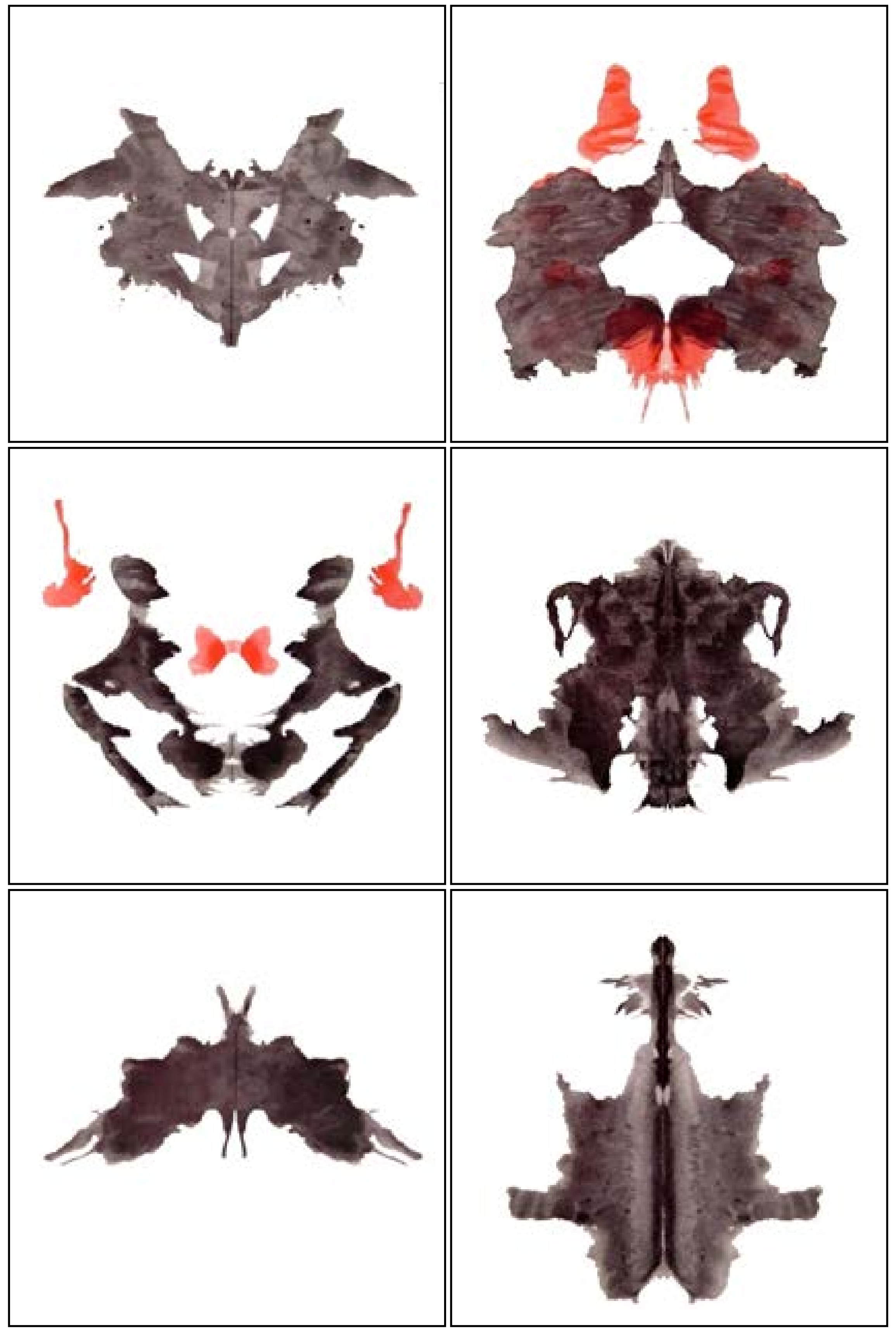


fig 52: First six inkblots from the Rorschach Inkblot Test (Harris, n.d.)

Superstitious or religious people are proven to be more likely to see faces where there are none. Cases such as these explain the existence of beliefs such as the fact that aliens built a mountain in the shape of a face on Mars or that Jesus revealed himself to someone in the form of burnt toast. Religious or supernatural figures revealing themselves in the universe around us also explains the existence constellations and the belief in myths tied to their creation.

HISTORY OF CONSTELLATIONS

To a species with a tendency to see familiar forms in random stimulus, the night sky represented many things to many different groups of people around the world. Naturally, people would attempt to make sense of the seemingly recognisable forms in the night sky which led to most societies having their own set of constellations or something to that effect. Each society around the world had its own constellations, the forms of which were influenced by their own experiences and societal makeups. This has led to the same stars having several different constellations associated with them. For instance, Orion the Hunter to the Makonin people of Zimbabwe was Mwuetsi, the first human. As humans tend to assign meaning to pareidolic apparitions, societies often associated the appearance of constellations to certain natural events that coincided with their appearance in the sky. For instance, to many cultures, Aries represents the harvest and abundance. To pre-6th century Greeks, the stars in the constellation Aries represented a farmer, possibly because of it's presence in the sky during the harvest. In China, the stars in Aries were used in a constellation called Lou, translated to "sickle"; these same stars could also represent a woman carrying a basket on her head, and a constellation named Wei which takes the form of a fat stomach. In Peruvian astronomy, most of the stars in Aries were used in a constellation whose name translates to "Market Moon", a reminder to hold Ayri Huay, the annual harvest festival. This is also an example of how constellations were used by most people around the world - as time keeping tools. This, and its relation to architecture, will be discussed in more detail later in this chapter.

For most of human history, people have observed the night sky without aid from special equipment. This is called naked eye astronomy and for thousands of years played a huge role in the lives of people living under the night sky. These naked eye observations can help observers figure out a lot about the universe, even without equipment, provided that they pay attention over the course of weeks or years. There are approximately 1000 stars that are visible to the average person and with sharp enough vision one can see up to 6000 stars in the night sky, with varying brightnesses because of the size of the star or the distance away from Earth. (CrashCourse, 2015) The creation of constellations comes from two factors: that some stars stick out as brighter than others and that stars are not spread evenly across the entire sky. The scattering of stars is mostly coincidence but because of humans’ pareidolic tendencies, these groups of bright stars were understood to belong together. In the modern day, Western astronomy recognises 88 official constellations, dividing the night sky into different boundaries; even if a star doesn’t form any portion of constellation itself, it can fall within a constellations boundary and therefore is part of that constellation. Orion is the most widely recognised constellation in the night sky today, with stars that are bright enough to detect with naked eyes and of a familiar enough shape that many civilisations recognised the form of a man with his hands raised up.

fig 53: An engraving of Orion from Johann Bayer’s Uranometria, 1603 (Kim, 2015) with the official modern Orion delineation superimposed

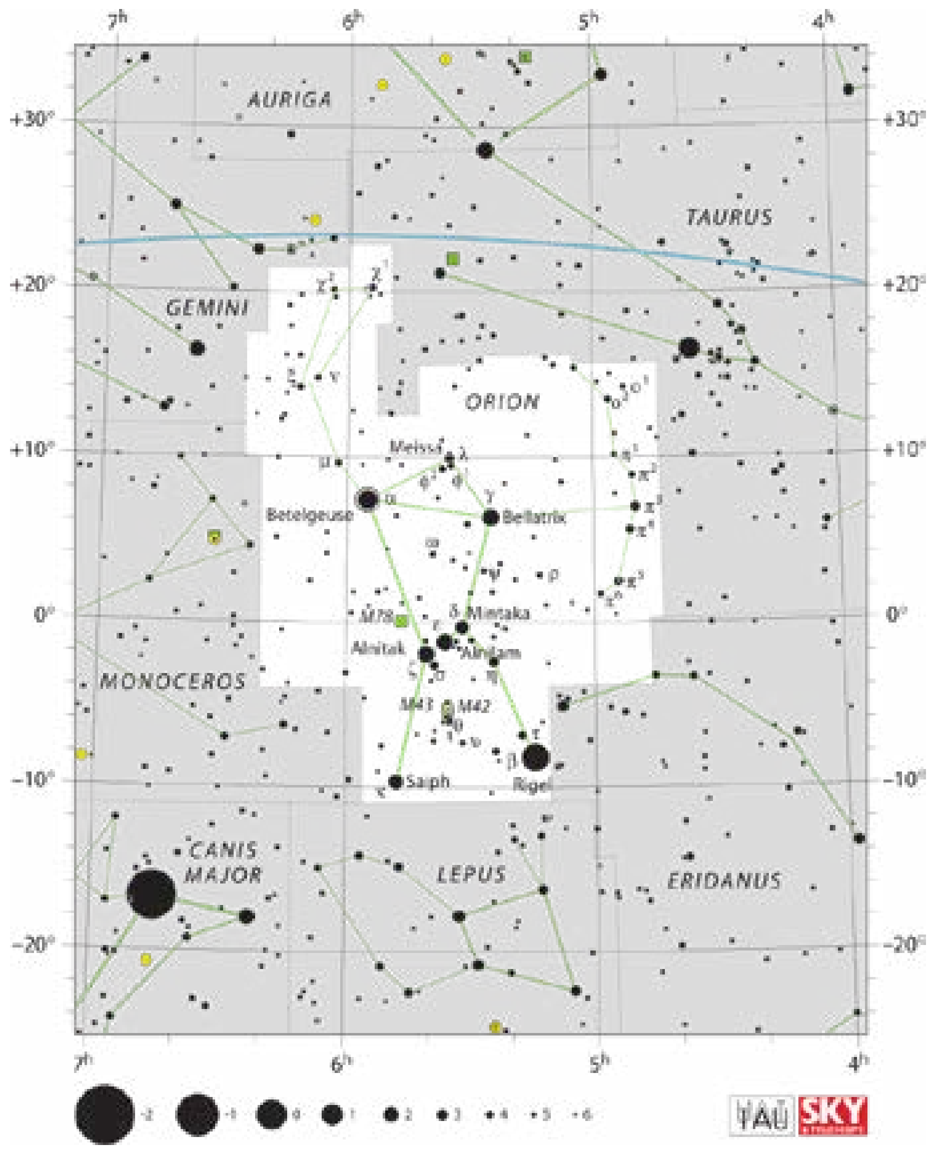


fig 54: IAU Orion Chart showing the boundary of the constellation and the stars included in the constellation (IAU and Sky & Telescope magazine, 2011)

HISTORY OF CONSTELLATIONS

There are several reasons that constellations played a bigger role in the lives of people in the ancient world than in the modern world: modern humans have other systems to keep track of dates, times and locations; cultures generally have different beliefs now, placing less importance in the constellations; and modern civilisation makes it harder to see the night sky with light pollution being so prevalent around human settlements, meaning that once prominent constellations are barely visible.

fig 55: Orion in the night sky with light pollution (left) versus without light pollution (right) (CrashCourse, 2015)

Constellations also change over time; as stars move through the galaxy their position in the night sky also changes. However, they also change in terms of the stars that are associated with them. One of these examples is Aries: the shapes that the stars made were once a farmer and were later associated with the ram. Or the Chinese constellations that shared stars with Aries - even at the time, the same stars were used in three different Chinese constellations. Another instance of a constellation changing is Ursa Major changing to The Big Dipper. The need to change Ursa Major into The Big Dipper may have been because the stars that defined the rest of the bear's body had become less noticeable in the night sky over time, so what is left as being very noticeable is only the back and tail of the bear. However, bears don't have tails so while ancient astronomers might have been excellent astronomers, they lacked zoological skills. This might also be a reason that the Big Dipper is the more recognisable constellation - the shape of Ursa Major is inaccurate and so has been replaced with something more contemporary and recognisable, a soup ladle.

fig 56: Ursa Major (Jamieson, 1822) with the official modern Ursa Major and Big Dipper constellations superimposed

The Zodiac calendar takes twelve constellations that align with the plane of the solar system and use them to delineate certain periods of the year. While these constellations coincide with the same dates every year, the time they spend in the sky, the solar stay, are all different. Scorpio has the shortest solar stay at 7 days, and Virgo has the longest at 45 days. So while their appearance might coincide with certain events and for ancient peoples, might have been a good way to track major events, their distribution throughout the year is uneven and so using their appearance as a formal calendar is not viable in modern times. Not only do the lengths of the solar stays differ from Zodiac sign to Zodiac sign, but their presence in the night sky changes - albeit, over a very long time. Over the course of 26000 years, the dates of the Zodiac Equinoxes change. This is one of the arguments leveled against astrology: the dates of ones "star sign" do not coincide with their appearance in the sky as the signs essentially drift over time, meaning that character traits dictated by star signs do not coincide with ones date of birth.

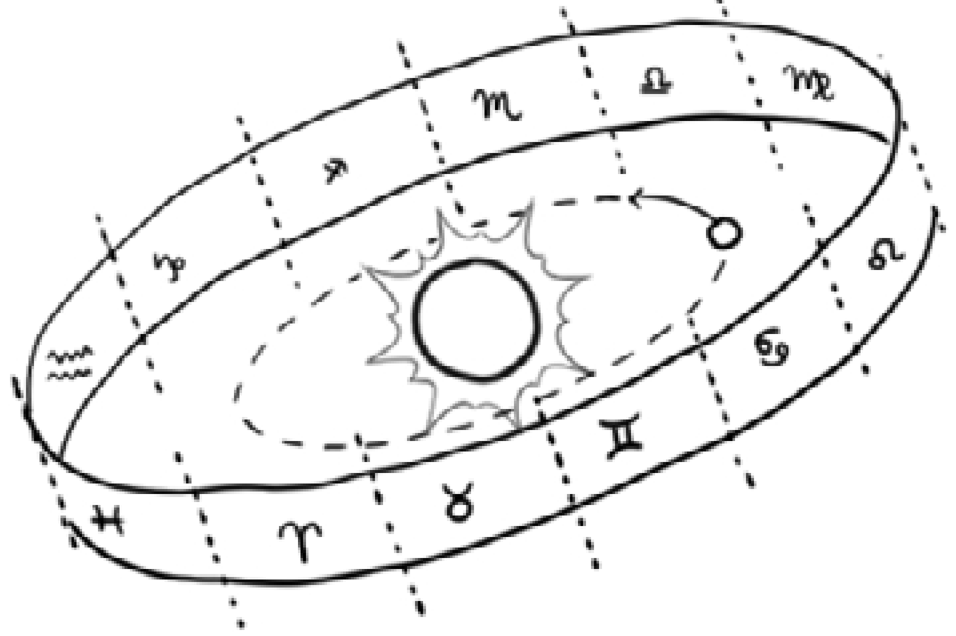


fig 57: The twelve Zodiac signs divided into the night sky, each taking up 30° of the sky and changing as the Earth orbits the Sun

ARCHITECTURE AND THE SKY

As discussed previously, most cultures around the world had an intimate relationship with the sky, whether that relationship was because a culture worshiped the sun or used the stars for navigation and time keeping. Archaeoastronomy is the study of how people "have understood the phenomena in the sky, how they used these phenomena and what role the sky played in their cultures." (Bostwick & Bates, 2006) Much archaeoastronomical study is dedicated to understanding the tools that people used for their astronomical observations.

Naturally, as people used the sky in some capacity throughout their lives, they began to build tools for or methods of keeping track of astronomical events. One of the most well known of these tools is Stonehenge, however Stonehenge was not the first piece of archaeoastronomical evidence to be studied. As early as the 1600s, antiquarians sought evidence of the orientation of churches as being tied to their relationship to the solar system. These studies were essentially a precursor to the modern study of archaeoastronomy, however the significance of church orientation was more likely related to the significance of the Sun in religious symbolism rather than as a tool for tracking the movement of the Earth. In the early days of archaeoastronomy, before it even had a formal name, researchers Richard Proctor and Charles Piazzi Smith were investigating the relationship between Egyptian architecture and the stars. One of the most cited relationships, although it is often critiqued, is the Giza pyramid complex and Orion's belt. Osiris, the Egyptian god of the afterlife, is associated with the stars of Orion, (Mackenzie, 1978) and the stars in Orion's belt seemingly align with the pyramids of Giza. The fact that Egyptologists believe the Pyramids were used as tombs further supports this theory.

fig 58: Photograph of Orion's belt (Scudder, 2016) superimposed on onto a Google Earth image of the Giza pyramid complex

Interest in archaeoastronomy increased in the '60s when engineer Alexander Thom and astronomer Gerald Hawkins proposed that Stonehenge was used as Neolithic computer, not in the contemporary sense but rather as a tool for calculation - specifically for calculating the movement of the sun. For 5000 years after its creation, the purpose of Stonehenge was lost to time. The site became a site of worship for the ancient druids and it was rumoured to be the site that King Arthur was crowned. It was evident, based on the amount of work that would have been needed to create the structures, that the site was incredibly important to the Neolithic people that created it, however its exact purpose was unknown.

In the '60s, Hawkins conducted a study that proved that the site aligned with numerous solar events, the most notable of which was the summer solstice. Over the years this theory was expanded upon and helped to explain much of the presence of structures around the rest of the site. The theorised method of calculating the day of the solstice was to stand in the centre of the site and look north-east toward the rising sun. (SunEarthDays, 2014) On any other day, the sun would rise next to the heel stone, a stone or pair of stones, placed approximately 80 meters from the site; however, on the morning of the summer solstice, the sun would align with the heel stone, eventually appearing over the top of the stone.

fig 59: The Heel Stone, seen through the Great Trilithon (Banton, 2014)

However, the prevailing theory now is that the site was most likely built primarily to calculate the winter solstice. As the days become shorter leading up to winter solstice and begin to grow in length following it, the winter solstice would have been an important time for the Neolithic people of the area. To the people who built Stonehenge, the winter solstice represented the turning of the seasons and the beginning of spring, and therefore food security. (Vox, 2017)

STONEHENGE ANALYSIS

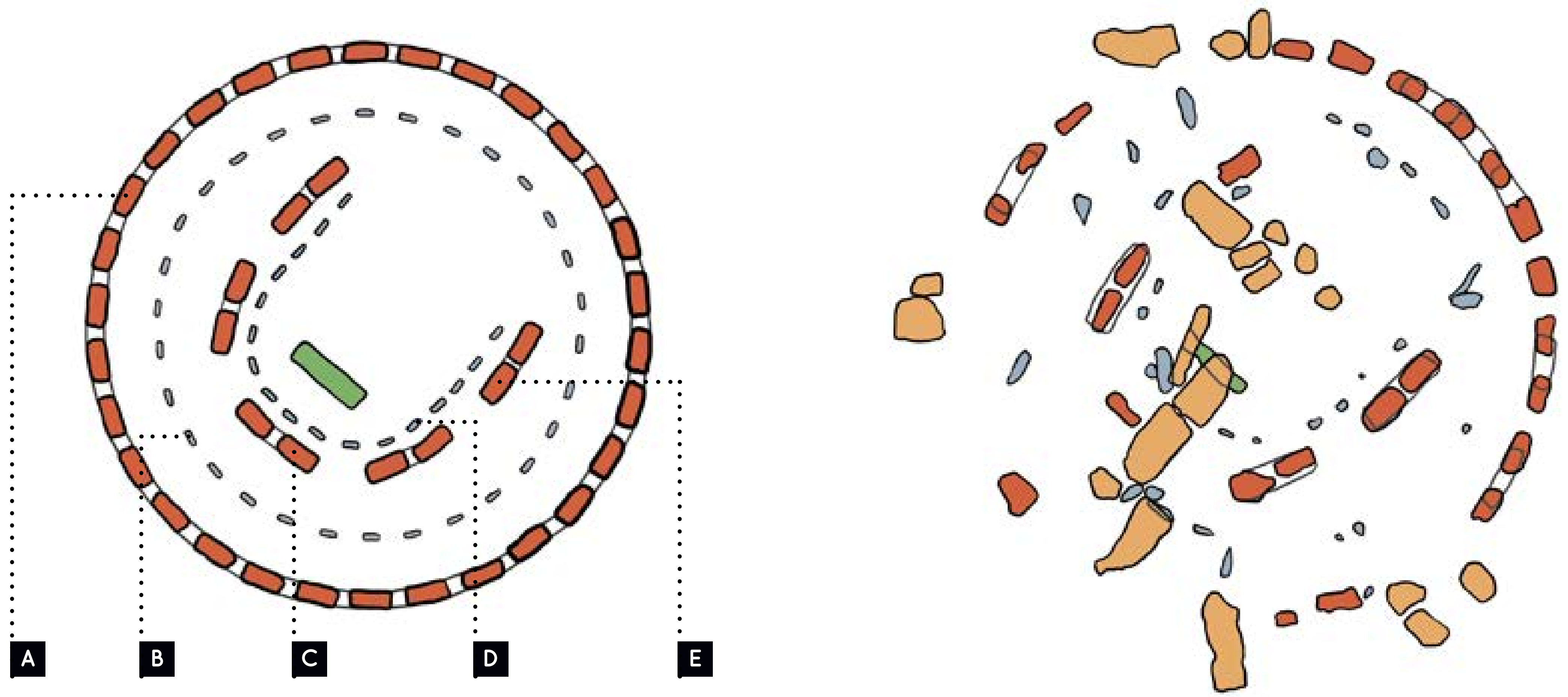


fig 60: Stonehenge as researchers believe it originally stood (left), and as it currently stands (right)

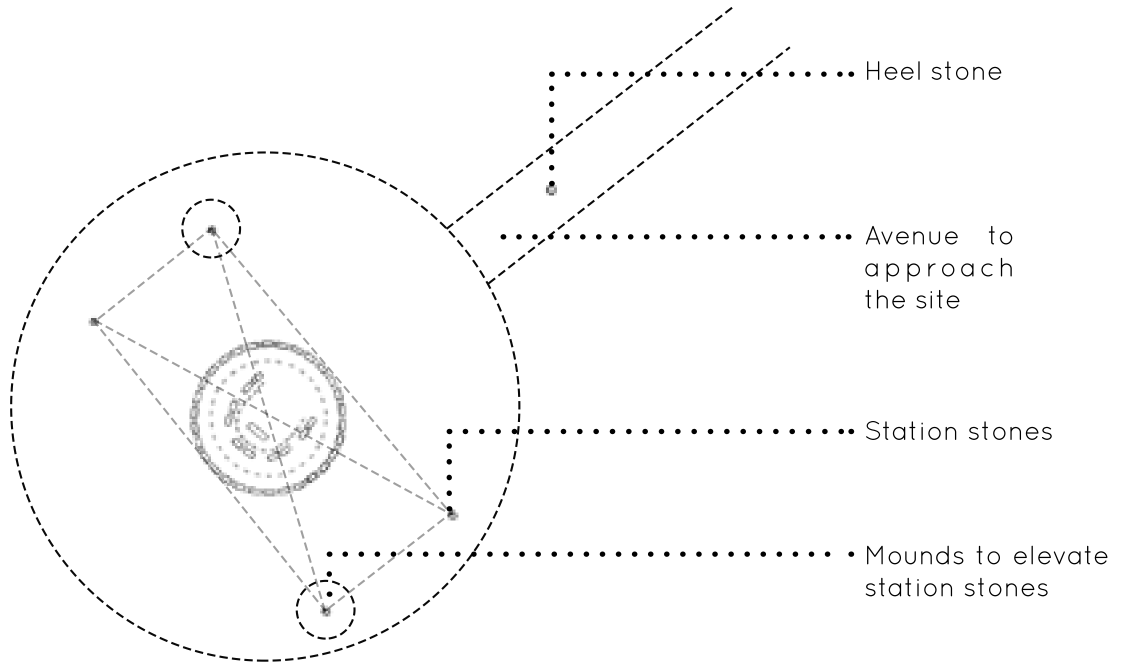
A. Sarsen circle
B. Bluestone circle
C. Great trilithon
D. Bluestone Horseshoe
E. Sarsen Horseshoe

Standing sarsen
Standing bluestone
Standing sarsen
Standing bluestone

The creation of Stonehenge is a testament to the importance of the Sun to the people of the area. The amount of work required to erect a structure like this is impressive and the construction methods are still unknown, although there are several theories. The stones themselves came from different parts of Britain, the reason for sourcing stones from different areas, especially considering the amount of work required, is debated. The sarsen stones were brought from a site 32km to the north and weigh an average of 25 tons, the tallest of which, used in the great trilithon, are 9m high. The bluestones, named because of their colour when broken open, weigh up to 4 tons and were brought from a site in Wales, 225km away. (SunEarthDays, 2014) The methods of transportation are also debated: some theorists state that the stones were transported downriver by boat, some theorise that the stones were rolled on top of wooden logs and some say that the stones were moved to the site by glaciers long before they were used in the structure (Vox, 2017). In any case, the use of the stones in the site was impressive. Moreover, the work needed to erect the stones was not merely in their transportation and erection: the stones were cut and shaped in order to fit specific criteria for the site.

The stones were not simply placed on top of each other, as is often thought. The builders of Stonehenge used woodworking-like joints in order to secure the stones to each other. Each of the lintels in the sarsen circle had a tongue and groove on opposite sides which would be inserted into its neighbours tongue or groove. In addition to that, on top of each sarsen was a tenon, a round protrusion, which would fit into a a mortice, a divet, on the underside of the lintels to ensure they were secure. The site of Stonehenge is also not perfectly level, and in order for the structure to be level, some stones had to be shortened or modified. The builders were able to make the necessary changes to the stones with smaller rocks and with red deer antlers. which would have taken a long time. The use of antlers as tools is how researchers were able to determine the age of Stonehenge; by radiocarbon dating the antlers, they are able to determine when the animals were alive, and therefore when its antlers were taken to be used as carving tools.

The site wasn't used solely to calculate the dates of the solstices, Hawkins theorised that it was also used to track the movement of the moon. There is evidence of a large rectangle created on the site, the corners of which are defined by large stones called the station stones; the short edges of the rectanlge line up with the sun on the solstices and the longer sides align with the most northerly and southerly moonrise and moonset. Only at the latitude of Stonehenge would these lines meet at 90 degrees, which may be an indication of why this specific location was chosen.



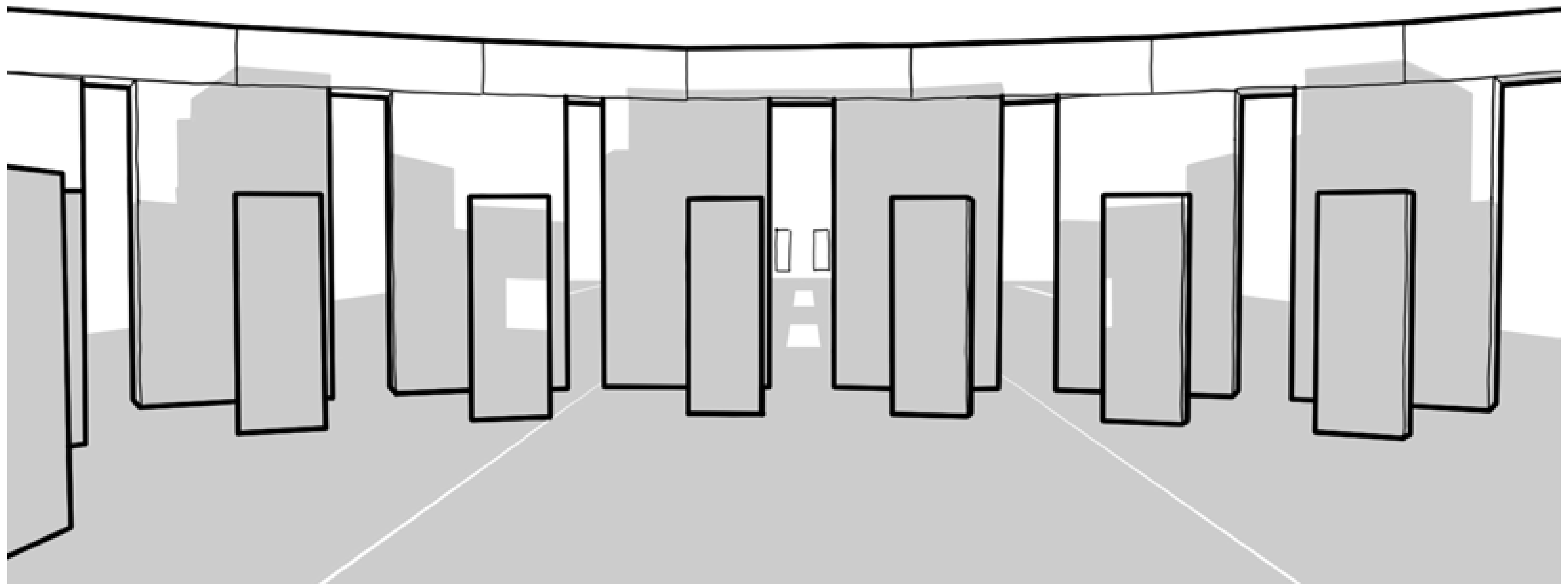


fig 61: Alignment of the shadows on midwinter's day, looking towards the heel stone from the altar stone

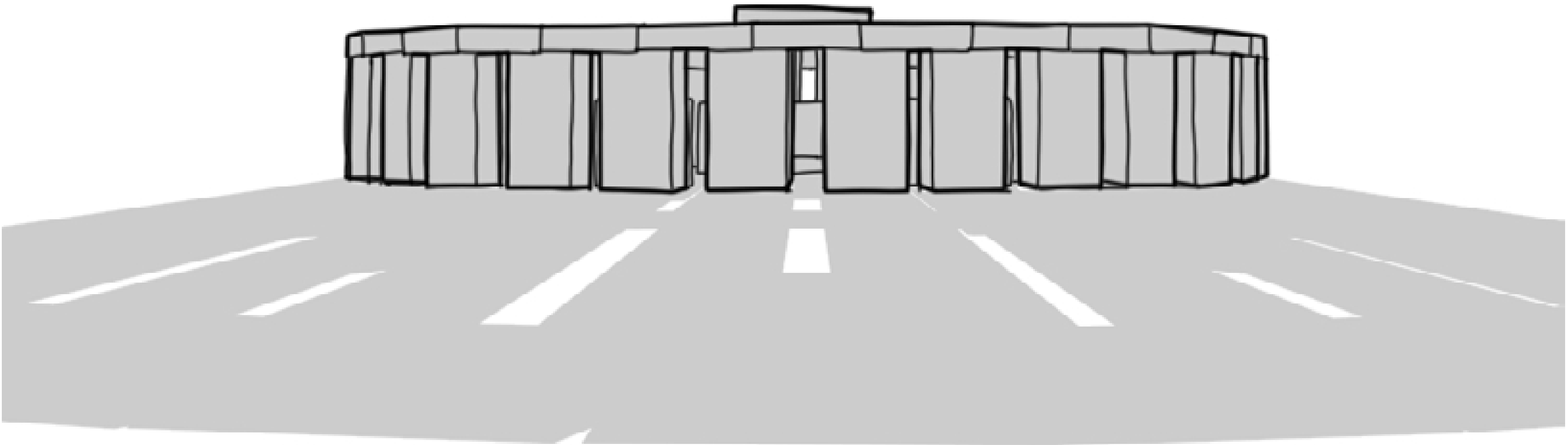
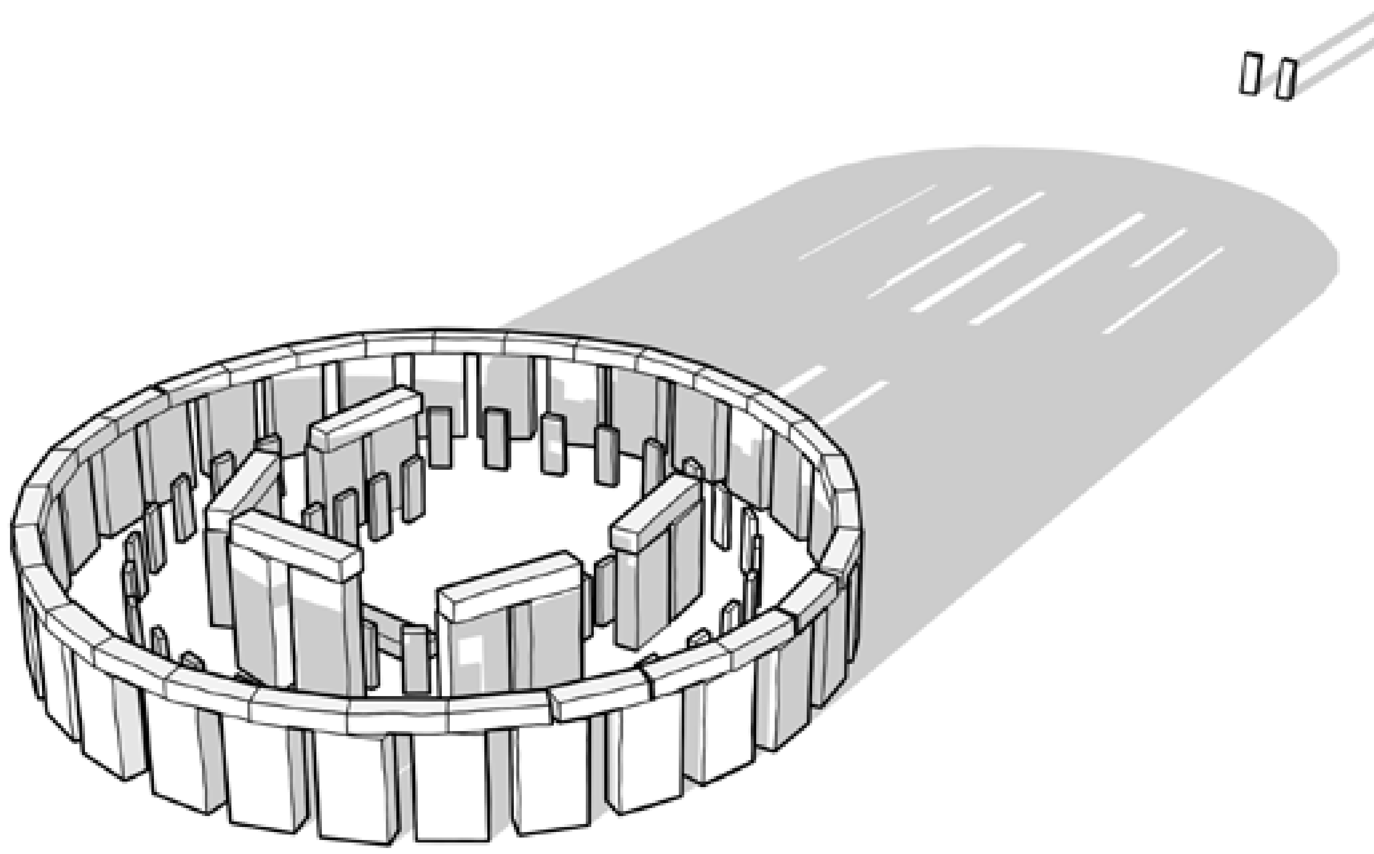


fig 62: Alignment of the shadows on midwinter's day, as seen between the heel stones looking towards the sarsen circle. Note the gap through the entire structure through which the sun would appear.

Understanding the approach to site was important to determining the most likely purpose of the site. As mentioned previously, Hawkins initially assumed that the site was used to determine the date of the summer solstice. From the centre of the sarsen circle, looking north-east would help to determined the day of the solstice. However, the site is approached from the north-east; on midsummer's day, people congregating at the site would approach the site with their backs to the sun. What seems more likely is that the site was designed to frame the sun on the winter solstice. As seen in the shadow study above, approaching the structure on midwinter's day, or the winter solstice, would frame the sun just before sunset - the sun would align with the great trilithon, the altar stone and the heel stone or stones and would be framed by the "keyhole".



ARCHITECTURE AND THE SKY

One of the issues that archaeoastronomy faces is confirmation bias. Confirmation bias is the tendency to interpret or search for information that will confirm a preconceived hypothesis and is part of the reason that there are so many misconceptions regarding archaeoastronomy. Ancient "astronomers" were not necessarily seeking answers in the sky or designing their monuments as reflections of the stars, but were likely more pragmatic than that. Considering the amount of work required to construct these monuments, many of which were done with minimal technology over a long period of time, it is more likely that these structures were built as part of the survival of those civilisations; little is as motivating as trying to keep your species safe. While many of these ancient structures did align with astronomical events, this is most likely for keeping track of time for food security, as was the case with Stonehenge. Even ancient structures that would appear to be monuments to the heavens, just based on their size or complexity, were not necessarily that. Many monuments were placed as ways to assist navigation; in times when the land was heavily wooded or landscapes were not easily navigable, people may have created structures as waypoints or simply as beacons to assist in navigation. (Shuttleworth, 2019) Naturally, structures like Stonehenge and Newgrange, being associated so strongly with the solstices and being the most famous of the archaeoastronomical investigations, have skewed the public's understanding of what archaeoastronomy focuses on. Moreover, the popularity of these structures has led to many theories about how unrelated structures might be ancient observatories or temples to the stars.

fig 63: One of the many stone ruins at Blaauboschkraal (Hill, 2015)

One example of misassociation is the Blaauboschkraal stone ruins in Waterval Boven, Mpumalanga. The ruins were discovered in 1891 by an English explorer Theodore Bent. Historians at the time assumed that the ruins were the remnants of cattle kraal or other structures left by African people as they settled further south in the 16th century. (Esterhuysen, 2015) This seems like the most logical explanation and was widely believed until the "rediscovery" of the ruins by Johan Heine when he crashed a plane in the area in 2003. Naturally, he assumed that the structures were used as a calendar of sorts, like Stonehenge, by the first people on Earth and dubbed the structure "Adam's Calendar".

fig 64: Andrew Collins visits the site to investistigate that Adam's Calendar is an ancient observatory (Hill, 2015)

Out of the many structures in the area (claims range from between 4000 to 100 000), Adam's calendar in particular is a set of stones sticking out from the ground along the escarpment.

The site has since been investigated in an attempt to confirm its possible use as a calendar, however no evidence has thus far proven this. In 2011, history writer Andrew Collins and technical engineer Rodney Hale set out to investigate Adam's Calendar. They were joined by self-proclaimed experts on the subject, Johan Heine and Michael Tellinger. As part of their investigation, Hale, with guidance from Heine and Tellinger, mapped out the calendar as it was allegedly used by ancient Africans. However, the plan does not align with any of the purported astronomical events or objects, neither now nor through simulations that recreated the astronomical conditions of the supposed time of creation, 75 000 years ago. After their investigation of the site, Collins stated "I can categorically say that I have seen nothing that might convince me that Adam's Calendar was constructed beyond the currently held time-frame of megalithic construction. Moreover, there is no argument that might be used to argue that any proposed alignment towards the belt stars of Orion only makes sense if the site was constructed 75 000 years ago. No calculations can be used to prove such an idea, not precession (a 26 000 year cycle), obliquity of the ecliptic (a 41 000 year cycle), or even much longer Milankovitch cycles." (Collins, 2011)

It is true that some ancient civilisations created structures for keeping track of astronomical events, as evidenced by Stonehenge. However, the attribution of astronomical studies or observations to unrelated ancient structures detracts from the research conducted of viable structures and dilutes the recognition that these garner. In addition, the inclusion of "alien civilisations" as a possible answer to the presence of these structures further detracts from the seriousness that archaeoastronomy demands, as serious research becomes associated with unsubstantiated or supernatural speculation.

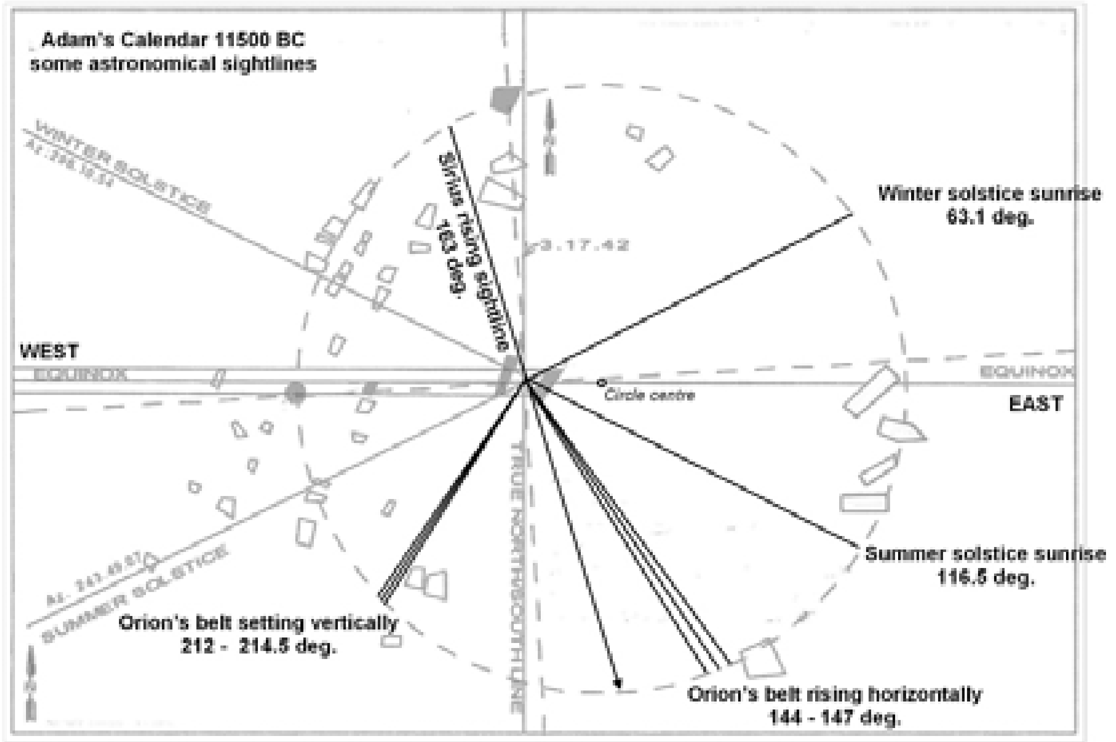


fig 65: Rodney Hale's plan of Adam's Calendar. Note that supposed tracked events do not align with the stones on the site. (Collins, 2011)

There are other structures around the world that do successfully map astronomical events, and that have been proven to do so. Unfortunately, many of these claims are not taken seriously enough or are drowned in the sea of speculation. Researching these structures or monuments is crucial in understanding how these civilisations functioned, what they valued and what they were willing to erect monuments for. Analysing these structures is also crucial in understanding how one should approach the intersection between architectural design and astronomical observations, something that the design of the Observatory satellite research centre aims to achieve.

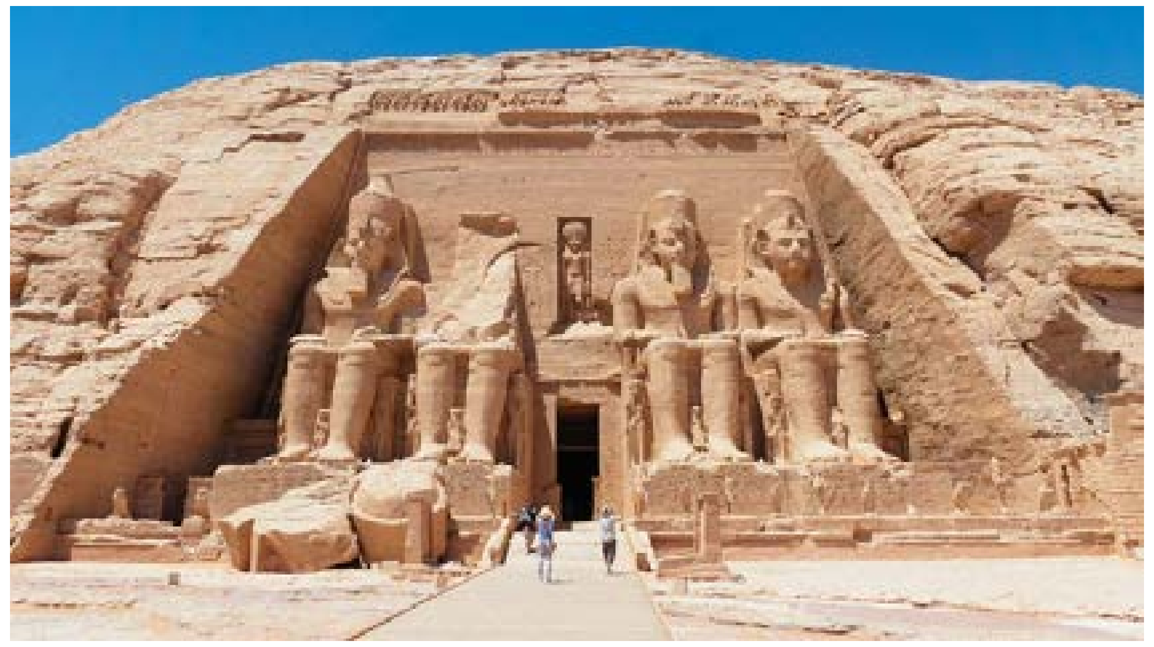


fig 67: Entrance to the Great Temple at Abu Simbel (Daily News Egypt, 2019)

While most ancient structures that are designed to correlate to an astronomical event are not made merely to celebrate or worship the stars, there are some that do - or at least seem to. The Egyptians are well known for their symbolism and their structures that celebrate the solar system - the sphinx points east to face the rising sun, most likely to praise the sun god, Ra. This architectural-astronomical intersection has often led to conjecture regarding the connection between some of their architecture and the stars, sometimes seemingly correctly and sometimes at a stretch. In any case, there is proof that they may have built structures, much like the Britons, to track significant dates throughout the year. In fact, much like Stonehenge, some of their temples were aligned with the axis of the midwinter sun as an indication of when to plant crops. (Shuttleworth, 2010)

One significant example of the Egyptians dedication to creating architecture that celebrates the sun and all its symbolism is the Great Temple at Abu Simbel. It was built during the reign of Pharaoh Ramesses the Great and was dedicated to the gods Amun, Ra and Ptah, as well as the deified Ramesses. On the back wall of the last chamber, the sanctuary, are statues of each of these deities. It is believed that the Great Temple was positioned in such a way as to illuminate the sanctuary on a specific day, or pair of days, of the year. Currently, on both the 22nd of October and the 22nd of February, the sun penetrates through all four chambers of the temple and shine on Amun, Ra and Ramesses - Ptah is said to not be illuminated because he is the god of the underworld. (Álvarez, 2019) By having the sun shine on the statue of himself, Ramesses would be deified and would be able to take his place next to the other gods. By designing the temple to allow the sun to shine on the statues every year, Ramesses would continue to be deified even after his death. The choice of the specific dates is only speculated currently; some say that the 22nd of October and February are the dates of Ramesses birth and coronation, however this isn't definitively proven.

fig 66: Amun, Ra, Ramesses and Ptah in the Great Temple at Abu Simbel (Wang, 2006)

RESEARCH NURTURING ARCHITECTURE

As the Observatory scheme is partly focusing on satellite research and development, it is important to understand how one can effectively design the spaces needed to facilitate that program. This means looking at studies that focus on how research is conducted and how to design spaces that can maximise the potential of that research.

In her thesis *Architecture for Science: Space as an Incubator to Nurture Research* (Shafiee, 2014), Maryam Mohammad Shafiee looks at this particular issue: the architectural design of research spaces and how they can be designed in order to not only maximise on the potential of the research but addressing issues beyond purely functional needs. Her research purports to address and study different scientific spaces over the last few centuries and also questions the impact of the architecture on research being done.

Shafiee notes in her critical analysis of Skirkanich Hall at the University of Pennsylvania by New York firm Tod Williams Billie Tsien Architects, the balance required when designing research laboratories. On the one hand, laboratory buildings – especially when designed for educational institutions – should be landmarks for the university; "emphatic physical statements about the place of advanced scientific thinking within the university". (Stephens, 2007) Whereas on the other hand, the function of the research space should not be compromised by the "architecture" of the building. One such example is Louis Khan's infamous Richards Medical Centre opened at the University of Pennsylvania in 1965.

fig 68: Richard's Medical Research Laboratories (Smallbones, 2010)

While the building itself may have been successful on a superficial level, it left much to be desired as a functioning medical facility. Some of the strongest criticisms of the buildings design can be attributed to Kahn's seeming lack of experience designing a medical centre such as this. Kahn famously enjoyed working in full natural daylight and wanted to incorporate this working condition into the research laboratory. Unfortunately, this working condition was not suited for the research staff and the building notoriously suffered issues with glare. (Rosenfield, 2016) Kahn also designed the laboratory spaces to be open studio settings, believing that this would allow scientists to conduct research more effectively, however the medical staff and the laboratories did not feel the same way and soon after the creation of the building, erected partitions to ensure privacy between scientists. (Ellis & Cuff, 1989) In addition to this, Kahn designed the services to be exposed, both as an architectural statement and to allow easy access should researchers choose to change the layouts of the services. However, Kahn failed to realise the strict regulations that laboratory spaces require, especially in terms of air circulation and dust control and many labs were later fitted with a dropped ceilings. The criticism and shortcomings that the building suffered are a testament to the research and dedication required when designing architectural spaces.

Many commissioners of research facilities feel that they need to make a choice between functional research spaces and beautiful architecture – especially because of the high level of engineering or technology required in research laboratories. As the space needs to be highly functional and precise (and because institutions often need to enforce a stricter budget), the inspiring potential of architecture is often the first aspect of the design to be "value-engineered" away (Shafiee, 2014). Historically, architecture was simply used as a tool to facilitate the research being conducted in a space and had little value outside of this space besides ensuring that the laboratories adhered to building codes and regulations. As Shafiee asks in her thesis, "is there any room for moments of inspirational architecture in designing laboratories for the future?" (Shafiee, 2014)

If one is to design a scientific research lab that can effectively house and facilitate academic research, one needs to understand the process by which scientific research happens. Scientific research has changed over the years and what were once seen as sufficient research spaces have been replaced by more appropriate research spaces, based on the nature of scientific research of the day. The evolution of scientific research and architecture's response will be covered further in the section. Shafiee does a study on the process of scientific study; as she points out "science is a circle of continuous systematic inquiry that leads to acquiring knowledge. That systematic study is based on past attainments, which supply a base for future discoveries" (Shafiee, 2014). As one conducts research, one asks a research question, hypothesises the outcome and that hypothesis is either proven to be correct or incorrect which then leads to new knowledge. That new knowledge is then used, as she says, "to supply a base for future discoveries." This process is then repeated. This circle of research can be shown in a simple flow diagram:

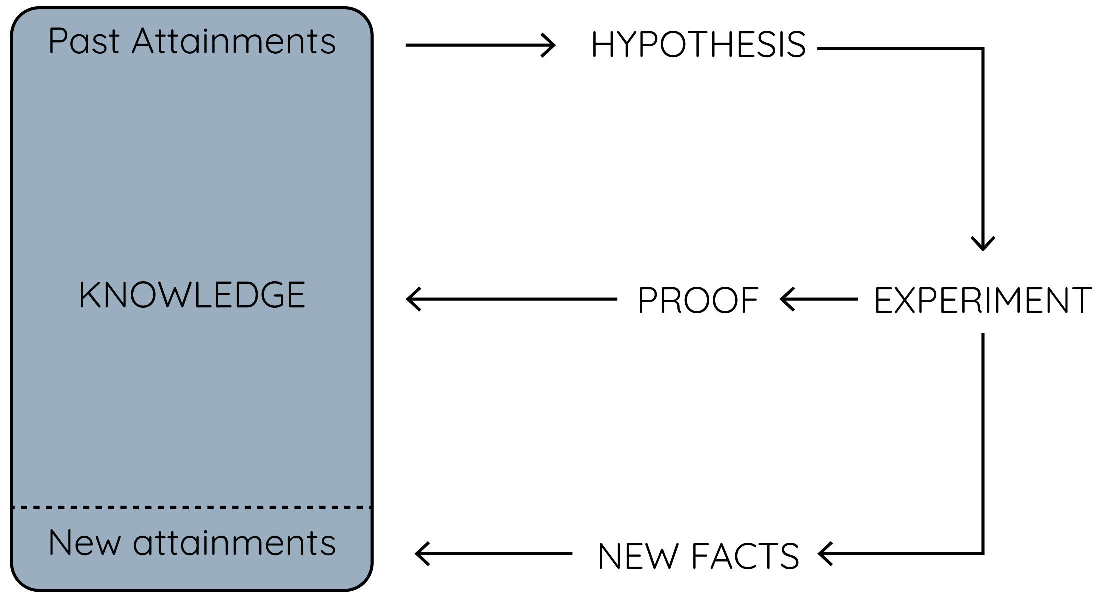


fig 69: Recreation of flow of research diagram (Shafiee, 2014)

According to this definition of research, the most important part of the research being conducted is to hypothesise based on existing knowledge and research in order to expand on that knowledge and create more research material for future researchers. Or as Thomas S. Kuhn says in his book, *The Structure of Scientific Revolutions*: "… research under a paradigm must be a particularly effective way of inducing paradigm change. Produced inadvertently by a game played under one set of rules, their assimilation requires the elaboration of another set. After they have become parts of science, the enterprise is never quite the same again." (Kuhn, 1970) This understanding of how science works forms the basis of Shafiee's thesis and is the governing ideal of how research works for the purposes of designing a satellite research and development centre. To put it into terms relating to satellite research and development, the basic principle does not change – however, the specific application does.

In his thesis *X-Band Antenna Design for Nano-Satellite Applications*, Sinamandla Mvuyisi Maqina outlines the workflow required for satellite component fabrication in a simple flow diagram (right), similar to the one created by Shafiee.

Note that the first stage for both flow diagrams is to base the research on previous attainments; Maqina starts his flow diagram with literature study, obviously using previous attempts at fabricating x-band antennae as a basis for his own research. The major difference between Maqina's flow and Shafiee's flow is that Maqina's project doesn't end with a proven or disproven hypothesis. The end product of the entire class is a working nano-satellite that can be launched into space; as such, if the hypothesised antenna configuration doesn't work, a new approach needs to be taken and a sufficiently effective prototype needs to be fabricated. This is evident in his work flow diagram: if the requirements from the simulations are not met, a new proposal needs to be designed, et cetera.

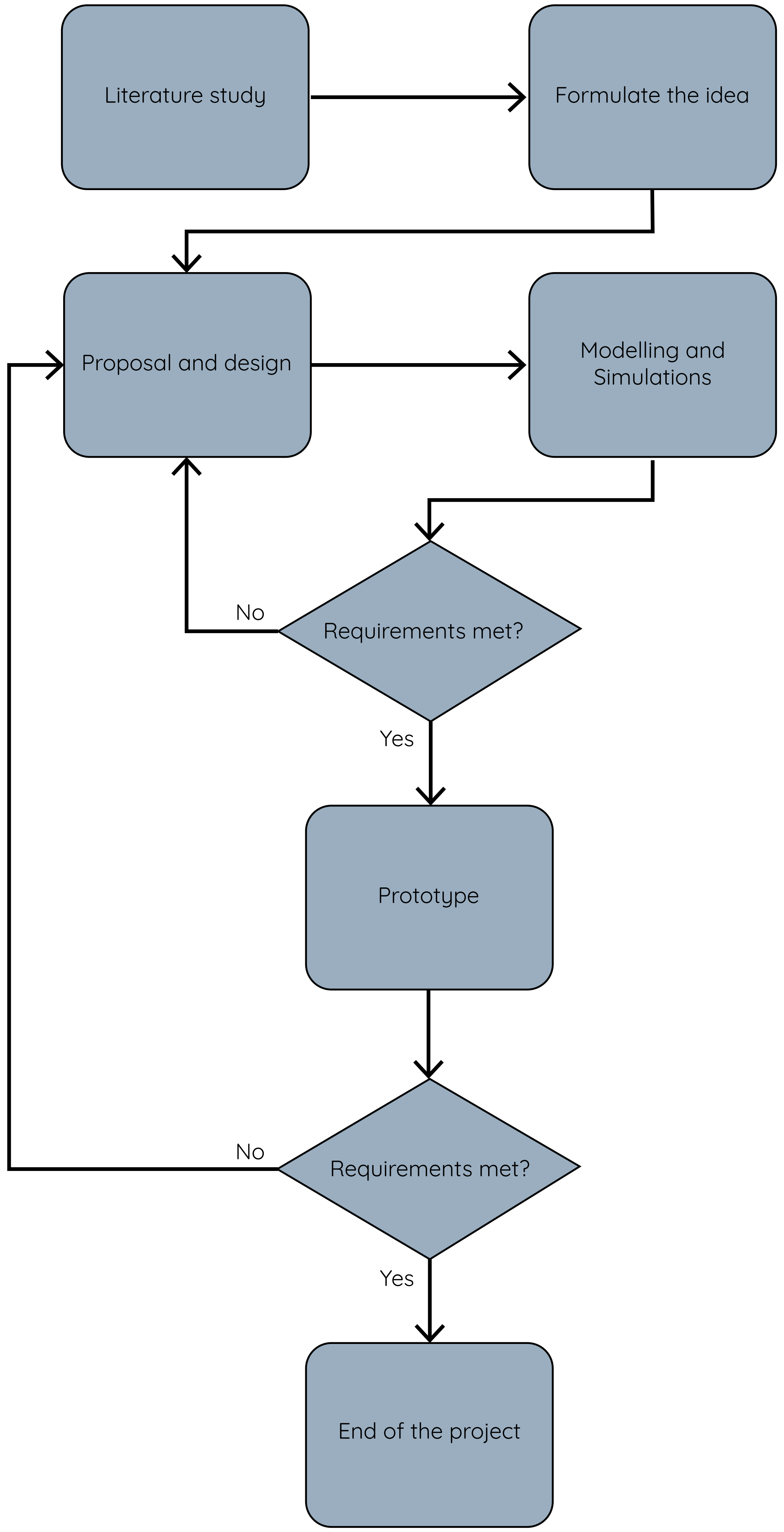


fig 70: Recreation of work structure diagram done by Sinamandla Maqina (Maqina, 2018)

Since the dawn of science, as we understand it in the modern age, architecture has been a tool with which science is conducted. According to Khun, as science has gone through paradigm shifts, so has the architecture in which the research is conducted. As scientific research evolved from a form of knowledge into a specific activity, architecture evolved as well – creating spaces that are specifically designed for those activities and by defining the activities inside the spaces it has allowed us to measure the force of the paradigm shift. That is to say, we can map out the changes in scientific research because of the changes in spaces associated with it.

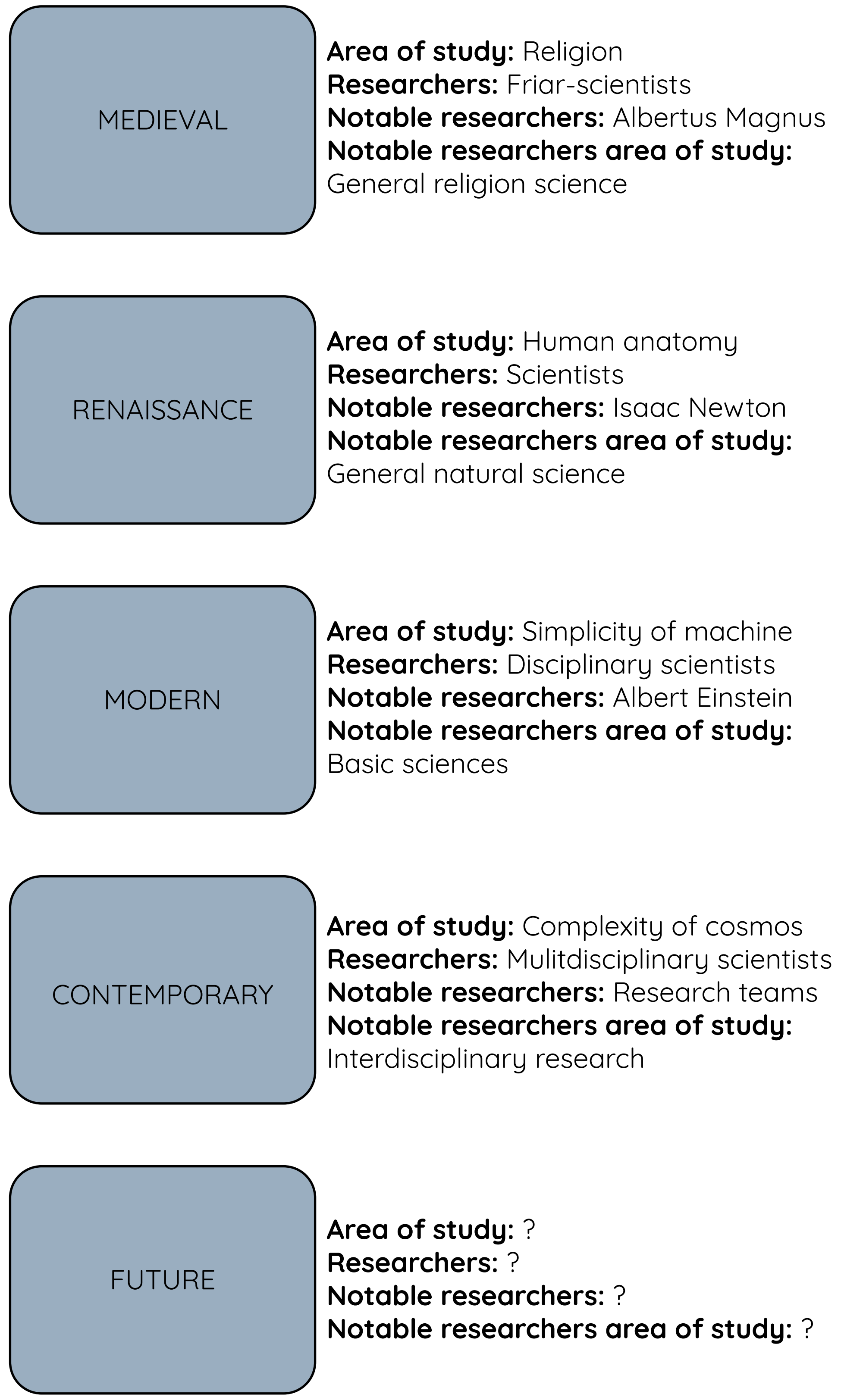


fig 71: Recreation of science history diagram done by Shafiee (Shafiee, 2014)

As seen in Shafiee's diagram, formal science essentially evolved from being religion-based to being totally separated from the church. In medieval times, religious explanations were widely accepted to be the answer to many of life's mysteries. Revolutionary thinkers soon after the dark ages, such as Nicolaus Copernicus and Johannes Kepler, were responsible for a shift from religious explanations to scientific explanations. As these paradigm shifts changed the way that research was conducted and science was understood, it also changed both the architecture in which the research was conducted and the classification that scientists took. For instance, during medieval times, scientists were extremely multi-talented, researching every aspect of the human condition. Albertus Maximus was known for pracIticing Catholic saint-bishop logic, theology, botany, geography, astronomy, astrology, mineralogy, alchemy, zoology, physiology, phrenology, alchemy and music. (Knight, n.d.)

As science has undergone paradigm shifts, scientists have gotten more focused on single fields; The architecture in which the research was practised showcases this paradigm shift. "Friar-scientists" would practise their craft inside a study, normally a simple office with a table and some tools and generally not designed as a research space, rather a different space that they adopted as their own study. Famously, Roger Bacon, a 13th-century friar-scientist, practised his research in a study in a defence tower on Abingdon Road in Oxford, England.

fig 72: Roger Bacon's study on Folly Bridge (Shafiee, 2014)

Sir Isaac Newton, a Rennaissance scientist, had a more formal study in the gardens of Trinity College in Cambridge, specifically designed for him to conduct research and experiments.

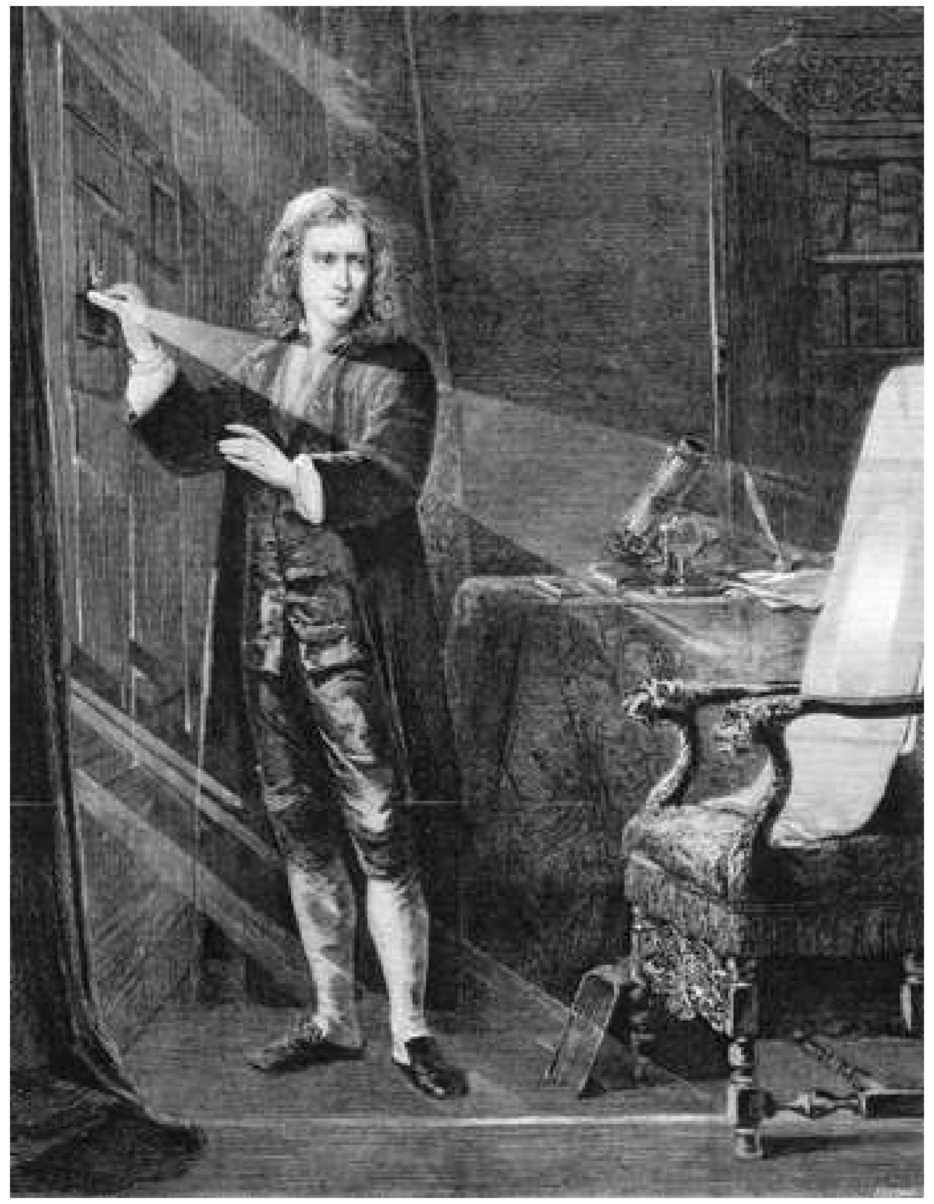


fig 73: Newton in his study (de Andrade Martins & Celestino Silva, 2015)

Albert Einstein, being a faculty member at the Institute of Advanced Study, had a private office at the university where he spent most of his time as a researcher. This marked the beginning of the "disciplinary science"; the practice of disciplinary scientists was to take a field of research which had a very large content of knowledge and divide it up into specialised fields of research. The architectural response was then to supply each specialisation with its own building. This is the model that modern institutions use; buildings categorised on department basis: physics, biology, astronomy, chemistry, et cetera. This model of research laboratory presents a novel problem to research architecture: spaces that are too specialised. The inflexibility of buildings designed for specific uses led to buildings that later needed to be repurposed or were outdated in some capacity.

As part of her research, Shafiee looks at a number of buildings that were deemed to be "inflexible" and were, by her account, unsuccessful as research laboratories. This is partially true, as some of the buildings she looked at have since been renovated or changed. One particular example is the West Experiment Station at the University of Massachusetts. The major flaw in the design of the research laboratories was that they were designed for one very specific discipline of scientific research: soil studies. However, the inflexible design of the buildings means that it could not be repurposed as a laboratory for another discipline - it needed to be repurposed as offices, a project that is currently being undertaken.

fig 74: West Experiment Station, University of Massachusetts (Peschard, 2015)

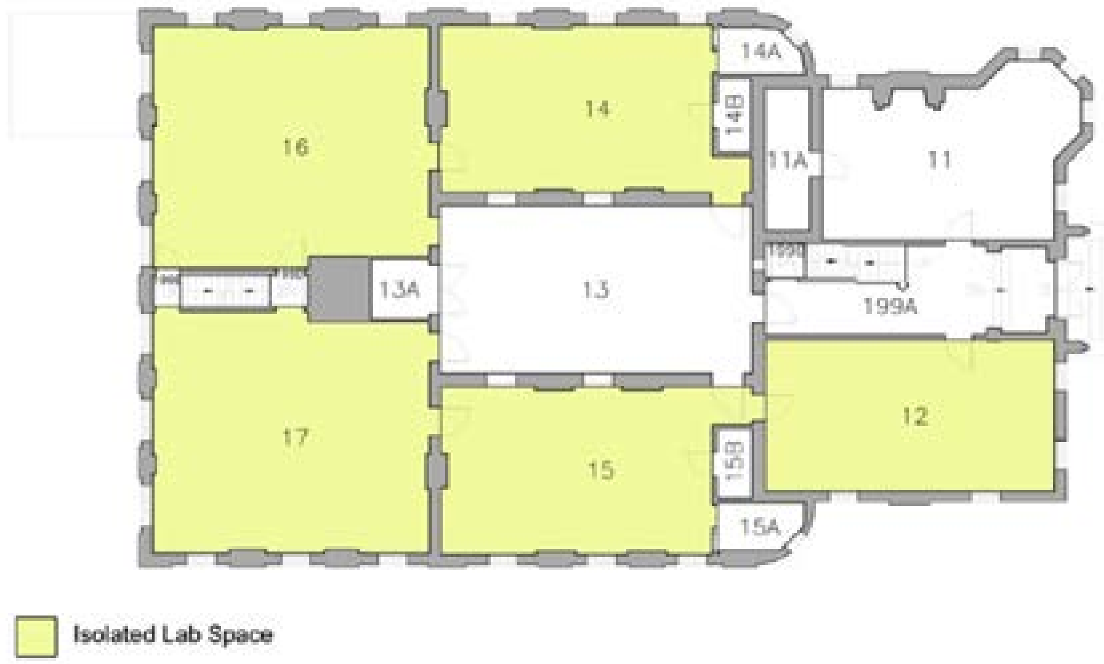


fig 75: West Experiment Station plan (Shafiee, 2014)

The issue with approaching the design of a building like the West Experiment Station is that it becomes very limited to adaptation later on. The plan above shows that the building mostly consists of isolated lab spaces to be used only by researchers of that discipline.

Similarly to the West Experiment Station, the Flint Laboratory was built to house one specific discipline - dairy research. It was considered to be a cutting edge dairy research centre at the time of its creation in 1912. Today the building is mostly office space and the dairy bar that was once housed in the building has been made into a restaurant.

Like the West Experiment Station, the Flint Laboratory houses in inordinate amount of isolated lab space, especially considering that the lab space was only designed for one purpose, dairy research.

fig 76: Flint Laboratory, University of Massachusetts (Simtropolitan, 2011)

fig 77: Flint Laboratory, University of Massachusetts (Shafiee, 2014)

As discussed, scientific research has evolved over the last 100 years. Science has moved from the disciplinary field it was during Einstein's time to the multidisciplinary field it is now; not multidisciplinary in the way that renaissance science was, where one person studies multiple fields, but rather multidisciplinary in the sense that there is more communication between disciplines and it is more collaborative. Even during Einstein's era, multidisciplinary science research was beginning to materialise. Einstein's first paper on general relativity was facilitated by his collaboration with Marcel Grossmann, a mathematician who specialised in descriptive geometry.

This interdisciplinary scientific research is the standard practice today and science research buildings are being designed accordingly. The key to facilitating communication between fields of research is to create spaces for collaboration between disciplines.

Satellite research and fabrication itself is a multidisciplinary science. As Aleksander Lidtke points out (AMSAT-UK, 2015), the creation of CubeSats involves not only all branches of engineering (space systems, mechanical, software, electrical, et cetera), but it also involves future satellite data users who might use the data for physics, geography or oceanography research, et cetera. The means that the design for the Observatory research centre might be focused only on the creation of CubeSats, there are many different specialists that could collaborate on these projects. In addition to that, one of the major design intentions for the site is specifically to create collaboration between universities, the industry and other professionals, further necessitating the need to create successful collaborative spaces. As Shafiee says in her thesis, "presuming that a positive influence on the society is the actual objective of the scientific research, this goal will not be plausible if the produced knowledge does not go beyond the body of science and translate into practical applications", which is the goal of creating collaboration between industry and academia with regards to CubeSat creation.

Shafiee proposes four points that need to be addressed in order to consider the design of a multidisciplinary research building successful:

• **Human connection** is severed when researchers essentially live in their research labs. The goal of a research building should be to allow scientists to connect with other humans and that their happiness and comfort are important in the design of their research spaces.

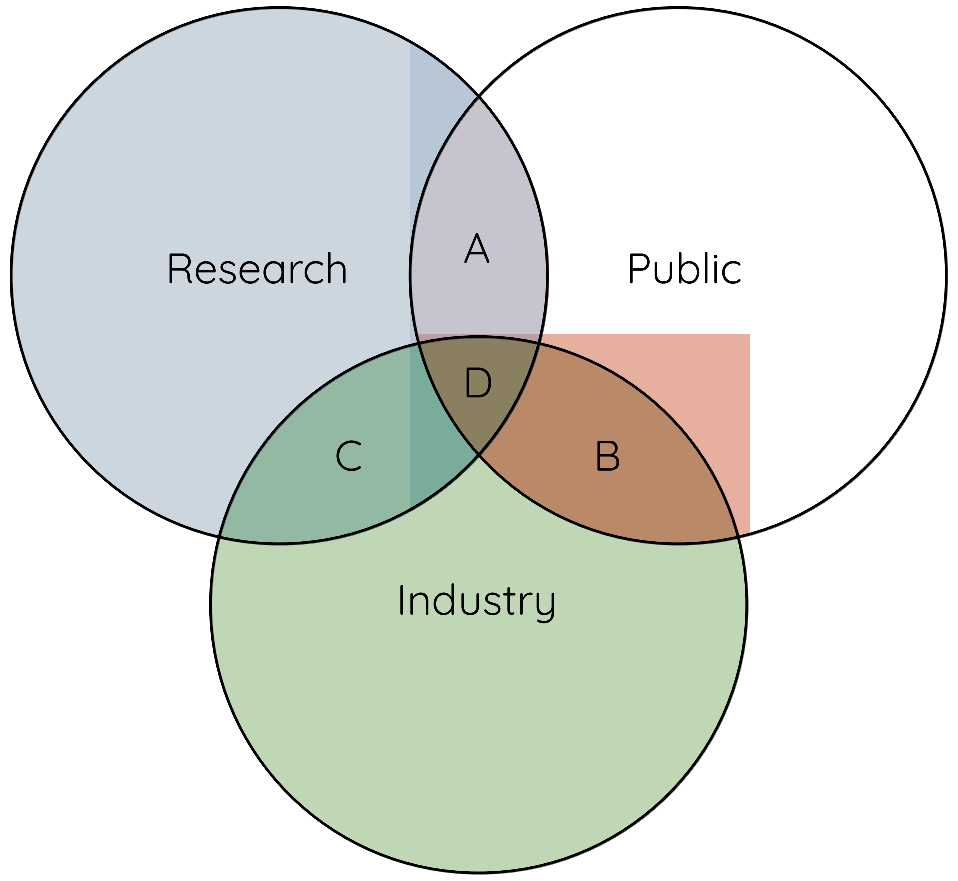
• **Adaptable spaces** are necessary to not only allow the scientific field to grow, but allow researchers to adapt the spaces to their own needs, safely and inexpensively.

• **The response to site** need to be carefully considered to allow public accessibility, visual connections and mitigate isolation of the researchers and research field.

• **Science, Industry, Society**. The architecture should be designed in a way that facilitates connections between different schools of thought. Not only between different scientific fields, but different levels of the respective scientific fields. "Architecture [should be used] to create opportunities for collaboration between academia and industry [and] will help researchers to test their experimental products in a fast track process in connect with industry." (Shafiee, 2014)

DESIGNING EXHIBITION SPACE

The Observatory Satellite Research, Development and Visitor's Centre focuses largely on facilitating the interaction between the public at large and the satellite industry, whether with academics or professionals. A major part of this interaction happens through the inclusion of the visitor's centre portion of the scheme, both within the research spaces and within the museum itself. The design of this portion of the scheme is essential to fulfil the goals of the project, specifically for making space an approachable subject.



A. Exhibition in lab
B. Exhibitions in museum
C. CubeSats and collaboration
D. Observatory centre

fig 78: Venn diagram of the program of the scheme

The public portion of the scheme will be designed to interpret space as a more intuitive subject that the public can engage with. This will be the portion of the scheme that is inspired by humankind's attraction to the universe. The argument is that people have an intrinsic draw to the universe and that by creating a site that can exemplify that magnetism, one can instill into people a more personal interest in space. People have come to associate "space" as a concept with politics, inconceivable sizes and numbers, wastage of resources, and corporate greed. By creating a site that would showcase the aspects of space that people have always been drawn to, one can foster a love of space in the visitors.

In an interview with Metropolis Magazine, Renzo Piano pointed out that creating a successful museum or exhibition space is creating a building that "should talk to the city, talk to the people. Buildings like this allow people to share experiences together, to enjoy and share life" (Clemence, 2014), and later clarified that one does this by "allowing the ritual of the city life to merge with the ritual of the building life." (Clemence, 2014) The buildings he is referring to in this context - Beauborg, the Nasher Sculpture Center, the New York Times Building, the Harvard Art Museums, the Whitney - are all situated in dense urban fabrics. The Observatory centre is in a much more secluded context than Piano's museums generally are. However, the spirit of this design philosophy can be translated. If successfully designing a science museum is about merging the context and the buildings, one could argue that the larger context of the site is the cosmos and that creating a strong relationship between the cosmos and the architecture is important. Moreover, it can be inferred that one can design a successful museum by merging the ritual of the building to the ritual of the site.

In the case of the Observatory centre, the ritual of the site is clearly defined: people having an intimate experience with space from the site, whether the solar system or deep space. This then needs to be translated from the ritual of the site itself to the ritual of the building. As with archaeoastronomy, the movement of humans through the site is closely tied with the movement of the cosmos. While this should be true for the design of the overall site, it should also be true for the design of individual buildings on the site and people's movement through them. This could manifest as a great many things and the design of the Observatory centre will explore these possibilities, informed by the history that architecture and astronomy have together.

However, the scheme is primarily a research centre that is conducting high-tech research and the public's engagement with that research is pivotal to the success of the scheme. While the design of the exhibition spaces as tools for astronomy is important, these spaces are primarily museum spaces and need to be designed carefully to allow them to function as such. The exhibition spaces on the site are the facilitator for the engagement of the public with both the industry and research. In a research paper titled *Designs for Learning: Studying Science Museum Exhibits That Do More Than Entertain* (Allen, 2004), Doctor Sue Allen discusses the process by which people more readily engage with exhibition spaces.

Dr Allen says that the objective is to have people enter a "flow state", wherein "visitor's become fully involved with mind and body in an intrinsically motivated way." (Allen, 2004) Once visitor's have entered a flow state, their interest and engagement with the exhibitions are sustained. Visitors' initial interactions with the architecture and with the exhibitions will either create or disallow this flow state, so the goal is to design the museum in a way that visitors are initially curious and interested and can proceed further into the museum and engage fully.

Naturally, the design of the entire museum is important, but visitors' first impressions will determine whether or not their visit will be meaningful and informing. Immediate apprehendability is crucial for the initial framing stages of an experience; the design of the first nodes of a museum should be used to create enough interest but to not overstimulate, thus overwhelming visitors. The first steps in a museum should feel natural, the user's curiosity should be drawing them inward and any extraneous stimulus can break that engagement and therefore their flow state.

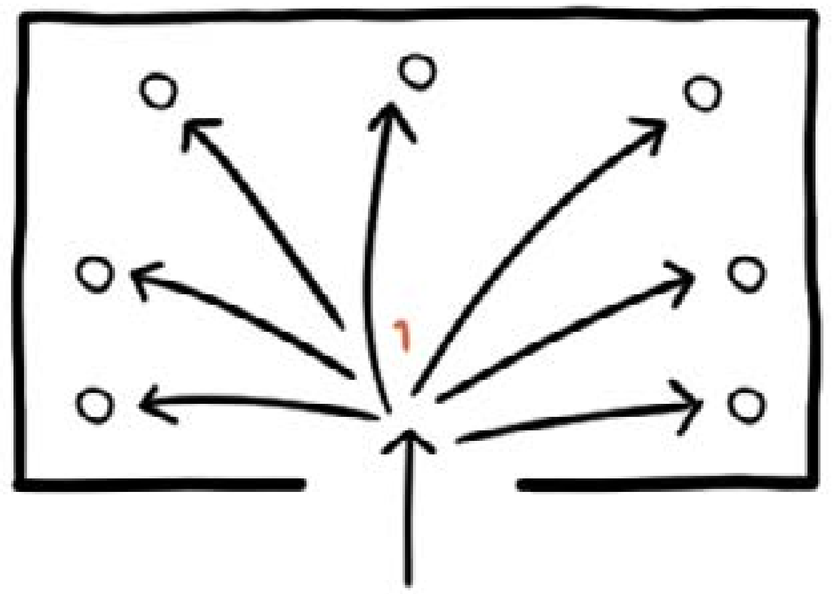


fig 79: Open-plan exhibition hall

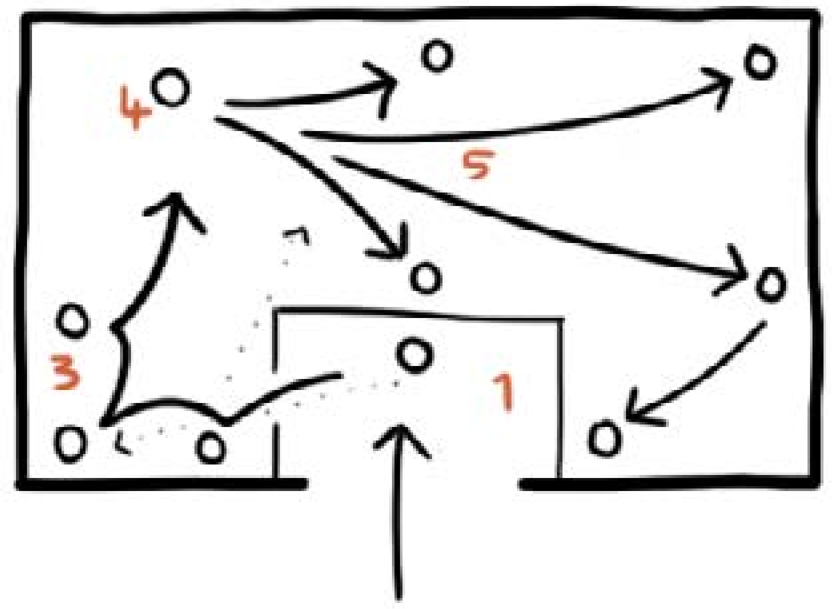


fig 80: Linearly planned exhibition hall

The simple diagrams above explain Dr Allen's research into immediate apprehendability. In the first diagram, users enter into an exhibition space and have a choice of any exhibit to move to, which can be overwhelming. The museum design needs to limit the initial movement of visitors through the space and provide enough interaction in a smaller scale to create the flow state, and then introduce them to larger exhibitions. "Without restrictions, visitors have complete freedom to follow their interests and impulses as they move through a public space packed with exhibits all vying for attention. This quality of totally unrestricted choice in what to attend to has huge implications for learning in the museum setting." (Allen, 2004)

One problematic break of flow that Dr Allen mentions is the front door to the Exploratorium, a museum in San Francisco at which she was the Director of Visitor Research and Evaluation. The front door is a Norman door - a door whose accidental bad design confuses users. As she says, "visitors should not struggle to figure out how to open the front door (a problem we actually have, incidentally, due to handles that afford pushing but in fact pull to open)." (Allen, 2004) It should be noted that a certain amount of challenge is essential in a museum or exhibition space, but designers need to be aware of when it is appropriate to create a challenge and when it is not - having visitor's struggle with a door before they've even entered the museum discourages them and detracts from their learning experience.

One challenge that museum and exhibition designers face is the balance between entertainment and education. Naturally, most people go to museums as a leisure activity with the expectation that they will be mentally stimulated and possibly learn something; the challenge comes in with creating an experience that is fun enough that people will continue to engage and learn, but also challenging enough that they will gain knowledge through their use of the space. Dr Allen talks about a phenomenon called "museum fatigue" wherein the attention spans of users is limited, usually to 30 minutes, after which they will stop challenging themselves mentally and begin to "cruise", going only to the most interesting looking exhibits. This generally happens when the exhibitions are too mentally challenging: too much reading, people don't understand the source material, they can not figure out the controls for an interactive exhibit, et cetera. This is essentially when the exhibition stops being educational. In the conclusion to the research paper, Dr Allen questions whether an open plan movement or a linear path through the site would be an effective way to direct people. On the one hand, people should feel like they're making the choice to be there and what to do, so one path through the museum can detract from this experience; on the other hand, too much freedom can mean that visitors quickly suffer from overstimulation and don't properly engage with anything.

The most likely solution seems to be a balance between the two; a suggested path that users can follow, but are able to stray from and follow their own interests, to a certain degree. This might look something like a series of nodes with loosely defined paths that connect them to create a logical movement through the space. It's also possible to use narrative as a guide through the spaces. For example the first space could be an introduction to the content, followed by a history of the exhibitions which then leads to the applications of that research, et cetera. This creates a logical sense of guidance through the space without necessarily physically directing people. Naturally, the most appropriate answer depends on the specific museum and the intended goals of the spaces.

ARCHITECTURE THEORY CONCLUSION

The architecture theory itself has covered two major sections: exploring an architectural concept for the scheme and understanding the specifics of the spaces on the site.

The architectural concept of the scheme is essentially creating an experience in a contemporary scheme that is inspired by ancient astronomical architecture. Effectively doing this requires understanding humankind's relationship with the stars, and specifically using architecture as a lens to investigate this relationship. By tying the architecture to "space" as a broad idea, one can create a more interesting and unique experience in the scheme. This gives the architecture, and the scheme as a whole, more depth; it elevates the buildings from simple museum and research space to architecture that creates an experience that effects peoples' lives outside of the bounds of the site. Naturally, exploring this relationship architecturally means understanding it in theory. This includes understanding why people are drawn to space, and how we have used the sky to progress as a species. If the design of the scheme is to embody these principles, it would mean unpacking humankind's relationship with the sky. For instance, designing a courtyard that acts as a naked eye observatory would need an understanding of how the stars move over the course of the year or how humans used to identify and track these stars. The specifics of the design will depend on the final design intent, however the general knowledge of the system remains the same. Furthermore, creating an interesting space for people to experience the solar system or the stars in a unique will allow people to approach the subject in more earnest way and instill in them a better appreciation for space.

One of the early concepts for the design of the building was to use the essence of constellation creation (pareidolia) and apply this to a possible building or form exploration. This was to create a stronger connection between the architecture and the stars that it celebrates. The early design exploration, especially the design charette, was inspired by the idea of abstracting information from random stimulus, much the same way that the constellations were created. This also played a part later on in the second revision of the design, however this process was slightly changed and the randomness of the stimulus was negated, relying rather on the creation of stimulus from points on the site. This is explained in further detail in the design chapter, with the relevant drawings.

The scheme, in many ways, represents the relationship between astronomy and architecture, something that has been evident in the way that humans have lived for many millennia. This history was explored further to understand this relationship in more depth. Many people believe that humans simply worshiped the stars or the sun, however this relationship is more complicated than mere worship. That worship takes root in the understanding that the sun provides life and that the stars can represent the progression of the year, for better or worse. This more complicated relationship can fundamentally change the approach to designing architecture for the scheme - especially the elements which focus on celebrating space. On the surface level, these elements may appear to be, in some ways, worshipping the stars. However, as humankind's history with space is more complicated than that, so too should be these elements of the scheme, or more accurately, what these elements represent. While allowing people to understand space is important, our history dictates that this relationship can be worth more than that; this should be explored and reflected in the architecture. This can represent many things to many people, and the site can be a tool for people to explore how the universe reflects their own lives. This intimate relationship is one that humans used to have with the stars, and the intent of the scheme is to encourage people to foster that relationship. This design intent can only be fully realised if one were to understand the workings of the movement of the stars and can design accordingly.

Programatically, this theory chapter covered the design of research spaces and museum spaces. Naturally this is to maximise on the potential of these spaces, designing them in line with what others have researched. For the research spaces, this consisted of both understanding how research is conducted as well as how effective research spaces are designed. One of the largest take aways from the research is that collaborative research spaces are, in today's scientific climate, the most effective typology in which to conduct research. Multi-disciplinary scientific study is the current norm, and the research spaces should be focused around facilitating this collaboration. Moreover, understanding exactly how research is conducted is also important for the design of the spaces. For instance, if one is to design a cleanroom, one needs to understand the purpose and limitations of those spaces.

Similarly, exhibition spaces should be designed with input from researchers who have conducted studies into how these exhibitions work and can be designed most effectively. This means understanding the context of the museum and designing accordingly; specifically, how is space used outside the building and how is it used inside, and how does one merge these two? As Dr Sue Allen points out, the greatest challenge in exhibition design is the balance between interesting spaces and challenging spaces. Spatially, one can effectively balance these two elements in museum design by, among other things, designing the movement through the site. For the Observatory visitor's centre, this means planning a route through the building that uses line of site, reward systems and a planned "narrative" through the site to generate interest and help to create a "flow state" so that visitor's feel that they are learning and engaging as much as possible in the scheme. This is explored extensively in both the first and second revisions of the building and will be explored in even more depth for the final revision of the design.

3 / 7 Viability

"For me it was never about money, but solving problems for the future of humanity"

- Elon Musk, (December 2012)

fig 81: Satellite Tigris-Euphrates basin taken with GRACE and Landsat 5 to track water loss (NASA, 2013)

CHAPTER CONTENTS

CHAPTER INTRODUCTION

As discussed in chapter 1, it is crucial that the South African government and research sectors concerned with the advancements of space technology embrace the ever-growing research sector of satellite development. While South Africa has had some experience with satellite research, the number of companies and institutions that are involved in this research is minimal. However, there are several companies and institutions in South Africa that are involved and many that are doing research adjacent to satellite research.

One of these bodies is the National Research Foundation (NRF), whose mandate "is to promote and support research through funding, human resource development and the provision of the necessary research facilities in order to facilitate the creation of knowledge, innovation and development in all fields of science and technology" (National Research Foundation Act 23 of 1998). This mandate bodes well for trying to establish a satellite research and development centre in South Africa, as funds will have been set aside for just this kind of centre and research.

The satellite research and development centre will be proposed to be placed in Observatory, Johannesburg - something which will be covered in the next chapter. The specific site is the home of the eponymous observatory, which was bought and taken over by the South African Agency for Science and Technology Advancement (SAASTA) in 2003; SAASTA is a business unit of the NRF, with a more focused mandate to "advance public awareness, appreciation and engagement of science, engineering, innovation and technology in South Africa" (SAASTA, n.d.).

This chapter will explore the potential of the Observatory Satellite Research, Development and Visitor's Centre to be a financially viable project. This will be done by proposing a client and funders, outlining the financial considerations and choice of site and exploring the technology, sustainability and materiality and their impact on the cost of the project. Furthermore, a brief program will be outlined as a way to explore the building cost versus the funding possibilities. Lastly, a breakdown of expected income versus cost of operation will be conducted as a way to understand the economic viability of the project.

Cost calculations will be based on estimated rates from construction companies in South Africa and the rough sizes of spaces outlined in the program breakdown - however, this cost calculation was done before the final draft of the building was done and so this may change as the building evolves. Naturally, the estimated fees are based on this building cost and so it may also not be indicative of the final product of this research report.

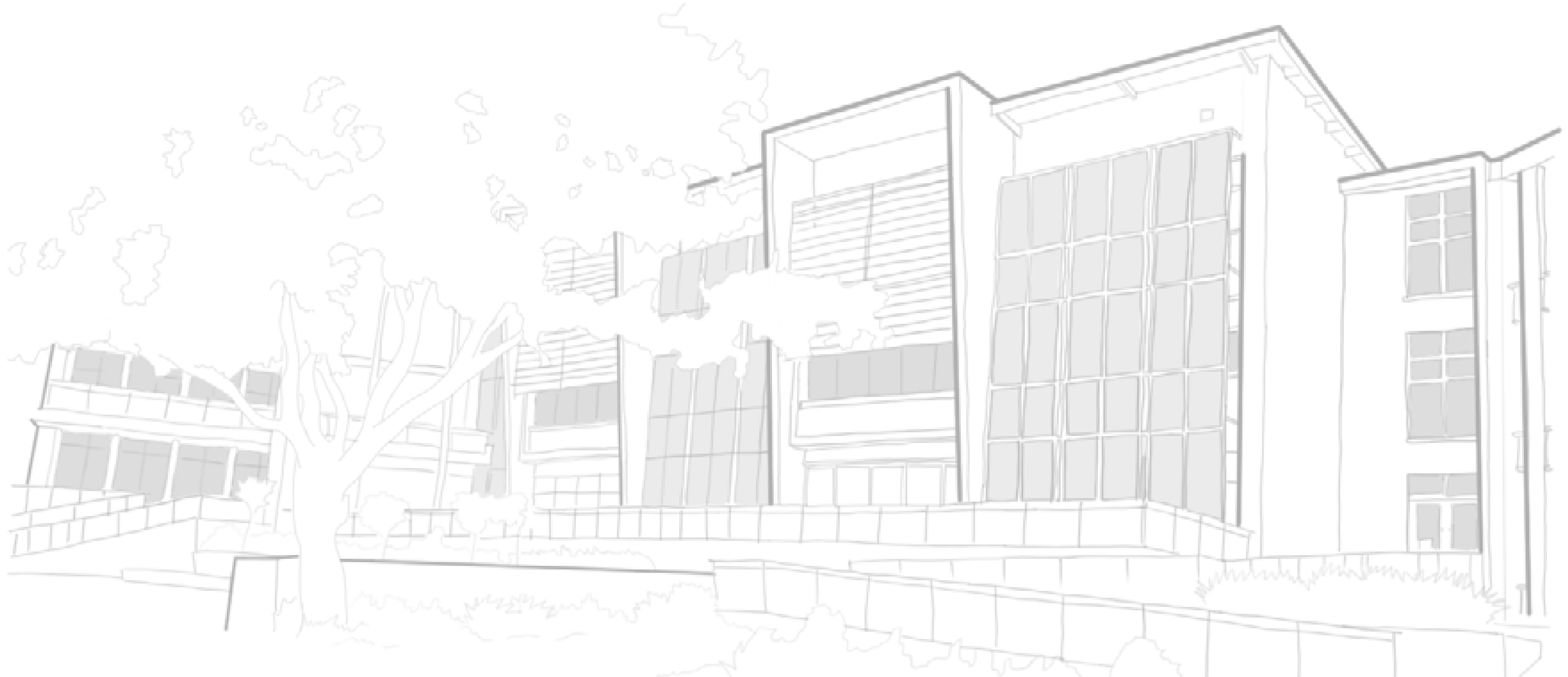


fig 82: NRF Headquarters, Pretoria (Author's work)

THE CLIENT

In 2003, the South African Agency for Science and Technology Advancement (SAASTA) procured the Johannesburg Observatory as a way to establish a learning centre in the city. According to SAASTA, the site was acquired in order to refurbish it "to accommodate a multifaceted interactive science awareness facility with a specific focus on astronomy and engineering." (SAASTA, n.d.). The site houses the following programs: forensic science laboratories for learners between grade 9-12, an interactive experiment centre meant to teach problem solving methods; a technology research activity centre; a computer laboratory for learners to be able to do school work, training to use computers and is also meant for teachers to incorporate technology into their teaching; and a resource centre with spaces for reading, studying, borrowing laboratory equipment and chemicals as well as a library for the public.

Evidently, there is already an established presence of education on the site. However, the site is currently underutilised and has the potential to reach a larger user base than just the niche, high-school user base that is currently using the site.

The development of the site is currently proposed in several stages, the first of which has already been completed which consisted of implementing the programs mentioned above. Because of the ongoing nature of the development of the site, the implementation of the satellite research and development centre would be proposed to be the next phase in the development of the site - expanding the user base to institutions, researchers and a wider range of the visiting public.

As covered in the chapter intro, SAASTA is one of the business units of the National Research Foundation whose mandate is "to promote and support research through funding, human resource development and the provision of the necessary research facilities in order to facilitate the creation of knowledge, innovation and development in all fields of science and technology". This mandate provides justification to propose the NRF as a potential client - or more specifically, SAASTA, as SAASTA is the legal body which owns the proposed site and runs operations on the site.

SAASTA has a more focused mandate, specifically one that focuses on bringing awareness of science research to the general public: "To advance public awareness, appreciation and engagement of science, engineering, innovation and technology in South Africa." This is important to note because one of the main goals of the Observatory centre is to inform the public about the research being done in South Africa to advance the country's space technology industry. Many people are unaware that South Africa has a space program, let alone that the country has been involved in several satellite launches and international space missions.

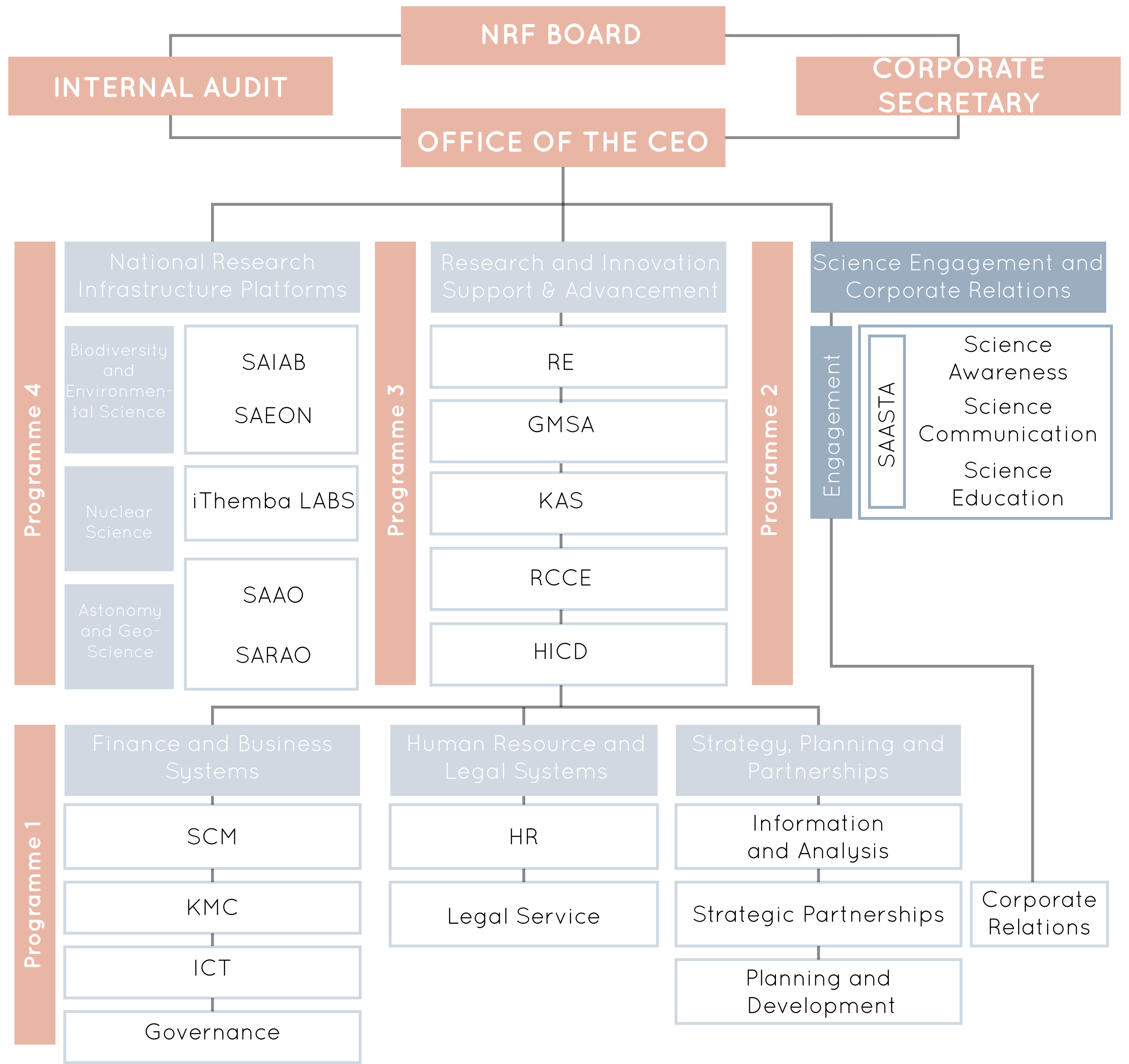


fig 83: NRF Organisational Structure (National Research Foundation, 2017)

FUNDERS

National Research Foundation

According to the NRF's annual financial statements summary for 2017/2018 (National Research Foundation, 2018), the NRF has three primary and one minor source of income, as follows

- **Parliamentary grant**: The MTEF parliamentary grant is the primary funder of programs and operational activities of the NRF.
- **Ring-fenced funding**: The DST provides ring-fenced funding to fund specific projects.
- **Contract income**: The DST and other governmental branches grant contract income to the NRF for specific research projects. Like the ring-fenced fund, this must remain untouched unless used for tasks laid out in the contracts in question.
- **Other income**: This is trading income and interest earned on funds invested.

The amount of money in each of these income streams is as follows:

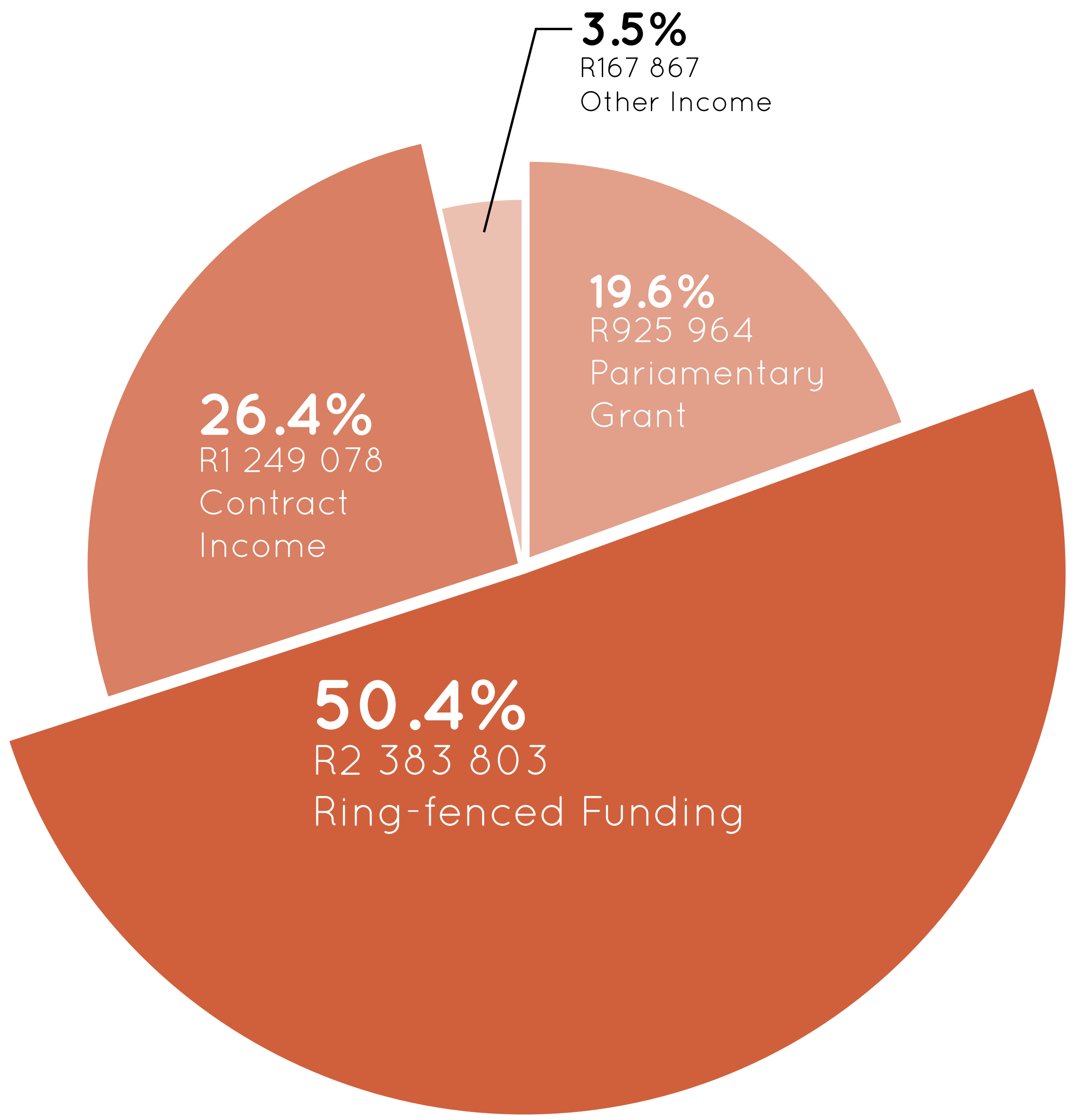


fig 84: NRF Income Trend (National Research Foundation, 2017)

The ring-fenced funding is, by far, the largest portion of income that the NRF receives for research funding. Being a ring-fenced fund means that the money cannot be touched unless it is for that specific project or use, for instance if a portion of it has been set aside for a research centre. There is a portion of the ring-fenced fund that has been set aside for projects like the Observatory centre: R534 900 000 in 2017/2018 for "high-end research platforms". So far the following high-end research platforms have been funded by the NRF:

- iThemba Labs: a particle and nuclear research centre
- SAAO: the South African Astronomical Observatory, a centre for optical and infrared astronomy research
- SAEON: the South African Environmental Observation Network, a national platform for detecting, translating and predicting environmental change
- SAIAB: the South African Institute for Aquatic Biodiversity
- SARAO: the South African Radio Astronomy Observatory, a research facility involved with radio astronomy programs such as the MeerKAT and HartRAO telescopes
- SKA SA: the Square Kilometer Array, an observational astronomy array in the Karoo

The success of these programs, funded by the NRF's ring-fenced funding, shows the importance of funding high-end research platforms. Many of the above mentioned facilities have played a role in international research projects and are internationally recognised as successful endeavours. The support of the government in funding these programs has been crucial in developing those industries in the country. The proposal in order to receive funding would be that the development of a satellite research centre would also be crucial in the development of another potential industry in the country, would bolster the country's economy and help gain international recognition in that field of research - much like what has happened with the fields of research for which the above platforms were built.

The NRF would be approached with the design proposal outlined in this research report in order to attempt to secure funding for the research centre, the NRF would supply the majority of the funding. However, it is possible that not all of the funding could be secured from a single legal body and so a proposal would also be made to an international research funder.

FUNDERS

BRICS
South Africa's inclusion into BRICS, the Brazilian-Russian-Indian-Chinese-South African economic alliance, has provided major funding opportunities for South Africa. Funding by BRICS is granted from BRICS' bank, the New Development Bank.

In 2018, the bank lent R114 billion to its constituent countries, and while that is a substantial amount of money, Kandapur Vaman Kamath, chairman of the New Development Bank, stated in 2018 that it was the bank's goal to double the loan amount from R114 billion to R228 billion in the following year.

This funding money is, however, limited to certain applications with most of the money (80%) being dedicated to projects that are focused on transport, green energy, water and sanitation. Which leaves the other 20% of the loans left to be split amongst the following categories, according to the BRICS 2019 Call for Joint Project Proposals:

- Aeronautics
- Astronomy
- Biotechnology and biomedicine including human health and neuroscience
- Geospatial technology and its applications
- Information technologies and high performance computing
- Material science including nanotechnology
- Ocean and polar science technology
- Photonics
- Prevention and monitoring of natural disasters

According to the call for proposals, the maximum amount that one is allowed to request is R2.64 million per project which is a substantial amount for individual researchers, but not nearly enough to make a substantial contribution to the creation of a research centre such as the one being proposed. However, amount of money being given as research grants may be enough to initiate research on the site. If given research grants, the researchers would be free to explore technology more creatively and be more experimental and could rely less on the income being generated by the research centre itself, or self-funding, for research capital.

Private Funding
If there is not enough funding that can be secured via the NRF and BRICS economic alliance, there are options for private funding - especially with a research centre that is closely tied to industry research such as the Observatory research centre.

Historically, the components used in the fabrication of satellites have been manufactured in-house to a very specific requirement. This is because the equipment is very specialised and, since the industry involved in the fabrication of these satellites was very niche, could not be mass produced nor were there enough companies involved to be able to outsource component manufacturing. However, in recent years the research and production of these nano-satellites has become common place enough for several companies to have shifted focus to the production of off-the-shelf satellite components; these companies are often international because of the nature of the research and application of the technology, however South Africa does have several of these companies within its borders.

In an emerging market such as this, companies who establish themselves early on as forerunners in the industry stand to gain the most in the long term. This desire for publicity would be the business pitch presented to private companies interested in gaining traction and recognition as industry leaders. In return for investing in the scheme, companies would receive publicity: for instance, if a company invests capital to fund the creation of a research lab, that research lab would be named after the company involved; or if a company funded the research being done over any given year, the result of that research would be named after the company itself.

The objective would be that the added capital from these funding opportunities would be able to facilitate the creation and/or operation of the research centre. The costs of the individual facilities are covered later in the chapter and would be presented to companies as funding goals in order to name a portion of the building after themselves.

THE PROJECT

Project Overview
The objective of the Observatory research centre is to provide a base of operations from which institutions and the private sector can collaborate to research and develop satellites and new technologies for artificial satellites and the space industry. Currently, there is a very high barrier between conducting research and implementing research into industry and so often it is not worth pursuing the implementation of that research into the industry. This is why one of the objectives of the Observatory research centre is to provide a platform through which academic researchers and industry professionals can collaborate; because research is being done in tandem with industry professionals, that research becomes work that is being produced for the real world.

The secondary objective of the project is to publicise the development of these satellites and the technology in order to educate the general public about research being conducted and technological developments as a way to generate interest and excitement. One of the shortcomings of South Africa's satellite research and development industry in the past has been the lack of engagement with the public. Many people are unaware that South Africa has a space agency, much less the work that is being conducted in the industry. While there is research being done on satellite technologies in South Africa, as evidenced by the existence of South African companies like SCS Space and the Space Advisory Company, the lack of awareness of these companies and the commonness of satellite development in the country means that the industry is not reaching its full potential. This can be corrected by providing facilities that capitalise on the research being done by creating interest in the industry, bringing in more researchers, press coverage and potential funders.

Financial Considerations
There are three major financial considerations when designing the centre itself and the planning for the centre.

As covered in the next chapter, the placement of the centre will be at the crest of the ridge in Observatory. This would provide substantial complications in terms of the actual construction and therefore there would be added costs in constructing the building. Firstly, this would need to be extensive site surveys by professionals - either site surveyors or geo-technical engineers. While there have been site surveys done, there have not been any site surveys which are as extensive as the building would require. Secondly, once the site is properly surveyed and a building is designed there would need to be extensive meetings done with structural engineers in order to find a construction solution which appropriately fits onto the site. The extensive consultations with professionals over the course of the project might prove to be costly and so would add additional costs to the project, something that one would need to consider when constructing a financial plan for the project. The extent of the solutions that the professionals present might also be an added cost to the project and would also need to be considered, over and above the regular engineering solutions that one would employ.

The second major financial consideration is the actual equipment used for the satellite fabrication. As discussed previously, based on case studies from other satellite fabrication facilities in the country and the rest of the world, the following facilities are required for satellite fabrication: radio frequency testing equipment, a thermal cycle chamber, magnetic characterisation and rapid prototyping equipment. Note, however, that while these facilities would normally be quite large, for the purposes of nonasatellite fabrication they can be quite small, with all of them fitting into the same laboratory. The cost of this equipment isn't in the space required but rather in the specialist consultation that would be required in sourcing or installing the equipment. While the industry of satellite fabrication is on the rise, it is certainly not popular enough for this manner of consultation to be inexpensive. This would be an added financial cost, especially if one considers that international help would more than likely be required.

The third financial consideration would be the operation of both the research institution as well as the public exhibition space, both of which can be costly to run.

As a case study of the cost of running a research institution, the expenditures of running the University of California was looked at (University of California, 2014). Note that this may not be directly proportional to the cost of running the Observatory research centre but would be a good guideline to understanding the operating costs.

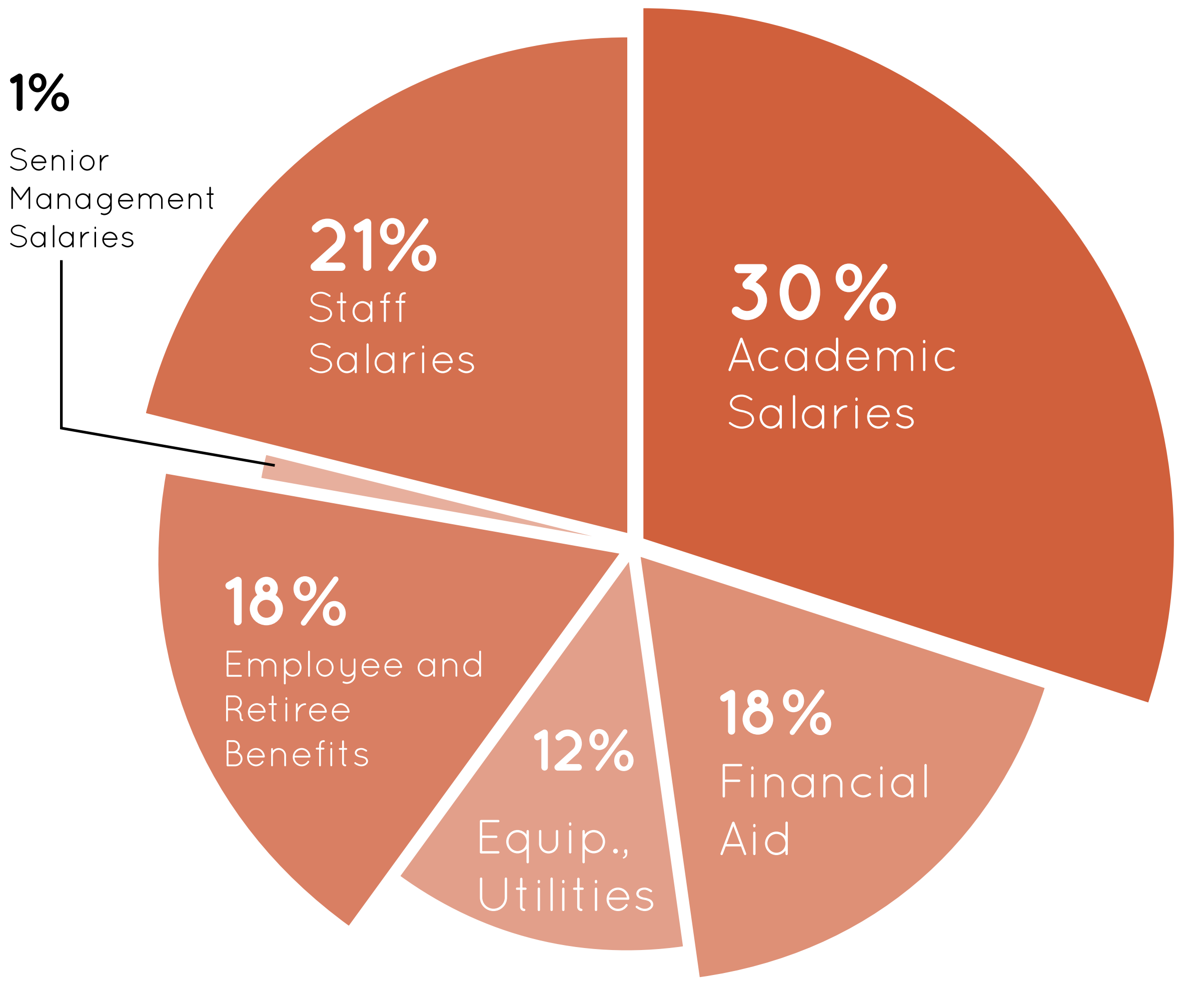


fig 85: Expenditures from Core Funds (University of California, 2014)

Note that individual proportions will differ for a major university and a specialised research institution. A large university with a diverse choice of courses will likely spend less on equipment and utilities than a specialised institution such as the Observatory research centre; all researchers at the satellite research centre will be using the equipment, so while the total cost might be less, the proportion of the total will be greater.

As stated previously, the exhibition will also have an inherent operating cost that needs to be covered in order for the project to be seen as viable. The exhibition space will consist of two major parts: a temporary, cycling exhibit whereby exhibition organisers will rent out equipment appropriate to the nature of the building; for instance, a Russian satellite replica or a rocket engine replica. This will have a cost associated with it and while there will be revenue generated by exhibiting this equipment, the cost profit margin would need to be carefully calculated to ensure that it is enough. The second type of exhibition will be a permanent exhibition space where research or fabrications from the research centre itself will be displayed. This would help visitors understand the work that is being done in terms that they can understand. This exhibition space would showcase replicas of satellites that have already been launched, have interacting exhibits that show how Earth orbits work, etc. These exhibits will have an upfront cost needed to cover the design, installation or purchasing of those pieces.

Every year, the Association of Art Museum Directors releases a report on what it costs to operate a museum, named *Art by the Numbers*. Their 2018 publication (Association of Art Museum Directors, 2018) has been used as a guideline in order to get a rough estimation on the cost of operating a public exhibition space. Much like the university operating costs, these numbers will differ slightly as the program differs.

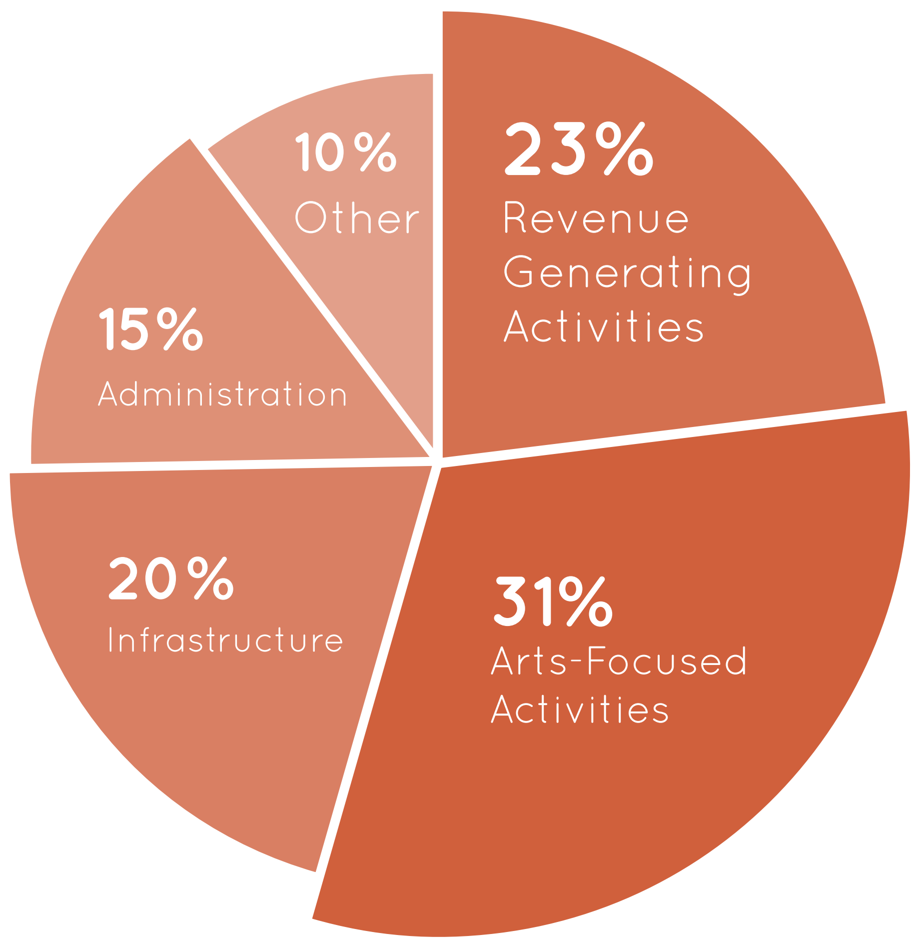


fig 86: Average Operating Expenses (Association of Art Museum Directors, 2018)

Technology, Sustainability, Materiality

The most complicated technology included in the facility will be for the satellite fabrication, as stated previously this equipment will include radio frequency testing equipment, a thermal cycle chamber, magnetic characterization and rapid prototyping equipment. The radio frequency testing equipment is not expensive or very extensive, but the testing chamber in which the satellites will be tested will need specialist consultation and installation. This is because it has to be constructed in a way that eliminates all outside radio interference. Secondly, the thermal cycle chamber and magnetic characterization equipment: the equipment is not large, no bigger than a small car, and will be easy to fit into the building. However the cost of the equipment and the specialist consultation required will be an added cost to the project. Lastly, rapid prototyping equipment such as CNC cutters and 3D printers will be required for satellite fabrication. The development of this technology over the last few years has ensured that it is getting cheaper, however equipment with the fidelity required for satellite fabrication will be more expensive and might require specialist training.

While the administration and public spaces may or may not require HVAC, the research laboratories definitely require an HVAC system. This is because the fabrication facilities need to be kept at a very specific temperature and air cleanliness. The fabrication spaces need to be clean rooms and would require an airlock style system to ensure air pressure and dust be kept out. This specialist HVAC equipment would also require additional space, consultation and would cost more.

Equipment used in the program of this building generally consumes a lot of power. Because of the large site or possibly the large building's roof, it would be possible to include photo-voltaic cells which could contribute to the generation of power that will be consumed on site, hopefully to offset municipality power consumption as much as possible.

COSTS

Building Program

A rough building program has been created as a way to explore the financial modeling for the research centre. This will be covered in more detail and altered later in the book and at this stage is used purely as an estimate for floor areas in order to calculate the building cost.

Building Cost

Given the areas of the estimated program and building cost rates taken from the *African Property & Construction Guide 2018* (AECOM, 2018), a rough estimation of the construction cost of the building was created below.

	Space	Area	Cost per m^2	Total cost
RESEARCH SPACE 445m^2 @ R5 166 000	Senior researcher office x 2	5m^2	R7 700	R385 000
	Researching assistant office x 2	15m^2	R7 700	R231 000
	Visiting researcher office x 2	25m^2	R7 700	R385 000
	Seminar spaces x 2	35m^2	R7 700	R539 000
	Satellite fabrication and testing rooms	110m^2	R13 300	R1 463 000
	Computer laboratory	150m^2	R13 300	R1 995 000
	Ablutions	25m^2	R7 000	R168 000
EXHIBITION SPACE 865m^2 @ R9 460 500	Exhibition spaces	500m^2	R1 330	R6 650 000
	Restaurant and coffee shop	40m^2	R7 600	R304 000
	Kitchen	30m^2	R7 600	R228 000
	Public foyer	150m^2	R7 700	R1 155 000
	Auditorium	105m^2	R8 000	R840 000
	Information desk	15m^2	R7 700	R115 000
	Ablutions	25m^2	R7 000	R168 000
ADMINISTRATION 205m^2 @ R1 669 500	Chief financial officer office	25m^2	R7 700	R192 500
	Administration staff office x 2	15m^2	R7 700	R231 000
	Marketing staff office x 2	15m^2	R7 700	R231 000
	Exhibition staff office x2	15m^2	R7 700	R231 000
	Reception and waiting area	40m^2	R7 700	R308 000
	Staff room	25m^2	R7 000	R308 000
	Ablutions	25m^2	R7 000	R168 000
SERVICE SPACES 940m^2 @ R13 540 960	Delivery area	40m^2	R7 600	R304 000
	Delivery officer's office	25m^2	R7 700	R192 500
	Goods/passenger lifts	5m^2	R7 700	R77 000
	Fire staircase x 2	25m^2	R7 700	R385 000
	Plant room x 2	12m^2	R7 700	R184 000
	Patch room	10m^2	R7 700	R77 000
	Security officer's office	25m^2	R7 700	R192 500
	Waste collection	40m^2	R4 400	R176 000
	Circulation	716m^2	R4 400	R3 152 160
	Parking	2000m^2	R4 400	R8 800 000
*2455m^2 @ R29 836 960				

*This excludes the area of the parking, but includes the cost

fig 87: Building Cost Estimation

Funding
As outlined in the "funders" section, the proposal for the funding of the Observatory research centre will work as follows: A private satellite/space technology company such as SCS Space will be approached with the proposal of donating funds for the construction of a space within the building with the incentive that the space will be named after the company. For example, the SCS Space Exhibition Hall will help bring recognition to the company in return for the sponsoring of the hall at R6 650 000, or 22% of the total cost of the building.

A proposal will be put together to approach the NRF to ask for the remaining 78% of the funding for the building, or R23 272 828. This money would come from their ring-fenced fund; specifically the R534 900 000 of their ring-fenced fund set aside for "high-end research platforms".

Lastly, once construction was completed, BRICS' New Development Bank would be approached with a proposal to fund the work of researchers at the centre; with their conditions for funding in mind, the New Development bank would be requested to provide sufficient loans for researchers, up to R2.64 million per researcher over the course of their education or project - although this amount of money may not be necessary, it would be the maximum request made.

Financial Viability
The financial viability of the project will come from the scheme's ability to generate revenue; this revenue will come from three different sources: research conducted on site, the admissions for the exhibition and the profit from the restaurant.

Research conducted on site will generate revenue in the form of research publications, generally in the form of collaborative research done between the researchers who use the site and institutions. Research publications can also be done by the senior, assistant or visiting researchers. This would generate more revenue for the researchers than collaborative research would and would follow their exploration of new satellite technologies or systems.

The public exhibition space would generate money via three avenues: admission fees for the general public, admission fees for visiting schools and possible renting out of exhibition space.

Lastly, the restaurant, coffee shop and a curio stall in the public foyer would all be able to generate revenue. However, as mentioned previously the spaces chosen for this viability study may not appear in the final design of the building and so at this point, these spaces are simply used as an estimate of the operating costs of the building.

All of these sources of income would be able to generate enough money to make the scheme viable, covering the overheads and salaries in order to keep the centre afloat. The estimation of these income sources is on the following page.

Operating Costs
Although the annual R8 837 750 income gained from running the research centre seems substantial, the cost of operating the centre would also be substantial. In order to be considered economically viable, the income gained needs to outweigh the estimated expenses.

Looking first at the cost of operating the research institution portion of the building, one can see that the largest portion of operational costs is paying salaries. This is similar for the exhibition space. A calculation has been done to estimate the cost of employing staff for a year (located at the end of this chapter); extraneous costs such as financial aid, equipment costs and exhibition spaces are assumed to have been covered thus far in the project with financial aid from the NRF, New Development Bank and private companies.

In addition to the salaries, general operational costs have also been calculated. These costs concern the non-personnel related costs of running the building.

According to the income estimation, the income potential for the research centre is R8 837 750. If the total estimated operational cost of the building is R5 502 854.92, it makes the profit margin for the building R3 334 895. Assuming that the cost of construction for the building was not fully covered by the funders, the remaining cost of the construction will be able to be paid off in a number of years, using a portion of the profits gained each year. Furthermore, the research centre may be able to provide financial aid to researchers to fund research.

Professional Team
The complexity of the building site, the size and complexity of the building itself and the design intention mean that a range of specialists need to be heavily consulted for the engineering design of the research centre. At the very least a structural and geotechnical engineer have to be consulted in order to find a construction methodology that will be successful on the top of the ridge. A mechanical engineer will need to be consulted because of the size and complexity of the building and the installation of equipment required for the clean room. Similarly, specialists will need to be consulted for the atypical part of the building: the fabrication laboratory. Because of the delicate nature of the satellite hardware and because of the precision required when assembling the satellites, special care needs to be taken with who enters and how they enter. Typically, these satellite fabrication labs are cleaner than operating rooms - not necessarily because of germs but because of dust and skin particles that can scratch surfaces or damage mechanical parts. This means that the space needs to be treated as a clean room with specialist equipment that removes loose particles from users. Because of the fidelity of this equipment, and the fact that it's rarely installed in buildings, a specialist will be required to design and install this equipment. The same goes for the satellite fabrication equipment: because it's rarely used in buildings, a satellite fabrication specialist will need to be consulted in order to achieve an acceptable level of design for these spaces. This consultation may even be from multiple specialists; because a range of equipment is needed (radio frequency equipment, thermal cycling equipment, vacuum chamber equipment, etc.), different specialists may need to be consulted.

Income Source	Quantity	Weekly Income	Number of Invalid Days*	Annual Income
Exhibition Space (Hire)	1	R10 000	14	R500 000,00
Exhibition Space (Public Admissions)	50/day@R200	R60 000	14	R3 000 000,00
Exhibition Space (School Admissions)	45/week@R50	R2 250	91	R87 750,00
Restaurant / coffee shop	100/day@R100	R60 000	14	R3 000 000,00
Public foyer (Curio sales)	50/day@R50	R15 000	14	R750 000,00
Conference on satellite development	4			R1 000 000,00
Research Publications				R500 000,00
			Department Income	R8 837 750,00

*because of public holidays

fig 88: Annual income estimation

Expenses	Monthly	Yearly
Utilities	R36 303,41	R435 640,92
Communications	R8 961,00	R107 532,00
Marketing	R14 091,00	R169 092,00
Insurance	R11 055,00	R132 660,00
Maintenance	R31 839,00	R382 068,00
Administrative Expenses	R5 911,00	R70 932,00
Total	R108 160,41	R1 297 924,92

fig 89: Annual expenses calculation

Professional Fees
A professional fees breakdown has been conducted in accordance with the professional fees guideline in Board Notice 122 of 2015.

Professional fees		
For Value of Works of		R29 836 960.00
Primary Fee	is	R1 346 249.00
Secondary Fee	is	(R29 836 960 - R13 000 001) x 9%
		= R1 515 326.31
Professional Fee	is	R1 346 249.00 + R1 515 326.31
		R2 861 575.31

fig 90: Staff salary calculation

Work stages 1 to 6	Proportion of Fee	Proportional Fee	Cumulative Total	Cumulative Total
1	5%	R143 078.77	5%	R143 078,77
2	15%	R429 236.30	20%	R572 315,06
3	20%	R572 315.06	40%	R1 144 630,12
4.1	20%	R572 315.06	60%	R1 716 945,19
4.2	10%	R286 157.53	70%	R2 003 102,72
5	27%	R772 625.33	97%	R2 775 728,05
6	3%	R85 847.26	100%	R2 861 575,31

fig 91: Staff salary calculation

Position	Count	Monthly	Yearly	Total
Administration staff				
Chief financial officer	1	R67 889.00	R814 668.00	R814 668.00
Administrative staff	2	R8 760.50	R105 126.00	R210 252.00
Marketing staff	2	R16 397.33	R196 768.00	R393 536.00
Exhibition staff	2	R8 760.50	R105 126.00	R210 252.00
Administrative assistant	2	R6 333.00	R75 996.00	R151 992.00
Security head	1	R4 490.08	R53 881.00	R53 881.00
Research staff				
Senior researchers	2	R26 260.58	R315 127.00	R630 254.00
Research assistant	2	R12 500.00	R150 000.00	R300 000
Laboratory manager	1	R9 692.08	R116 305.00	R116 305.00
IT administrator	1	R20 093.50	R241 122.00	R241 122.00
General staff				
Ticketing staff	2	R8 503.17	R102 038.00	R204 076.00
Security guards	2	R3 808.92	R45 707.00	R91 414.00
Delivery officer	1	R6 089.17	R72 350.00	R72 350.00
Cleaners	4	R3 083.92	R37 007.00	R148 028.00
Grounds keepers	2	R8 153.83	R97 846.00	R195 692.00
Kitchen staff				
Chef	2	R5 095.75	R61 149.00	R122 298.00
Wait staff	4	R2 996.42	R35 957.00	R143 828.00
Barista	2	R4 374.25	R52 491.00	R104 982.00
			Yearly total	R4 204 930.00

fig 92: Staff salary calculation

4 / 7 CONTEXT

"You are not in the universe, you are the universe, an intrinsic part of it. Ultimately, you are not a person but a focal point where the universe is becoming conscious of itself."

- Eckhart Tolle

fig 93: View over Observatory from ridge on the proposed site (Gauteng Film Commission, 2014)

CHAPTER CONTENTS

CHAPTER INTRODUCTION

In order to be able to design an effective research and visitors centre, it is important to understand the context within which that centre will be embedded. The examination of the context and how it will effect the design depends on the definition or definitions that one uses to outline said context. Johannesburg itself, with its rich and tumultuous past, presents several different types of context that one may or may not decide to consider.

Spatially, and related specifically to a space tech research centre, these contextual informants range from what is already existing on site to what and where are the closest research institutions that might be interested in collaborating research. The immediate context, in large part, has been covered by previous masters thesis projects and gives a well rounded understanding of the generic contextual features of the surrounding neighbourhood; such contextual analyses include surrounding communities, access and mobility, macro and micro green spaces, built space, land use, surrounding institutions and historical context. Because these fundamental contextual layers have been unpacked, this research report can focus on more specific contextual layers as well as an analysis of findings on site. This will help to inform certain aspects of the projects and careful analysis and consideration will improve the design of the research centre.

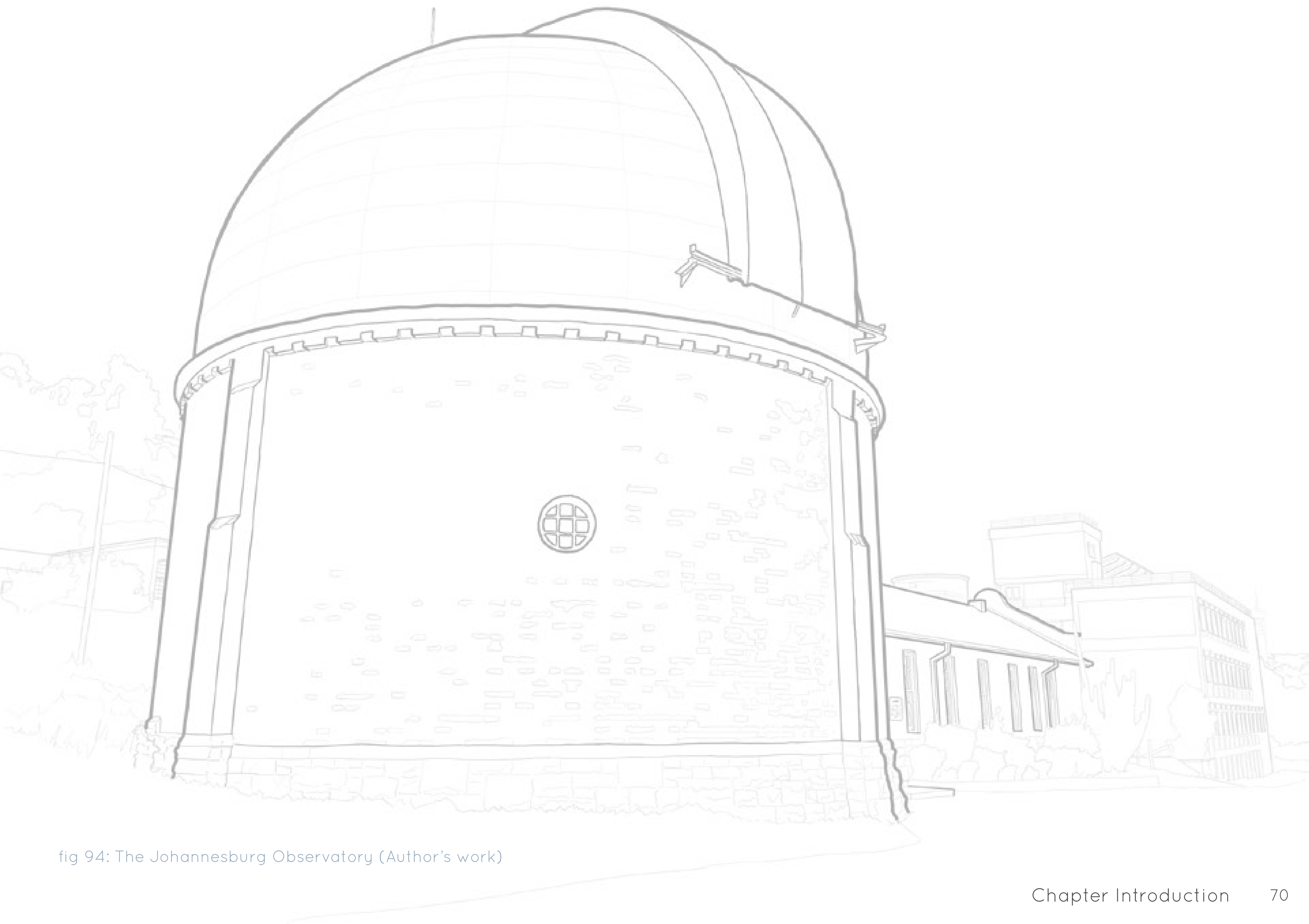


fig 94: The Johannesburg Observatory (Author's work)

SITE PROFILE

Before the site can be chosen, a site profile needs to be constructed that will help to inform which area will be best for the scheme. These are specific to the project and tie closely in with what the project aims to do and what the program of the scheme is. The Observatory Satellite Research, Development and Visitor's Centre aims to fulfil three main goals: create a platform that can catalyse the space industry in South Africa, use that platform to bring awareness to the South African space program and reframe space as an approachable subject for the public at large. The factors looked for in the site should, in some way, tie into these main goals. The site should be chosen specifically to help fulfil these goals as best as possible.

The following points were chosen as the primary factors when considering the site and were turned into a graphical representation afterwards.

Accessibility: Because a portion of the building deals directly with the public, access to the site is important. The interface between the researchers and the visitors to the site is important to whether or not the scheme can successfully bring awareness to the South African space program. Accessibility includes public transport, cars, and pedestrian access. It should be noted that these are, to a certain degree, programmable later.

Available space: The scheme itself will be large and so the amount of available space on the site is important. The scheme itself is going to be fragmented with a focus on outside space, so that should also be considered in the site profile. This largely rules out many options closer to city centres, as there may be land available but not the amount that may be needed for the scheme.

Communication possibilities: One of the more pressing issues that astronomy institutions face is the interference with communications technology. Being a satellite development centre, there will need to be a certain amount of radio communication with satellites. This rules out the option of being too close to the city centre. Although, typically ground stations for satellite development centres can be in large cities, it can cause a certain amount of complications. Communications possibilities also refer to communications in general. Collaboration between institutions is vital to the scheme and will form the majority of the research being done on site; sufficient communication ability is therefore necessary to allow that communication, whether cellphone or Internet connection.

Existing facilities: Part of the issue with starting a new educational facility or public centre is that its user base needs to be built up over time. Starting a new facility can be problematic when trying to gain popularity or even recognition. Therefore, one should consider the possibility of augmenting an existing facility or campus. Obviously, the existing facilities should tie into the program of the scheme.

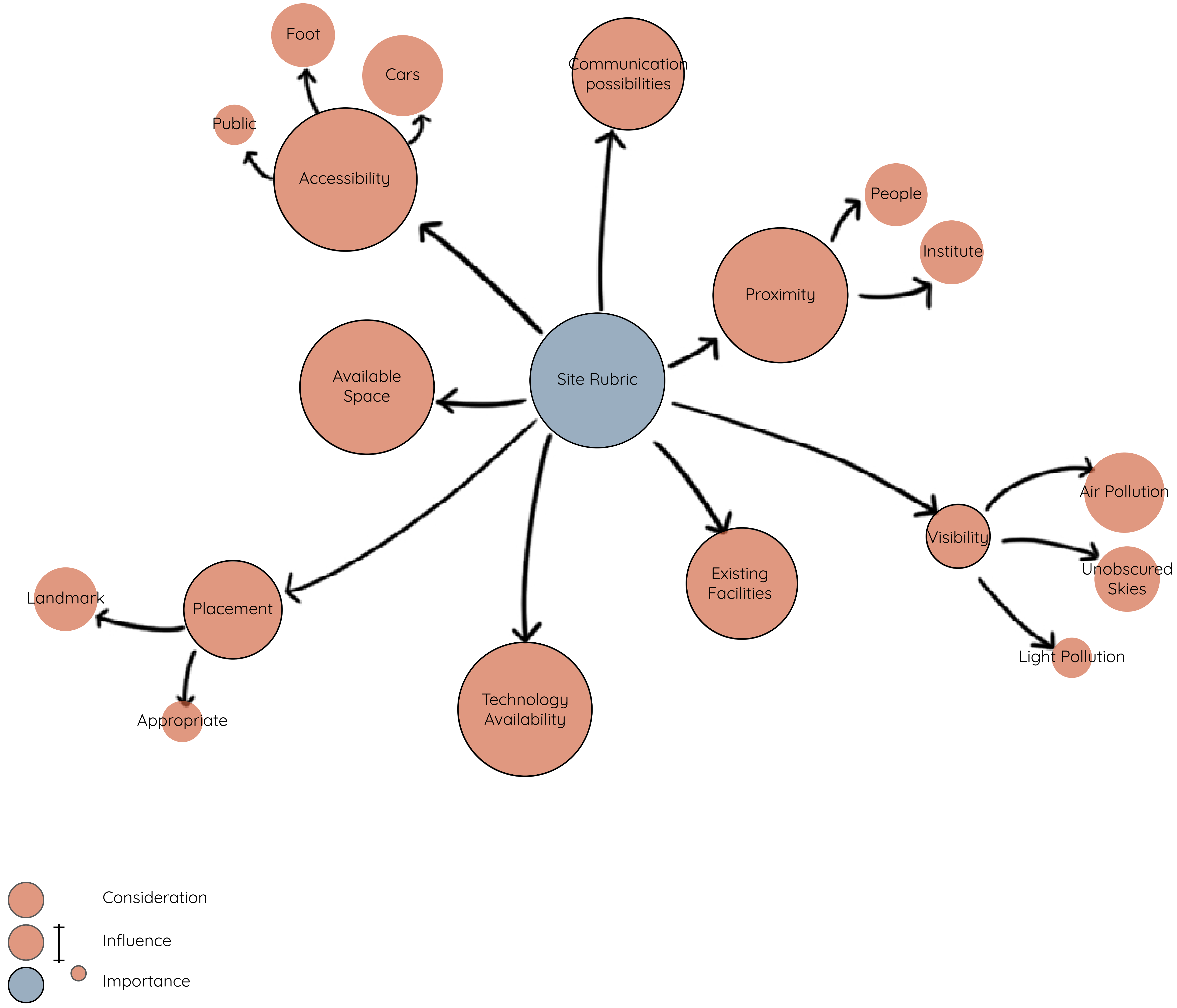
Placement: The placement of the building can, in many ways, determine if a scheme will be successful or not. The specific placement of the buildings will be decided during the design phase of the project, however one should consider the appropriateness of placing given program or building typology onto a site. It may not be appropriate to place a satellite research facility next to a football stadium, as there will be a certain amount of disturbance to the researchers. It may also be wise to consider that a large facility may become somewhat of a landmark - one should consider the appropriateness of certain landmarks in certain contexts.

Proximity: The proximity of the scheme to certain external factors is one of the most important aspects of the site profile. Researchers at the scheme will collaborate with researchers from other institutions and in the industry. Being too far from research institutions will cripple the scheme and ensure that it never becomes a successful research centre. Therefore, one should very carefully consider the proximity to Science, Technology, Engineering and Mathematics (STEM) institutions. Moreover, the collaboration of the scheme is not only with educational institutions, but also with the industry. This should also be considered when choosing a site for the building. The cross-platform collaboration of a scheme such as the Observatory centre is crucial in catalysing the space industry in South Africa and the importance of the proximity to these two elements can not be understated. Proximity to the general public is also important. One issues that museums or visitor centres that are placed far away from the public have is that people are not willing to travel to see them. This can cause a domino effect, of sorts. Fewer people means less publicity which leads to even fewer visitors, et cetera.

Technology availability: One of the possible challenges with a technology development scheme is the access to the technology used in the scheme. Firstly, this is in relation to the technology used in the satellites themselves: high-resolution imagers, solar panels, antennae, et cetera. Availability to these components will be necessary to making the scheme work. In addition to this, access to the right equipment is also necessary. This equipment includes the testing equipment discussed in the satellite theory section in chapter 2: radio-frequency testing and calibrating equipment, thermal cycle chamber, EMC reverberation chamber, et cetera. This is not only in terms of sourcing this equipment for the scheme, but possibly having access to these in other facilities around the site.

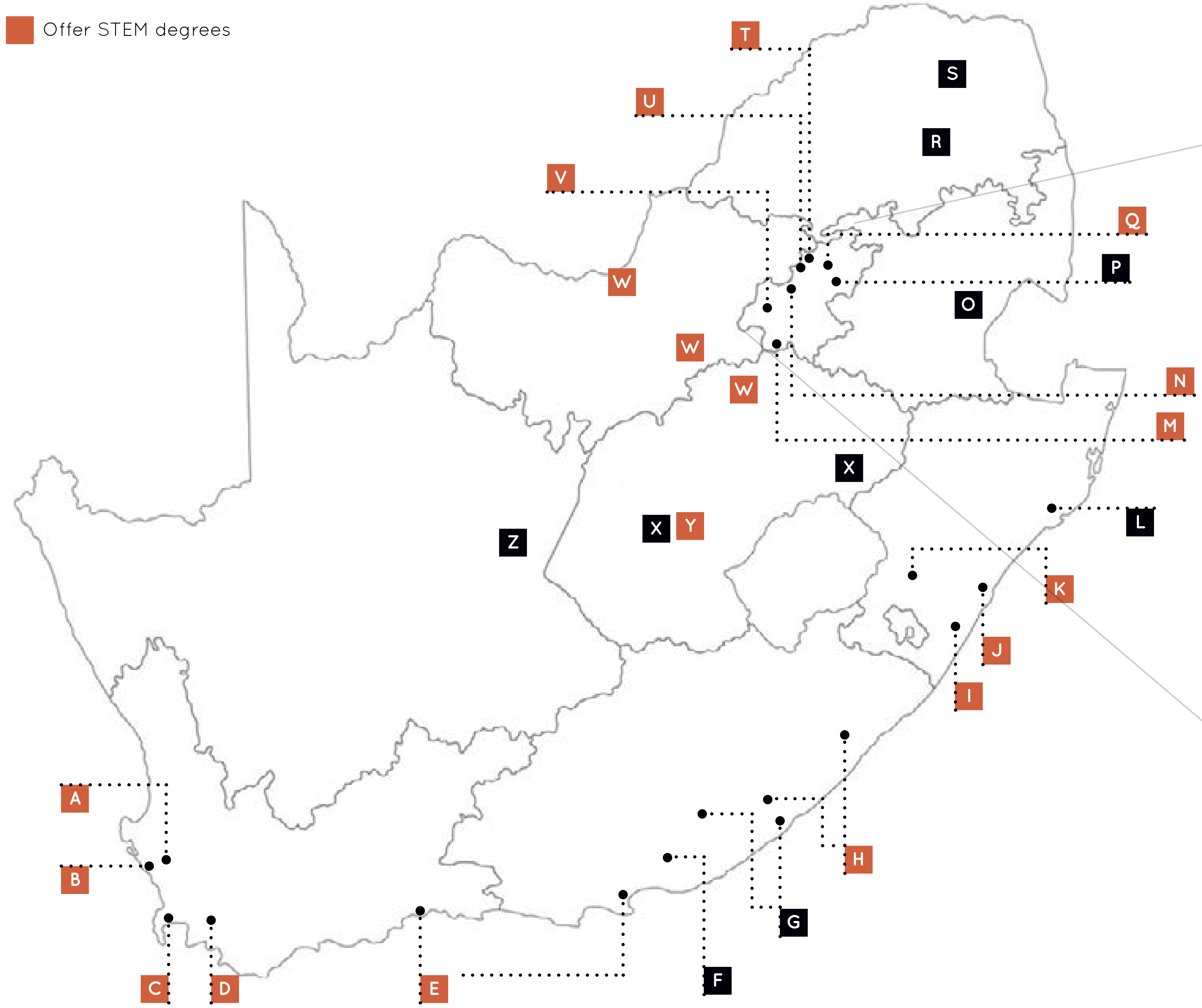
Visibility: Although this is one of the least influencing elements in the site profile, it should be considered to a certain degree. The scheme will focus a certain amount on naked eye astronomy and having access to clear skies for this is important. Clear skies, in this instance, mean less light and air pollution and unobscured skies. It is important to consider, but night-time observations are not central to the scheme and can be worked around.

Because of the number of different considerations in the site profile, it was necessary to weigh the importance of each of the elements of the profile. By essentially ranking the considerations, it was possible to make distinctions between different sites. For instance, if one site had a better proximity to institutions and another had better access to existing facilities, one would be able to weigh them against each other in a more objective way. The site profile diagram had two properties to the placement of each consideration: importance to the scheme and influence over the site. While similar concepts the difference is in the architectural response: Importance denotes how crucial it is for the scheme to work successfully, influence explains how much it will effect the design.



WHY JOHANNESBURG?

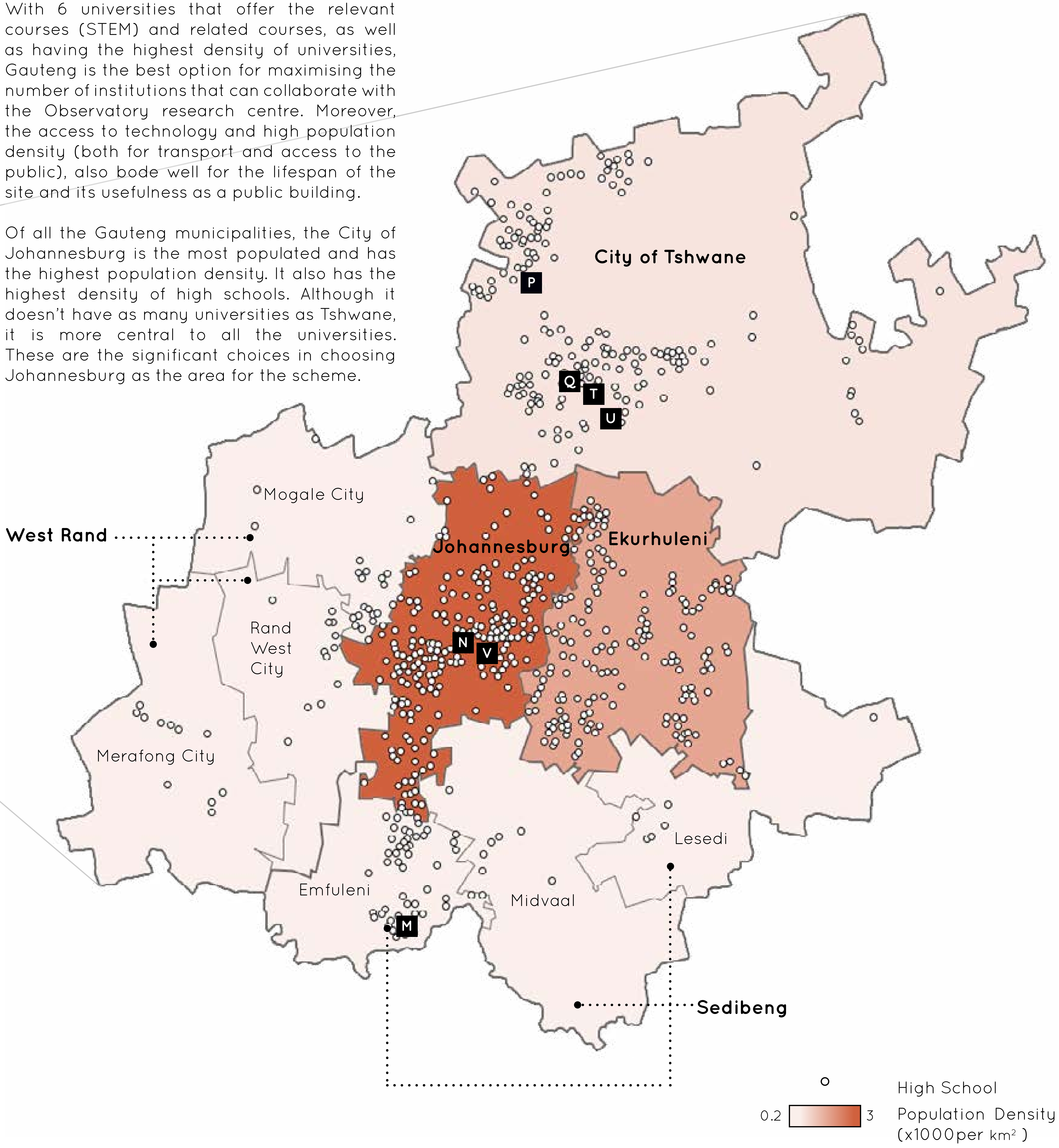
With proximity being one of the most important and influential considerations in the site profile because of the scheme's need to connect to educational institutions, the density of those institutions was very important. Not only was the density a consideration, but so was the type of institution; while the the universities or colleges that offered STEM degrees are important, they are not the only degrees that can effect the use of the scheme, as the applications of satellites are extending into other fields, such as oceanography, geography and physics. The manifestation of that investigation is below.



A. University of the Western Cape
B. Cape Peninsula University of South Africa
C. University of Cape Town
D. University of Stellenbosch
E. Nelson Mandela Metropolitan University
F. Rhodes University
G. University of Fort Hare
H. Walter Sisulu University
I. Mangosuthu University of Technology
J. Durban University of Technology
K. University of KwaZula-Natal
L. University of Zululand
M. Vaal University of Technology
N. University of Johannesburg
O. University of Mpumalanga
P. Sefako Makgatho Health Sciences University
Q. Tshwane University of Technology
R. University of Limpopo
S. University of Venda
T. University of South Africa
U. University of Pretoria
V. University of the Witwatersrand
W. North West University
X. Central University of Technology
Y. Central University of Technology
Z. Sol Plaatje University

With 6 universities that offer the relevant courses (STEM) and related courses, as well as having the highest density of universities, Gauteng is the best option for maximising the number of institutions that can collaborate with the Observatory research centre. Moreover, the access to technology and high population density (both for transport and access to the public), also bode well for the lifespan of the site and its usefulness as a public building.

Of all the Gauteng municipalities, the City of Johannesburg is the most populated and has the highest population density. It also has the highest density of high schools. Although it doesn't have as many universities as Tshwane, it is more central to all the universities. These are the significant choices in choosing Johannesburg as the area for the scheme.



SITE CHOICE REDUCTION

After narrowing the location of the site down to Johannesburg municipality, the rest of the site profile was used to narrow down the site choice further. The main considerations at this point were access to site, access to technology, existing facilities and availability of land.

Initially, sites with existing facilities were considered and formed the basis for the rest of the conditions. Access to site was a lesser issue for three reasons: access to site can be designed in at a later stage if need be, within the Johannesburg municipality, most places are accessible by car and narrowing down the site based just on this factor would prove to be a tedious, and ultimately fruitless, task. Access to site should rather be a consideration once a potential site has been chosen.

This is similar to choosing a site with an abundance of land. There are so many potential areas in Johannesburg with enough space to build a centre such as this, to comb through the entire city and metropolitan area in order to choose a suitable site would not be possible; rather, once having chosen a site or neighbourhood, one should investigate to see if there would be enough space for a new building.

Lastly, access to technology within the bounds of Johannesburg city can be considered as a given. Unless the chosen site had special circumstances surrounding it, this point could be considered moot. However, this does still play a role in the choice of site and should be considered important but will be confirmed based on the chosen site.

This leaves existing facilities as the major decider at this point, mainly because sites with access to existing facilities would be far less common than the other considerations were. By using this as the first condition to fulfil, the sites in the Johannesburg area from which to choose can be greatly reduced.

The next phase of choosing a site was to find facilities that could meet these conditions somewhere in Johannesburg.

CSIR

The first consideration for a site was one of the Council for Scientific and Industrial Research centres around Johannesburg. One of the mandates of the CSIR is to encourage collaborative research and would potentially be a valuable ally in the operation of a research centre. The CSIR has nine research clusters, however not all of them have relevance to the satellite research centre.

There are three clusters that can conduct collaborative research with the satellite research centre or would be able to provide a measure of support to the scheme: defence and security, NextGen enterprises and institutions, and future production: manufacturing.

However, not all of their research clusters have physical sites. Johannesburg itself is home to a CSIR Implementation Unit, a mining research centre and an occupational health centre. Obviously, none of these would be able to tie into the program of the satellite research centre.

CSIR does have offices and research centres in a campus in Pretoria and while some of these might tie into the program of the satellite development centre, the site does not fulfil the other conditions of the site profile - especially access to site and the placement of the building on the site. The site itself is heavily restricted with access gates, security personnel and high security fences. The nature of the site is extremely institutional with large research buildings and offices and does not fit the intended tone of the site for the satellite development centre. The site might appear to be too academic for the general public, who are meant to feel that space can be an approachable field of research.

fig 95: CSIR campus in Pretoria (Google, 2019)

HartRAO

The Hartebeesthoek Radio Astronomy Observatory is located just outside of Johannesburg municipality, in Mogale City. It operates under the National Research Foundation and is a radio astronomy observatory, meaning that instead of using the visible light spectrum to conduct astronomical observations, it used radio waves.

This was originally a choice for the site mainly because of the facilities on the site, the amount of open land and the quality of the air in the area, from a particulate and light pollution standpoint. Furthermore, the facility already has an established recognition in the scientific and public eye and the introduction of a new facility to the site could be beneficial to both the existing facility and the new facility.

However, the observatory has been placed far away from the city to avoid light pollution and radio interference, and introducing a museum and satellite research centre could potentially disrupt the operations on site. In addition to that, the placement of the facility so far from the city would make both the interfacing with the public and other research institutions difficult.

fig 96: HartRAO 26 meter radio telescope (NRF, n.d.)

Johannesburg Observatory

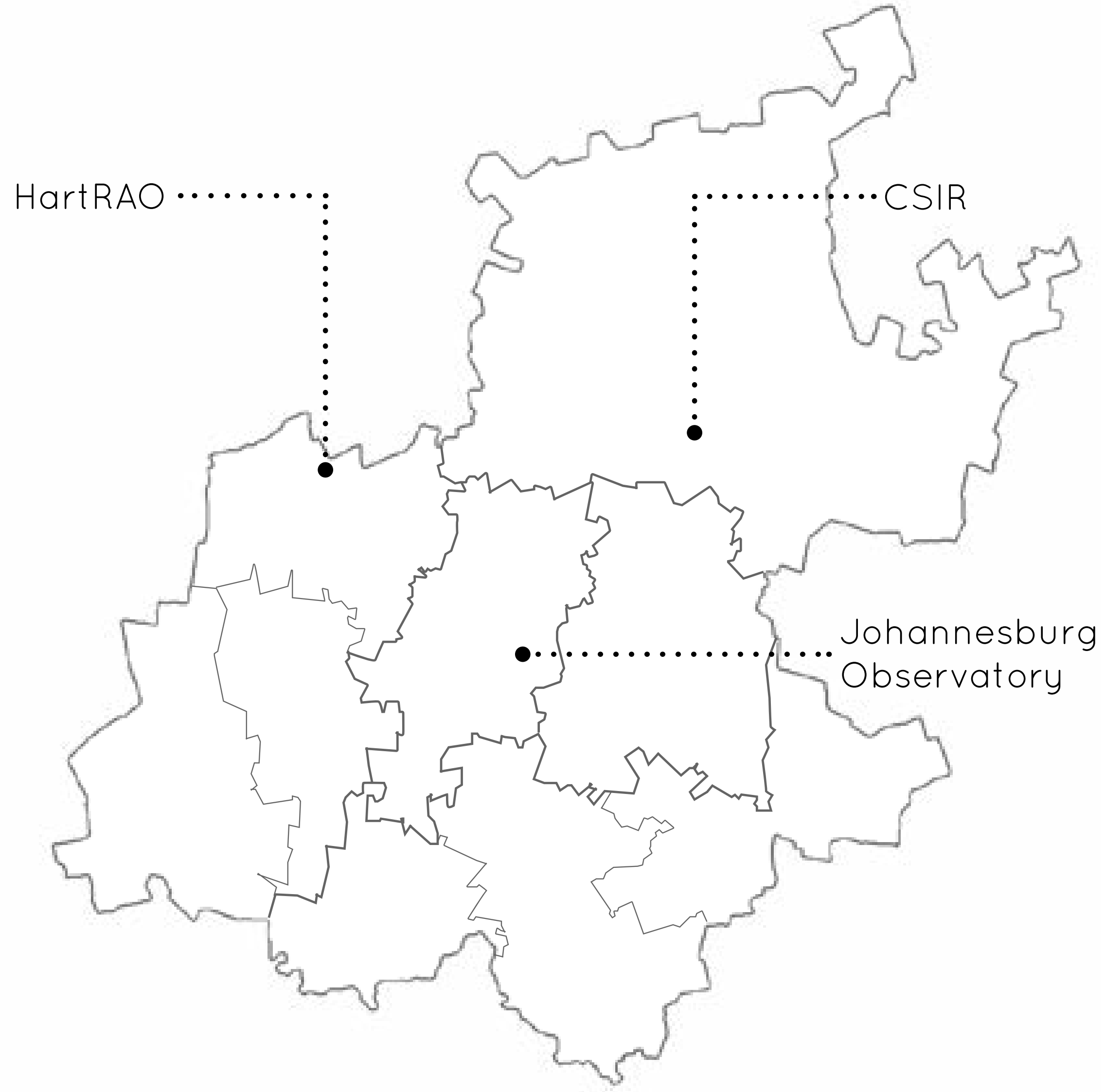
After considering HartRAO as a potential site, it seemed promising to look for a site that had a connection with the National Research Foundation.

The Johannesburg Observatory in Observatory was purchased by the South African Agency for Science and Technology Advancement (SAASTA) in 2003. SAASTA is a business unit of the NRF tasked with furthering science education, science communication and science awareness.

The site itself is on the Observatory ridge, and houses several existing buildings. The site is large however, and currently only has 15% coverage. It is within 7km of both the University of the Witwatersrand and the University of Johannesburg as well as many primary and high schools.

Access to site and the proximity to the city centre and surrounding suburbs would prove useful in bringing visitors and researchers to the site.

The placement of the site on top of the ridge would ensure than the building becomes something of a landmark and the higher altitude would mean marginally less pollution. This pollution would not be reduced enough to conduct academic astronomy observations, but would mean that visitors would be able to use telescopes or naked eyes to look at the stars.



SURROUNDING COMMUNITIES AND HISTORY

Like much of the rest of the Johannesburg area, the history of Observatory is in farmlands. The surrounding area was claimed and settled on by boer families who had come up from the Cape Colony in 1851. The surrounding area was made up of several farms, including Langlaagte, Braamfontein, Doornfontein, Diepkloof and Turffontein, among others. Observatory and the surrounding neighbourhoods sit on what was previously Doornfontein Farm. When gold was discovered in 1886, portions of the farms were sold off for their potential as mining land and the portions of the farms that had no mining potential were sold for less and eventually turned into suburbs.

In this process of selling portions of the farms, the area around Observatory was sold to a couple, Barend Christiaan Viljoen and Judith Cornelia Theresa. They would eventually have a daughter named Judith Cornelia Ethresia who would grow up to marry a man named FJ Bezuidenhout. The family farm would pass into Bezuidenhout and Judith Jr.'s hands. The two suburbs, Bezuidenhout Valley and Judith's Paarl, would eventually be named after them. Over the next few decades the farm was split and sold several times. Each new owner of a portion of land would split their land and sell a smaller portion of it. (SAHO, 2019)

Much of this land was purchased by urban developers who were hoping to develop the neighbourhoods into wealthy suburbs in the hopes of making money. An example of this is Bellvue, a suburb of Yeoville, which was originally purchased by Thomas Yeo Sherwell in 1890. Sherwell advertised the neighbourhood as a "sanitarium for the rich" in the hopes that wealthy families would move into the area. However, Bellvue and the surrounding suburbs instead became multiclass area, particularly as a stepping stone for migrarants coming into South Africa and as an aspiration for many of the poorer people living in Doornfontein to the south. (Anon, 2019) As people moved into the neighbourhood it became denser, more houses were built into available space and the community strengthened. The community that would eventually make up this neighbourhood created the fabric of the community that still exists there today. One can see by looking at the urban grain that the density of this suburb increased drastically, especially compared to the surrounding neighbourhoods.

Observatory itself has a parallel but slightly different history. During the selling of the surrounding areas, this portion of farm was sold and named Hospital Hill Ridge after the hospital that sat nearby, between Hillbrow and Braamfontein. Hospital Hill, however, had not been sold to be turned into suburbs. It was held, seemingly unused by the Bezuidenhout family until it was given to the government in the early 1900s. The Traansvaal Meteorological Department built the Observatory near the top of the Hospital Hill ridge in 1903 and it was officially opened in 1905, being equipped with its first telescope in 1906. This site was chosen because it is the highest point in Johannesburg and it was further away from mining operations, making it better suited for astronomical observations. Astronomer Dr Robert Innes moved from Cape Town to be the director of the centre. The suburb was named after the observatory shortly thereafter. The observatory itself has gone through many name changes since its creation, reflecting the changes in the political climate of South Africa. From 1903 to 1909 it was called the Traansvaal Meteorological Department; from 1909 to 1912 it was called Traansvaal Observatory; from 1912 to 1961 it was called Union Observatory, which it is often mistakenly called to this day; from 1961 to 1971 it was called Republic Observatory, at which point it stopped operating. Sources differ on whether it was named Union Observatory or Johannesburg Observatory from this point on, however it is now called Johannesburg Observatory.

After the creation of the observatory in 1903 the rest of the suburb was zoned as a residential neighbourhood and people began to move in. The majority of the people that moved to Observatory were Jewish from less wealthy neighbourhoods. "Those upon whom fortune smiled trekked northwards via Hillbrow and Yeoville, Bellevue and parts of Observatory." (Rubin, 2004) Observatory was a middle class neighbourhood and the coarse urban grain created by the late start of the neighbourhood made it appealing. Even today, the green fabric of the neighbourhood reflects the relatively recent life of the area as farmland. As the area was divided up for wealthier families later on, the plots are large and have an abundance of open space and vegetation.

A. Upper Houghton
B. Yeoville
C. Bellvue
D. Bellvue East
E. Observatory
F. Doornfontein 92-IR
G. Bezuidenhout Valley
H. Judith's Paarl
I. Randview
J. Lorentzville
K. Highlands
L. Bertrams

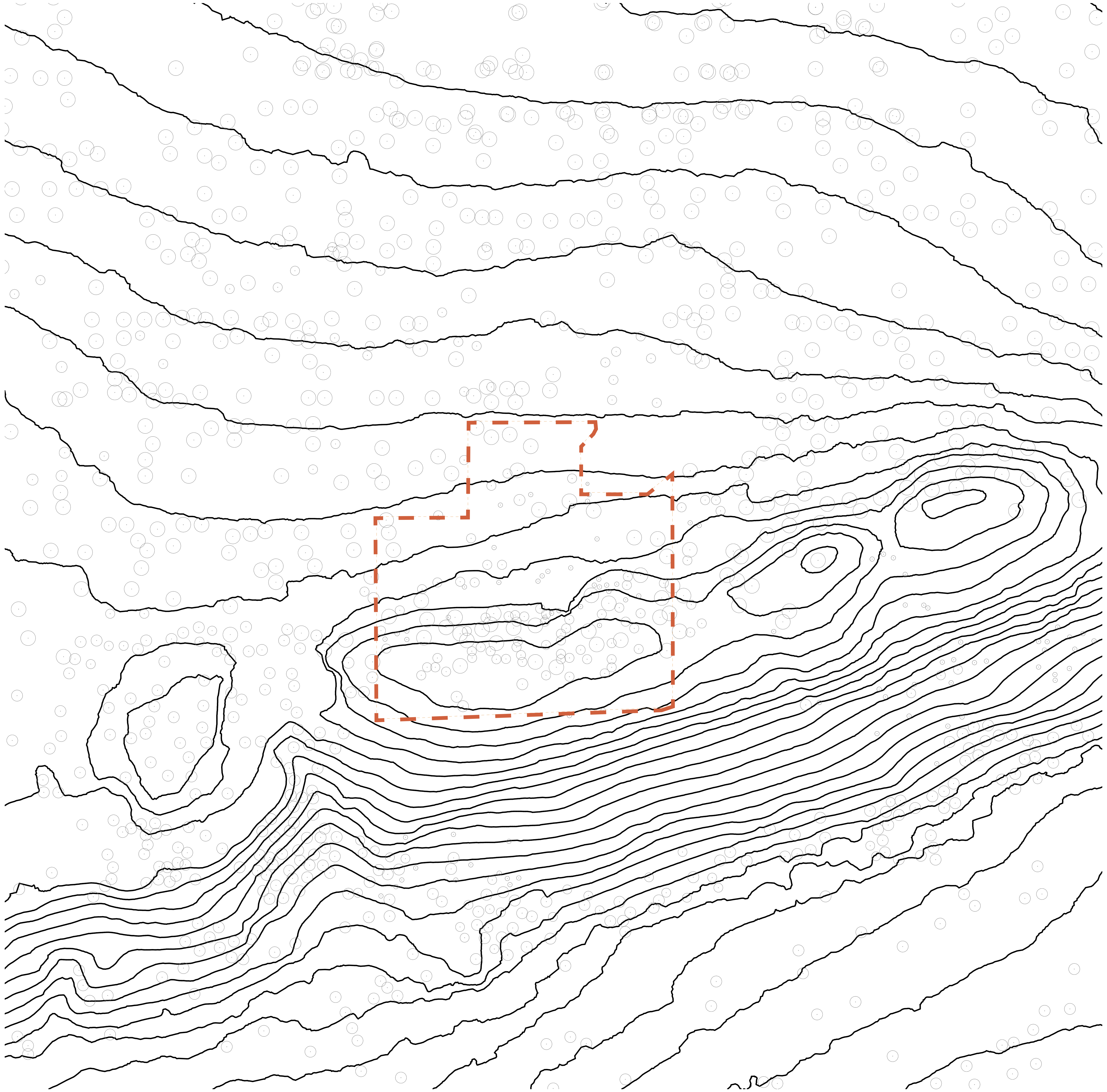
Chosen site (Johannesburg Observatory)

SITE ANALYSIS - SATELLITE IMAGE

The chosen site is at the top of the Observatory ridge, seen in the image below. There are buildings on site currently, which will be covered later in the chapter. As discussed previously, one can see the stark change in urban grain between Observatory to the north and the surrounding neighbourhoods - Bezuidenhout Valley to the south and Bellvue East to the west.

SITE ANALYSIS - TOPOGRAPHY

One of the more challenging aspects of the chosen is the topography itself. The placement of the building on the ridge potentially poses some difficulty with the design of the building and should be explored. When comparing the topography map below with the satellite image previously, one can see that there are very few buildings on the actual crest of the ridge and those that are present are relatively small.



SITE ANALYSIS - FIGURE GROUND

Below is a figure ground map of 1km² of Observatory, Johannesburg. One immediately obvious take-away is the difference in density between Observatory and the surroundings - especially Bellvue East to the west. While the difference in density was obvious in the satellite image previously, the figure ground below showcases it better.

fig 97: Figure ground plan

ANALYSIS - FIGURE GROUND

Density
As discussed previously, the density of the neighbourhood is very closely tied to the development of the neighbourhoods and the history of the area. At this scale one can begin to fully understand the difference in densities of the different neighbourhoods. Generally, the houses in Observatory are one family homes, where as the houses in Bellvue East are multifamily homes, often apartment blocks or houses with many additions.

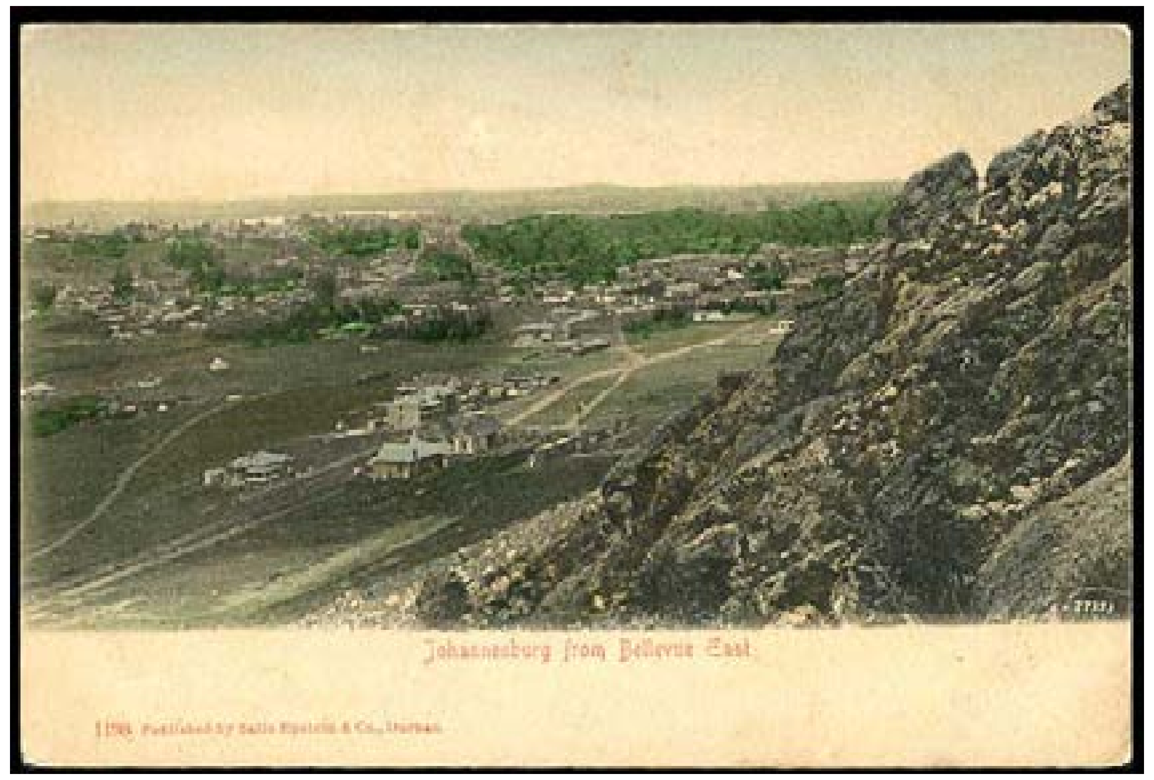


fig 99: Postcard from South Africa - Johannesburg from Bellvue East

One can see in the postcard above, taken around the time of the founding of Observatory, the density of the surrounding areas. Based on the content of the postcard, one can assume that the photograph is taken from Observatory ridge itself, looking south-west toward the Johannesburg. At this time, the Bezuidenhout Valley and the surrounding communities had not been fully established yet.

Density Factors
As well as having little to no yard space, Bellvue East also has much taller buildings, focusing on providing higher density housing at a lower cost instead of single dwellings on each site. In fact, this can be seen easily in the image below and in the south west corner of the plan. The building on the right is an apartment building (A on the plan) and the plot on the left is a regular house (B on the plan). As can easily be seen on the plan, the apartment building (554m²) takes up half of its site (1157m²) and the house (459m²) takes up only about one fifth of the site (2465m²). Additionally the apartment block is 3 storeys tall. This is indicative of the rest of the Observatory and Bellvue East. While Bellvue East isn't made exclusively of multi-storey buildings, a large portion of the neighbourhood are multi-storey like this.

fig 98: Difference in fabric between Bellvue East and Observatory, separated by De La Rey Street (Google Street View)

Observatory houses tend to be simple, one or two storey houses. Taking into account the size of the plots, this leaves the neighbourhood mostly small houses with very large gardens.

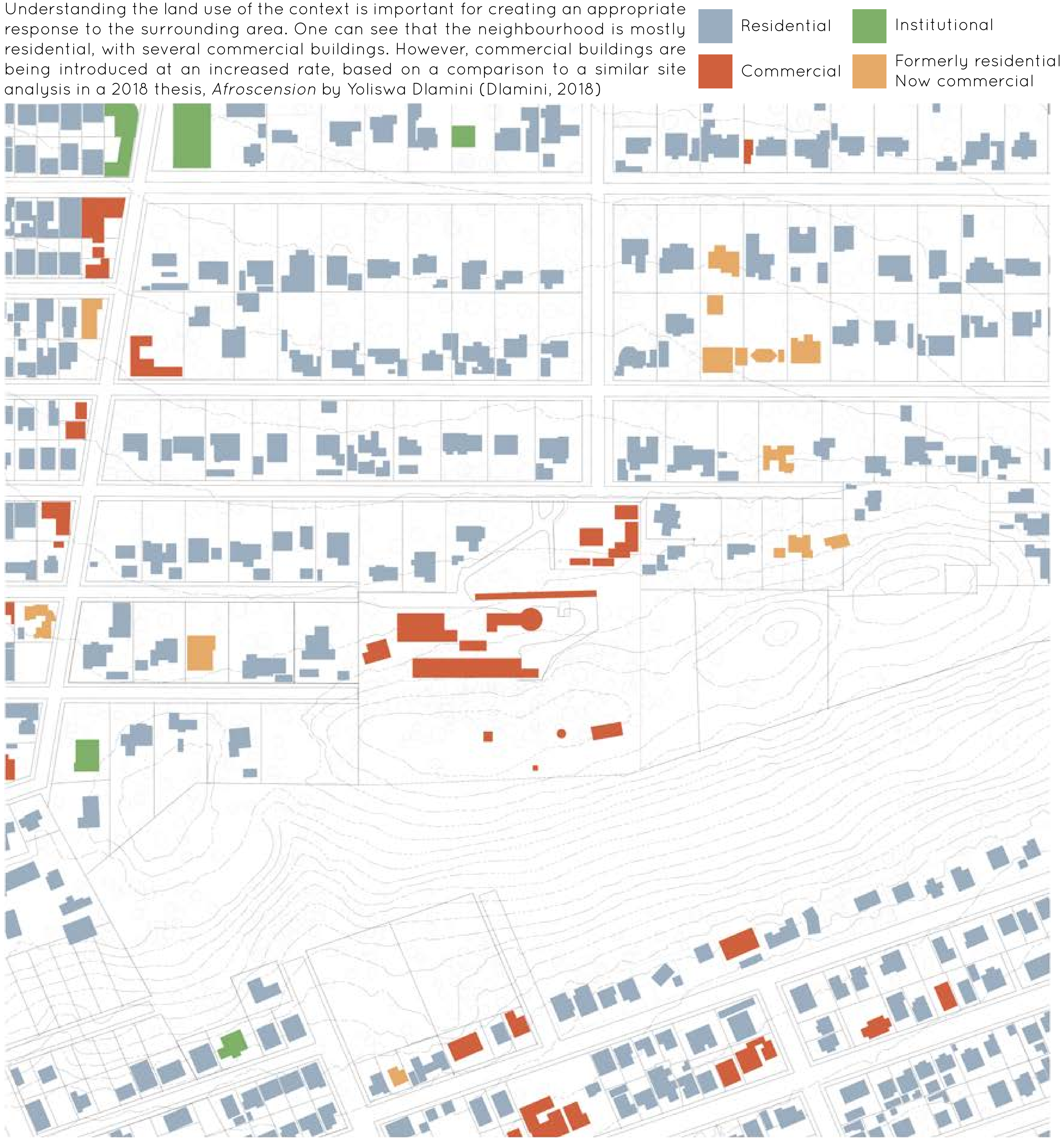
Ridge
The impact that the ridge has on the density of the Observatory is immense. The ridge is 114900m2, unable to be built on because it is too steep and rocky. While it would be possible to build on the ridge itself, it would require a lot of engineering and would require that the portion to be built on be properly studied and analysed. While the area on top of the ridge to the east of the site hasn't been built on, it was subdivided in December of 1940 and given ERF numbers so it would be possible to built here if necessary, however access is difficult.

SITE ANALYSIS - NEGATIVE SPACE

Essentially the same as the figure ground before, the negative figure ground shows the amount of open space in Observatory. In Bellvue East and to a certain extent, Bezuidenhout Valley, the void space represents the public domain. Comparatively, most of the void space in Observatory is private space in the form of gardens, generally. It's important to understand the negative space in Observatory because the design outcome for the research centre will eventually focus on using negative built form as a tool for astronomy.

SITE ANALYSIS - LAND USE

Understanding the land use of the context is important for creating an appropriate response to the surrounding area. One can see that the neighbourhood is mostly residential, with several commercial buildings. However, commercial buildings are being introduced at an increased rate, based on a comparison to a similar site analysis in a 2018 thesis, *Afroscension* by Yoliswa Dlamini (Dlamini, 2018)



SITE ANALYSIS - GREEN FABRIC

Much like the other neighbourhoods in Johannesburg, Observatory is home to a large amount of street trees; but even so, most trees in Observatory are in the large gardens of the residences. The placement of the Observatory centre in the site will need to consider the existing trees on site, depending on the design approach. Access to the site for construction vehicles would also be limited and should be considered when designing the approach to the site.

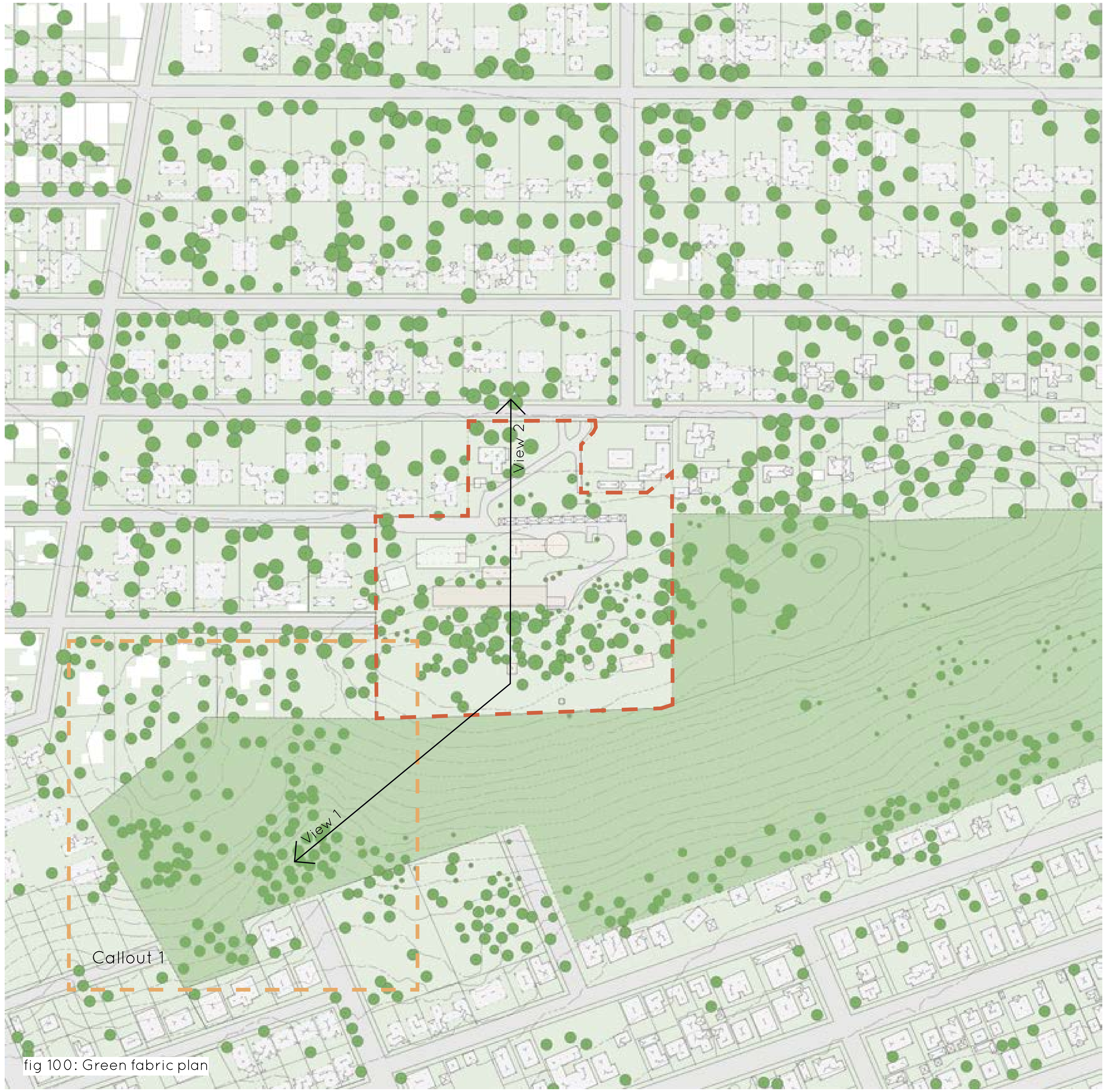


fig 100: Green fabric plan

ANALYSIS - GREEN FABRIC

Origin of Trees
Much like the rest of the city, Observatory has many trees lining its streets and even more in the gardens of houses. A lot of trees in the city were planted to be used as props inside the mines, however this was only after gold was discovered in 1886. Trees were first planted in the Observatory area in the 1860s by the Bezuidenthout family, specifically in Judith's Paarl to the south west of the site, and in Cyrildene to the east of the site. The trees planted were oak trees which have a lifespan of about 50 years, so while the original trees no longer exist, the planting of trees on the Doornfontein farm continued for many years. Many of the trees in gardens may be from this initial planting of trees, however many of the trees come from a conscious effort by the Parks and Estates Department of Johannesburg to plant trees along street edges, first in white areas in the early 1900s and later, in the 1950s, in black areas.

Density of Trees
Because of the placement of many trees in the area before the establishment of Observatory, once plots had been set out in the 1900s most of the plots already had many trees on them; this coupled with the fact that the plots were large and the houses didn't cover a lot of the plots, many of the trees stayed. The trees in gardens have continued to be manicured over the last century and many have been added since then. Naturally, the density of the trees changes from gardens to the ridge and other open spaces around the area. A lot of the ridge itself is very rocky and only grass and small plants are able to grow on the side of the ridge; however at top and foot of the ridge the tree density is much higher. Similarly, in the "valley" to the south west of the site (callout 1) the tree density is much higher. This is likely because of the tendency for the valley to catch soil and water, creating a good place for the trees to grow.


fig 101: Callout 1 (Google maps, 2019)

Ridge as an Open Space
The ridge was chosen as the site for the base of operations for the Johannesburg meteorological observatory in 1903 because it's the highest natural point in the city at 1809m above sea level. At this point is a beacon commemorating the British Indian Army. Much of the surrounding areas can be seen from the top of the ridge, especially with the help of a viewing deck that's been built at the top of the ridge. From the top of the ridge one can even see the Voortrekker monument 47km away, as well as Johannesburg city, Sandton and south over the southern suburbs. Currently there are only 6 structures at the top of the ridge: an unused library designed by Sir Herbert Baker, two small observation telescopes, two abandoned buildings and the viewing platform.


fig 102: View 1 (Author's own)


fig 103: View 2 (Author's own)

SITE ANALYSIS - ACCESS

Access to the site was one of the major points in the site profile originally created to choose a site. The site itself has a lot of potential with regards to access, however there are several factors that present potential problems. Namely, access restrictions and blocked roads into the site.

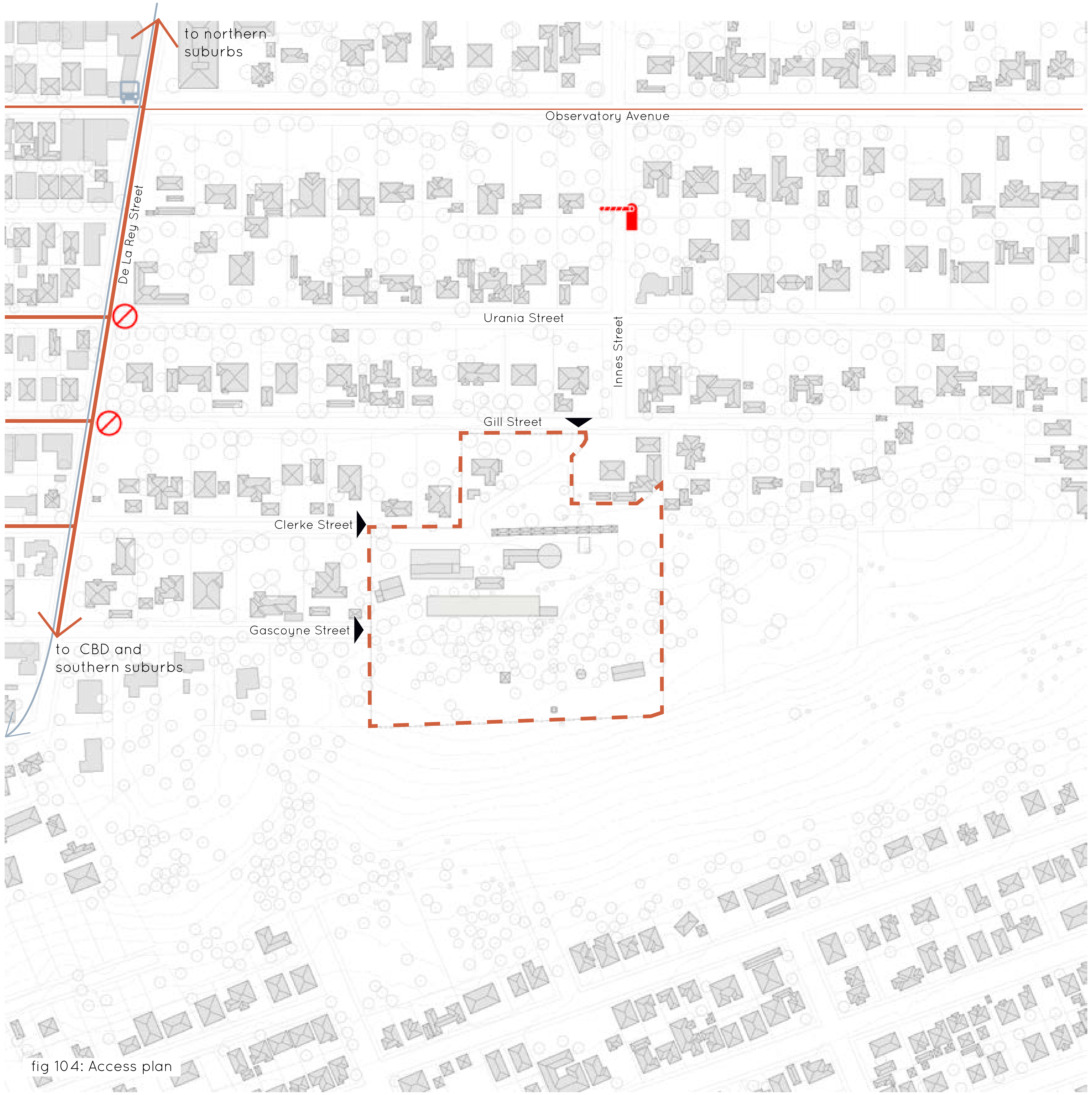


fig 104: Access plan

ANALYSIS - ACCESS

Access routes

Observatory sits on the divide between the north and south of the city, just east of the CBD. Access to the site itself is possible via 3 entrances: Gascoyne Street, Clerke Street and Gill Street.

The only entrance being used currently is the Gill Street access gate. A photograph of the entrance gate was unobtainable because of security reasons.

Clerke Street has a palisade gate that has been blocked by a chain link fence, so although there is an entrance there, it would need to be modified in order to be usable.

fig 105: Clerke Street Entrance (Google street view)

Gascoyne street doesn't currently have a gate into the site, but there is a fence at the end of street which could easily be modified to be a public access road. The proximity to residences is a potential problem and so the gate should probably be brought further into site in order to make an effective entrance.

fig 106: Gascoyne Street Entrance (Google street view)

The entrance to the site will depend on what's best for the public and the researchers. Because of the separate entrances on site that lead to different areas of the site (current buildings versus the top of the ridge), these different entrances can be used to separate different parts of the program - public and private.

Traffic

The main road that divides Observatory and Bellvue east, De La Rey Street, is the busiest access road in the area. During week days, peak times in the morning are between 7:00 and 7:50, with heavier traffic going north. This might be because the road connects to the M1 which then goes to Pretoria or the northern suburbs. In the evening, traffic peaks at 18:00 and that heavy traffic continues until 20:10. Weekend traffic peaks briefly between 13:00 and 13:30, again between 15:00 and 15:30 and finally between 16:30 and 20:00; weekend traffic, however, is much less severe that weekday traffic.

Importance of Access to the Site

It's important to note how access to site will affect the function of the building. If the general public is going to be accessing the site, their access times will likely be late morning to mid-afternoon on the weekend and so how one accesses the site for personal reasons plays a role in the choice of the site. The public on the weekend can access the site from the side roads, but during the week the public would likely want to access from the north because the traffic would be less severe. Furthermore, if there is a school field trip to site it would be best to access from the north because the traffic would be less severe and there would be more possibility for parking or moving buses. On a similar note, access to researchers and the staff for the site would be accessing the site during peak hours. This would mean that their access to the site should be via the north too. It's more private because of the access restrictions and they would be able to avoid a lot of the traffic. The area that the entrances provide access to, however, do play a greater role. As stated before, the separate entrances should grant access to areas of the site which will have separate programs. The top of the ridge, where the research/visitor's centre will be, will likely be the most important and so it's likely that the current facilities will be accessed via Gill Street and the new centre will be accessed via Gascoyne street.

Access Restrictions

Urania, Gill and the top half of Innes street are inside a gated community. Site access is permitted just above Observatory road and both sides of Urania and Gill streets are closed with a palisade fence. Although there is a security guard with a boom and a closeable gate, they don't require a book to be signed or take pictures of cars. This access restriction might need to be changed or removed - however if Gill street access is only for researchers, having the access restriction would be an effective way to separate public and private entrance.

SITE ANALYSIS - SHADOW

Because of the potential height of the building on top of the ridge, a shadow study of site should be conducted to understand the impact that a large building such as this can have on the site. A mock building has been put in place with dimensions similar to the final building in order to see the impact that such a building would have on the surrounding sites. Design-wise, the building will respond to the conditions of the sun or moon at particular times of the year, in the style of archaeoastronomy - this shadow study will need to be more detailed and will be conducted with the design exploration.

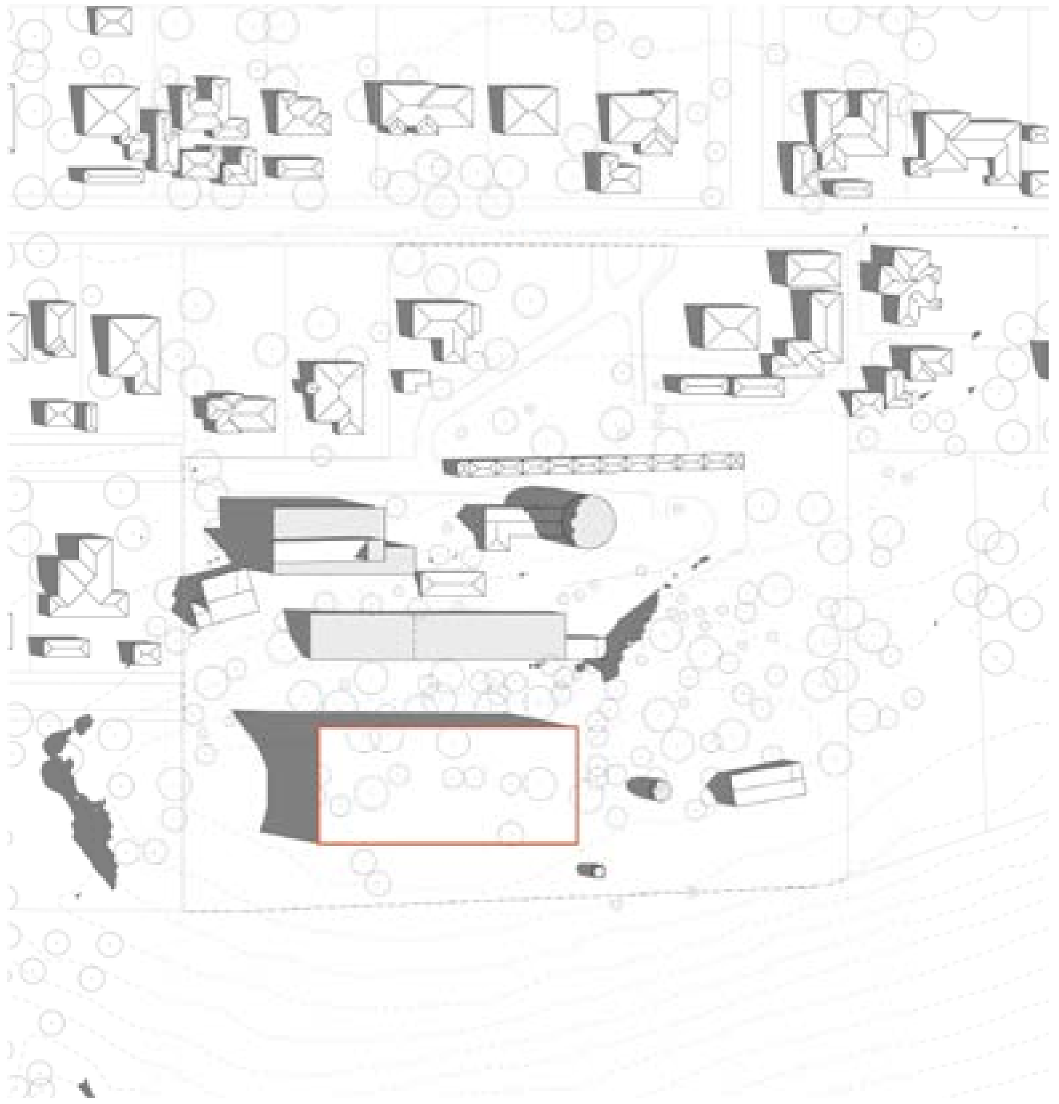


fig 107: Summer Solstice | 08:00

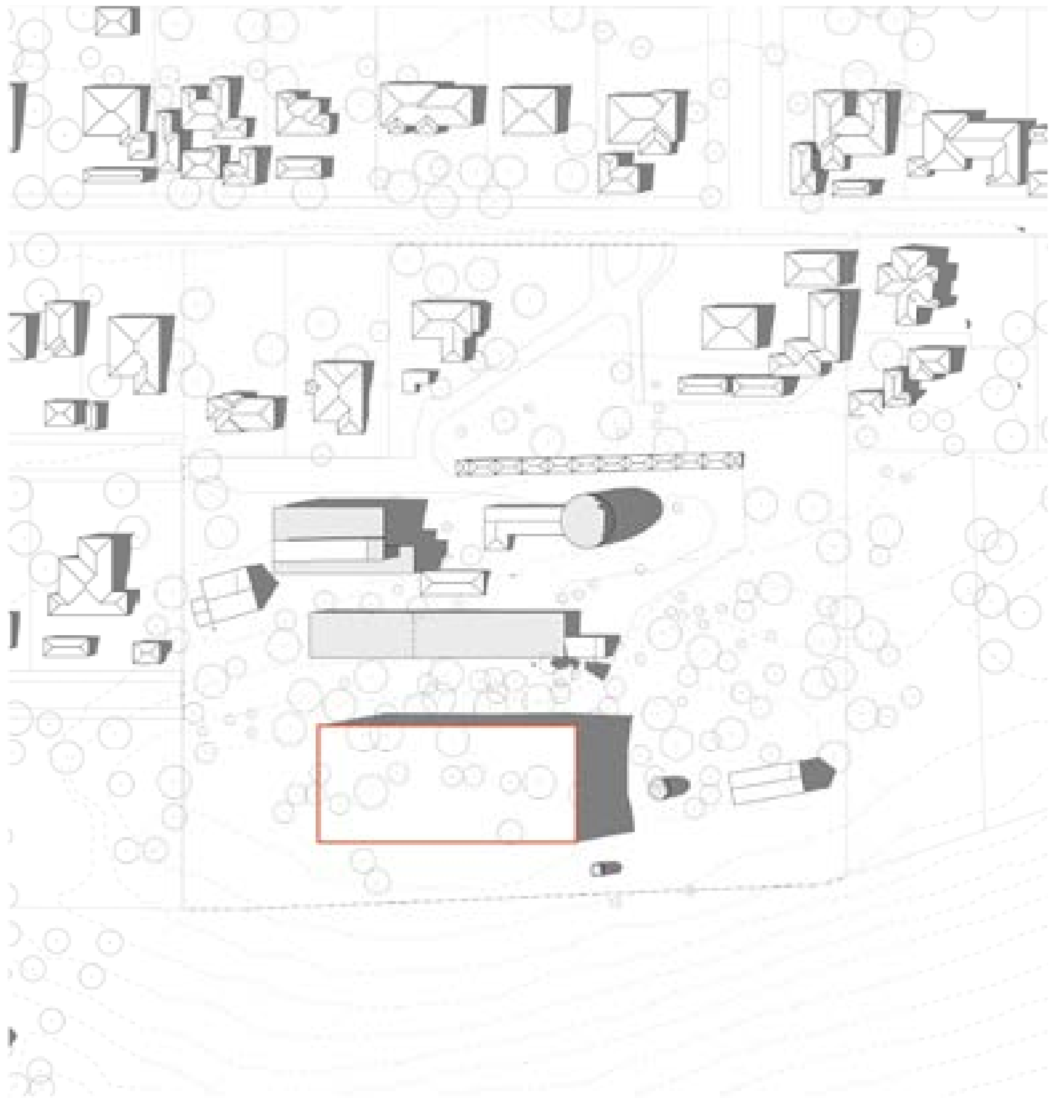


fig 108: Summer Solstice | 16:00

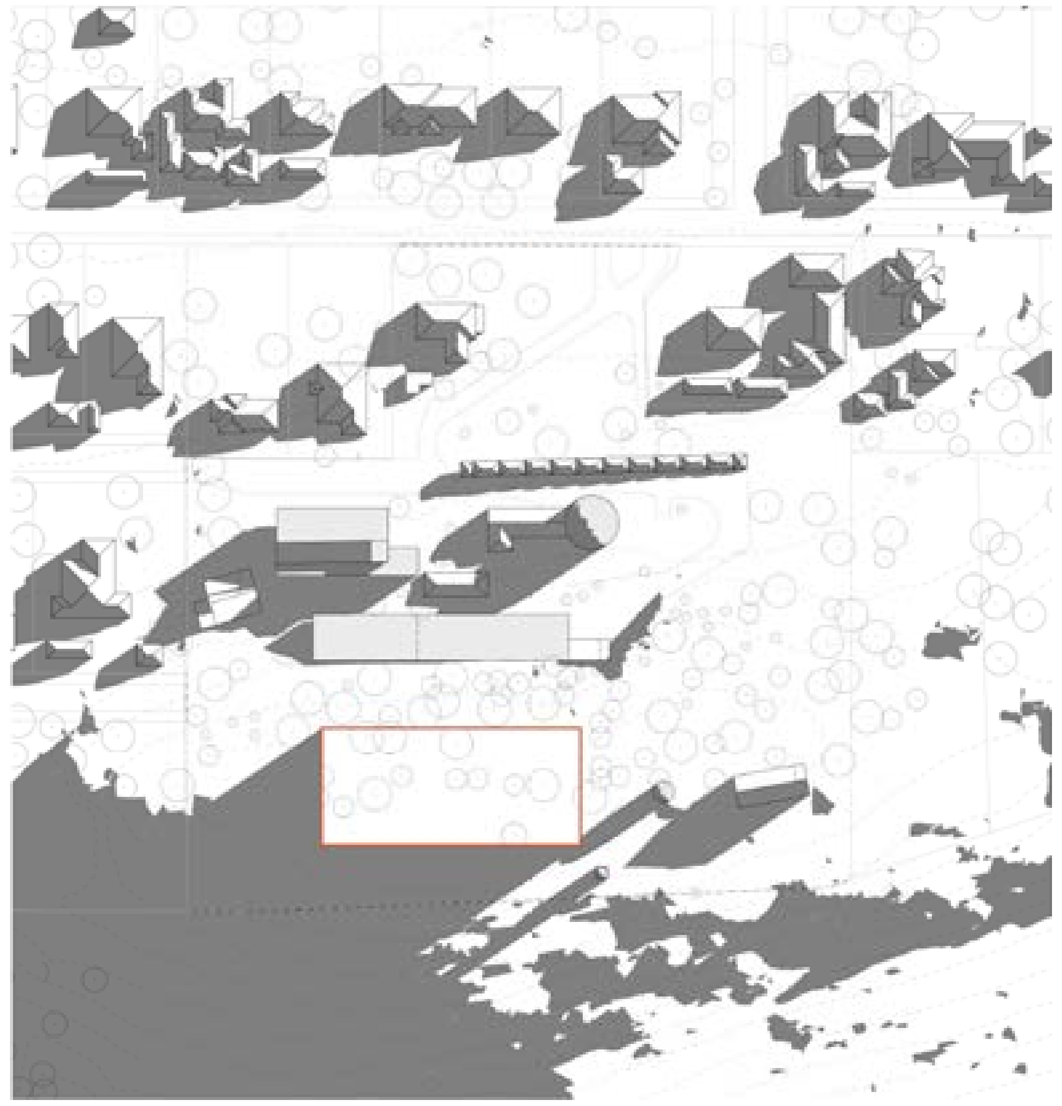


fig 110: Winter Solstice | 08:00

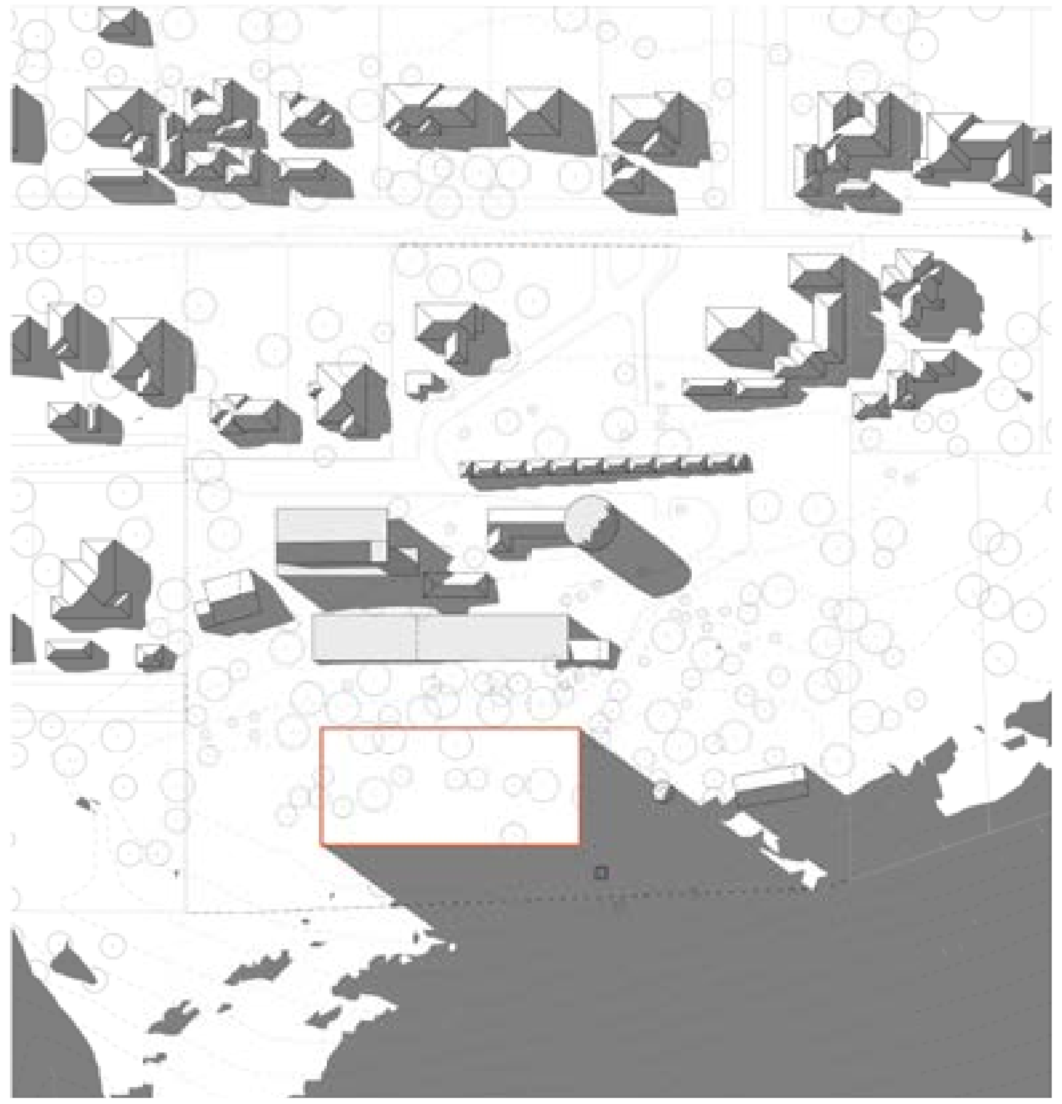


fig 109: Winters Solstice | 16:00

SITE ANALYSIS - TREE SHADOWS

The trees all over the site provide a lot of shade for the existing buildings and for the ridge in general. Understanding the presence of the trees and the way that their shadows behave will be important for the design of the building. The building will aim to assimilate into the nature of the site and studying the shadows helps to realise this design intention.

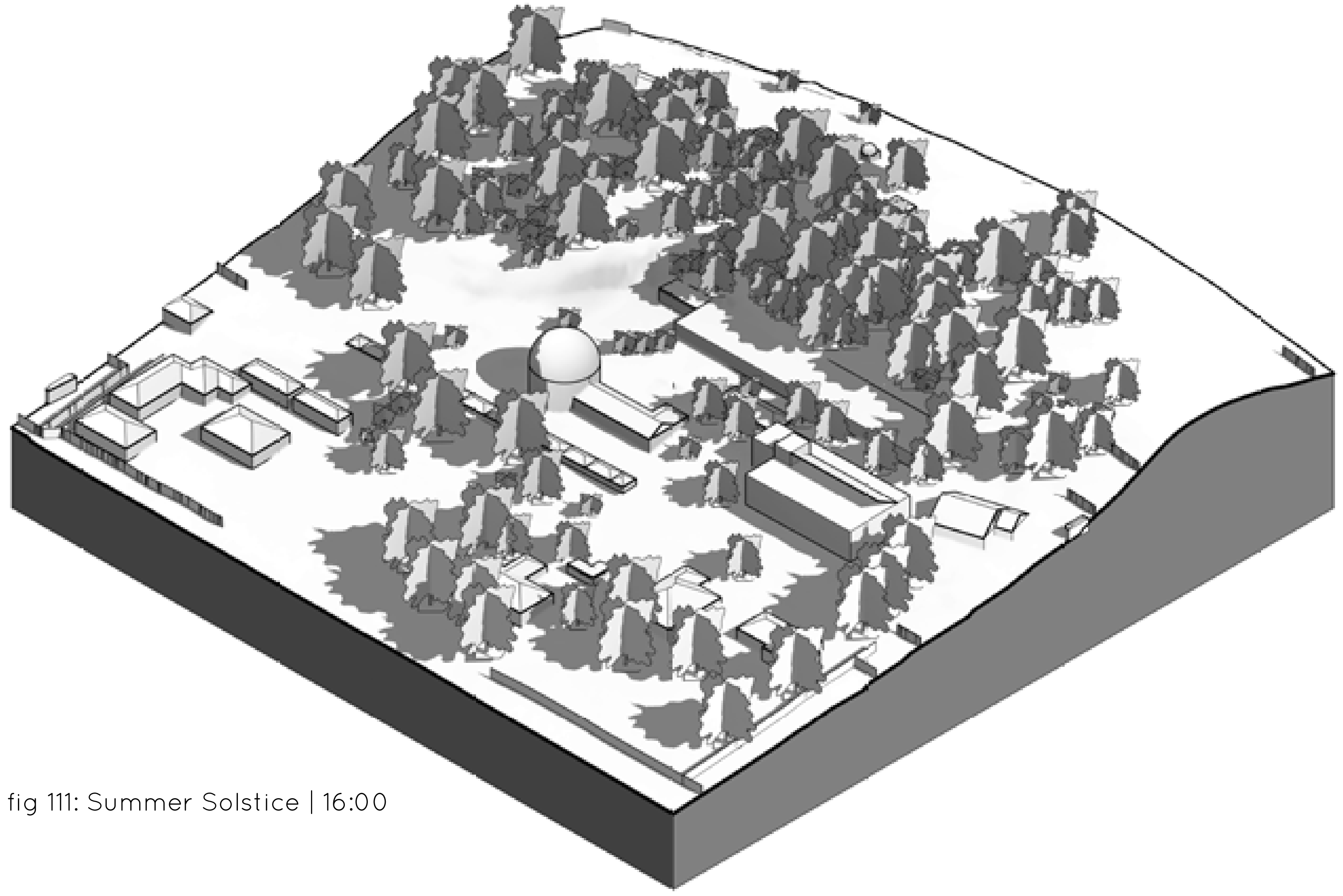


fig 111: Summer Solstice | 16:00

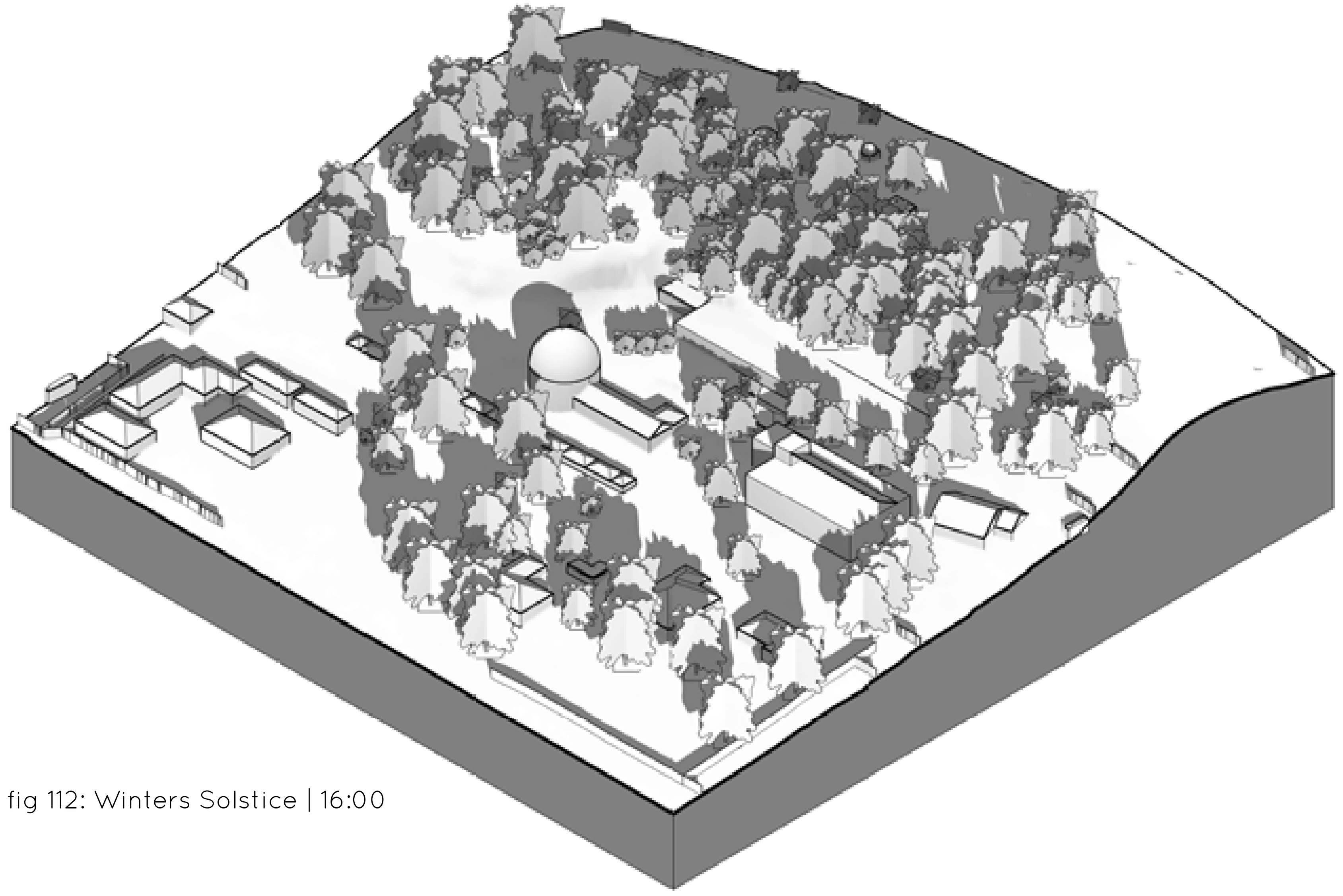


fig 112: Winters Solstice | 16:00

BUILDINGS OVERVIEW

A major design goal for the project is to design the Observatory centre specifically with views in mind; this is from two sides. Firstly, the view of the site from the rest of the metropolitan area and secondly the view of the surrounding area from the site itself. The placement of the building is complicated because of the layout of the site and with the added goal of making the building "iconic", the placement of the building becomes more complicated. In order to understand the layout of the site, two sets of sectional studies were done.

The first sectional study was to understand the topography of the site. This meant creating a site model in Revit and doing a study of the change in topogrpahy through the ridge along the width of the site.

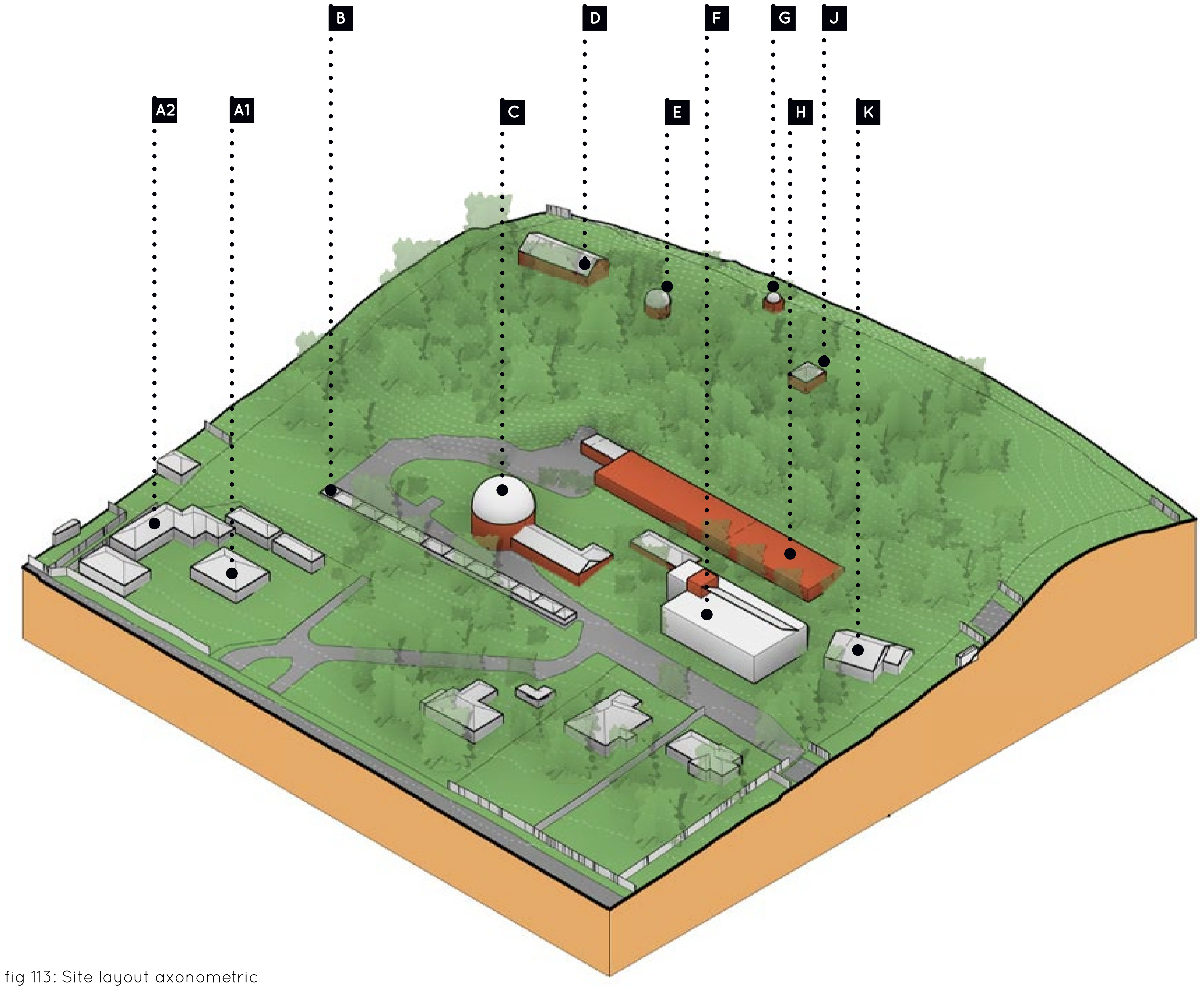


fig 113: Site layout axonometric

BUILDINGS ANALYSIS

Buildings

A1 - Originally built as a residence for chief astronomer Robert Innes, it replaced his original residence on the site, building K. The Innes House became his base of operations during his time as director of the Johannesburg Observatory. It later served as the headquarters of the South African Institute of Electrical Engineers, who have since moved to bigger facilities, A2.

B - There are currently 50 covered parking bays on site, available for staff and visitors. However, there don't seem to be facilities to park a bus or turn one around on site. Considering that there are a few facilities in building F that are meant to be used by high-school classes, it seems shortsighted to not have bus facilities on site.

C - The eponymous observatory is currently not used. The telescope that was originally housed inside the dome has been moved to Cape Town in 1971. The observatory was originally a meteorological institution but was later used for astronomical observation, which is when Robert Innes obtained the telescope. Attached to the observatory dome is a lecture hall; it's possible that this was originally the offices from which Robert Innes worked, but he tended to work from his home more often. The lecture hall is currently used if there are events or conferences on the site.

D - The library is technically the headquarters of the Johannesburg branch of the Astronomical Society of South Africa, however it is in a state of disrepair and not used for meetings. Meetings either happen in the lecture hall or off-site. The library is a Sir Herbert Baker building however very little information is available about the building itself.

E & G - There are another two telescopes at the top of the ridge but they do not appear to be in use at all currently. The vegetation around them is overgrown; there have been instances when the telescopes have been opened, however this has not been to use the telescopes themselves. These small buildings would house relatively small telescopes which, because of Johannesburg's air and light pollution would be useless for scientific astronomical observations today.

F - The South African Agency for Science and Technology Advancement acquired the Johannesburg Observatory in 2003 and have since implemented a learning centre, building F, on the site. The learning centre has laboratories for scholars from grade 9 to 12, a computer laboratory, a library and an activity centre.

H - The site also houses classrooms and offices

J - At the peak of the ridge there is a simple brick building with a corrugated iron roof. It also appears to be unused, the doors are closed up and don't seem to have been opened in a long time, there is nothing inside. Next to this building is a viewing platform raised about 3m up in order to get good views of the surround areas.

K - This is Robert Innes' first house on the site. He moved to building A1 soon after it was built and lived and worked from here thereafter. The building currently sits in disrepair, it hasn't been used or touched in a long time and it is falling apart.

Materiality

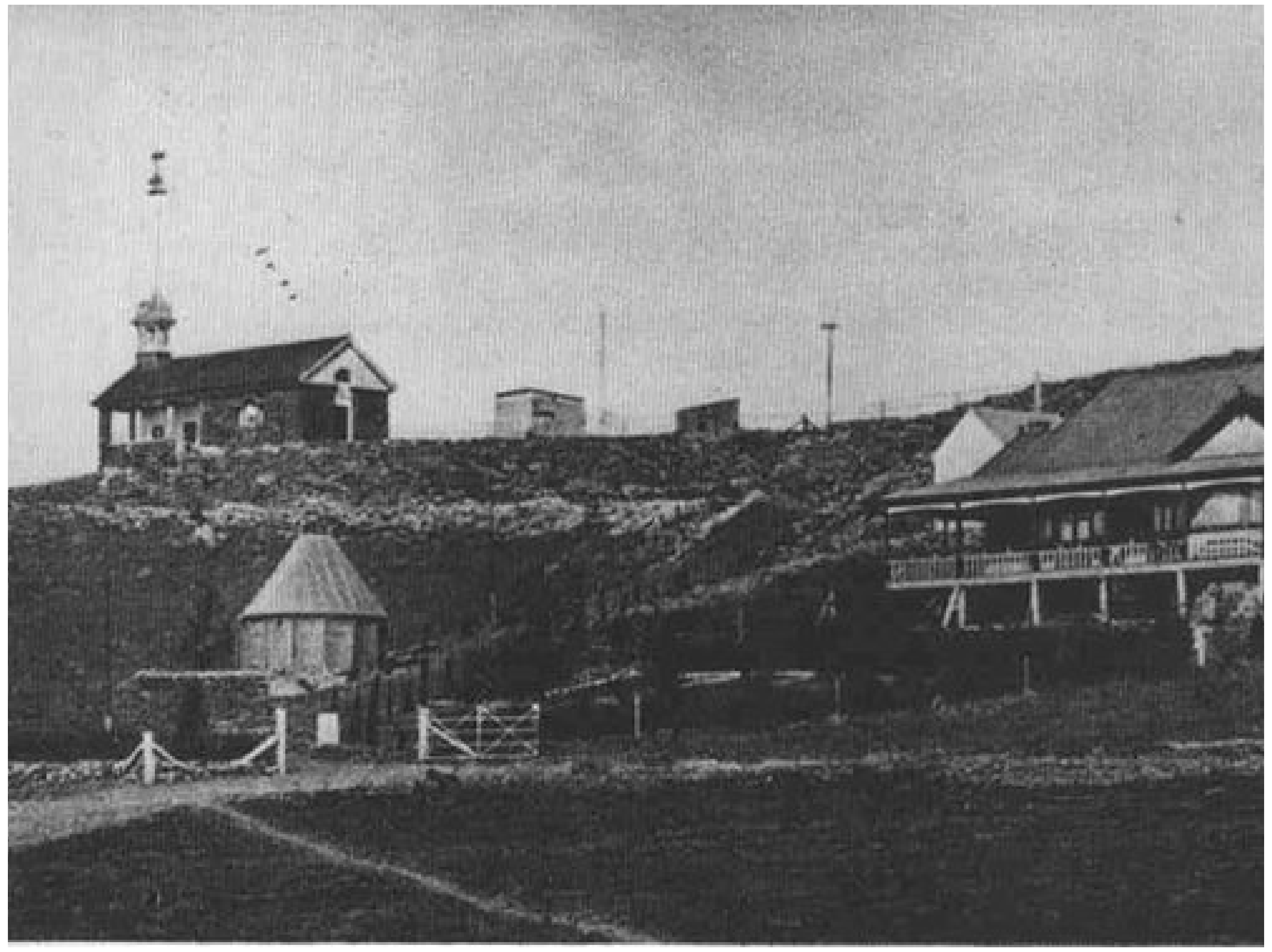
The observatory building itself, the Innes House and the smaller buildings on site are made from red-brown facebrick and have some stone additions such as the base of the observatory. The library appears to be made out of the same stone, orthoquartzite, as is used in parts of the observatory. The stone used in the building seems to have a strong connection to the quartzite of the site as they looks very similar.


fig 114: Rocks on site (Author's photo)


fig 115: Rocks on site (Author's photo)

The Johannesburg Observatory. The building is made from red facebrick and the base of the building is the aforementioned orthoquartzite. The dome of the observatory is made from sheet metal, although the specific material is not discussed or mentioned.

The Traansvaal Meteorological Department in 1905, later known as the Union Observatory. One can see that the presence of trees on the site is artificial as the site, at this point, did not have trees. One can also note the state of the observatory itself. Which evidently at a later point was upgraded to its current state. Also note Dr Innes' first house on the site which was later replaced with the newer addition to the site. (ASSA, n.d.)



The Herbert Baker Library sits in disrepair. From the outside, it looks relatively untouched. However after closer inspection and looking inside the building one can see that the building has not been taken care of for a long time. It is made also made from the previously mentioned quartzite or sandstone and white plaster.

The opening of the Traansvaal Meteorological Department by Lord Milner. (ASSA, n.d.)

The two smaller telescopes at the crest of the ridge were formally built later on in the life of the Johannesburg Observatory, however one can see in the historical images of the site that the telescopes that were housed in these buildings were possibly already present on the site. The materials used in these two buildings are similar to those used in the rest of the site: red-brown facebrick, white plaster and the sheeting used for the observatory domes. [E]

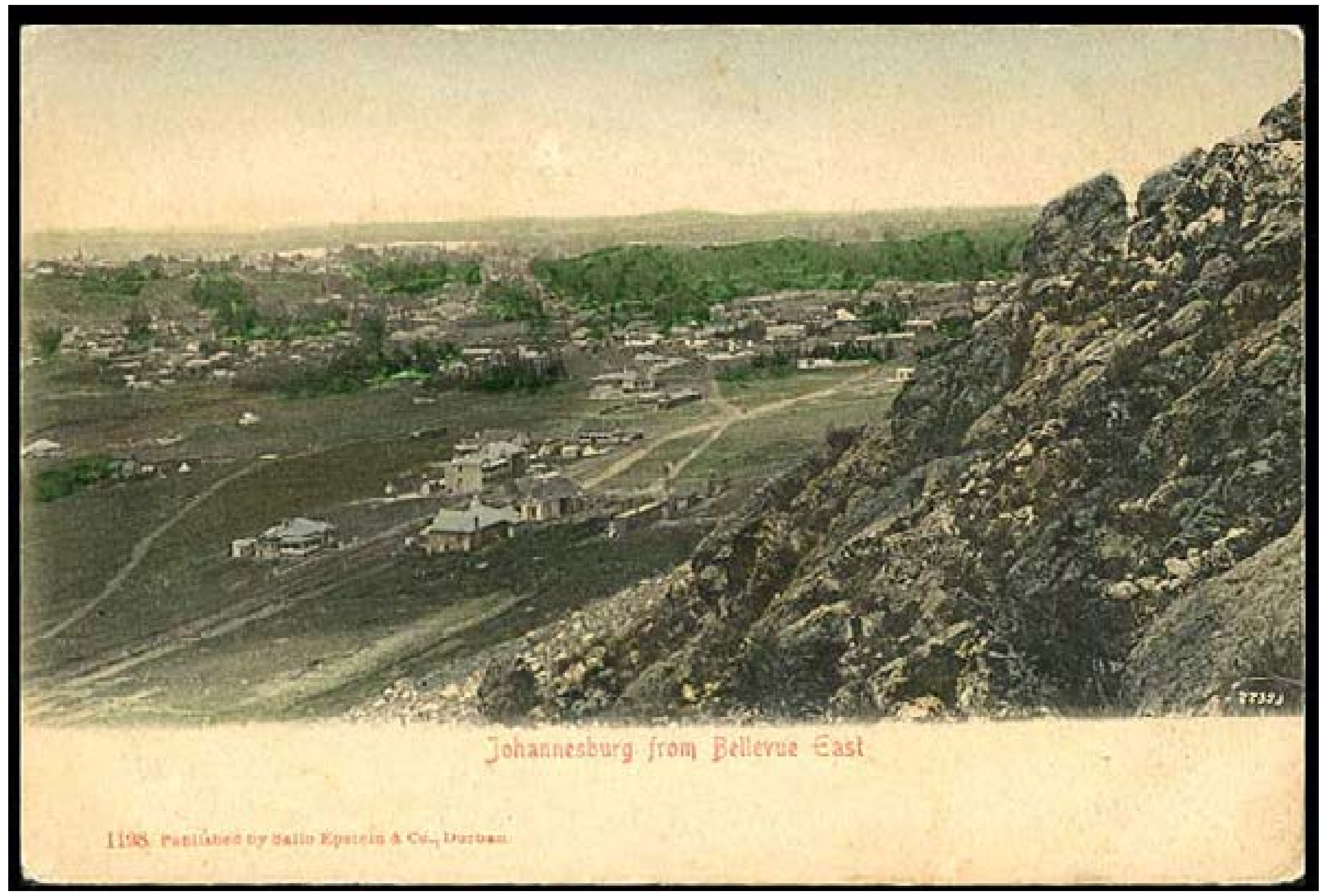
Further along the crest of the ridge is the second smaller telescope [G], which, similarly to the first small telescope, is built in facebrick and the sheet metal. Although both of these buildings are not particularly striking, they have significant historical value and are still used to tell the history of the site. Further along the ridge is light steel frame viewing platform used by visitors to see the entire Johannesburg, however at this point the trees on the site are overgrown enough that they obscure much of the potential views.

From the viewing platform looking due north, one can see over the site and over Observatory. As mentioned previously, much of the view is obscured by the trees on site, however this is also because of the location of the viewing platform. On a clear day one can supposedly see all the way to the Voortrekker monument, but as evidenced in the photograph even on a cloudy day one can easily see as far as Sandton.

The view of Johannesburg to the south-east of the site is one of the most embraced aspects of the site, visually. The buildings themselves are landmarks that can be seen from the surrounding area, and the proximity of the city should naturally be embraced as one of the attractions of the site.

The southern suburbs, Bezuidenhout Valley and Judith's Paarl are immediately obvious from the viewing platform. This means that the building should both consider views to and from the site.

Interestingly, one can compare the change in fabric from the site soon after the founding of the surrounding neighbourhoods to the current landscape shown above. As well as the fabric of the built environment changing, the natural environment has also changed over time.



5 / 7 Precedents

"Experience is a master teacher, even when it's not our own"

- Gina Greenlee

CHAPTER CONTENTS

CHAPTER INTRODUCTION

The precedent studies shown in the following section consist of several buildings that have dealt with a similar program to that of the Observatory Satellite Research, Development and Visitor Centre, either in the nature of the unusual visitor's centre or the merging of exhibition and research space.

The first is the Museum and Centre for Biodiversity at Hacettepe University, in Turkey. This building was originally studied because if its placement on a ridge and it's approach to that design. It also served as inspiration in the early stages of the design process with regards to how one should incorporate exhibition space into research space.

Secondly, the new Statue of Liberty Museum on Liberty Island, New York. The approach to the integration of public museum space and landscape was particularly fascinating.

The third precedent study is Freedom Park in Pretoria. The building served as an inspiration for the materiality of the project, and the approach to form making served as a valuable lesson in design phase 2.

Lastly, the Cahill Center for Astronomy and Astrophysics at the California Institute of Technology approaches the marriage of astronomy and architecture in fascinating ways and served as a valuable precedent study in this regard.

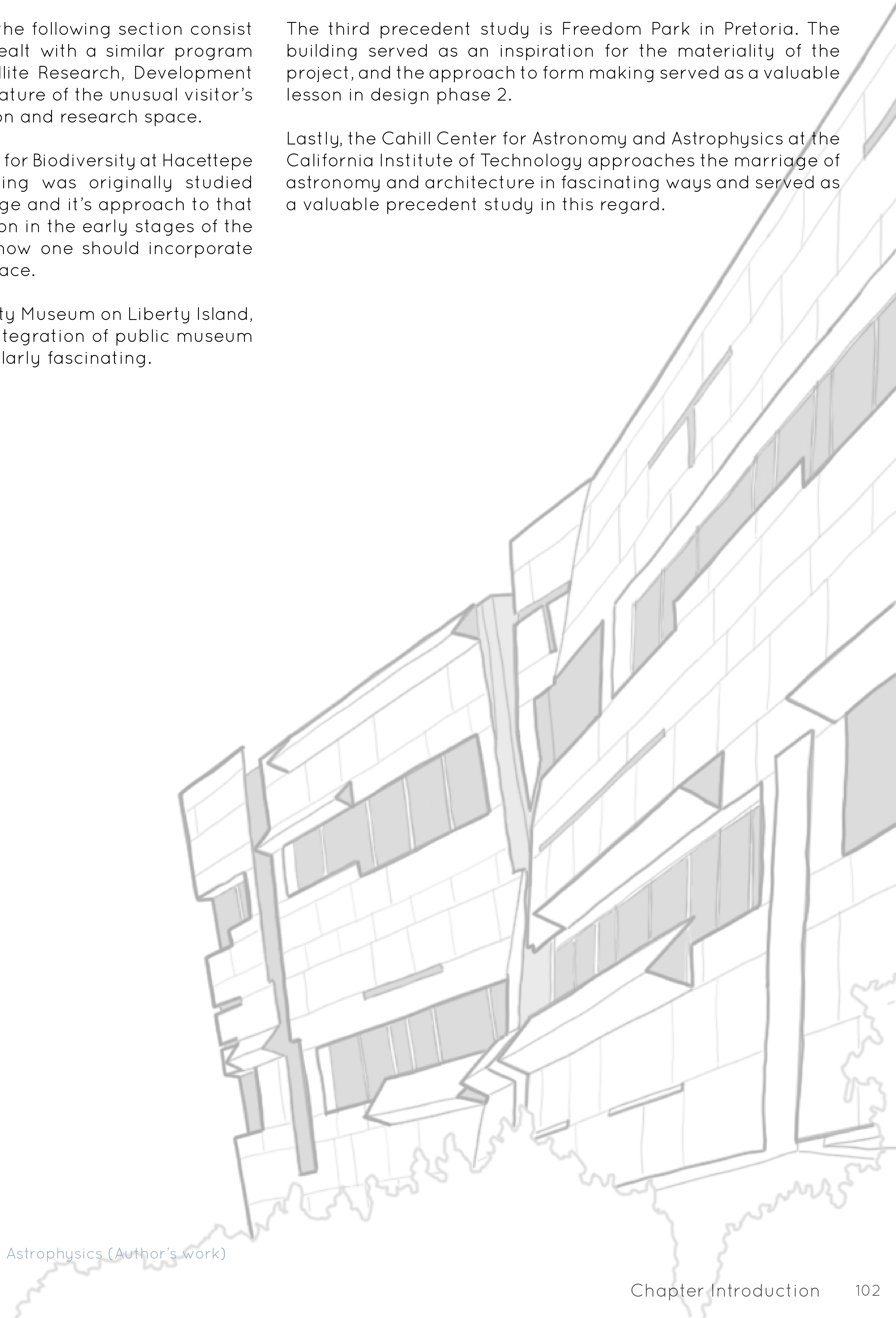


fig 116: Cahill Center for Astronomy and Astrophysics (Author's work)

HACETTEPE UNIVERSITY - MUSEUM AND CENTRE FOR BIODIVERSITY | **ERKAL ARCHITECTS**

Overview
The Hacettepe University Museum and Centre for Biodiversity (HUMCB) is in Ankara, Turkey. The centre itself sits on a series of interconnected valleys and ridges and a large part of the design revolves around the placement of the centre on one of the ridges and how it interacts with the surrounding ecosystems, a large part of the reason for the centre's creation.

Climate
Ankara appears to have a climate similar to that of the highveld in Gauteng, with a similar yearly high and low average and similar humidity - however, the amount of rain is a lot less; an average precipitation of 10mm compared to Johannesburg's average of 30mm. Thus, the approach to climate control can be seen as being quite similar. The HUMCB's approach to climate control is to create heavy thermal masses and utilise a courtyard, a common architectural element in Turkey's contemporary architecture. Possibly as a response to the (at times) hot climate, a lot of the views from the site happen from the courtyard itself while a large portion of the building doesn't have external facing windows and chooses to rather have windows facing internally; this is explored further on the following pages.

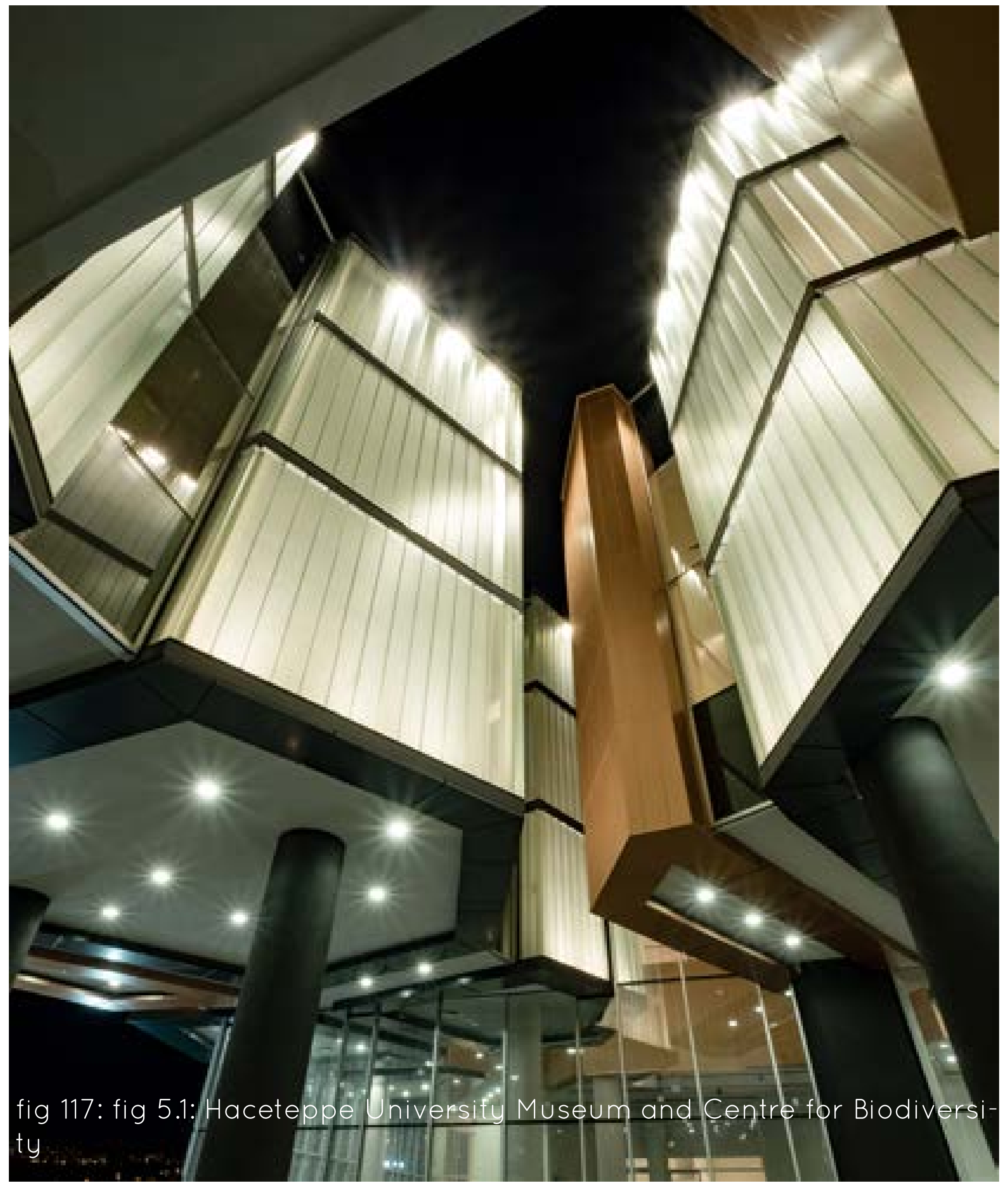


fig 117: fig 5.1: Haceteppe University Museum and Centre for Biodiversity

A lot like the proposed Observatory Research and Visitor's Centre, the HUMCB is made up of public exhibition space and research spaces. The exhibition space is focused on administration and research (collections, labs, offices, administration, library and meeting spaces), while the museum is made up of exhibition spaces for each of the research programs being housed in the centre, namely zoology, medical science, and anthropology. On the ground floor there is a botanical exhibit which will later connect to greenhouses, both of which will be used both for research and public interaction.

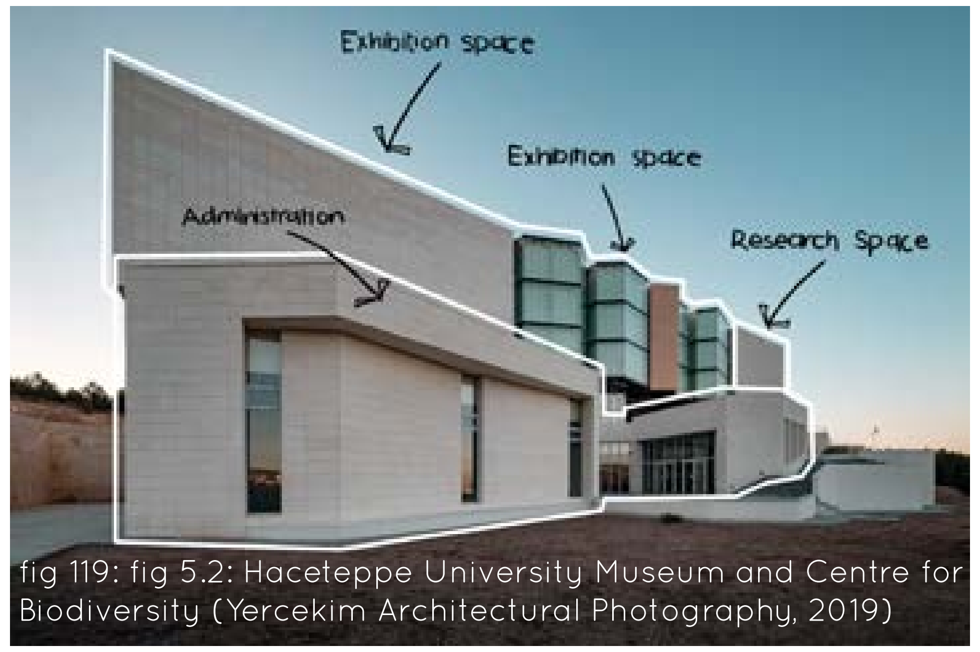


fig 119: fig 5.2: Haceteppe University Museum and Centre for Biodiversity (Yercekim Architectural Photography, 2019)

Form
The placement of the building on the ridge differs from the intended design of the Observatory Research and Visitor's Centre; the approach that HUMCB has to dealing with topography was to have the building "yield to the topography with a series of platforms and cascading levels", whereas the first draft of the Observatory centre was to essentially embed itself in the topography, grounding the building in the landscape.

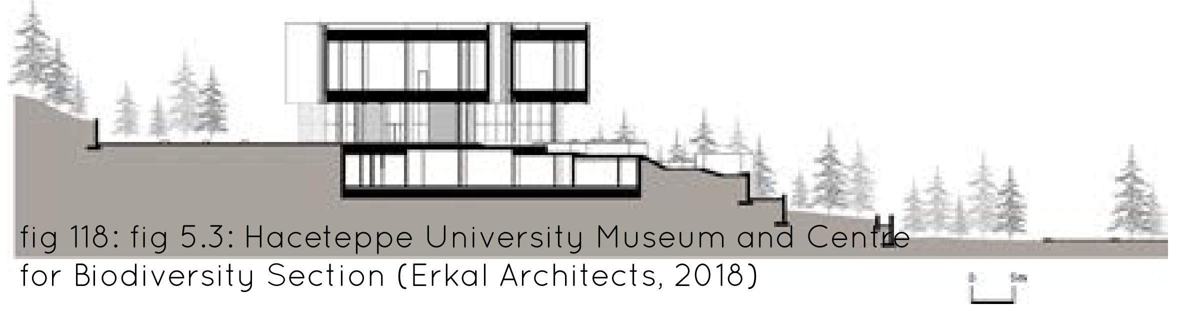


fig 118: fig 5.3: Haceteppe University Museum and Centre for Biodiversity Section (Erkal Architects, 2018)

The building is then essentially split down the middle, through the courtyard - this split divides the research from the museum space, the two programs then face each other across the courtyard. The layout of the research and exhibition space is then intertwined throughout the rest of the building, in spite of this initial division. The logic of the building is manifested in numerous biological phenomena - for instance honeycomb structure, the makeup of butterfly wings and the structure of a leaf's veins. This logic allows the program to be separated and thematised differently while still reading as a cohesive whole, since all the spaces follow the same spatial logic. This spatial planning has created a specific form in the building; essentially the building is split into 3 portions: a solid, rectilinear portion on each end and the "honeycomb" section in the middle. While the middle portion is quite interesting visually, the rectilinear portion is designed to blend in with the stark ridges rising from the surrounding forest.

Circulation
Circulation in the HUMCB is traditional; vertical circulation is via elevators and staircases in the two cores of the building. The elevated portion of the building is only one floor, which means the circulation between these "honeycomb" rooms is only horizontal, approached via doorways and occasionally short passages. The research and admin sections of the building are 3 storeys, meaning these have to be navigated with vertical circulation which in this case is fire staircases and elevators.

Structure
In order to achieve the aesthetic of the heavy top of the building sitting on the light structure of glass on the ground floor, the building makes use of a beam and column system, on the first floor and above it also makes use of structural walls. For the rectilinear portions of the building, the structural system it is quite straight forward, a simple column 7.5m x 7.5m column grid. The translation from the rectilinear sections to the honeycomb sections is seamless; looking only at the column grid one wouldn't assume that this portion of the building followed a different spatial planning logic, but it does. In fact the planning of the honeycomb structure around this grid has worked well. There are a few instances where the column lands in the middle of the room and looks to create potentially awkward spaces, but the resolution of those spaces in the actual building might redeem these column placements.

Materials
As mentioned previously, the aesthetic of the building is a reference the the landscape itself. The large, plain, pale walls refer to the large pale ridges rising out of the landscape, which helps ground the building in the context. The building makes use of contemporary materials (glass, aluminium, copper cladding) which merely make reference to the site through their similarity to the surrounding landscape. The architects have said that the diversity of the materials used in the facade and internally (as well as the varying sizes and shapes of the "honeycomb" shapes) allude to the biodiversity of the context that the building aims to celebrate.

Access and Approach
Understanding the approach to the building would be an important step in translating lessons learned by the architects to the Observatory research and visitor's centre; however, the architects have not directly addressed design decisions related to the approach to the site. Inferring design decisions from the plans and section, one can see that vehicles approach the building around the west side and enter parking/basement level via the north side of the building, then access the building via the staircases or lifts. The building would greatly benefit from designing the approach so that as one crests the ridge, the view over the valley is revealed to them - the view in figure 123 is indicative of the celebration of the site that the architects say the building achieves and this view could be even grander. Access to the building itself, once within the boundaries of the site, is via the atrium/void beneath the exhibition space.

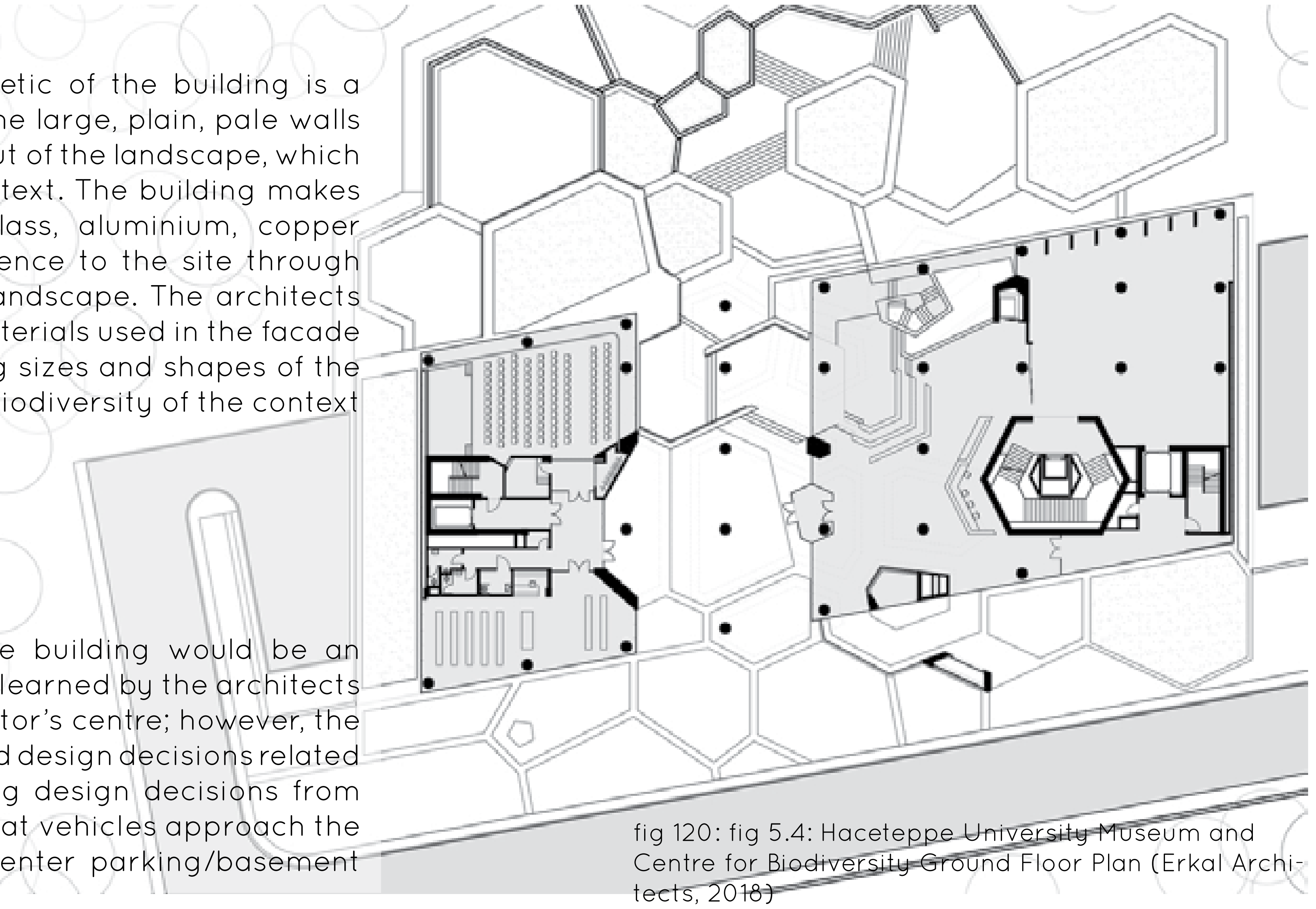


fig 120: fig 5.4: Haceteppe University Museum and Centre for Biodiversity Ground Floor Plan (Erkal Architects, 2018)

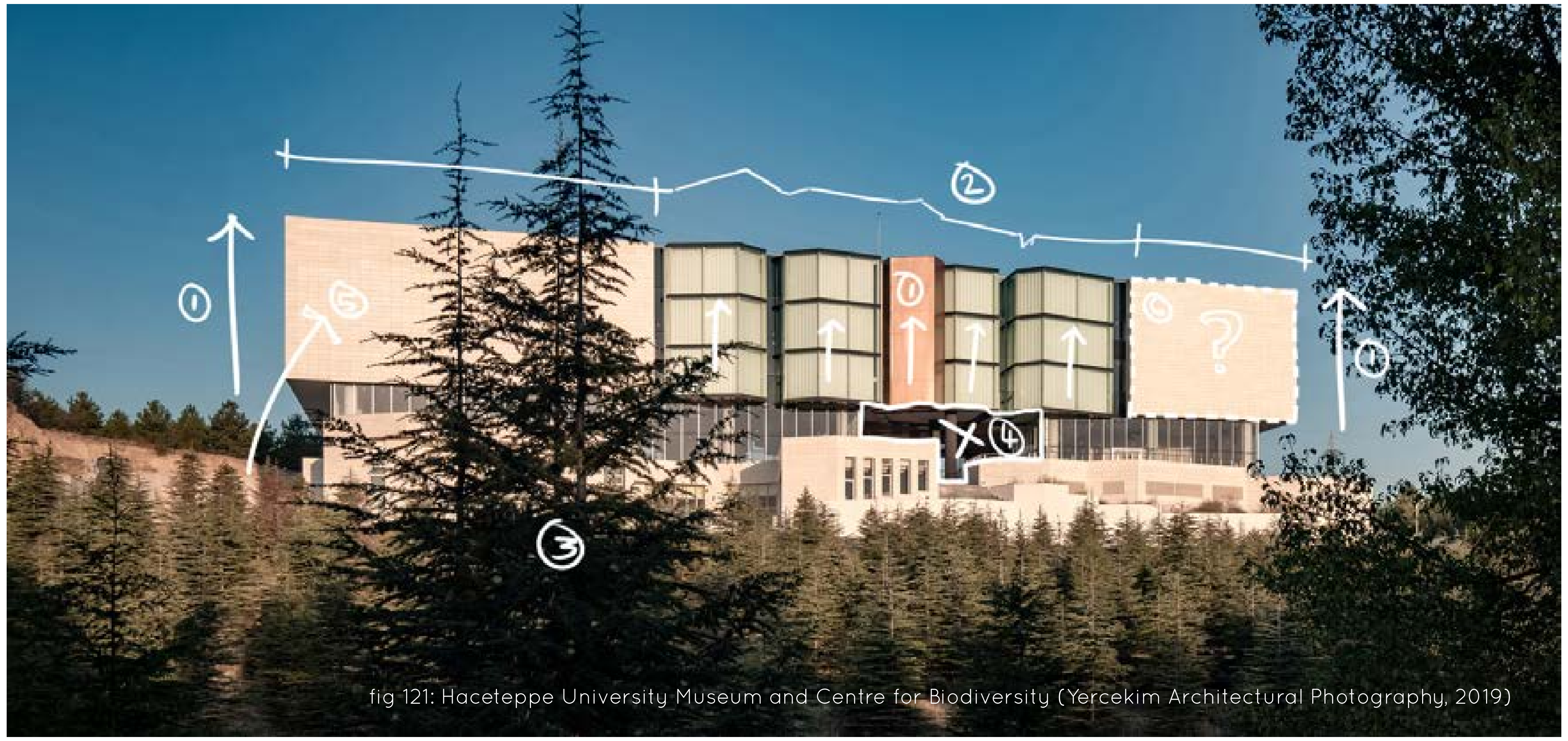


fig 121: Haceteppe University Museum and Centre for Biodiversity (Yercekim Architectural Photography, 2019)

First Visual Analysis
By quickly doing a "first impressions" mark up of the building, it allows me to quickly specify what I will be looking into or analysing in terms of the whole building early on and will create a list of criteria to analyse when it comes to looking at the form/program of the building. This is done by drawing over a photo and looking at the plans as well.

(1) Extrusions
One of the things that is immediately present in the form of the building is that the overall geometry is quite simplistic; the form of the building is essentially the footprint of the building extruded to the necessary height. This is true both for the "bookends" of the building and for the "accordion" portion of the building in the middle. This isn't necessarily a bad thing, it may be seen as an abstraction of the context: large, pale cliffs rise out of the valley and the building sets out to emulate this in the simplistic geometry. However, one might also argue that this simplistic geometry is also due to a lack of imagination or an attempt to take the "easy way out."

(2) Overall Geometry
As mentioned in the previous point, the building appears to be divided into three sections: an accordion like portion bookended by two rectilinear portions. This may be a reference to the program of the building - the eclectic nature of the ecology nature being researched in the building and the stringent nature of the research itself being conducted in the respective parts of the building.

(3) Context
As mentioned in the precedent overview, and elaborated on in the climate section, the building is located amongst the ridges and valleys Ankara in Turkey. The surrounding area is well known for its biodiversity, one of the things that the building itself has been created to protect. In fact the building itself is located on the upward climb to one of the peaks of the ridge with the orientation playing a very specific goal in the project. There is great potential in the exploration and celebration of the surrounding areas, something that would need to be approached cautiously so as to not exploit the surrounding ecology.

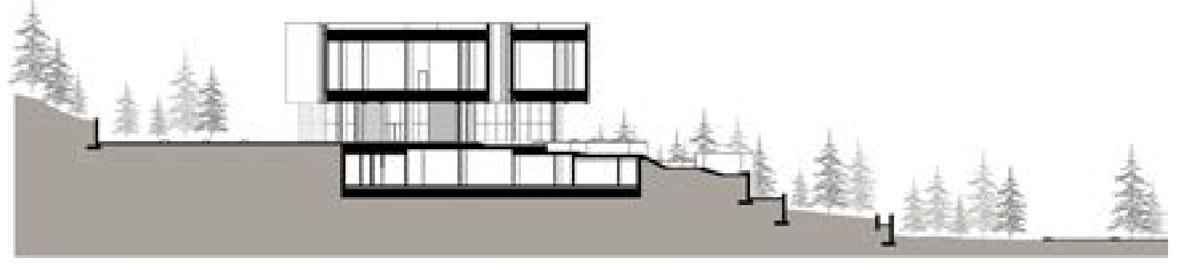


fig 122: Haceteppe University Museum and Centre for Biodiversity Section (Erkal Architects, 2018)

(4) Void
The ground floor of the building reads as a void, in two different forms: the most literal void is the void under the centre portion of the building which seems to play several roles. It becomes a grand entrance for the building, showing visitors the views out over the valley and it also becomes the entrance to the two rectilinear portions of the building. It is an interesting visual for the building, a seemingly very heavy top floating on almost nothing. This is also true for the bookends of the building. These visually heavy portions of the building seem to sit on the delicate ground floor windows. This contrast not only creates an interesting visual but also lightens the building when seen from the ground floor. It doesn't feel intrusive on the landscape as it floats above the landscape.

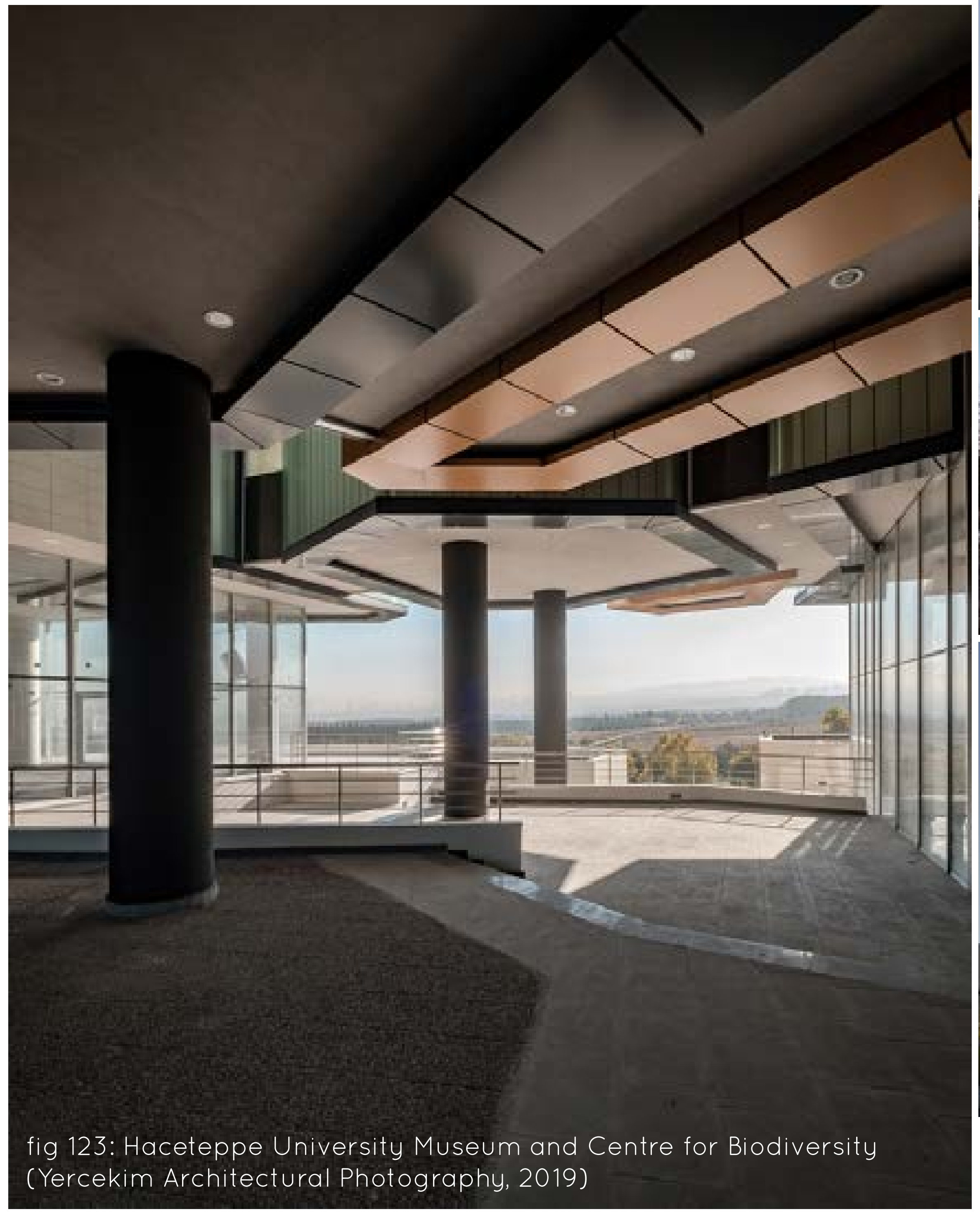


fig 123: Haceteppe University Museum and Centre for Biodiversity (Yercekim Architectural Photography, 2019)

(5) Abstraction of the Landscape
As mentioned in the first point, the building has been designed to emulate the nature of the landscape. The valley has ridges that rise out of the ground, exposing a pale crust underneath the forest. The large, flat faces of the building are an obvious homage to the surrounding landscape and have grounded the building in the landscape.

(6) Building Faces
The building itself has no external windows on the rectilinear portion of the building. While its understandable that this was because of the reference of the building to the landscape, it would seemingly also present other, more pressing issues. For instance, a portion of the building is dedicated to research laboratories which would mean that a lot of time is to be spent by students inside the building; extended periods of time spent inside researching the surrounding ecosystems with no visual connection to the ecosystem is problematic. It removes the researchers from the work they are doing and offsets any attempts by the building to celebrate the landscape by seemingly ignoring the landscape. That's not to mention the issue of not having natural ventilation or light inside the building.

fig 126: HUMCB
(Yercekim Architectural Photography, 2019)

fig 125: HUMCB
(Yercekim Architectural Photography, 2019)

fig 124: HUMCB
(Yercekim Architectural Photography, 2019)

In fact it's not only the facade in the first impressions mark up that doesn't have windows, no facade of the building has any windows above the ground floor. For a climate that gets colder than Johannesburg on average in the winter (-1 °C minimum in Ankara vs 0° minimum in Johannesburg), the absence of windows is quite problematic and not worth the trade-off for the visual appeal.

In fact, one can even see on the first floor plan below that some of the internal research spaces (on the north side of the building) have no windows out. There does appear to be a light well in the centre of the research space, but a photo of the roof (on the next page) reveals that it is most likely a service duct. This lack of natural light or ventilation for the research spaces seems shortsighted and is condemning for the project.

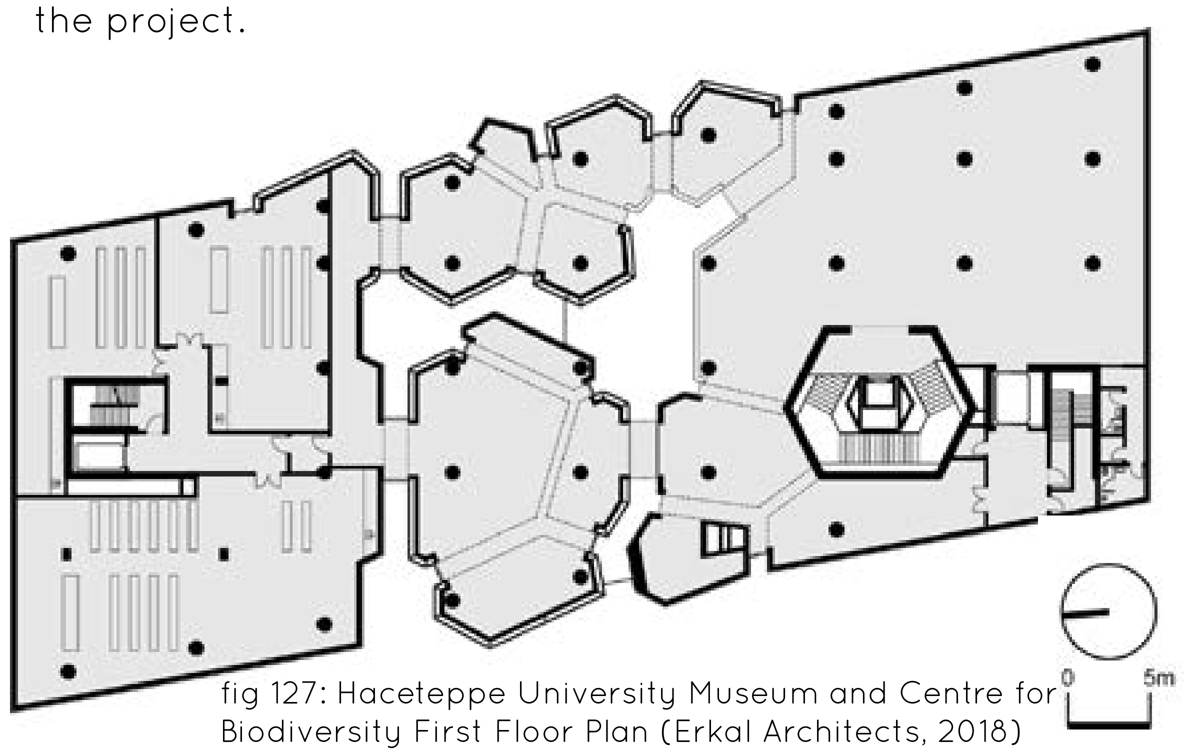


fig 127: Haceteppe University Museum and Centre for Biodiversity First Floor Plan (Erkal Architects, 2018)

STATUE OF LIBERTY MUSEUM | **FXCOLLABORATIVE**

Overview
The Statue of Liberty Museum has two main objectives: enhance the experience of Liberty Island for all visitors and to augment the island's open space through the design of a building that effectively incorporates landscape design and architecture into one effective project.

Climate
The placement of the museum on Liberty Island means that the integration of weather control has to be taken into account when dealing with the design of the building. The most prominent design decision for the museum with regards to weather is the recurrence of storms in the New Jersey island; the most notable recent storm was Hurricane Sandy in 2012 which shut down power on the island. Massive storms like this have required that the architects take into account the 500 year storm line, elevating the building to above this line has ensured that it will always remain safe from flooding and storm damage. Furthermore, the presence of the museum in the bay means there will always be salt present in the air, something that can cause damage to the building materials and so precautionary measures have to be taken to ensure that the materials used are durable, especially when it comes to contact with salty air and water.

Liberty Island, with its presence in the middle of New Jersey bay can also get quire cold because there is no protection from the wind that comes in from the Atlantic Ocean and so measures have been taken to ensure the building remains comfortable and usable, even in the winter. These measures include a lot of thermal mass, especially below the building as well as a design that reduces thermal bridging, both in the floor and in the walls with efficient insulation.

Required Spaces
Because the museum's primary function is as an exhibition space, most of the building's floor area is taken up by gallery space. Access to the museum's roof is via terraced steps to the east of the building; these terraced steps also serve as a viewing gallery to see the Lady Liberty herself and the rest of the island. The rest of the museum is made up of gallery space (an exhibit gallery, a theatre and the liberty torch gallery) and administration space (operations and support offices). The program for the building is quite simple as the building is meant to augment the experience of visiting the historic statue, not be an attraction in itself.

Form
The building's form is informed by the desire for a dramatic building that responds to its context as well as a desire to have a building that transforms as one moves through it. The desire for rich spaces that respond to the context (especially the irregular shape of the water's edge) led to the dynamic expression of the building's footprint. This was further enhanced by emulating the shape of the nearby fort's footprint; whereas the fort has acute corners, turning itself inwards, the museum reinterprets these angles, turning them outwards to celebrate freedom.

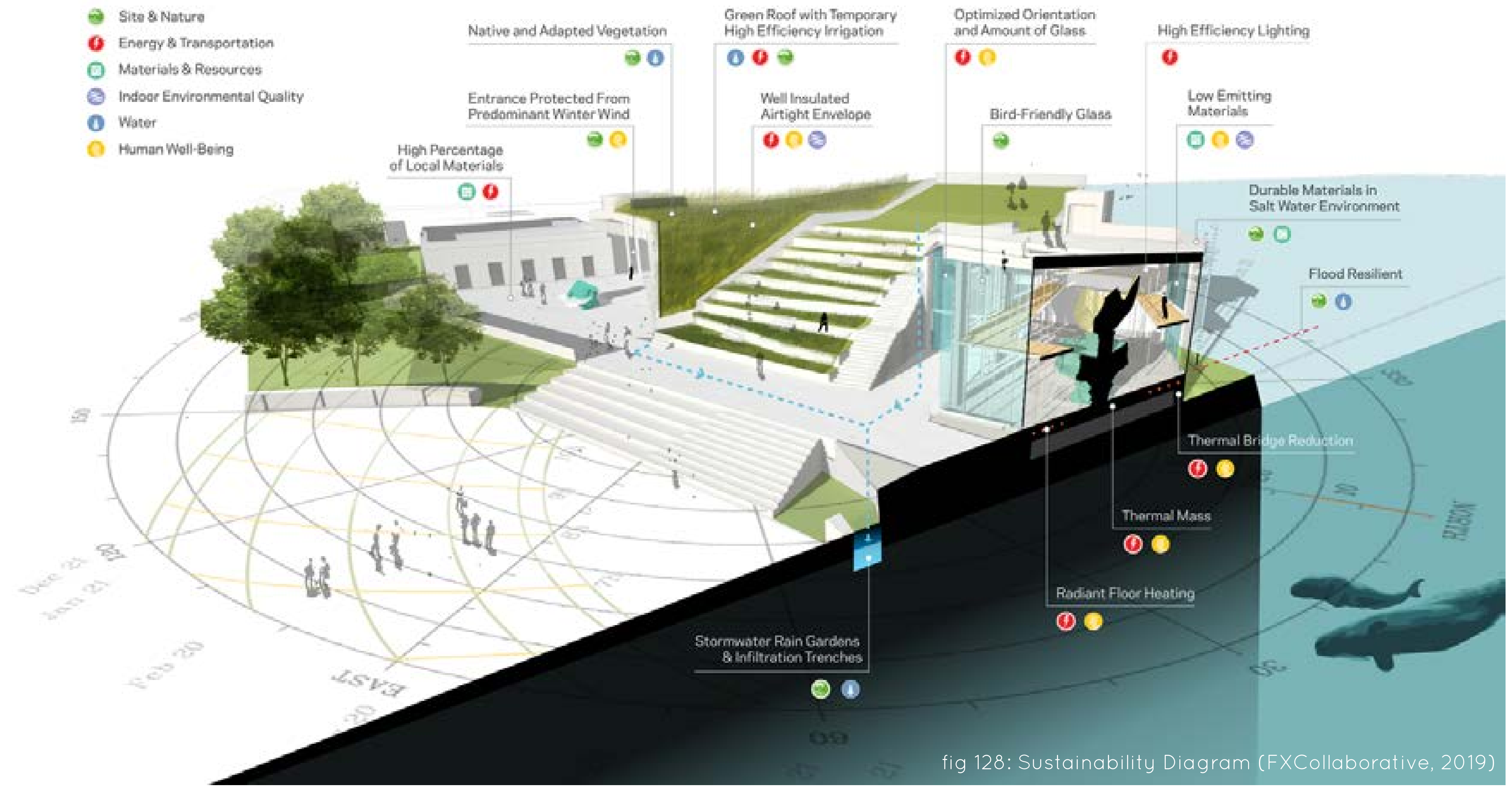


fig 128: Sustainability Diagram (FXCollaborative, 2019)

Furthermore, the building aims to merge architecture and landscape; in one way this is expressed through the building's formalistic response to the island itself (as well as the other architecture), but also to the landscaping of the island. The landscaping of the island is based on traditional French gardens and the museum's interpretation of this is to "[establish] a naturalised landscape that is "lifted" above the formal mall." (Pintos, 2019) This essentially gives the ground plane back to visitors, allowing them to view the surroundings, rest or have a picnic.

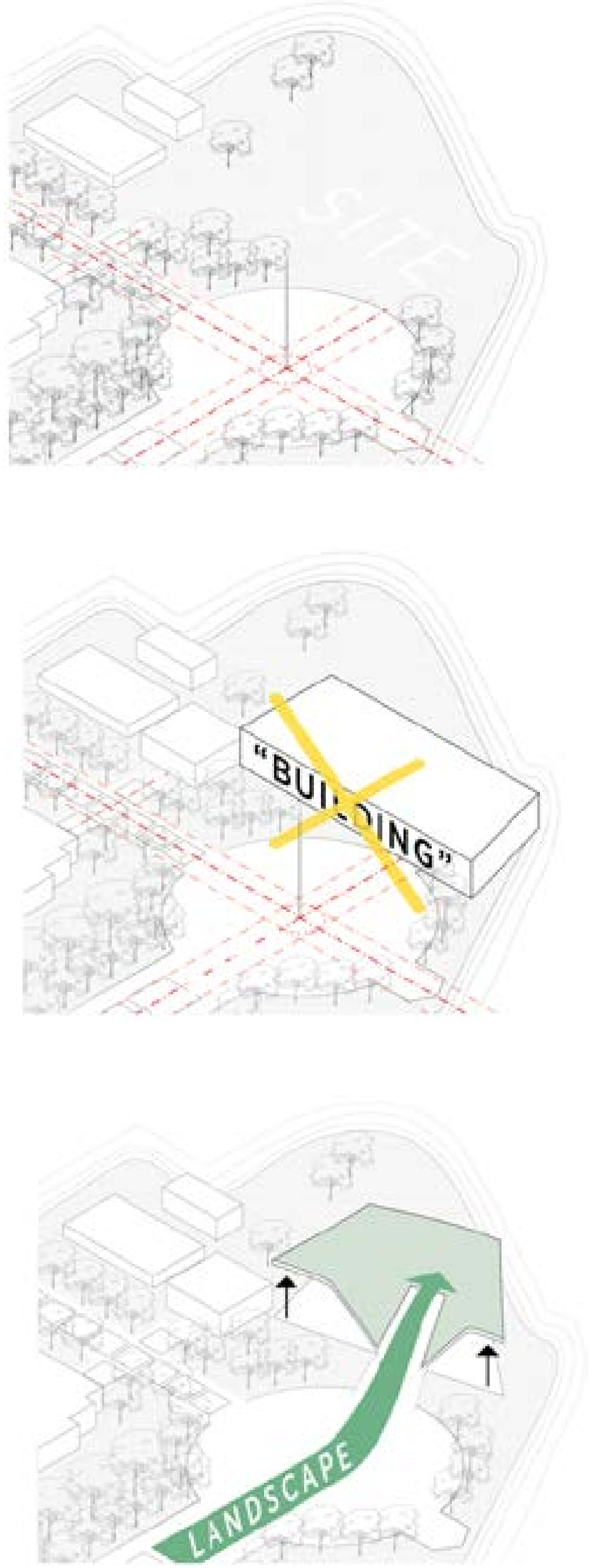


fig 129: Design Parti Diagrams (FXCollaborative, 2019)

Circulation
Circulation through the building itself is quite simple because of its open plan nature and the relatively small size of the building. The complicated circulation comes into play with regard to tying the building into the circulation of the rest of the site and having the habitable roof. The established presence of other buildings and spaces on the site means that the building cannot demand attention or be demanding of the existing circulation on site. As shown in the parti diagrams to the left, the approach for the design of the building was not to build a traditional, rectilinear building that would not cooperate with the existing axes on site but rather to design a building that would augment and celebrate the history of the site. The nearby flagpole plaza essentially becomes the public forecourt for the building and the architecture/landscape marriage that the building aims to achieve ties the museum comfortably into the rest of the site.


fig 130: Statue of Liberty Museum from Flagpole Plaza (Sundberg, 2019)


fig 131: Flagpole Plaza from Statue of Liberty Museum (Sundberg, 2019)

Materials
The use of materials in the building are chosen based on the existing spaces on site, as a way to pay homage to the historic island and the city at large. The building makes use of copper, stone and glass to tie the building back to the city and to allow it to seamlessly blend into the context.

fig 132: Statue of Liberty Museum (Sundberg, 2019)

First Visual Analysis
My first impression of the building is that it's very restrained; the design is subtle, it's not imposing or too bold - especially when compared to its subject, the Statue of Liberty. The use of materials is an obvious homage to the rest of the island and city.

(1) Building Form
The small, low-rise building has a simple form that is obviously an attempt to elevate the ground plane and integrate the spirit of the site into the landscape of the roof of the building. The building itself also reads as a podium of sorts, possibly a reference to Lady Liberty's podium. The overhanging eaves and the steps up to the roof make the form of the building read as an unused pedestal.

(2) Materials
The building makes use of materials that are an obvious reference to the other spaces on the island. The most obvious connection is the use of copper in the spandrel panels in the overhang. While the building is new the connection is symbolic, but as the copper oxidises over time it will tie the building to its muse and fulfill its homage. This is also true for the stone used for the steps. If the steps make the building read as a pedestal, the use of granite for both Lady Liberty's pedestal as well as the steps completes the metaphor.

(3) Open vs. Closed
The north side of the building is open because of the public exhibition space on that side of the building, the south portion of the building is administration space and so it remains more closed up. This is done with two methods: the manipulation of the envelope of the building to visually close off the administration section and open up the exhibitions; and changing the materials used (specifically darker glass and concrete screen in the administration) in order to open up the public portion of the building and close off the private section.

(4) Structure
In keeping with the spirit of Lady Liberty's design, the museum uses its envelope to hide the support structure of the building. The structure itself is very minimal and is hidden away in the building; while on one hand this is in the spirit of Lady Liberty's design, it also allows the building to be read as an extension of the site. The building no longer reads as a building but rather a continuation of the site - the heavy roof form seems to float on air, and is supported by the island itself instead of columns

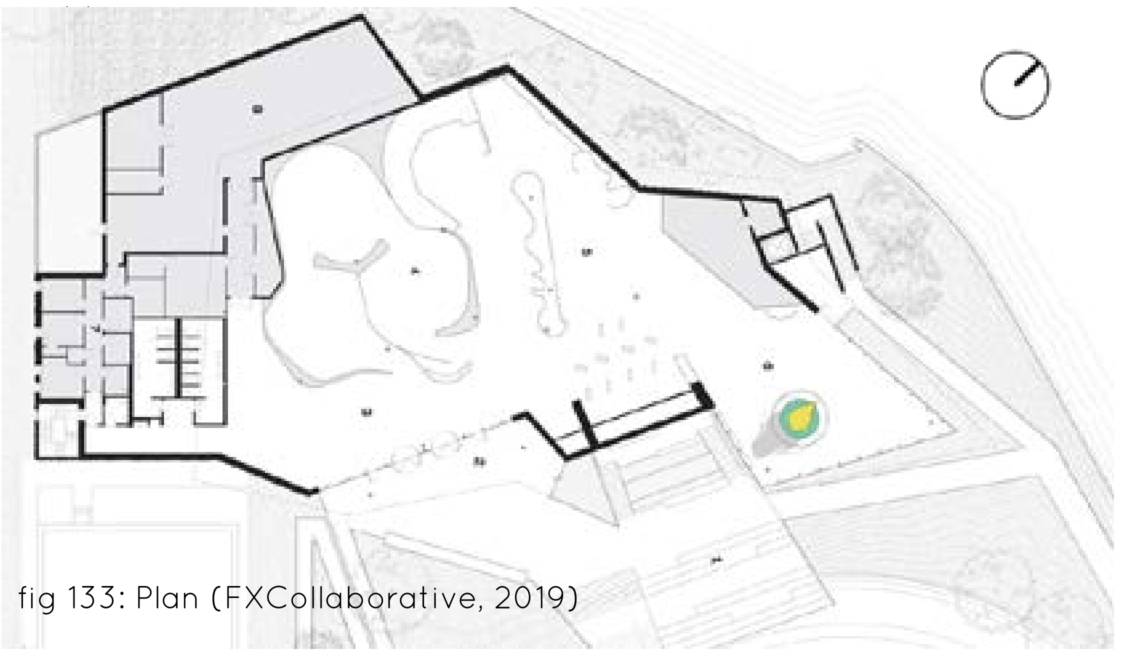


fig 133: Plan (FXCollaborative, 2019)

(5) Roof access
One of the most immediately obvious aspects of the building is the access to the roof. This major access is split into two sections, the first flight takes you to the pedestal that the building is placed on (to elevate it above the 500 year flood line) and the second flight takes visitors up to the roof where they can overlook the city. This also allows the building to become an extension of the site, with a natural flow from one space to another via a major axis.

(6) Exhibition Spaces
The building itself focuses on Lady Liberty and her history. The exhibition spaces are made from different facets of her being, from her history to her creation and her current manifestation. The two major exhibitions are the exhibit gallery which focuses on her history and creation, and the torch gallery which houses a replica of her torch and her face to allow people to understand her scale and see the details of her creation. This becomes a very approachable way to understand the scale of the statue and grounds the creation; the gallery spaces essentially become an analysis of Lady Liberty, allowing people to study her as a piece of history rather than simple at face value as a statue or landmark.

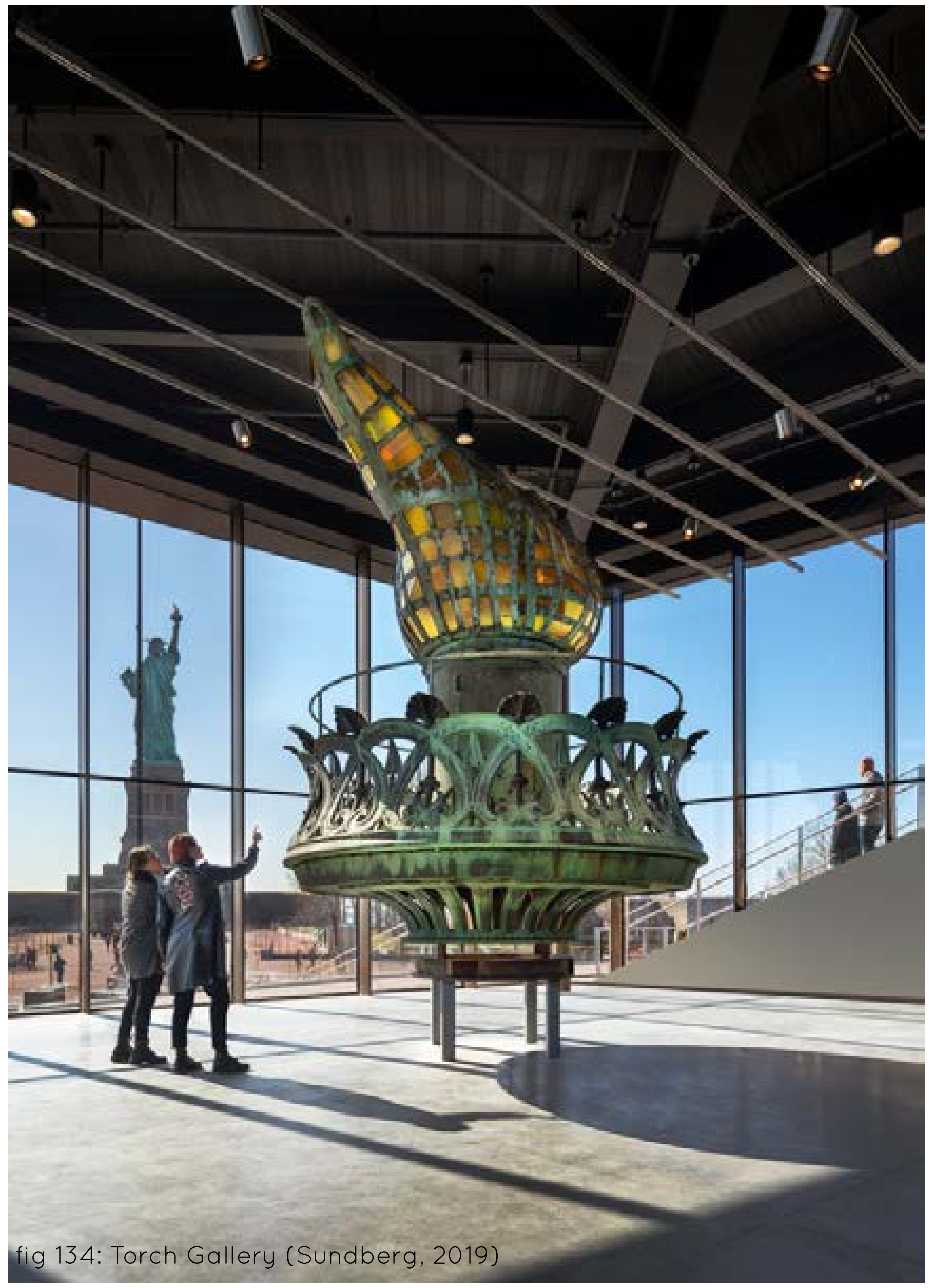
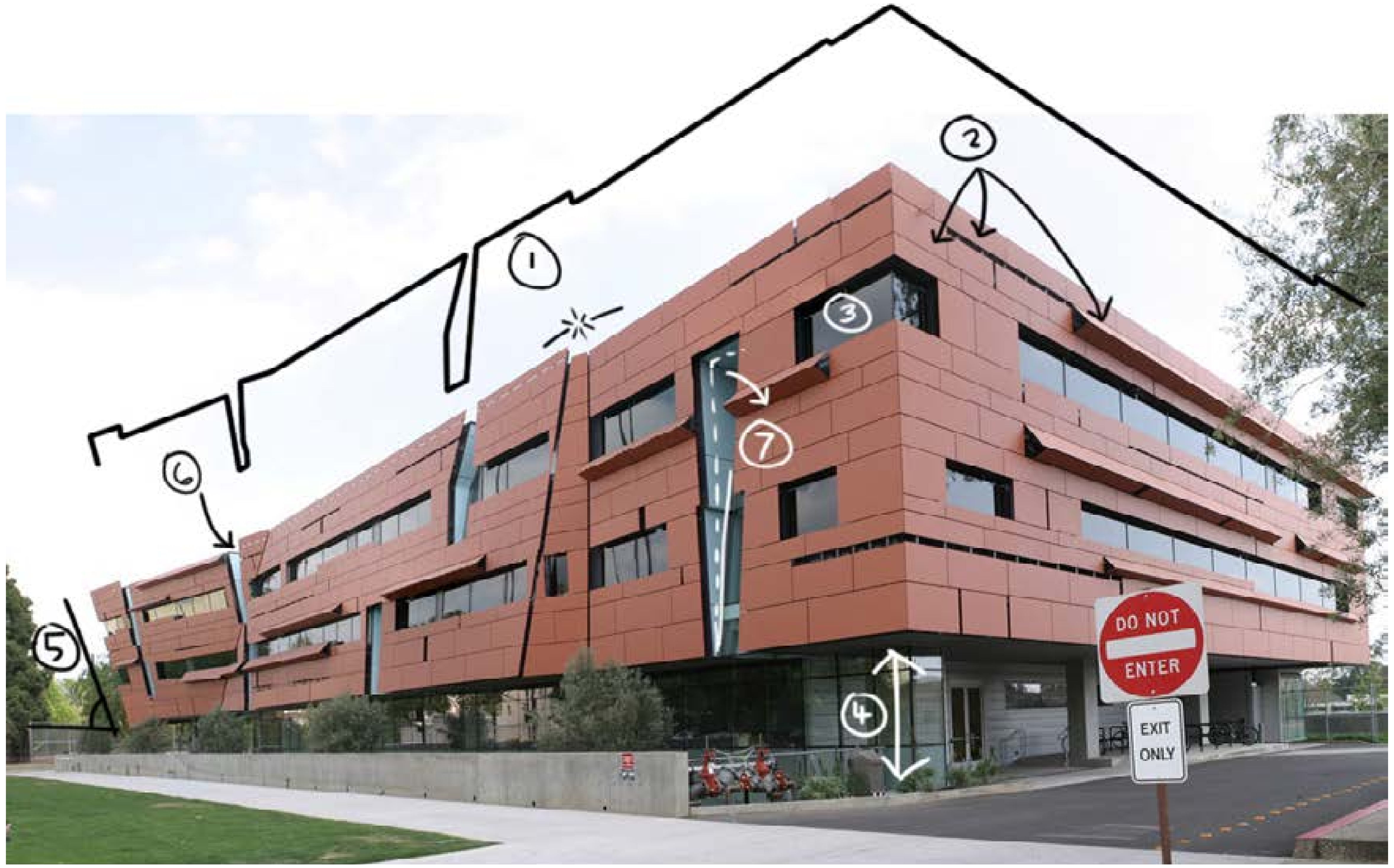


fig 134: Torch Gallery (Sundberg, 2019)

(7) Roof Access (Elevator)
The staircase as a form of access to the roof is, by its nature, exclusionary to the differently-abled visitors to the centre. The solution has been to provide elevator access to the roof. Surprisingly, the noticeable elevator doesn't detract from the building and its ties to the site. The elevator box sticking out above the building itself becomes a reference to the city skyline, easily seen from the site.

CAHILL CENTER FOR ASTRONOMY AND ASTROPHYSICS | MORPHOSIS ARCHITECTS



First Visual Analysis
Visually, one of the most obvious and striking parts of the building is the bold masses of the museum. The tall, monolithic faces of the buildings create such simple but distinct forms, however the specific execution of the building is what makes the geometry successful. This analysis is an exploration of how the specifics of the execution make the forms interesting and successful.

(1) Building Form
The program of the building is quite formal as it is primarily laboratories, research rooms, lecture rooms and offices. This means that the overall form of the building is rectilinear and follows the general language of the typology. However, the rectilinear form of the building is broken up several "chasms", similarly to the Freedom Park museum buildings. These chasms will be discussed further in a later point. Moreover, the materiality of the building overall means that the building reads a certain way from far, but under closer inspection it appears to read in a completely different way. Similarly, the form of the building from far reads as completely rectangular, however as one approaches and the angle of approach changes, one can see that the form is somewhat meandering. The facades of the building generally read as a single element, however it appears to have "breaks" along the length of the building, each break inducing a change in angle for the following panel. This is what gives the building its signature shape.

(2) Materiality
The architects have not publically discussed the materials or the reason for the choice of the materials. However, one can make guesses as to the reason for the choice of materials. The entire facade appears to make the use of faceted panels, perhaps to further the aesthetic of a fractured facade. This faceting also allows the building to physically change along the length of the facade, as the material itself is more flexible. It appears to, in some places, change slightly to possibly allow light into certain spaces, or to accentuate a certain feature, however the architects have no spoken about it and the documentation of the building, by photographers or critics, fails to mention these gaps.

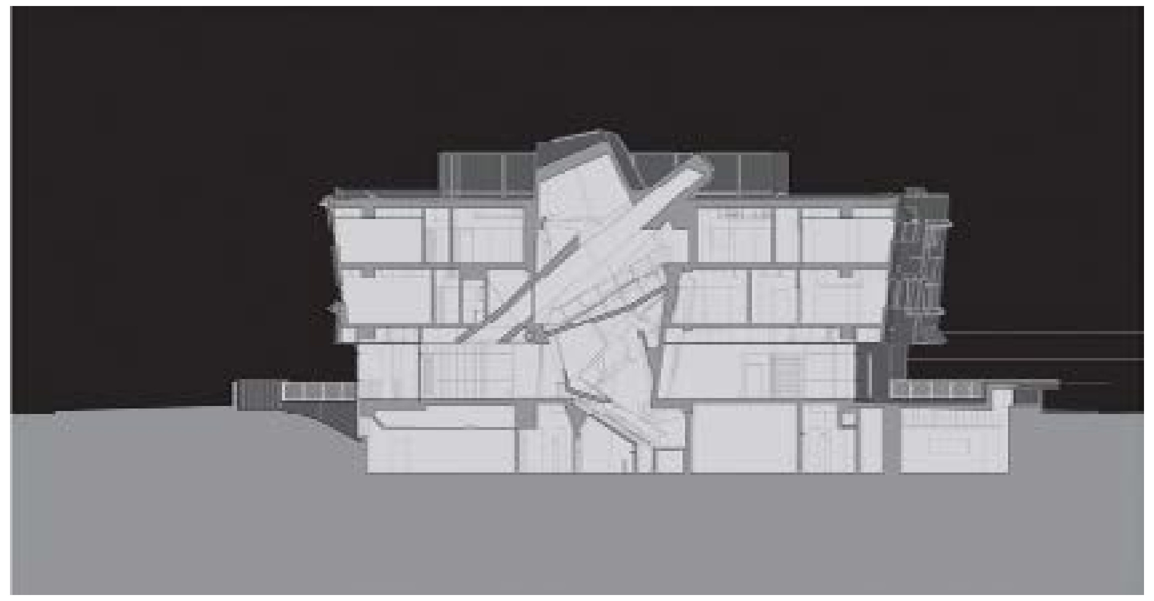
(3) Fenestration
The fenestration in the building is achieved by omitting wall panels in certain areas, the substructure beneath containing a wall in that location. This creates an interesting situation in some areas where the panels around the chasms reveal the substructure underneath, as seen in at (7) in the marked photograph on the facing page, and the image below.

The detailing of the building appears to emphasise this connection, essentially putting the mechanical connection on display. As is often the case with science-related buildings, the architect may have wanted to use this detail as a metaphor for the field of research: both are about understanding how things work together and being able to analyse individual elements.

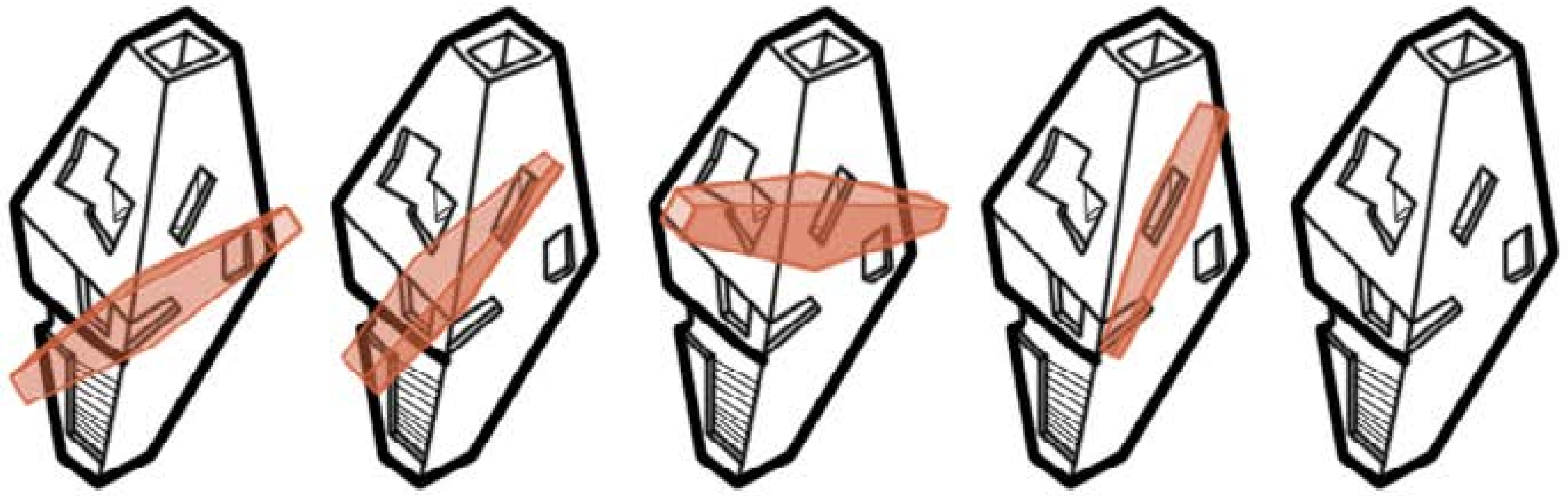
(4) Lifting the Mass
Again, much like Freedom Park museum, the mass of the building is articulated in some ways, but lifting up the building. A heavy, somewhat monolithic form such as this would appear as being much heavier had the architects not lifted up the mass in this way, Furthermore, some parts of the building are to be used as public space and lifting the mass in this way opens up the building to the public plane.

(5) Entropy
Although the architect has not been vocal about it, it is possible that the building's form becomes chaotic as the facade continues as a metaphor for the field of study that the building houses. Entropy is a scientific term used in astrophysics, and essentially means a gradual decline into disorder. The facade portrays this decline into disorder along the length of the building. However, this has not been outwardly stated and may merely be a coincidence.

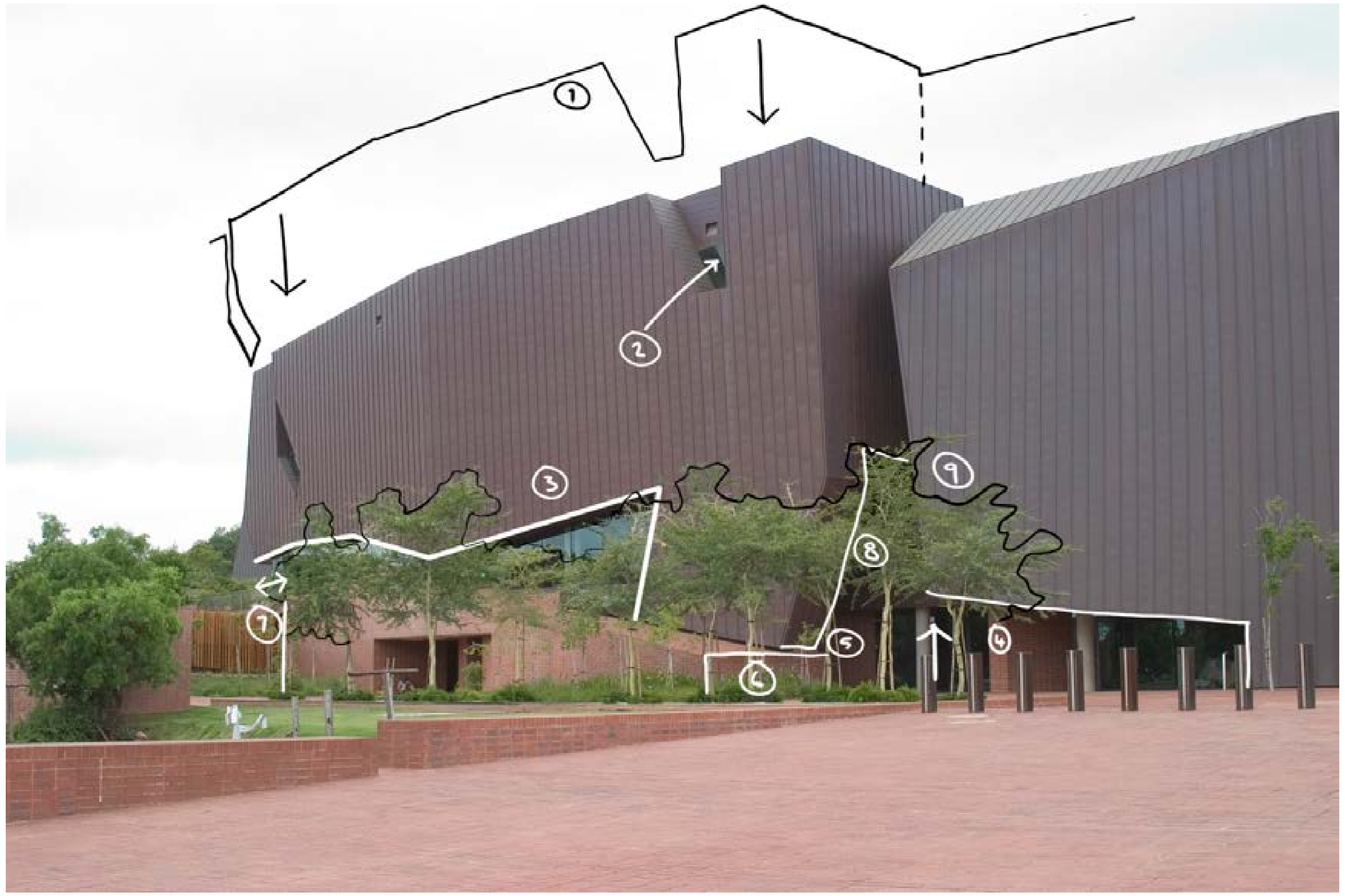
(6 & 7) Observation
One aspect that the architect has been very vocal about is using parts of the building as tools for astronomy. "In the tradition of ancient and modern architectural observatories found around the world, the building itself conceptually acts as an astronomical instrument". In some parts of the building (7) this is merely about focusing visitor's eyes on the sky via careful design of windows, however the main element used to achieve this is a circulation void in the eastern side of the building. The void consists of a series of seemingly chaotic staircases and puncturing voids, however these are carefully planned to create a connection to other researchers through the circulation and lines of site, and to the heavens with voids punching out the building.



The image below is from a case study that the architects conducted. The orange shards are the sun's direction at specific times of the year, the "cone" itself is the circulation void. As the shards of light collide with the cone, the architect has created a void in the element, opening the space to astronomical occurrences and thus, turning the building into an astronomical observatory, of sorts.



FREEDOM PARK PHASE 2 | MASHABANE ROSE ARCHITECTS



First Visual Analysis
Visually, one of the most obvious and striking parts of the building is the bold masses of the museum. The tall, monolithic faces of the buildings create such simple but distinct forms, however the specific execution of the building is what makes the geometry successful. This analysis is an exploration of how the specifics of the execution make the forms interesting and successful.

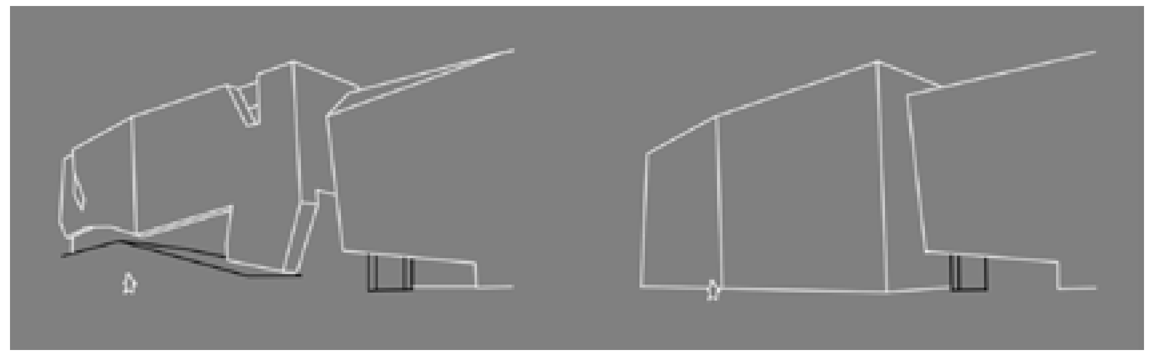
(1) Building Form
The most obvious part of the envelope of the building is the large, copper sheeted masses. There are very few facets in the makeup of these forms, possibly part of why they are successful. Each cardinal side of the building has no more than two facets. The footprints of the buildings are essentially rectangles that have been pushed or pulled in certain places, making the overall geometry very easy to process - rather than the building being a mess of faces and angles. The forms of the buildings read as having been very confidently shaped, rather than being randomly molded.

(2) Fenestration
The fenestration of the building is very scarce. The large faces are not punctured at all, unless on the edge. Once again, this keeps the geometry as very unified and homogeneous. The placing of the fenestration serves to bring light in at very specific locations, and naturally, the shape of the windows serves two purposes: the bring light in in a particular way, and to allow to geometry to be read in the same way. In fact the placement of the fenestration helps to break up the potentially uninteresting form, making it more dynamic.

(3) Lifting the Mass
As well as having openings near the top of the mass, the building also lifts up in certain locations. Naturally this is to allow access underneath the building, but aesthetically it lightens the building as well. This large window allows the building itself to sit on the pedestal below without necessarily touching the pedestal. This articulation is very important in making the building appear more elegant. Instead of coming heavily down to the ground, it appears to plummet downwards and then float above the pedestal. As a common aesthetic around the building, this playful form making also serves in other areas and is a dynamic way to achieve a similar aesthetic while simultaneously using this style in different approaches.

(4) Lifting the Mass (2)
The usage of the aesthetic of the lifted mass is used here in a similar way: the building is essentially "carved away" in this area and the piece "removed". However the specifics of this lifted geometry are different. There are likely rules set up to ensure a similar geometry is met, however none of the architects have spoken publically about this. A discussion of these possible rules will follow. However, such rules would likely not be the only thing governing the form of this opening, or the other geometries of the building. Time, iterative design, patience and intuition would all be necessary for perfecting these forms, not only in the building itself but the combination of the form and the function beneath. These "lifted" areas of the building are also used in the administration block attached to the museum, and among other elements, tie the aesthetics of the buildings together.

(5) Articulation
The articulation of these masses is crucial to making them work aesthetically. The forms themselves have very simple geometries, before any "alterations" are done. The combination of the lifts, voids and facet alterations create a much more complex geometry that conveys more in terms of the intended aesthetic. The achieved forms appears to me geological in appearance and the inclusion of these articulations are what elevates the form from being "a wall of metal" to geological and complex - the nuances of these elements allow the building to read completely differently.



(6) Pedestral
Throughout the building, there are places where these geometries appear to sit on a pedestal of sorts. This would seem to perform multiple functions. As discussed, it provides a platform to express the articulation, and therefore geometry, more elegantly; it articulates the different functions; and it adds to the metaphor of a geologically inspired architecture. The pedestal and the mass above both read as monolithic elements and when "stacked" they appear to make a pile of rocks. This intended aesthetic could also be the reason that the meeting of different buildings is irregular.

(7) Separation
There are places in the building, especially the area captured in the photograph, that are intended to be entered into. There is an overhang at the end of the building above, giving people a space to stand before entering the museum. The overhang also accentuates and emphasises the heaviness of the building itself.

As the building is primarily read as a large form, and the fenestration of the building is scarce, the areas where the building steps back read as the softened parts of the building. This allows for a lighter feeling over all from the outside, and from the inside, one reads the mass of the building as well, feeling as if enveloped by the earth. These chasms throughout the scheme also add a more dynamic feel to the building. The articulation of these spaces is also very particular, so as to avoid a clash of styles or to have the gaps feel arbitrary. The architects have obviously gone to a lot of effort to detail these areas as finely as possible to achieve a level of polish and homogeneity across the entire scheme.

(9) Planting
The choice of planting around the building, and the placement of the building within the landscape in the chosen way, appears to allow the building somewhat blend in with the landscape. The trees envelop the bottom of the building, and so only the "rocky" tops of the building appear from a distance. Furthermore, the choice of the material for the scheme, one it has gained a patina, will also appear to be more one with the landscape, further embedding the building in the site.

ASTRONOMICAL PARK OF ZHENZE HIGH SCHOOL | SPECIFIC ARCHITECTS + UNIT ARCHITECTS

Location: 1750 Pang Yang Lu, Wujiang Qu, Suzhou Shi, Jiangsu Sheng, China
Area: 6330m^2
Category: School
Project Year: 2018

One of the most interesting features of the Astronomical Park is the naked eye observatory, or as the architects call it, the "astronomical stadium". This was the inspiration for the inclusion of a naked eye observatory into the first revision of the design for the Observatory scheme and the architects' discussions about the design of this courtyard space formed the basis of the understanding of what would be required in the naked eye observatory and courtyard in both revisions of the design project. That is to say, designing the space in a way that excludes outer interference and creates a pure connection between the floor and the sky.

Furthermore, the space itself is designed to slot into an existing campus, which means that the space gets used a lot more. "The park has been well integrated into the daily campus life" (Wong, 2018). This is something that the Observatory scheme aims to do - to make the space approachable and accessible, both physically and programatically.

fig 135: Inner courtyard being used by school children as peaceful reading space (Wong, 2018)

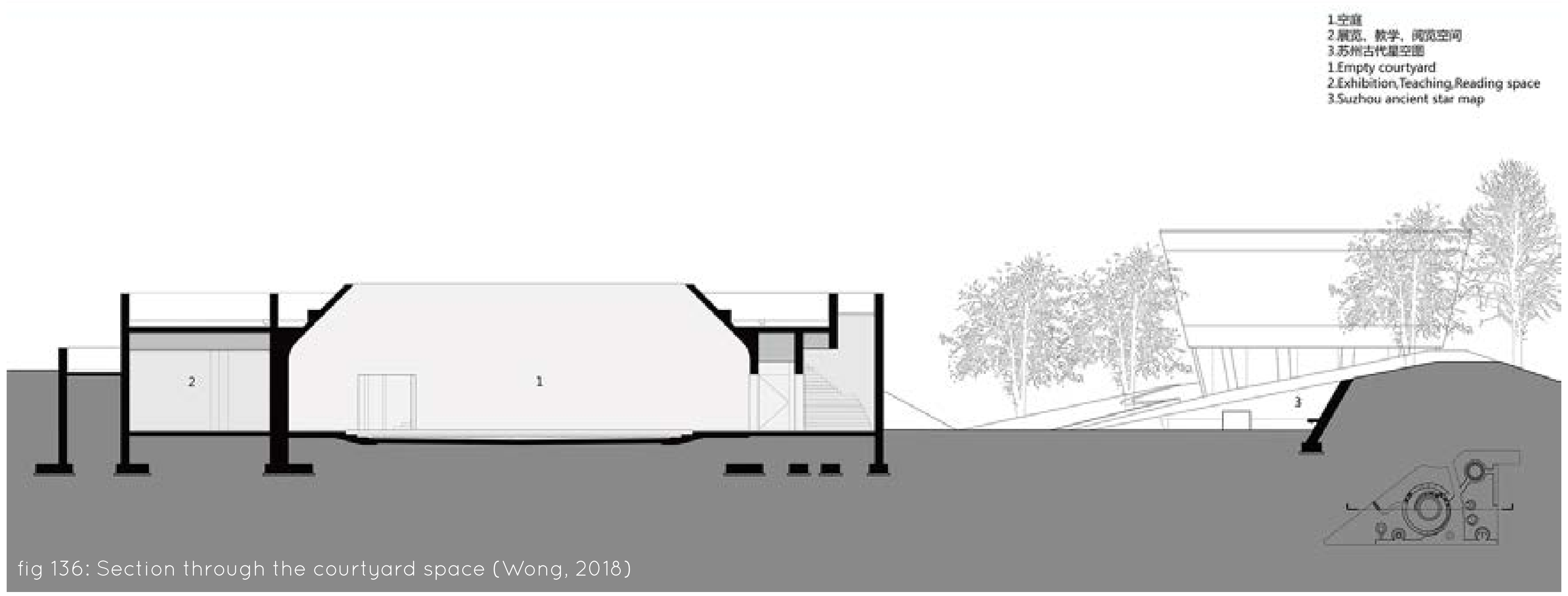


fig 136: Section through the courtyard space (Wong, 2018)

AGORA PÔLE DE RECHERCHE SUR LE CANCER | BEHNISCH ARCHITEKTEN

Location: Lausanne, Switzerland
Area: 22500m^2
Category: Research
Project Year: 2018

The AGORA Pôle de recherche sur le cancer is a research centre in Switzerland that focuses on cancer research. The architect say that the focus was on "comprehensive, holistic concept to design communication and working spaces" (Castro, 2018) for the centre. Naturally, this would be important to consider for the Observatory scheme because of the focus on the intersection between the different aspects of the site. The building is specifically designed to focus on interdisciplinary research, however the building makes accommodations for 400 researchers so the specific approach to creating communication spaces may not be appropriate to the design of the Observatory centre.

The building also focuses heavily on the views from the building. Similarly to what Shafiee said in her research, the architects felt that creating comfortable spaces for the researchers was necessary to maximising on the potential of their work. This is something that the Observatory centre will focus on, particularly in creating comfortable spaces for the researchers using the centre.

fig 137: The AGORA Pôle de recherche sur le cancer (Castro, 2018)

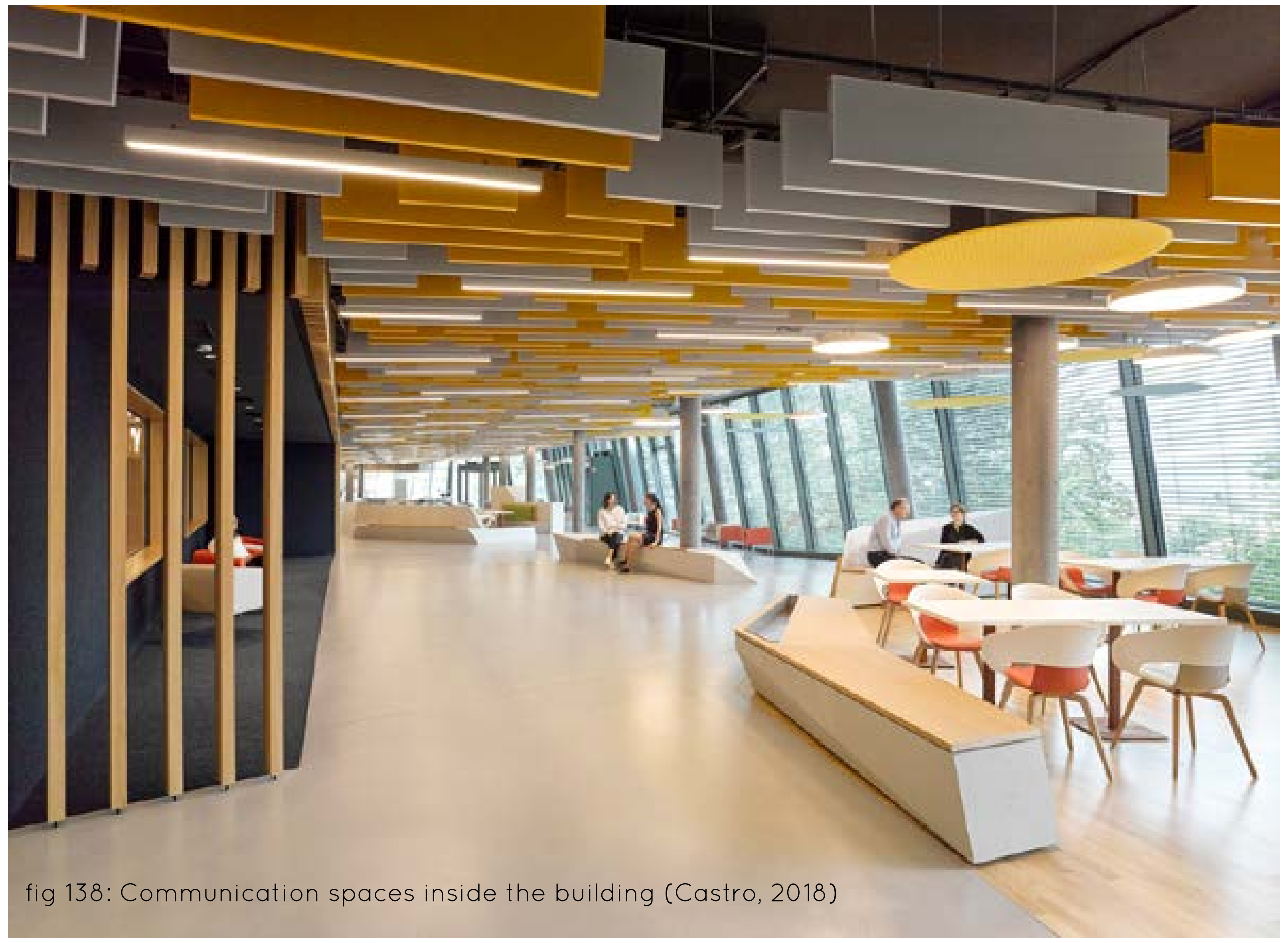


fig 138: Communication spaces inside the building (Castro, 2018)

METALSA CENTER FOR MANUFACTURING INNOVATION | BROOKS + SCARPA

Location: Monterrey, Mexico
Area: 4700m^2
Category: Research
Project Year: 2013

The focus of the Metalsa Center for Manufacturing Innovation was on creating an industrial building that felt comfortable and was "equally attuned to the occupants' needs as for the machinery's needs." (Vinnitskaya, 2012)

The reason for choosing this precedent was to be able to fully understand the requirements of a high-tech research building and how one would go about designing the spaces inside. The architects state that this was achieved in the building by focusing light in on the human spaces and "emphasising the outside world through various architectural moves". (Vinnitskaya, 2012) The building also focuses on renewable energy solutions for the building as the nature of the program is energy intensive.


fig 139: Office space (Vinnitskaya, 2012)


fig 140: Sweeping forms of the building create an interesting spaces from within (Vinnitskaya, 2012)

SMART INNOVATION LEARNING CENTER | NEILI LAB

Location: Ganquan Foreign Languages Middle School, Shanghai, China
Area: 800m^2
Category: School
Project Year: 2017

The Smart Innovation Learning Centre was initially looked at as a way to effectively design learning spaces in the hope that this would help to inform the design of the exhibition spaces for the museum portion of the Observatory scheme. The Smart Innovation Learning Centre focuses on creating rich experiences for students to be able to encourage learning in these spaces. The architects said that they "follow the design concept of the "hidden education" (ie, children's psychology, behavior & cognitive science etc.) and emphasize this point on all the design elements, thus to create the most appropriate smart innovative environment." (Han, 2018)

The building attempts to create these rich experiences by fostering the connection between the students, learning and nature. The spaces are designed to emulate the harmony between human beings and nature. The design concept for the space came about as an approach to dealing with the many columns in the spaces, the aesthetic was embraced and added in as the main design approach for the scheme. There is a parallel between creating learning experiences


fig 141: Learning spaces that emulate forests (Han, 2018)

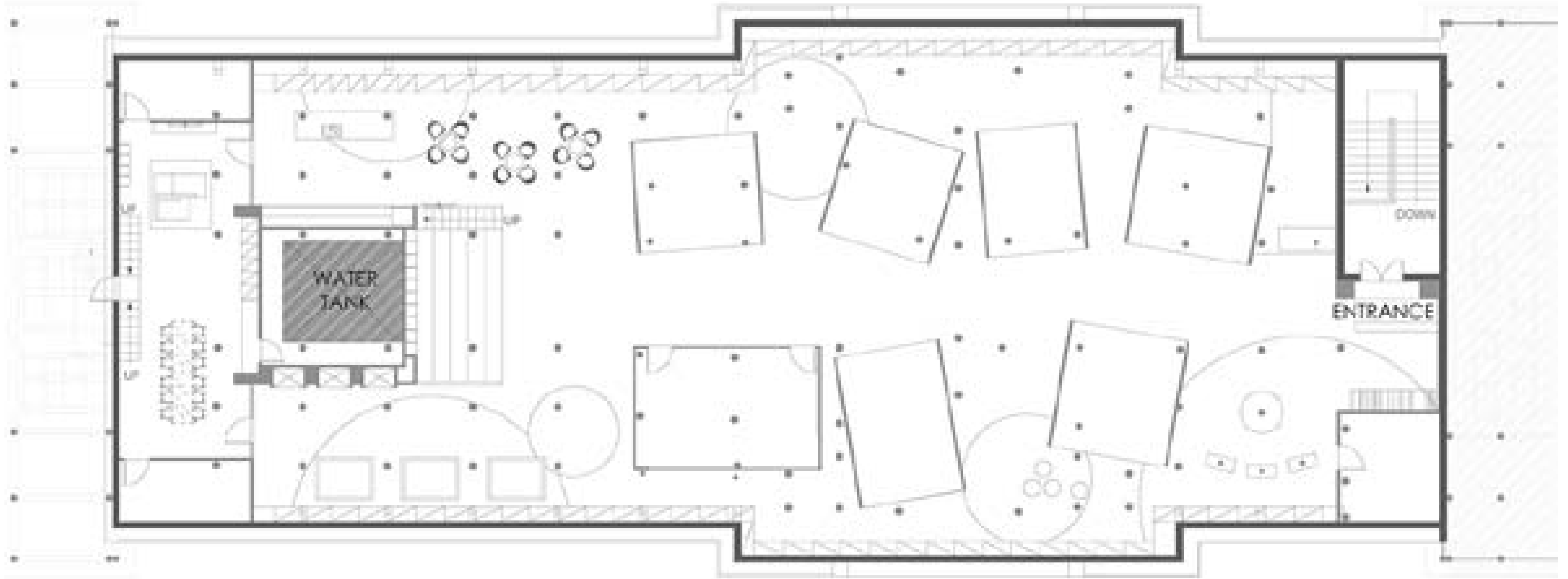


fig 142: Plan showing the many columns that needed to be designed around (Han, 2018)

6 / 7 Design

"The human brain now holds the key to our future. We have to recall the image of the planet from outer space: a single entity in which air, water, and continents are interconnected. That is our home."

- David Suzuki

CHAPTER CONTENTS

CHAPTER INTRODUCTION

The Observatory Satellite Research, Development and Visitor Centre will aim to achieve three primary goals: create a research platform that can be the catalyst for widespread adoption of South Africa's space industry, facilitate the collaboration between academics and industry in the space program and use the site and program of both as a tool for educating the public and to generate public interest in South Africa's space program.

The following chapter will be an exploration of these mandates, first as the initial design approach and later as the current design approach. Both of these will discuss the design's approach to fulfilling the design concepts. The chapter will also discuss the design approach necessary to creating meaningful spaces from the research laboratories, exhibition spaces and naked eye observatory.

The final design also has a construction exploration to aid in realising the limitations of the chosen materials and forms and how they can best be utilised.

Lastly, final design drawings will follow once the building has been fully resolved.

EARLY DESIGN CHARETTE

Even though for most people pareidolia has little effect on their day to day lives, as a progenitor for an architectural concept it holds a lot of potential. The power of pareidolia, as demonstrated by the existence of constellations, is not in the presence of the lights or darkness, but rather what we recognise and what we can project onto that stimulus. The reason that every culture has different stories and constellations is because every culture values or experiences very different lifestyles. What we recognise in patterns presented to us is what gives the patterns meaning - otherwise patterns are just lights in the sky.

Using this logic to search for patterns in Rorschach style ink stains was the progenitor for a design exploration concept. This exploration took the following form: create an ink stain and draw into that ink stain with the hope that certain architectural inspiration could be drawn from this exploration. For example:

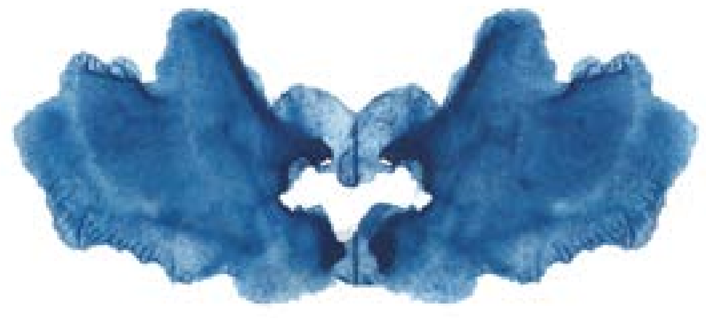


fig 143: Original ink stain 1

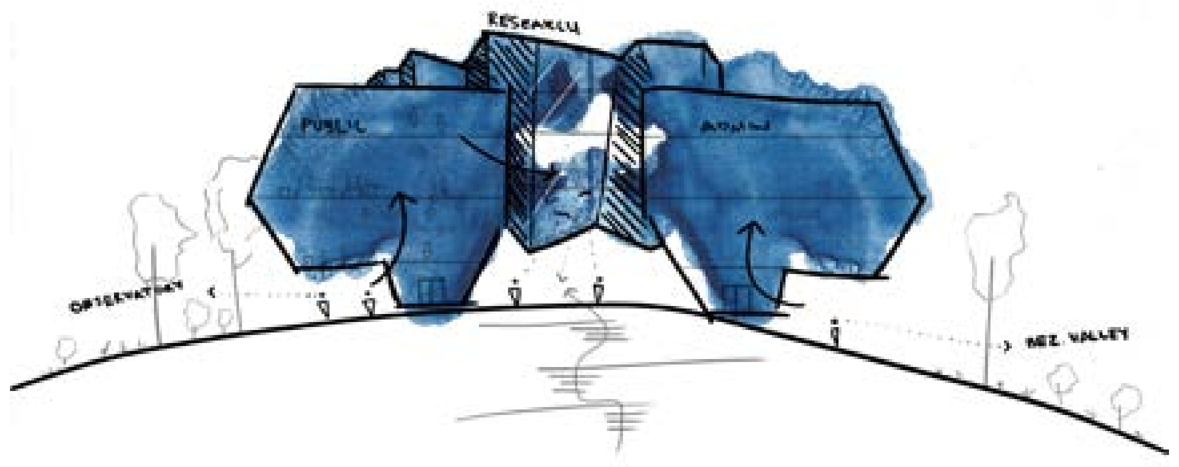


fig 145: Explored ink stain 1

fig 146: Original ink stain 2

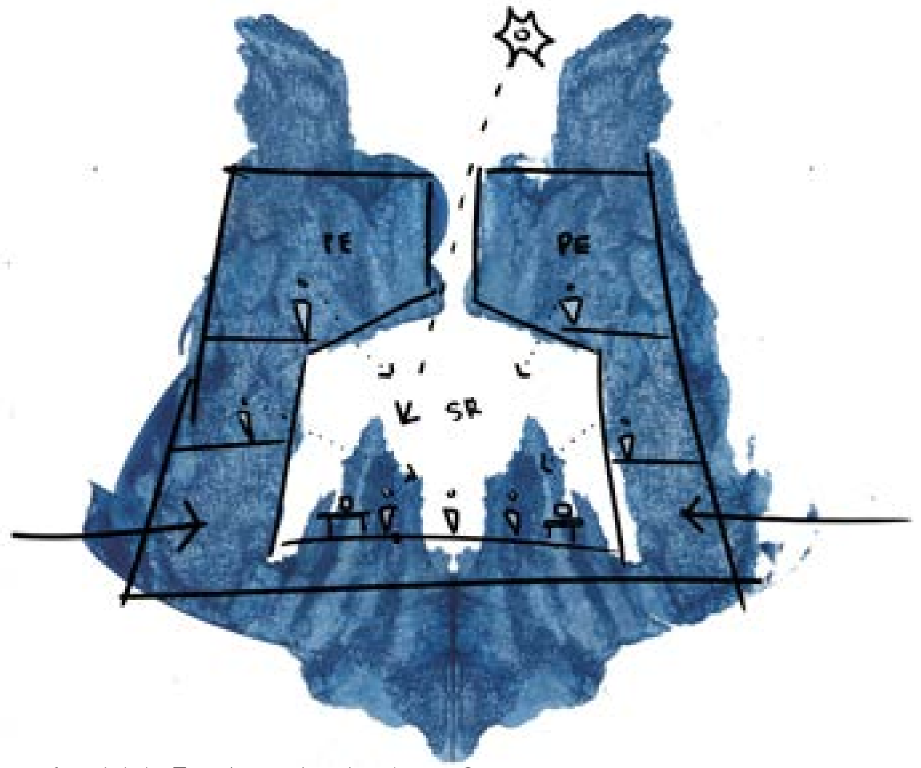


fig 144: Explored ink stain 2

While this type of exploration is interesting in theory, it can be limiting. Unfortunately, a lot of the time the superimposed ideas don't necessarily stem from pure inspiration but instead become a post-rationalisation for ideas that have already been had. However, specifics of forms or tweaks that occur in the application of these ideas onto a "random" shape can be valuable. For example, the idea explored in the second stain above already existed. Putting the satellite research facility on display to the public exhibition space has been a concept for the design since the inception of the project. However, due to the nature of the ink stain the form for this "publicness" has been explored: A skylight and double volume space. Public space is a lot less extensive than the satellite fabrication space and so three floors of public space can use the same research lab as a part of their exhibition, possibly looking at the same space through separate lenses.

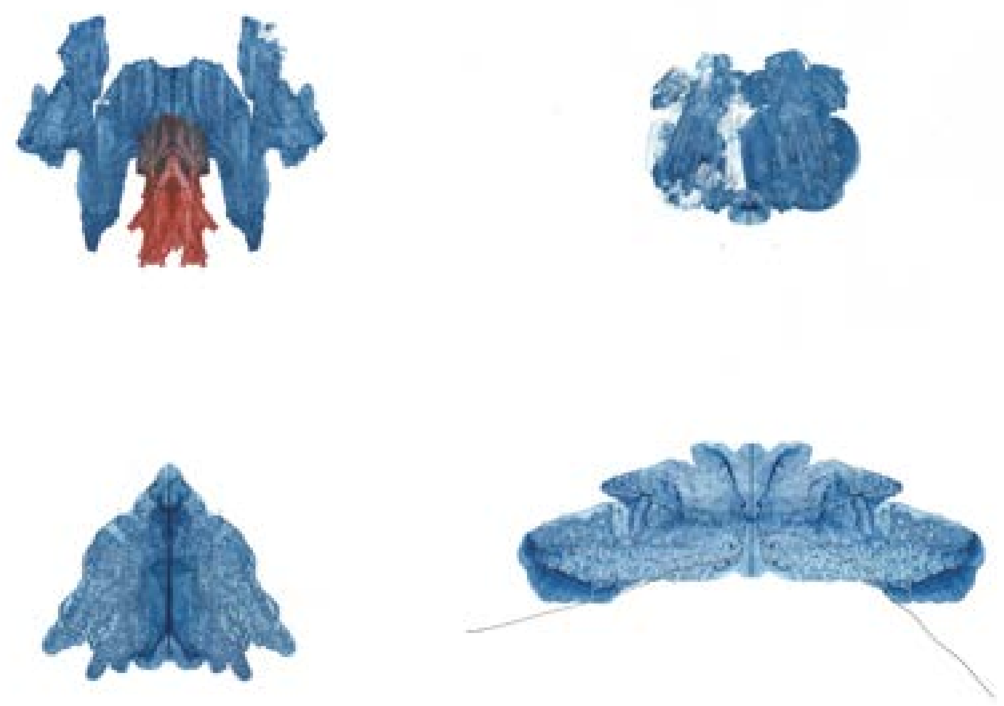
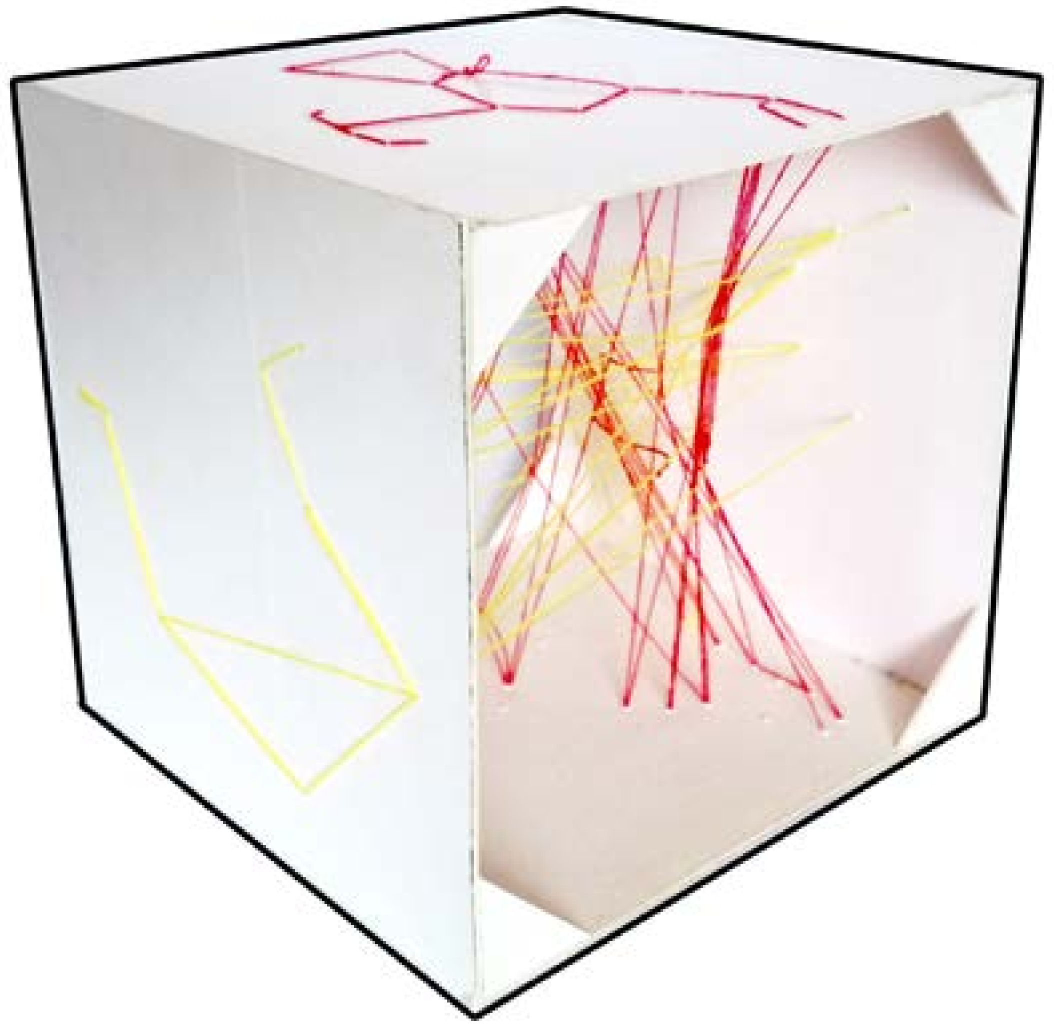


fig 150: Ink stains

The next iteration of the pareidolic design exploration was to take the idea of pattern recognition and apply it to something that was more suited to the overarching theme of this project and the pareidolic exploration concept: constellations.

This design exploration consisted of taking constellations and abstracting them in order to create a random stimulus which could be explored. This consisted of creating a triplex box and essentially "sewing" the constellations into the walls of the box. The strings crossing in the center of the box is what creates a random pattern through which designs could be explored.



A shadow study was then done of the crossing strings, essentially turning the three dimensional model into two dimensional images.

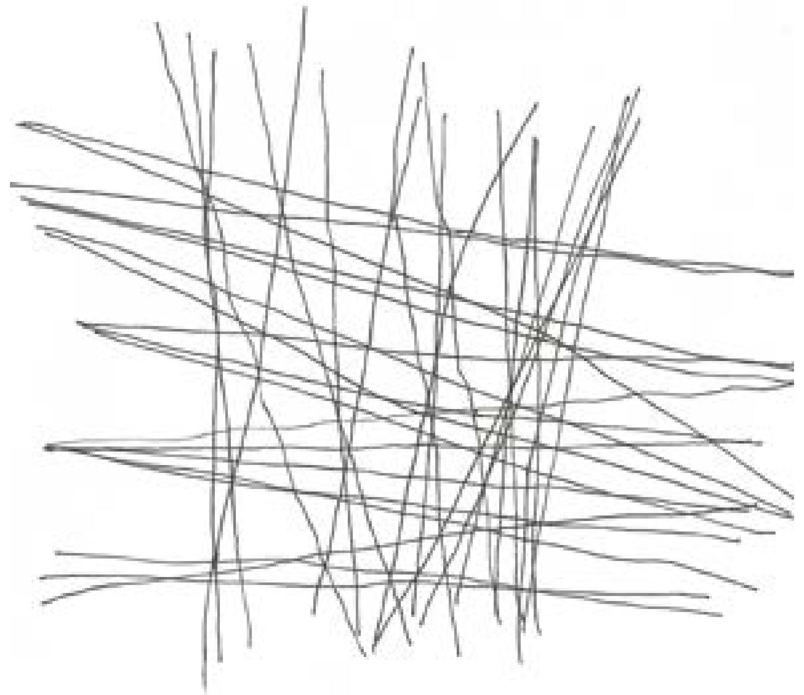


fig 147: Shadow Study 1

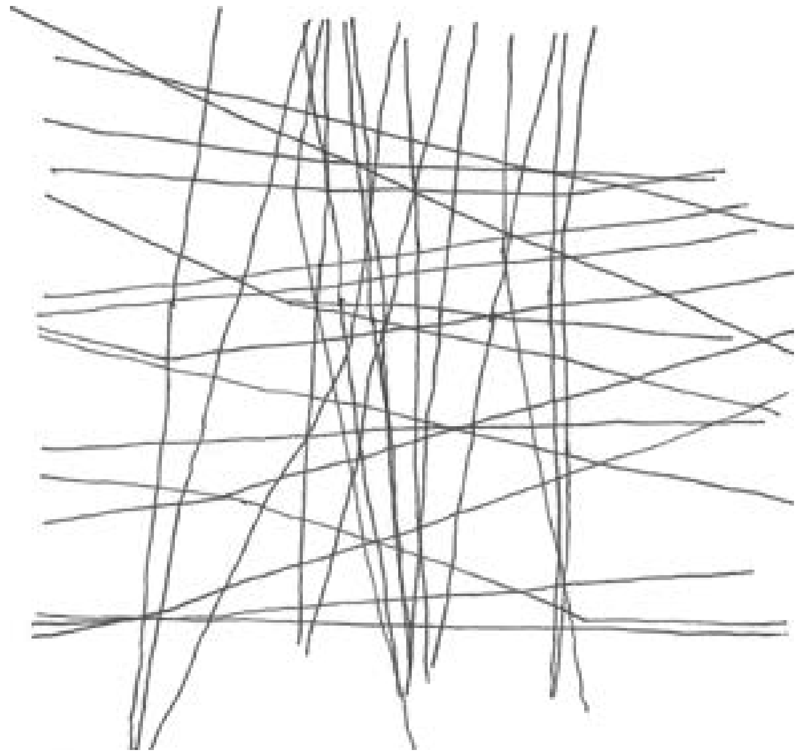


fig 148: Shadow Study 2

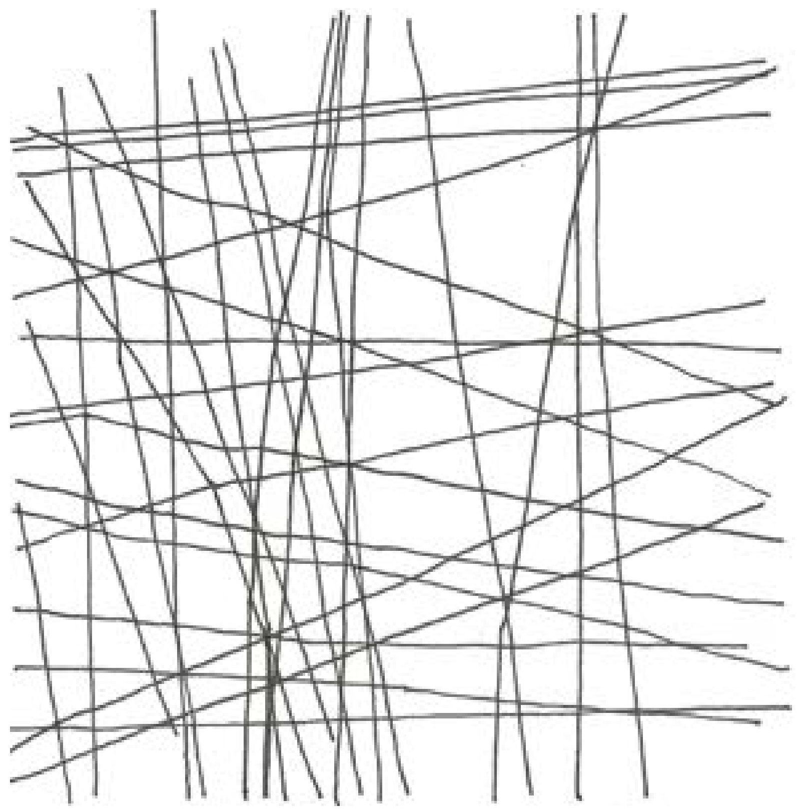
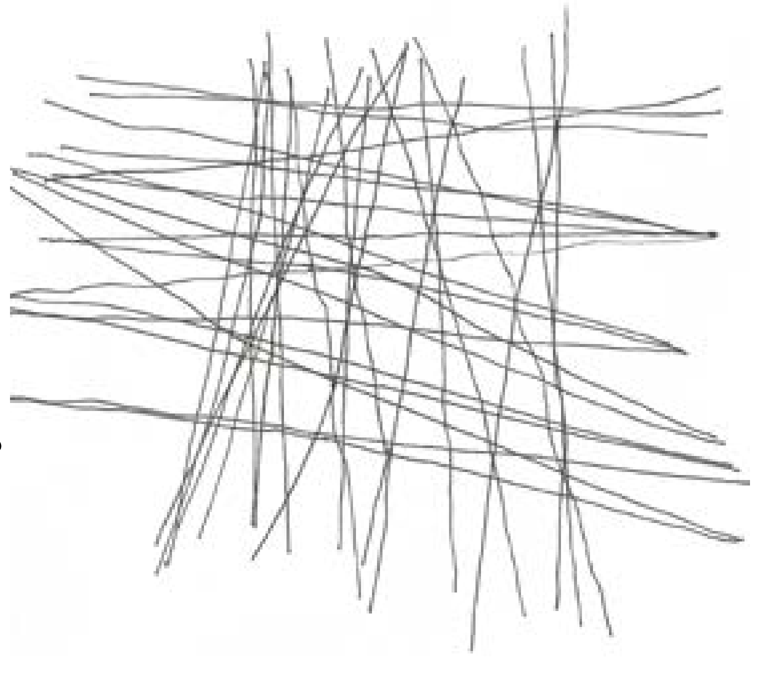
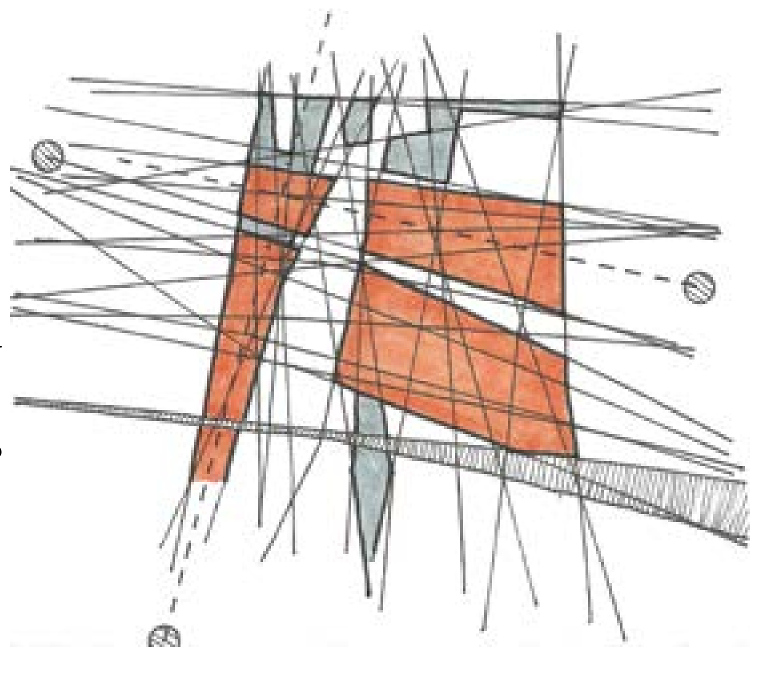


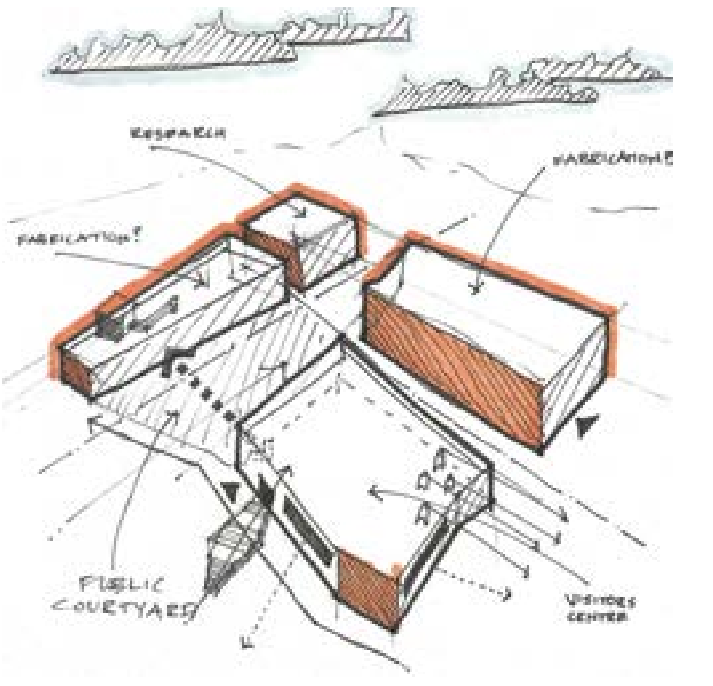
fig 149: Shadow Study 3

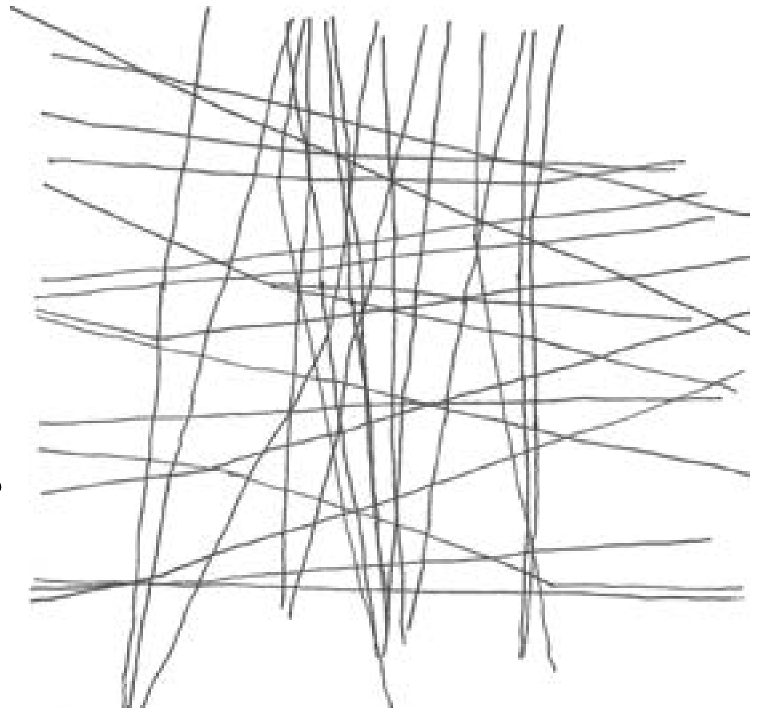
SHADOW STUDIES

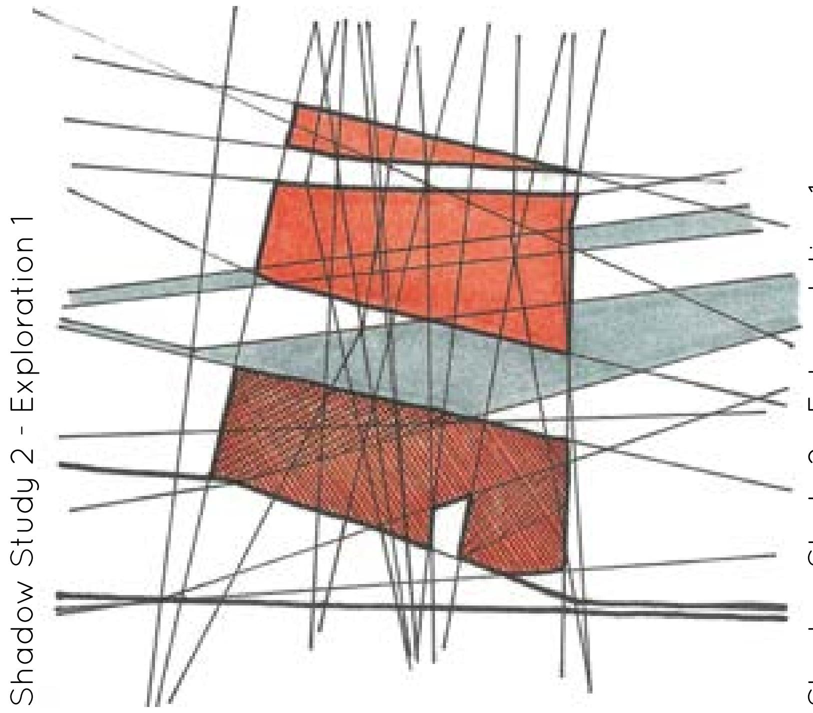
Much like the Rorschach ink stains, the next step of the exercise was to draw into the images. This essentially consists of studying the image and then drawing in recognisable or interesting patterns, ultimately creating quite an abstract pattern.

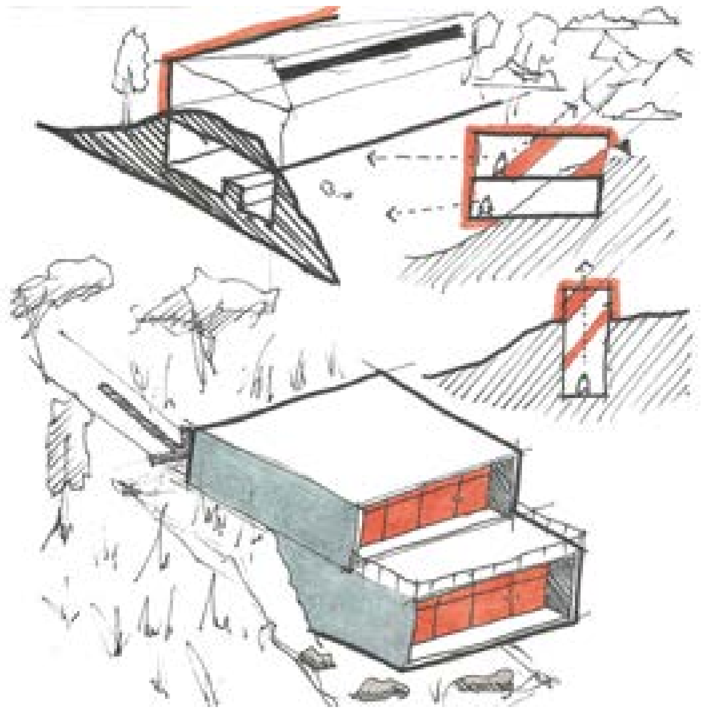

Shadow Study 1

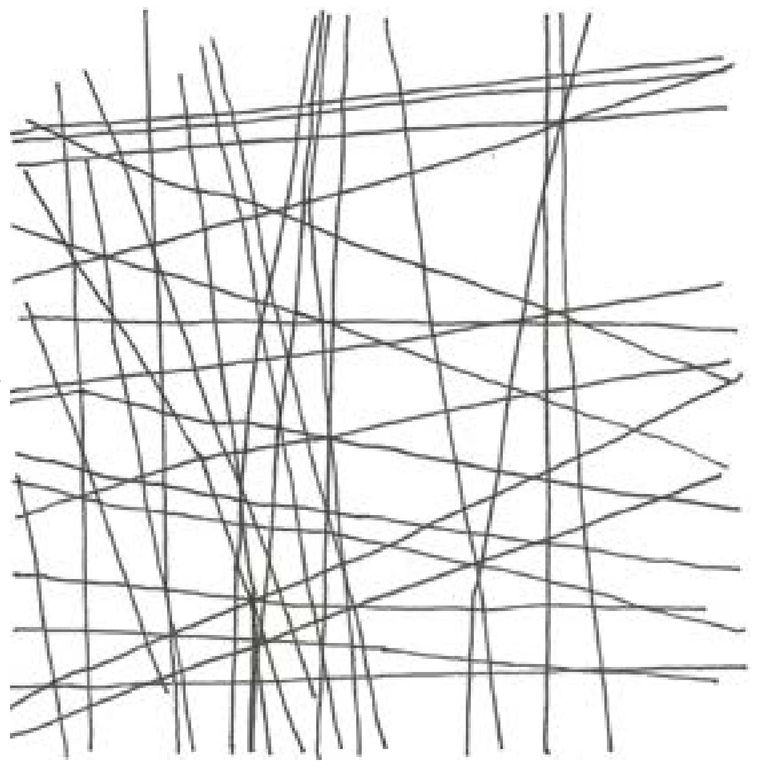

Shadow Study 1 - Exploration 1

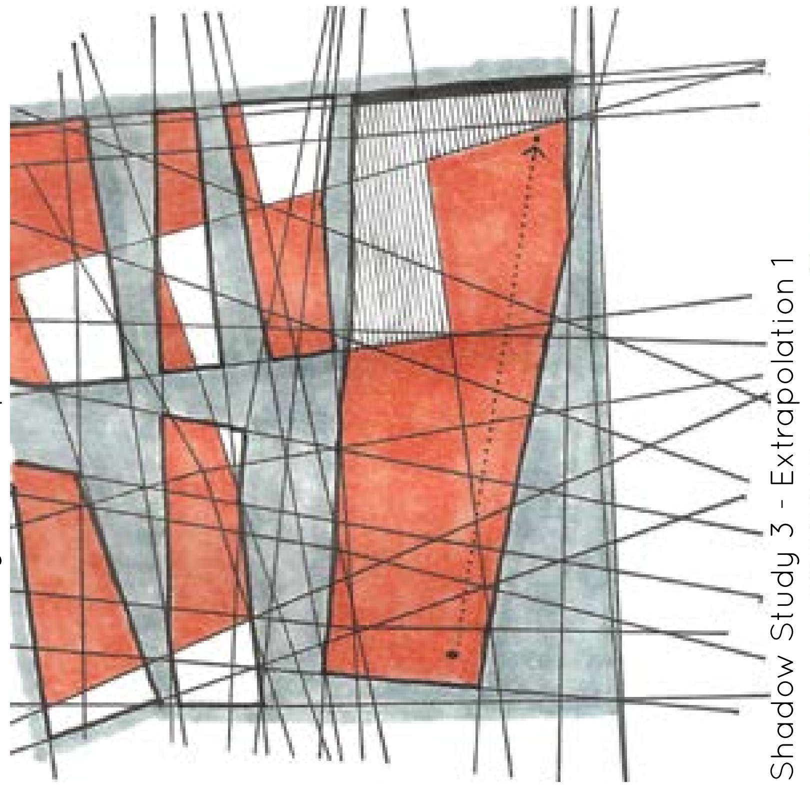

Shadow Study 1 - Extrapolation 1

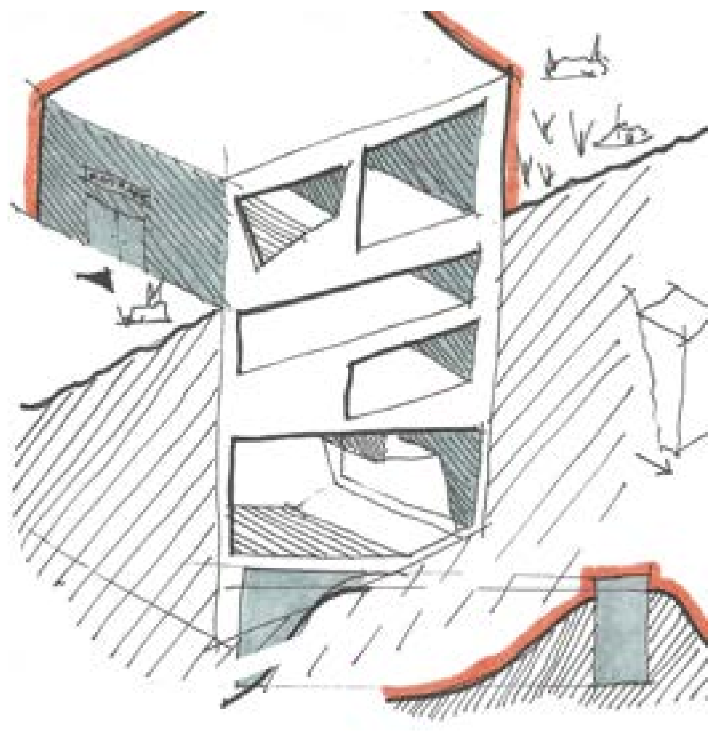

Shadow Study 2


Shadow Study 2 - Exploration 1


Shadow Study 2 - Extrapolation 1

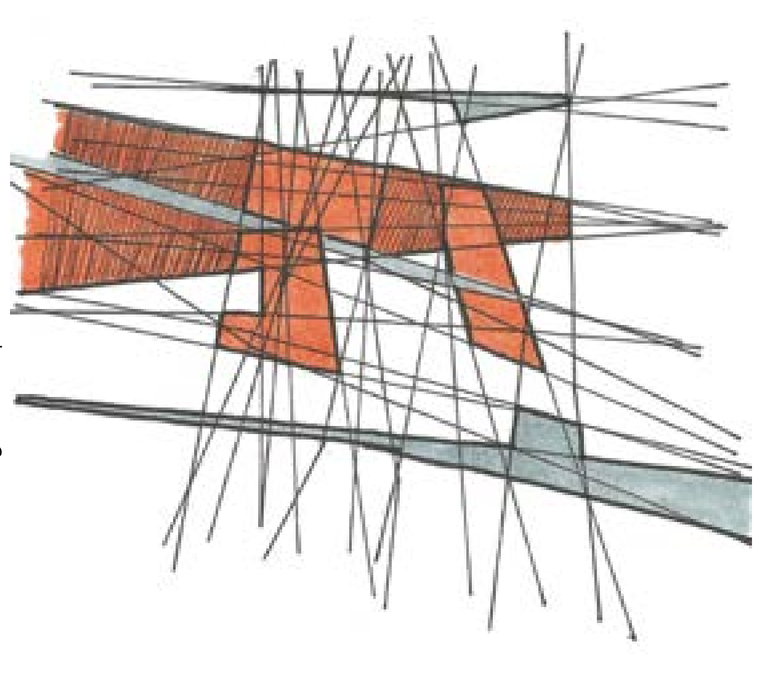

Shadow Study 3 - Extrapolation 1

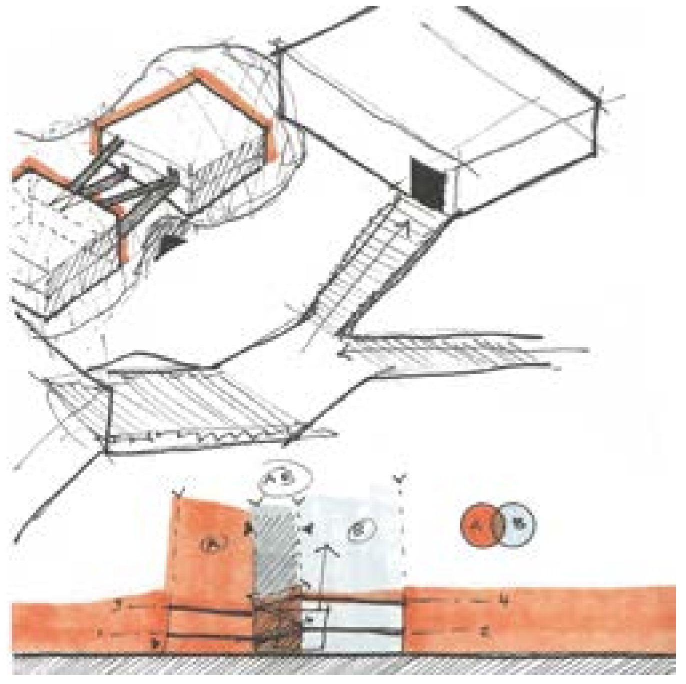

Shadow Study 3 - Extrapolation 1


Shadow Study 3 - Extrapolation 1

◄The first shadow study extrapolation explored the idea of a decentralised scheme; separating different programmatic elements of the scheme would allow more open space between the buildings and allow external exhibition space as well as more control over how different spaces relate to each other.

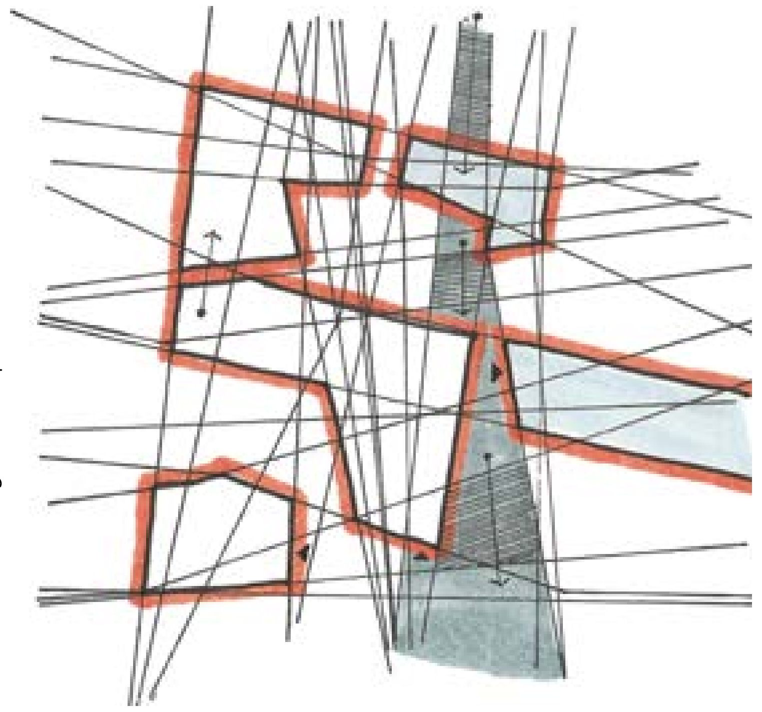
The second extrapolation of the► first shadow study was an exploration of the idea of creating separate buildings for the public and private, the space between essentially becoming the part of the program that publicises the research being done and exposes it to the public.

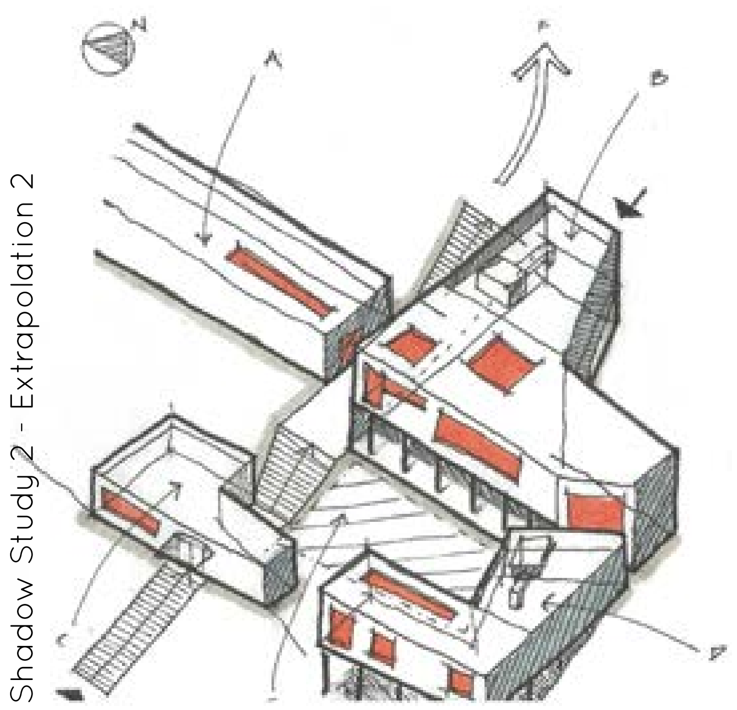

Shadow Study 1 - Exploration 2


Shadow Study 1 - Extrapolation 2

◄The first exploration of the second shadow study looked like the section of a building half embedded in the ground which gave way to a brief exploration of the possibility of partially embedding the building in the ground and creating an experience around seeing the world through spaces built around that concept.

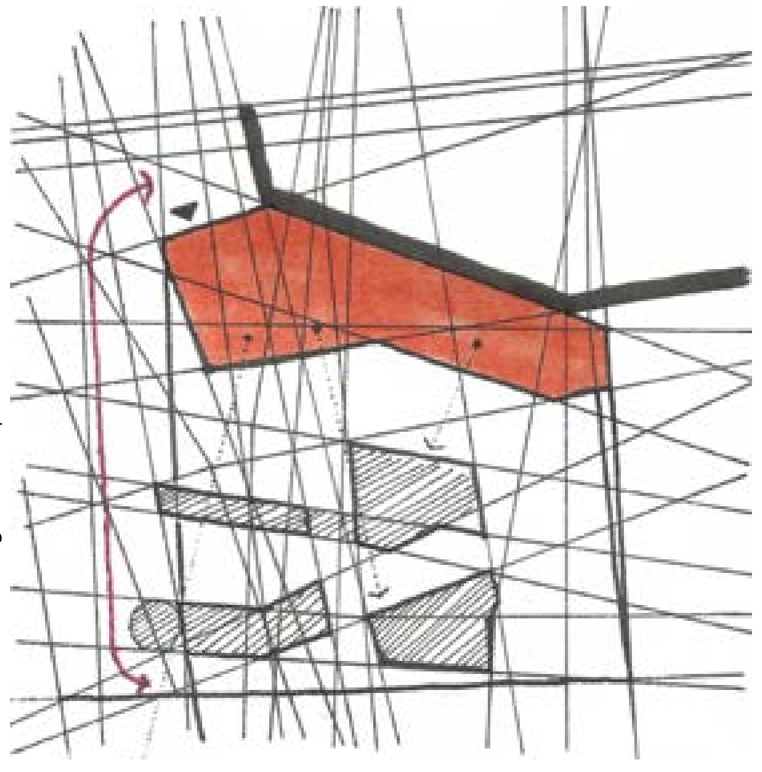
The second extrapolation of the second► shadow study focused on the idea of creating a precinct out of the buildings on site - each building housing a different program and then looking into how that building would work on the ridge topology. This would involve designing views to and from site and playing around with ground levels and circulation between those elements.

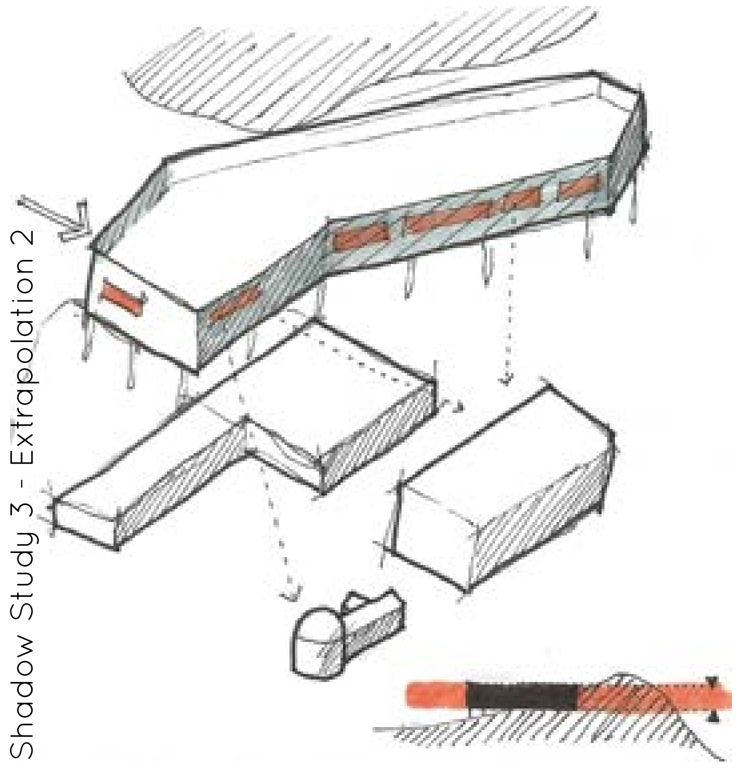

Shadow Study 2 - Exploration 2


Shadow Study 2 - Extrapolation 2

◄Much like the shadow study above, this extrapolation looked into the possibility of submerging part of the program under ground. This would play a part in the first draft on the design for the building, focusing on grounding the building in the landscape and using the depth of the building to focus on views to the sky.

This shadow study seemed to take the► form of the buildings already on site. It focused on the possibility of wrapping the research centre around the side of the ridge, essentially keeping the character of the ridge intact while making use of the views from the site. It also focused on stronger integration between the research centre and the other buildings on site.


Shadow Study 3 - Exploration 2


Shadow Study 3 - Extrapolation 2

0 | design brief

PROGRAM

Since the inception of the project, the Observatory Satellite Research, Development and Visitor's Centre was meant to focus on the interaction between the public, the satellite industry and satellite research academia. Naturally, the specifics of how this interaction was meant to happen would be realised in the specifics of the program for the scheme.

The program has four major components: research facilities and public exhibitions make up the spirit of the site, and administration and service spaces facilitate the operation of the research and exhibition spaces.

The research facilities have three facets: researcher's spaces, satellite fabrication spaces and public interaction spaces. Even within these three spaces there should be overlap, especially considering the intended interaction between the public and the academics. For instance, the public should see a certain amount of the research that is done and so the design of the satellite fabricaiton laboratories should consider this. The spaces required for satellite fabrication was chosen based on the spaces included in case studies: specifically F'SATI/CPUT and Spire Labs. This is also the case for the square meterage of the spaces.

The public exhibition spaces were decided primarily based on the narrative of the space, especially in the second revision of the design. The spaces were chosen based on spaces included in traditional museums, with the consideration that the exhibits might differ from traditional museum exhibits.

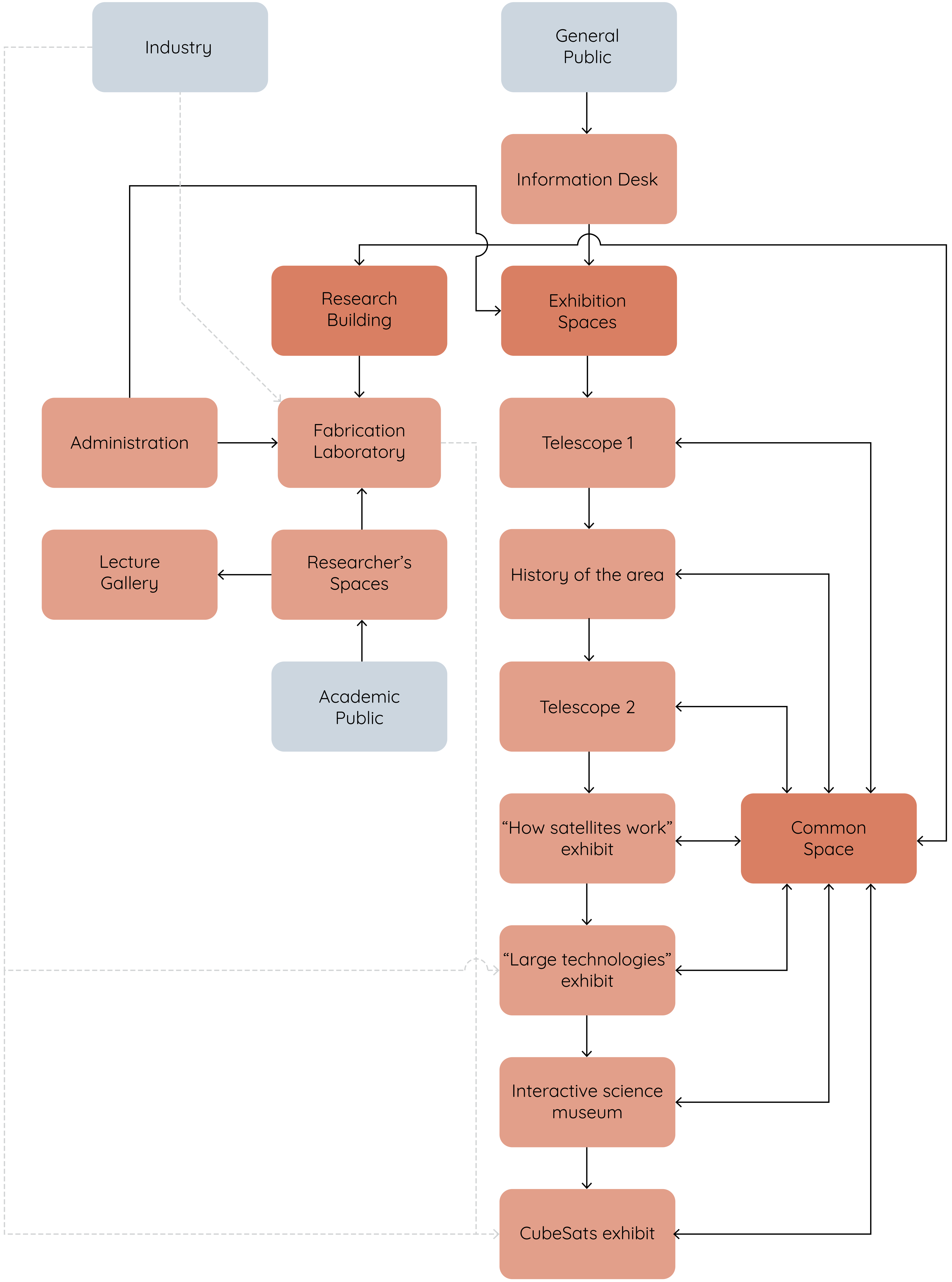
Administration and service spaces were chosen based on both personal experience in the design of administration offices and by looking at precedents of similar projects. These spaces, as well as the spaces outlined in the rest of the program outline, will likely change as the building itself becomes more finely resolved, so are by no means an indication of the final design program.

Research Facilities
Offices
• Senior researchers offices x 2: 25m^2 each
• Assistant researchers offices x2: 25m^2 each
• Visiting researchers offices x 2: 25m^2 each
Seminar spaces x 2: 35m^2 each
Satellite fabrication lab: 70m^2
Satellite testing lab: 70m^2
Computer labs: 100m^2
Ablutions: 25m^2

Public Exhibitions
Exhibitions space: 750m^2
Exhibitions back of house: 500m^2
Restaurant/coffee shop: 70m^2
Public forecourt: 1000m^2
Auditorium: 105m^2
Information desk/reception: 100m^2
Ablutions: 75m^2
Gift shop: 25m^2

Administration
Offices
• CFO: 25m^2
• Admin staff x 2: 15m^2
* Marketing x 2: 15m^2
• Exhibition staff x 2: 15m^2
Reception/waiting area: 40m^2
Staff room: 25m^2

Services
Plant room: 12m^2 each
Patch room: 12m^2
Security officer's office: 25m^2
Waste collection: 40m^2
HT/LT room: 30m^2
Generator room: 30m^2



1 | revision one

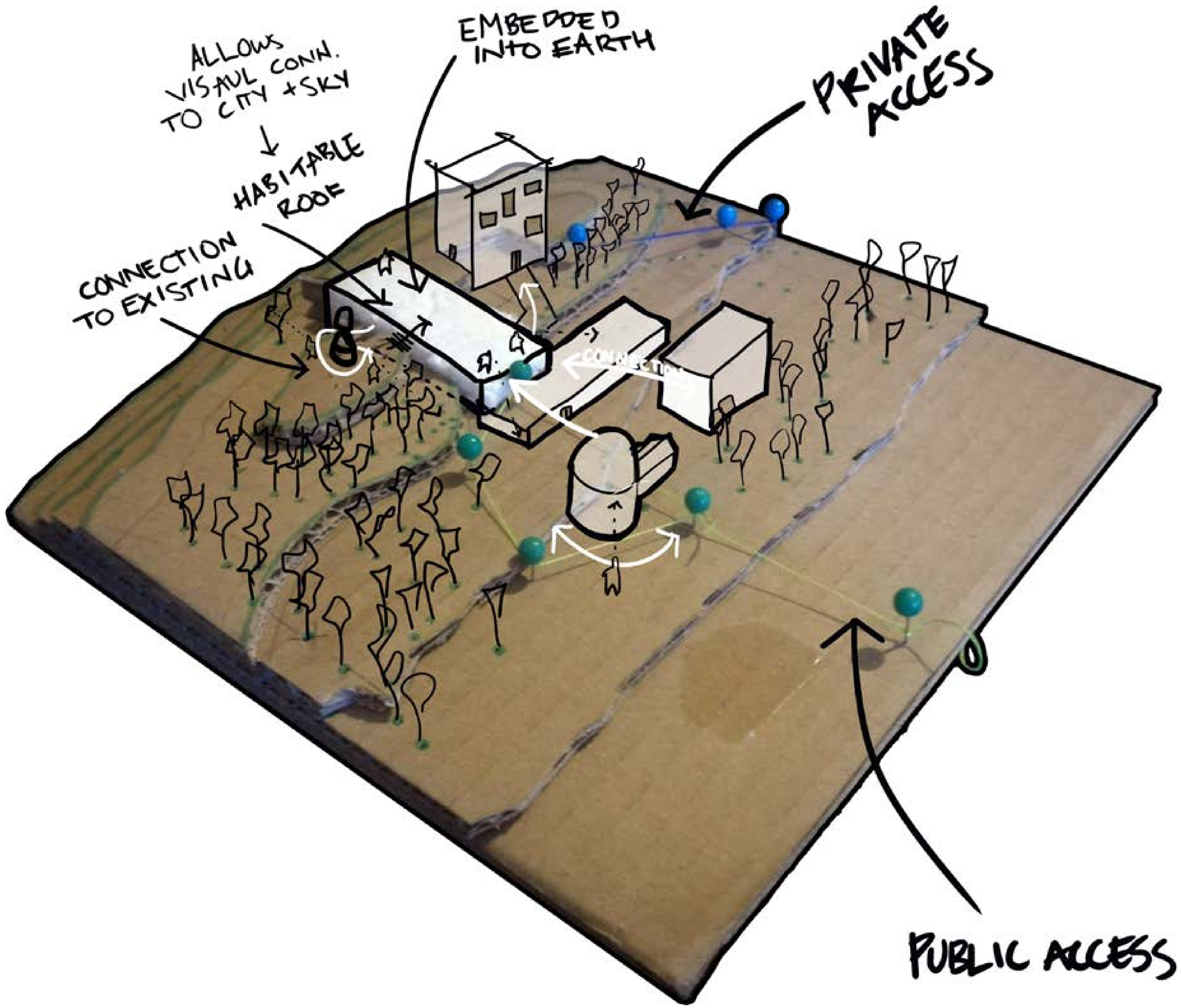
EMBEDDED APPROACH TO BUILDING PLACEMENT

The first revision of the Observatory Satellite Research, Development and Visitor Centre looked to embed the building in the site. This was done in an attempt to ground the building in the area, creating a relationship between space research and the city and by extension, the rest of the country. The idea emerged from the fact that humankind's interest in outer space started while still living as one with the Earth. A building embedded in the landscape mirrors the history of astronomy and space research - one that is catalogued in cave paintings of constellations all over the world.

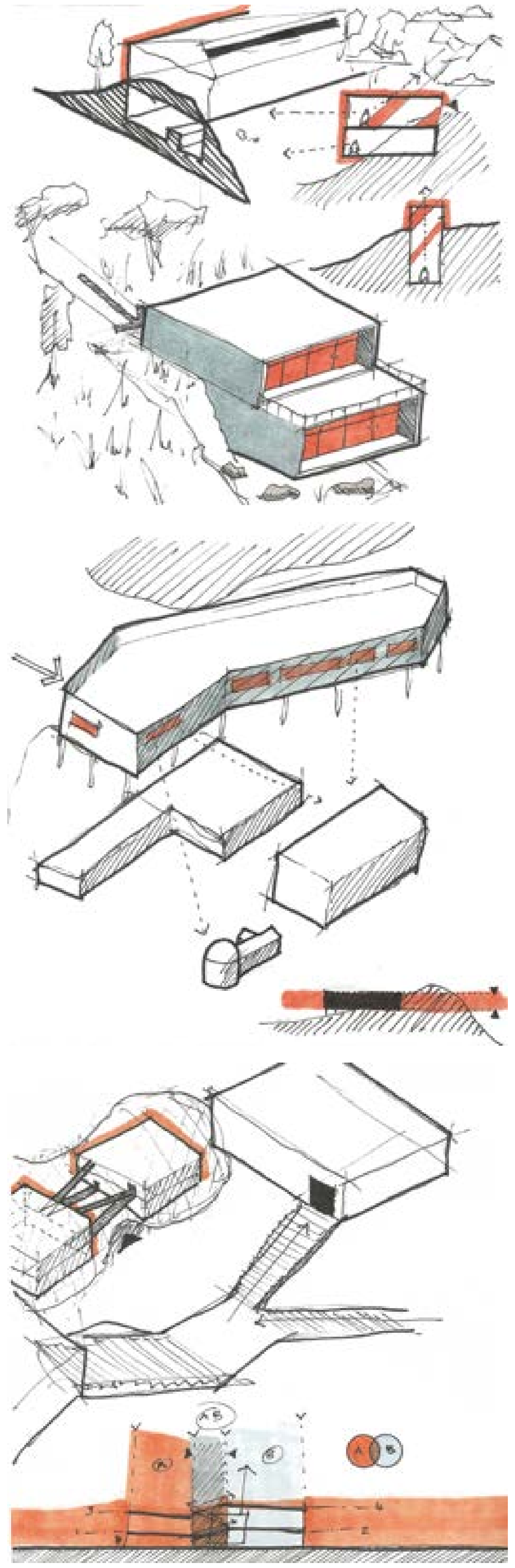
The research and visitor centre was broken up into two major parts: the public exhibition spaces and the private research spaces. This was to simulate a journey through the site, starting with the history of astronomy and space research, moving through the exhibition space and eventually to the research space in the building next door, briefly moving through the external exhibition space.

Architecturally, the design of the building was an exploration of the connection between ancient astronomy and contemporary architecture. Architecture used to be practiced by people with a stronger connection to the earth and this building was meant to emulate that. This was done firstly, by embedding the architecure in the ground and secondly by merging the circulation of the site and the circulation of the building - one can move from the space around the observatory to the exhibition space, back outside to the telescopes on the crest of the ridge, onto the roof of the building and then move into the research centre. The constant connection between the architecture and the landscape is the manifestation of archaeoastronomical observatories which married landscape, architecture and astronomy.

The objective of the exhibition centre is to generate excitement in real world science and show visitors the application of real world science and how it can affect them. The space is designed as a journey, each node in the exhibition tells the next part of the story until one has experienced the whole exhibition. The development of a narrative through the building is what draws people in and ensures that they learn as much as the can; with the last node in the exhibition being the research space, visitors can see the result of the history of the space program that they have learned about and understand the purpose of the satellite development centre outside of politics and economics.

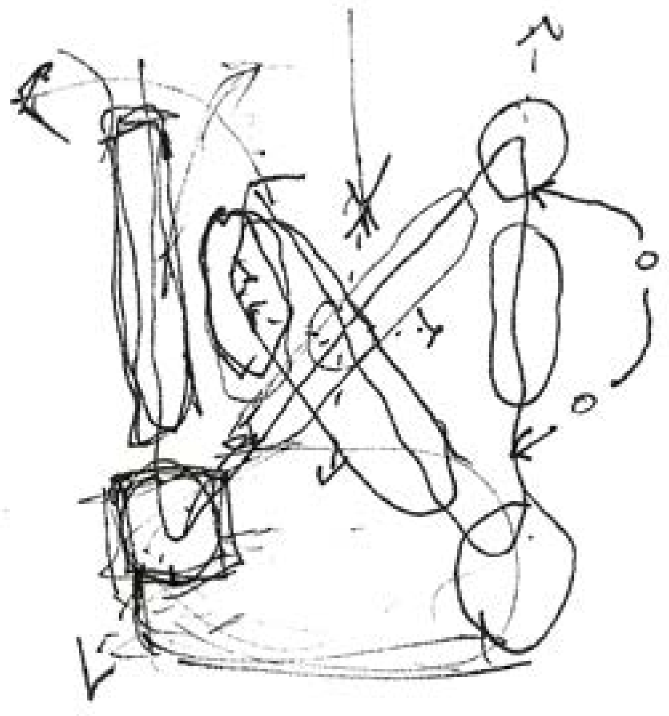


Inspiration from design charette

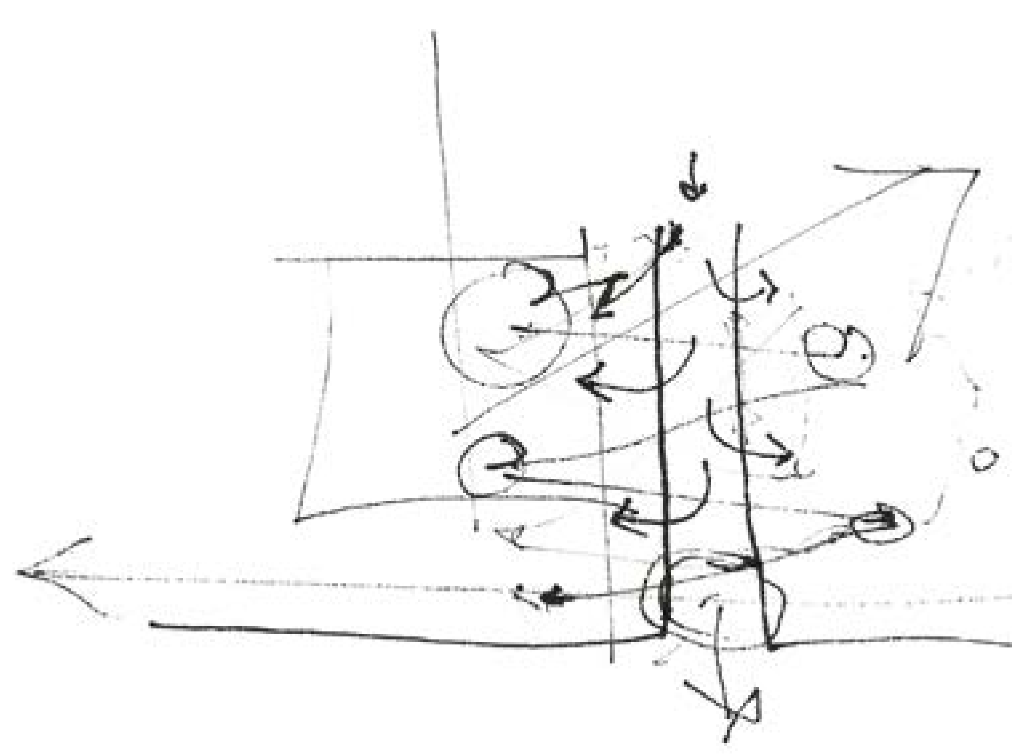


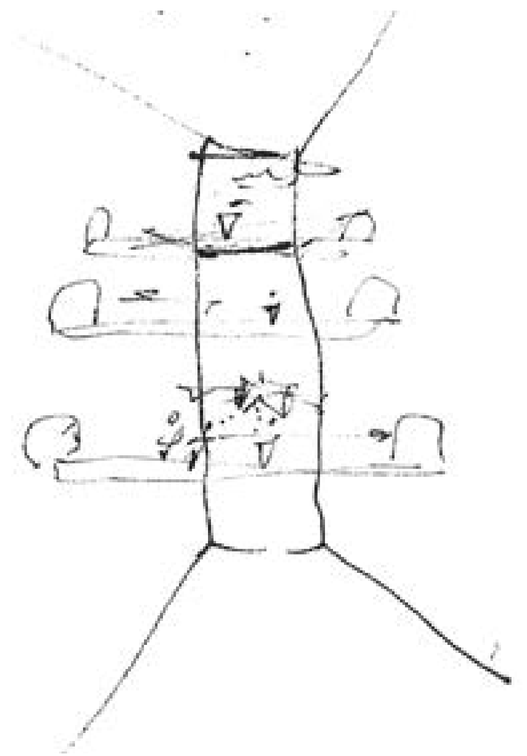
CONCEPT SKETCHES

This initial concept sketch is what would eventually lead the to design of the exhibition hall. The simple idea is that as one moves through the museum in one continuous path, the route wraps around on itself giving new perspective to the space as one moves through it.

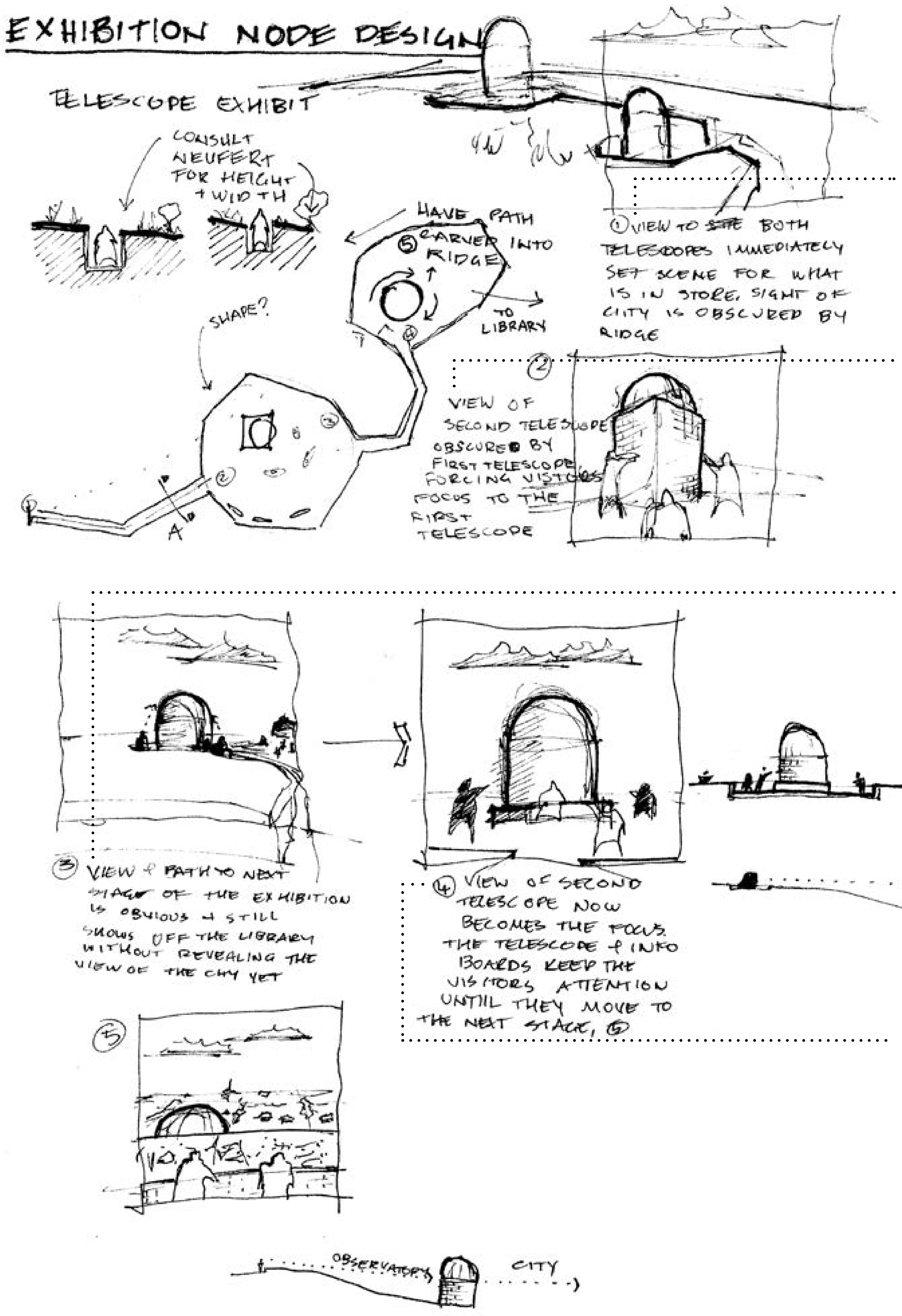


This idea was expanded upon, aided by the research done by Dr Allen covered in chapter 2. The idea that exhibition spaces could be linear paths, punctuated with nodes - resembling something of a constellation - would form the overall design intention of the exhibition space.





Later, this design goal led to the realisation that as one moved from node to node, the in between space could be the common space; as one moves through the museum, this common space continually changes - or rather, one's perception of the space does. This common space could also be opened up to the sky to allow visitors to see the stars during the night or specific sun-related events throughout the year.



1. "View to both telescopes immediately set scene for what is in store, sight of city is obscured by ridge"

2. "View of second telescope obscured by first telescope, forcing visitors focus to the first telescope"

3. "View + path to next stage of the exhibition is obvious + still shows off the library without revealing the view of the city yet"

4. "View of second telescope now becomes the focus, the telescope + info boards keep the visitors attention until they move to the next stage"

5. Eventually the view over observatory and the Observatory is revealed

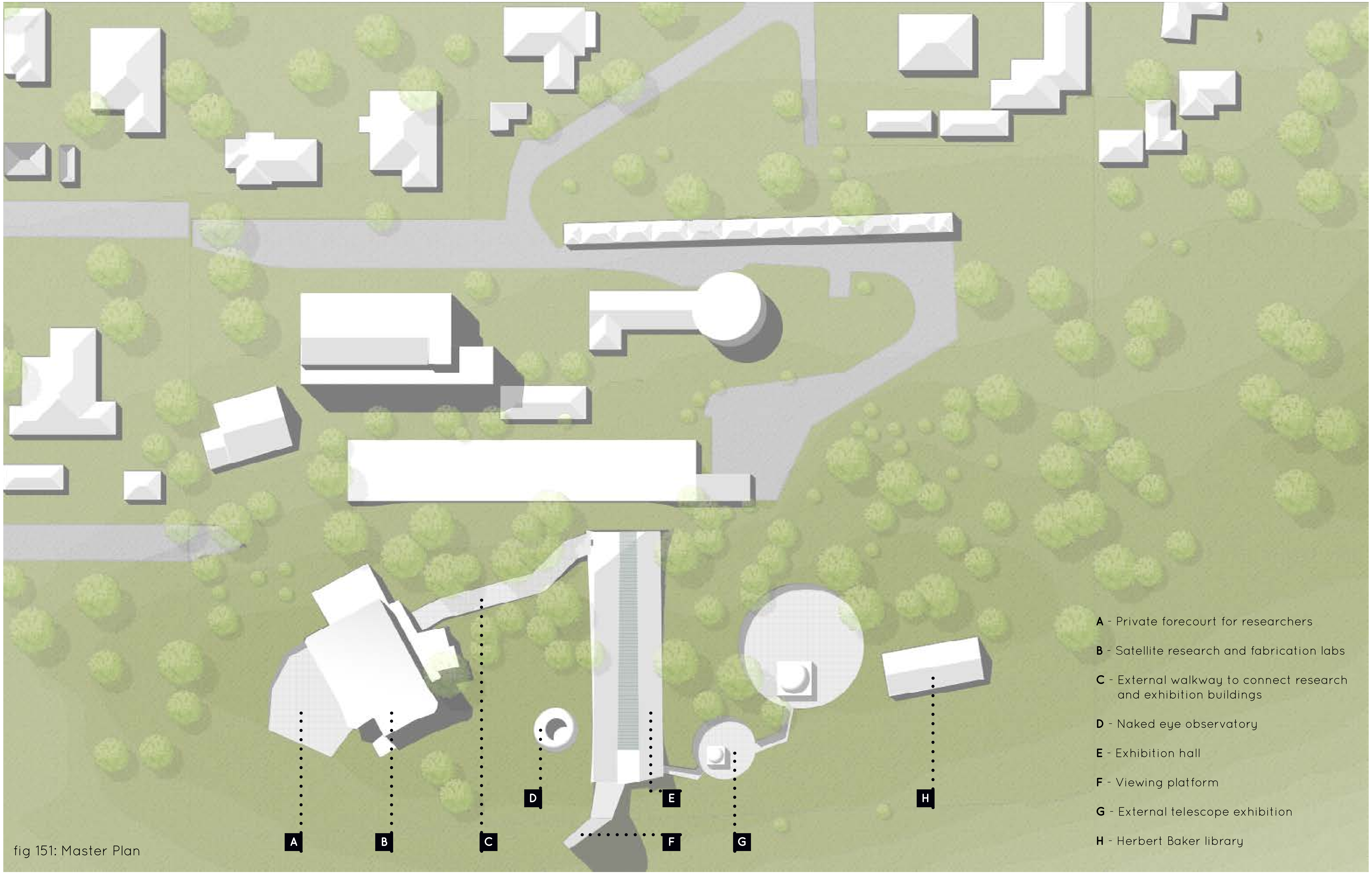


fig 151: Master Plan

fig 152: Exhibition hall render as seen from the entrance foyer

EXHIBITION HALL

The design of the exhibition hall focuses on allowing for a very dynamic exhibition floor which can easily accommodate any cycling, temporary exhibition pieces. The main hall is open plan compared to the rest of the building which relies on a linear movement through the spaces. The linear path through the different exhibitions starts near the entrance to the building and leads to smaller exhibitions, with the pathway criss-crossing through the main exhibition hall.

The path of the entire exhibit is seen as one enters the space and the journey through the building slowly reveals new perspectives for the elements of the exhibitions; as the technology on exhibition will typically be large enough to fill the voids in the exhibition hall, these new perspectives will need to be seen in order to fully realise the size and importance of the pieces.

The design of the exhibition hall is centered around moving through a string of small spaces connected by a single, long path that winds through the entire building, unraveling the narrative of the satellites as one proceeds and ending in the research centre.

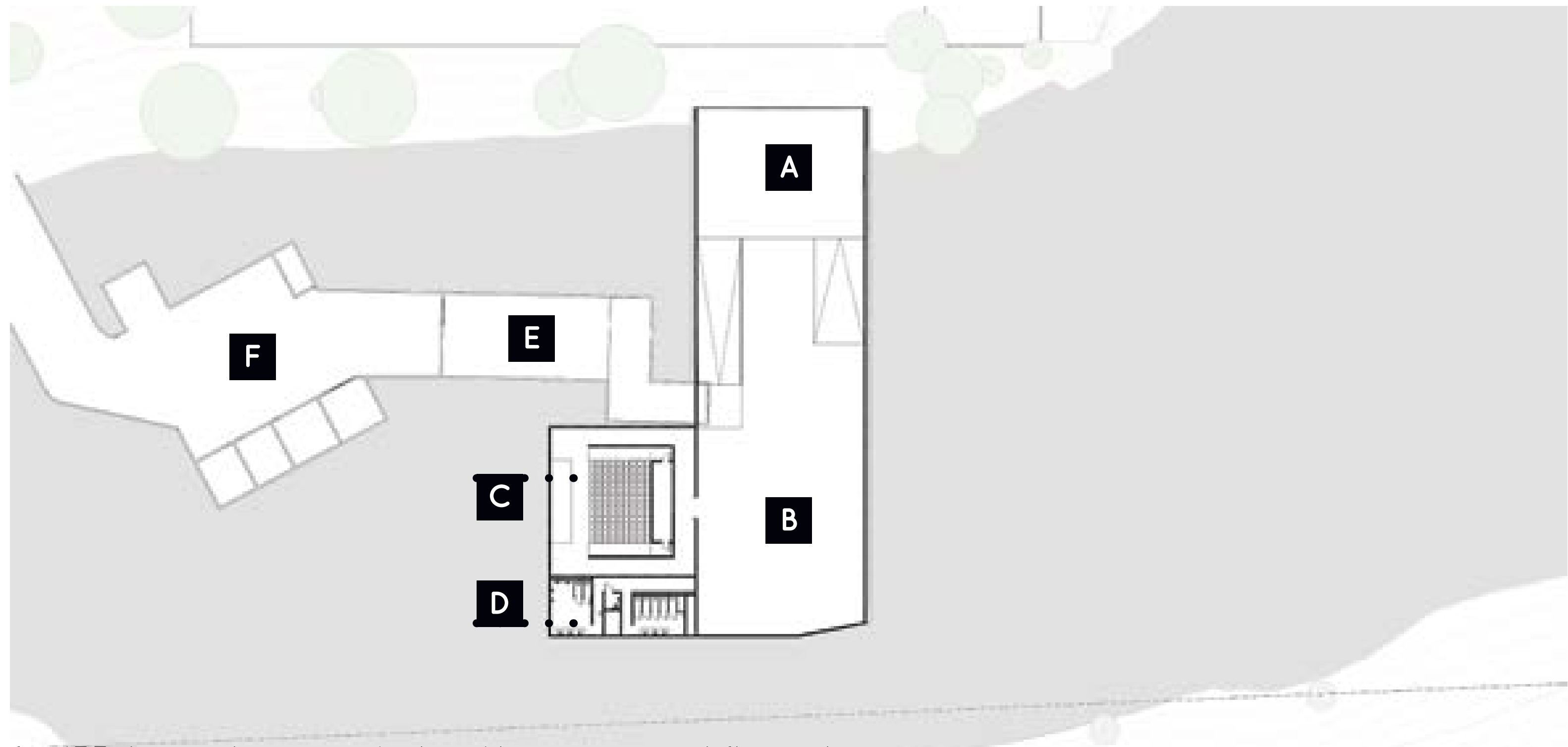


fig 153: Lower basement plan / Lower ground floor plan

Lower Ground Floor
A - Entrance foyer
B - Exhibition hall
C - Theatre/cinema/lecture hall
D - Ablutions
E - Workshop
F - Private parking

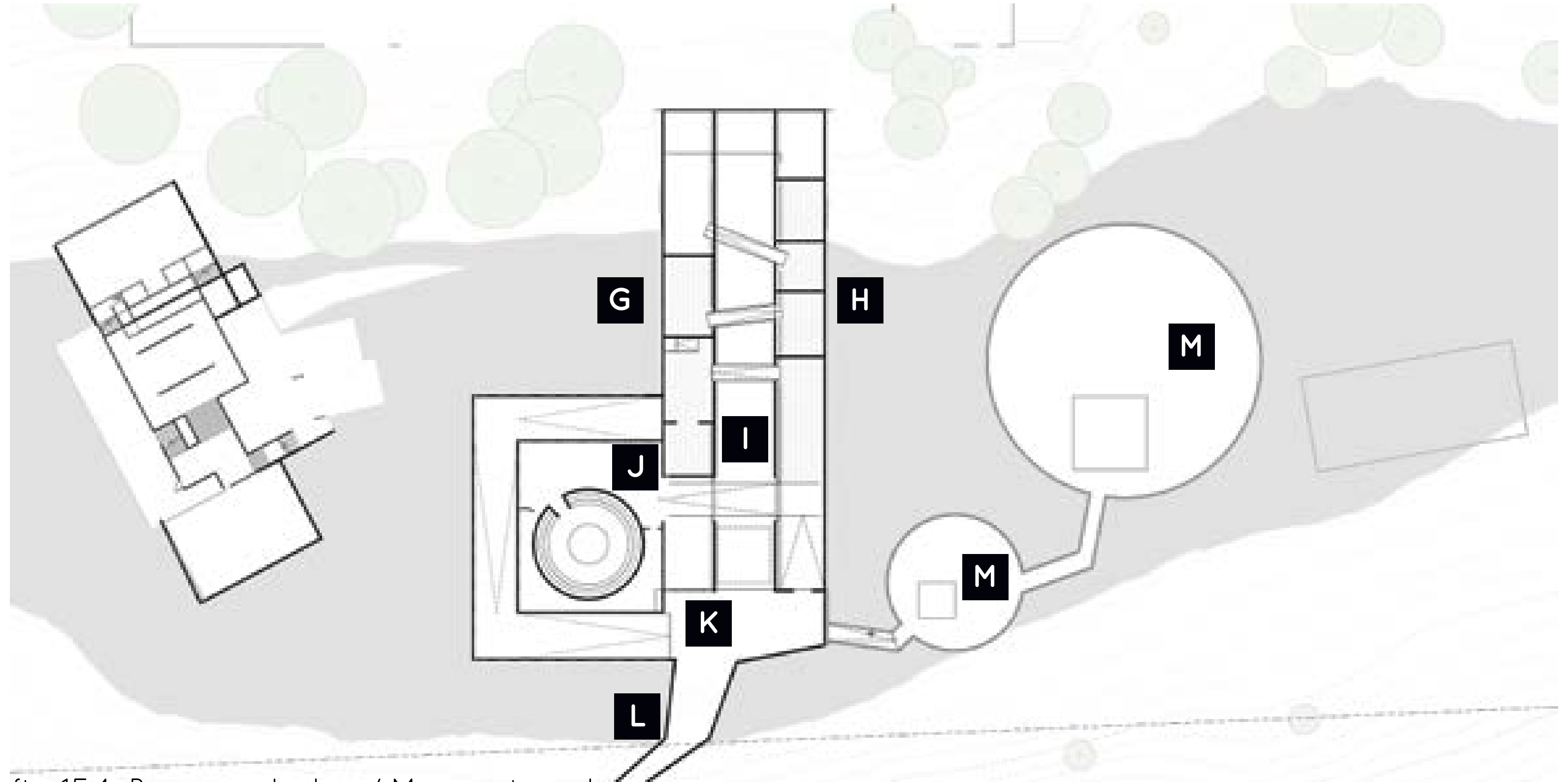


fig 154: Basement plan / Mezzanine plan

Mezzanine
G - West exhibition wing
H - East exhibition wing
I - Exhibition voids
J - Naked eye observatory
K - History of Observatory exhibition
L - Viewing platform
M - External telescope exhibitions

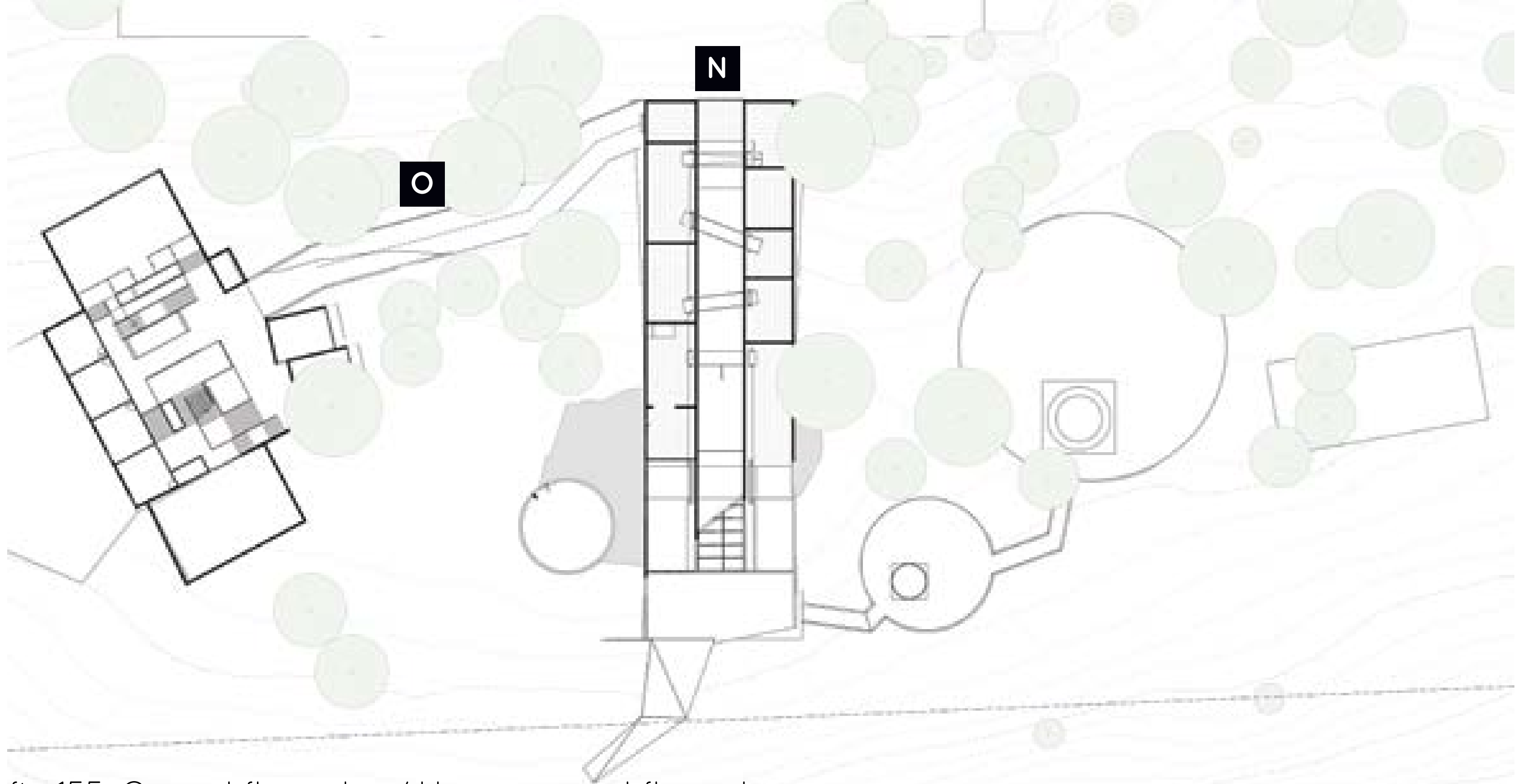


fig 155: Ground floor plan / Upper ground floor plan

Upper Ground Floor
N - Viewing platform
O - Walkway to research labs

Exhibition hall section
A - Entrance foyer
B - Exhibition hall
C - Theatre/cinema/lecture hall
D - Ablutions
I - Exhibition voids
J - Naked eye observatory
K - History of Observatory exhibition
N - Viewing platform

fig 156: Longitudinal section of exhibition hall

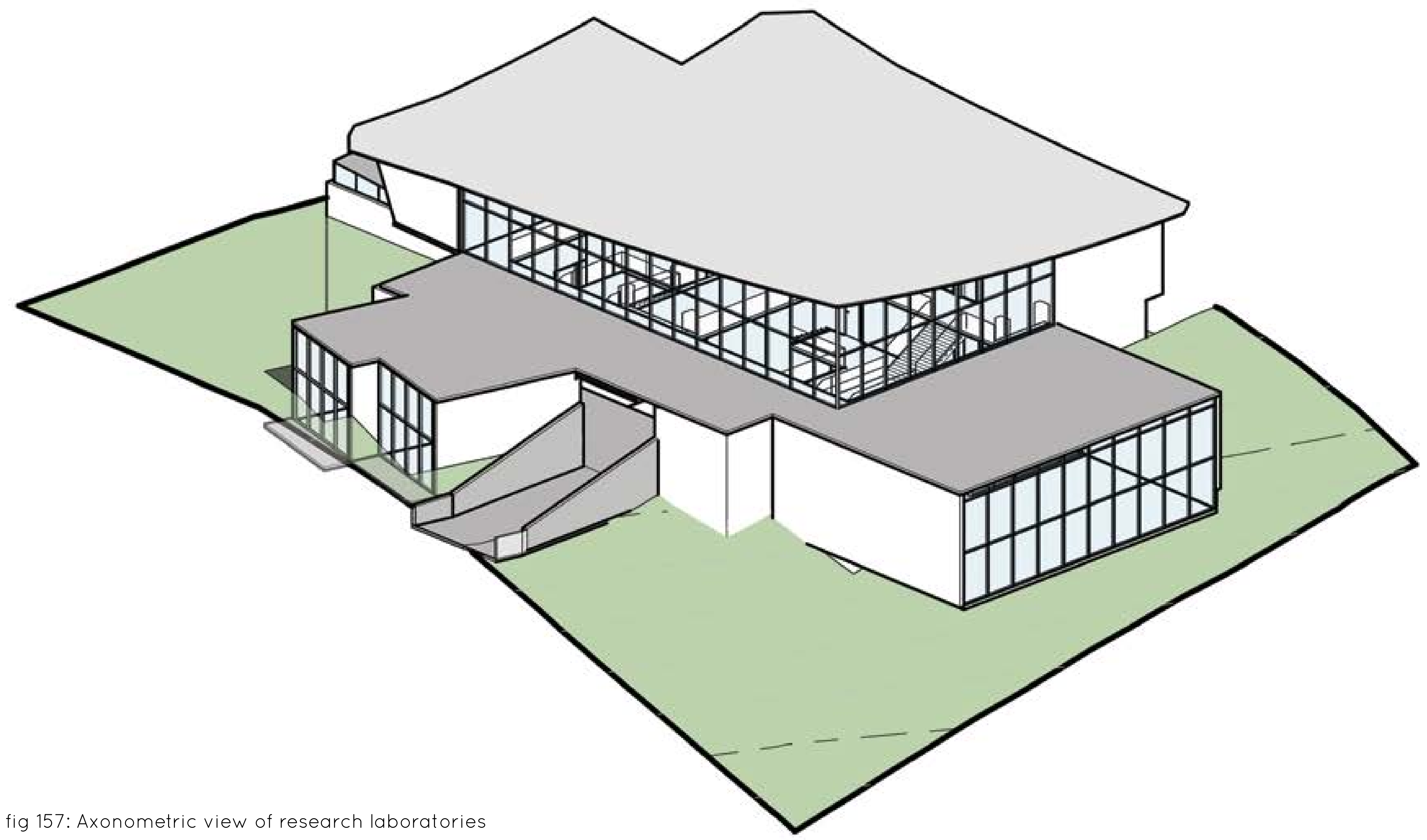


fig 157: Axonometric view of research laboratories

RESEARCH CENTRE

The research and fabrication laboratories are the heart of the Observatory scheme. The research centre is the tool with which South Africa is going to carve out a place in the world of space exploration. The labs are both the last node in the string of exhibitions that run through the site and the ultimate goal of the entire scheme - a space that researchers can use to collaborate and create satellites.

The design goal for the research labs was to create a space that both researchers and visitors would feel comfortable in, without the presence of either disturbing the other. This was the deciding factor in the design of the circulation for the space.

Entering into the ground floor level, visitors are greeted by a triple volume. Looking down into the basement, visitors can watch public lectures in the lecture gallery. These would be conducted by visiting researchers sharing their own research with on-site researchers, other researchers or visitors from institutions. As part of the mandate of creating openness between the public and academia, in terms of the research being conducted on site, this lecture gallery is crucial in creating a truthful image about what research toward space technology is.

The satellite testing and fabrication laboratories are the heart of the program, both for the research centre and for the entire scheme. The research laboratories are bookended with floor to ceiling glass to symbolise the transparency that the scheme has; this literal openness also allows the public to see the work that is being done in the scheme, further yet generating interest and excitement in the research.

The research centre is also equipped with computer labs for visiting classes to use and possibly engage with research being conducted on site.

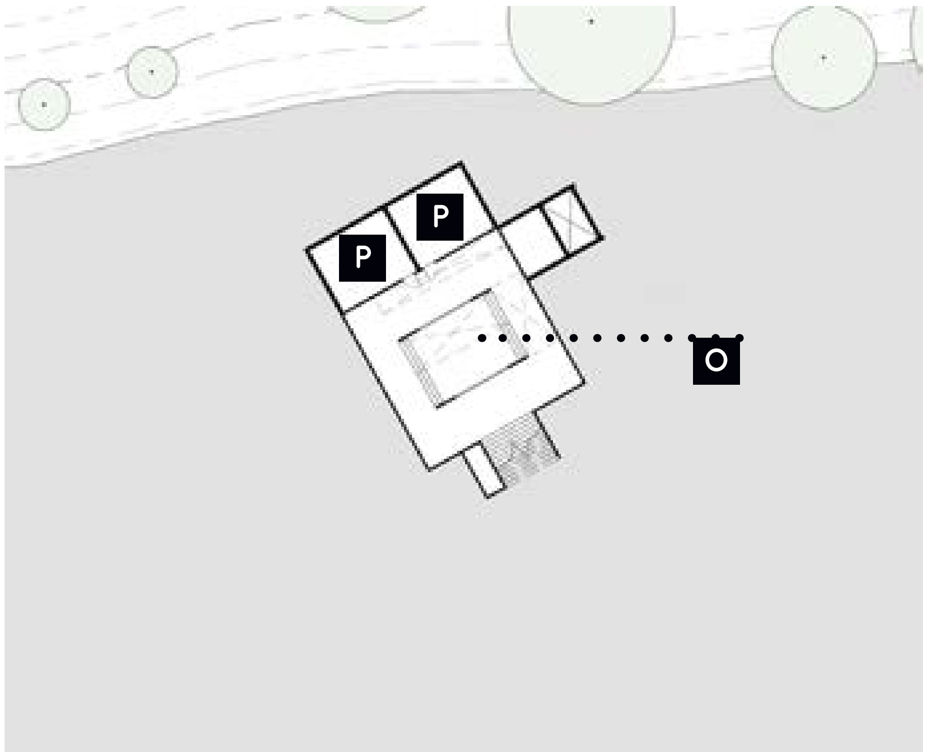


fig 158: Basement plan

Lower Ground Floor
P - Visiting researcher's office
O - Lecture gallery

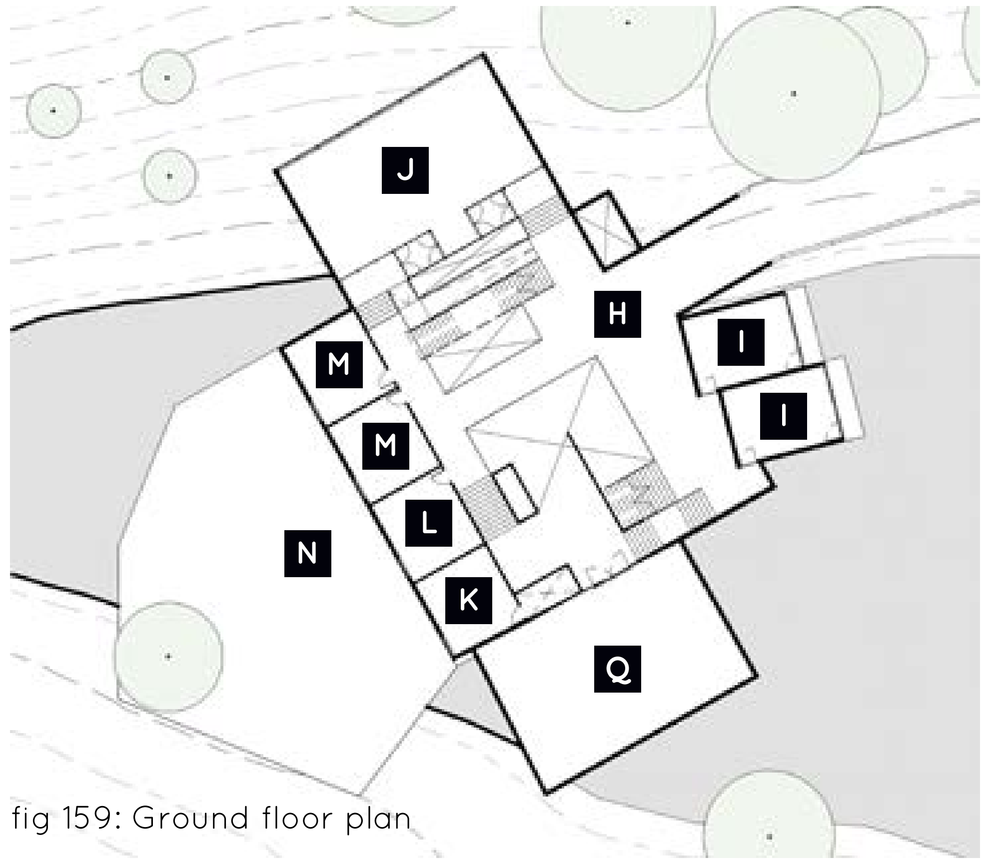


fig 159: Ground floor plan

Lower Ground Floor
H - Waiting area/reception
I - Meeting room
J - Satellite fabrication labs
K - Security/IT
L - Assistant researcher
M - Senior researchers
N - Researcher's forecourt
Q - Computer labs

fig 160: First floor plan

Lower Ground Floor
A - CFO's office
B - Reception
C - Staff room
D - Exhibition staff
E - Administration staff
F - Marketing staff
G - Viewing balcony

fig 161: View from reception in research labs

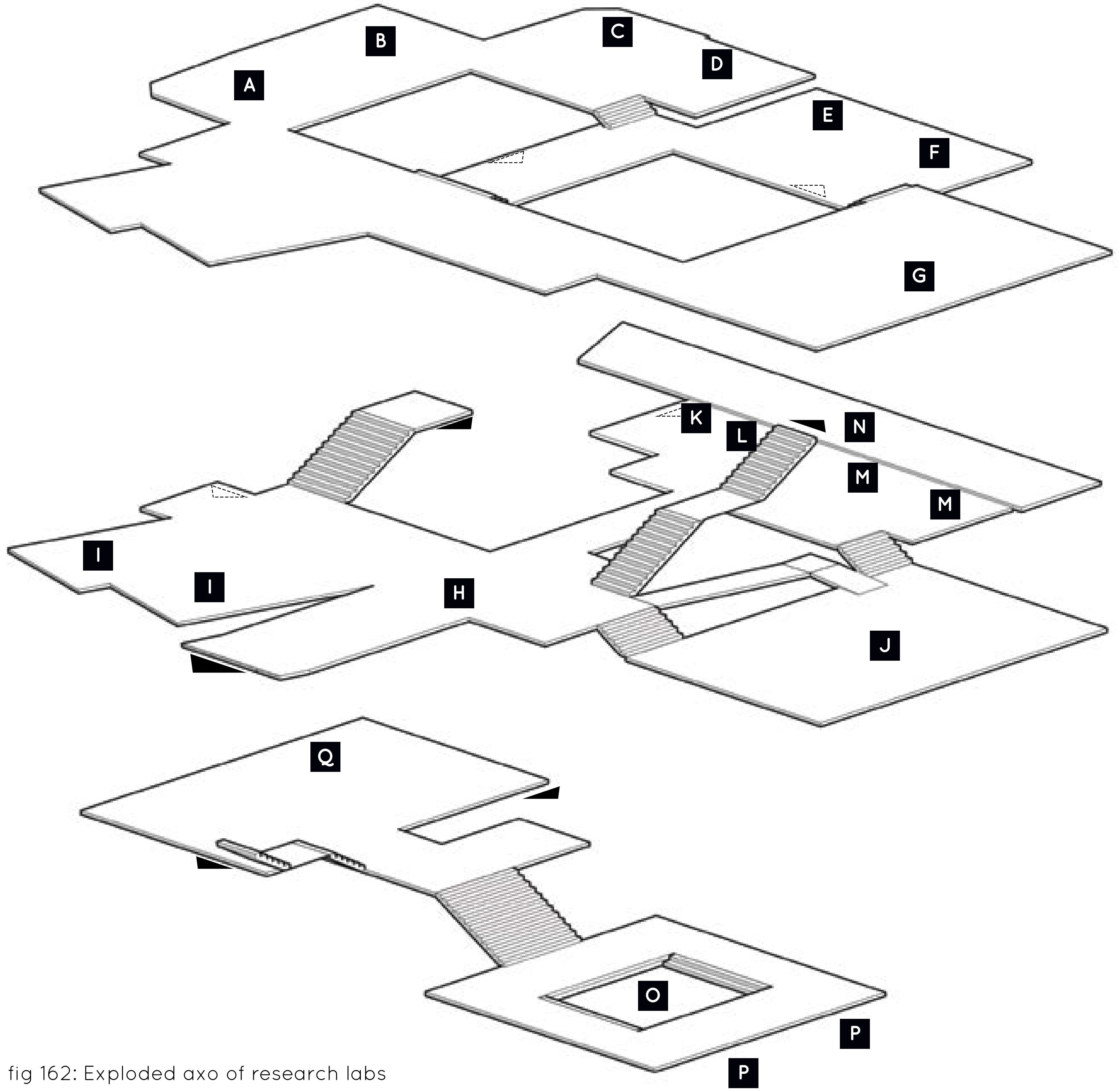


fig 162: Exploded axo of research labs

First Floor
A - CFO's office
B - Reception
C - Staff room
D - Exhibition staff
E - Administration staff
F - Marketing staff
G - Viewing balcony

Ground Floor
H - Waiting area/reception
I - Meeting room
J - Satellite fabrication labs
K - Security/IT
L - Assistant researcher
M - Senior researcher
N - Researcher's forecourt

Basement
O - Lecture gallery
P - Visiting researcher's office
Q - Computer labs

Research Labs Section
E - Administration staff
G - Viewing balcony
H - Waiting area/reception
M - Senior researcher
N - Researcher's forecourt
O - Lecture gallery
P - Visiting researcher's office

The researcher's forecourt is intended to provide a space for researchers to be able to converse and collaborate on work in a more relaxed setting, also providing the researchers with a more comfortable work environment.

Researcher's spaces face onto this courtyard in order to generate a more social feeling in the building. These researcher's spaces are also grouped together.

The lecture gallery sit in the centre of the building. The circulation throughout the building turns inwards to share in the discussions taking place in this space.

Entering the building through the public foyer, one is immediately greeted by the collaborative spirit of the building, particularly in the triple volume space.

fig 163: Section through research centre

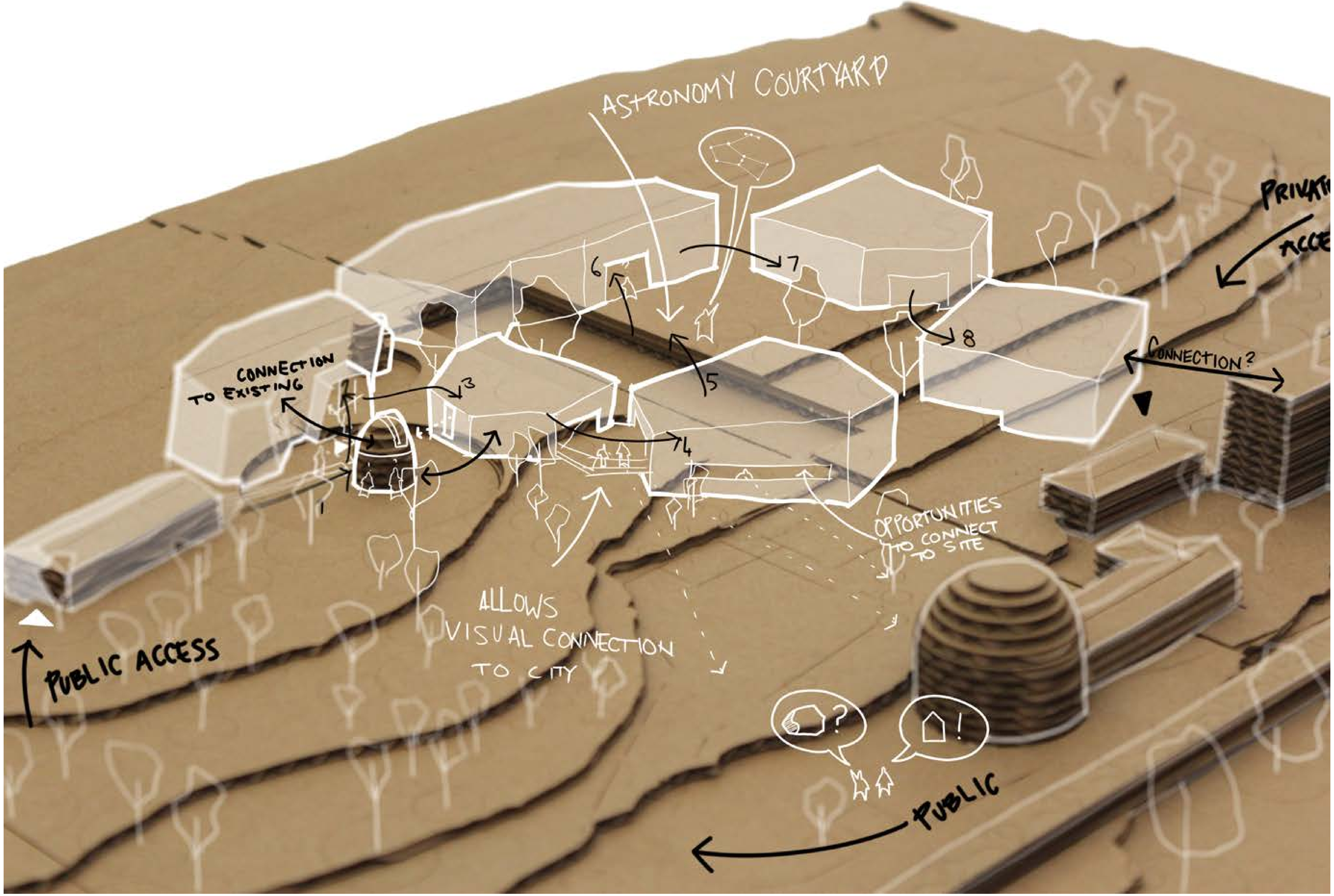
2 | revision two

FRAGMENTING THE BUILDING ACROSS THE SITE

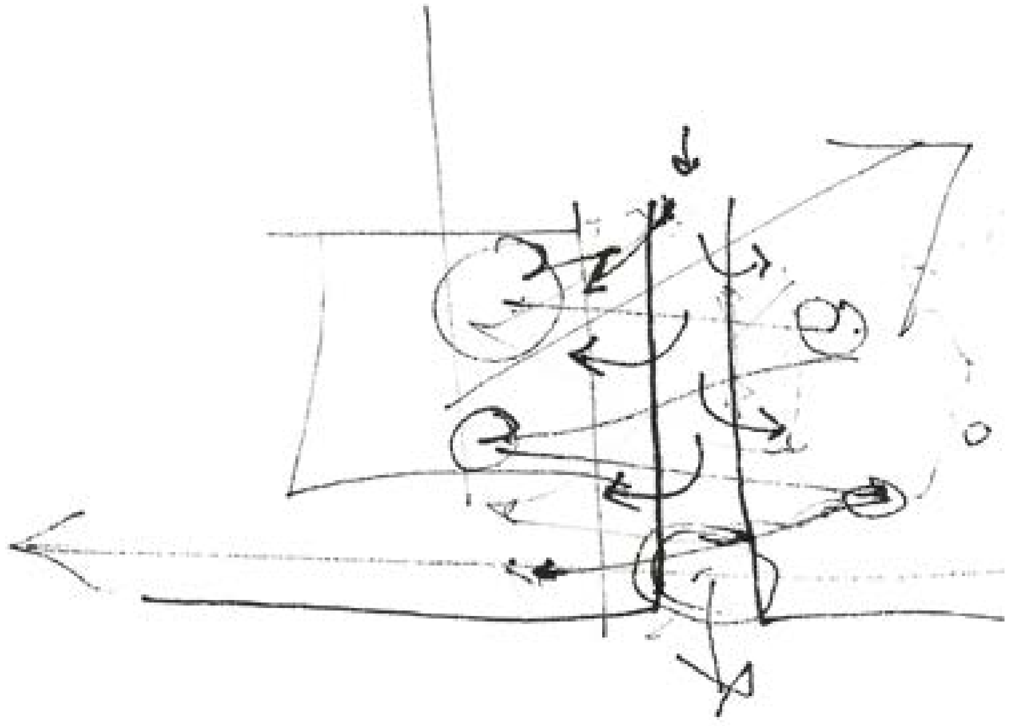
Although the form of the building changed drastically from the previous design iteration to this one, the program and design intent for the building have not changed - they have just became more central to the typology of the building.

The primary design alteration is the fragmentation of the exhibition building from the previous design. The scheme was always intended to be used as a vehicle to encourage an interest in space, and specifically use the elemental connection between the ground and the sky to facilitate that connection. Unfortunately, the previous design failed to create this strong connection between the scheme, the ground and the sky. The solution is to fragment the exhibition spaces across the site, the built form becoming traditional exhibition spaces focused on satellite technology and its history, the negative space becoming a tool for astronomy and exhibition space in its own right. The envelope of the buildings themselves should also become tools for astronomy, in the style of ancient astronomical observatories. There are several events in the year that could or should be focused on: the current zodiac sign, the summer and winter equinoxes, et cetera. This will further help develop more refined forms for the buildings.

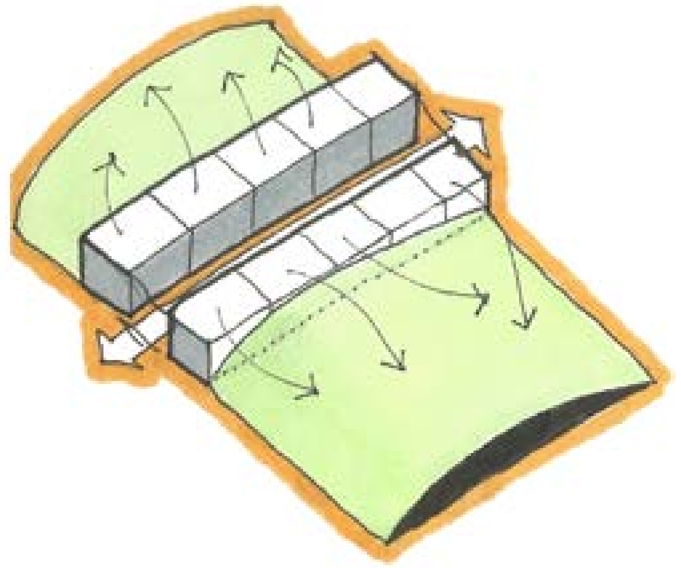
The research laboratory has largely stayed the same, however it has moved closer to the exhibition spaces to create a stronger connection between the two, considering that the research labs are essentially the last node in the exhibition. The exhibition laboratory will also change further in response to the immediate context, the larger context of space and the scheme itself. Currently these changes haven't been explored or developed; the changes will be to the building itself in terms of layout and envelope, however the program will remain the same. The research labs will also tie more closely into the existing buildings on site - the classrooms and the SAASTA learning centre - and the current configuration will help to facilitate that connection.



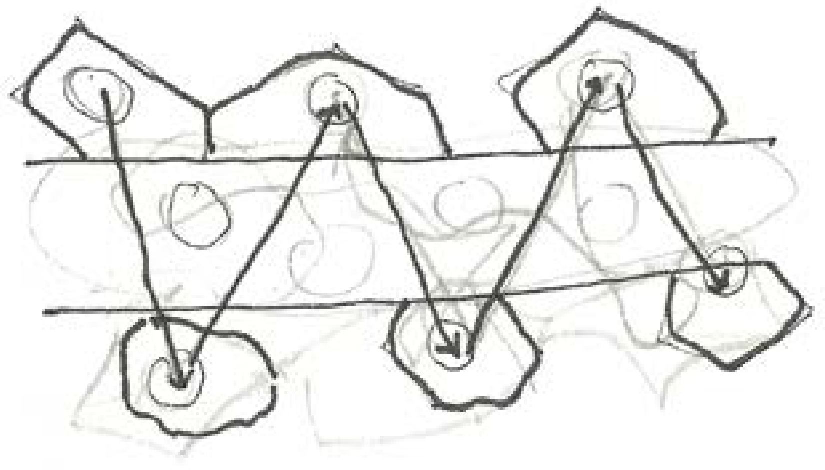
CONCEPT SKETCHES AND DEVELOPMENT



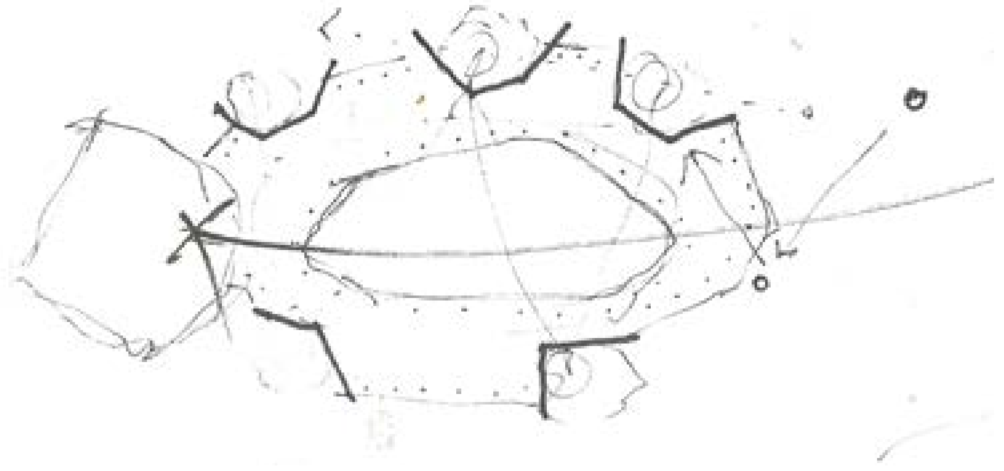
◄ The outcome of the previous design was an exhibition hall centred around a common space that served as both exhibition space and as a tool for experiencing astronomy. However, the built form of this exhibition space was not in line with the initial idea for the scheme - a connection between the site (i.e., the openness to the sky) and the architecture (i.e., the exhibition spaces)



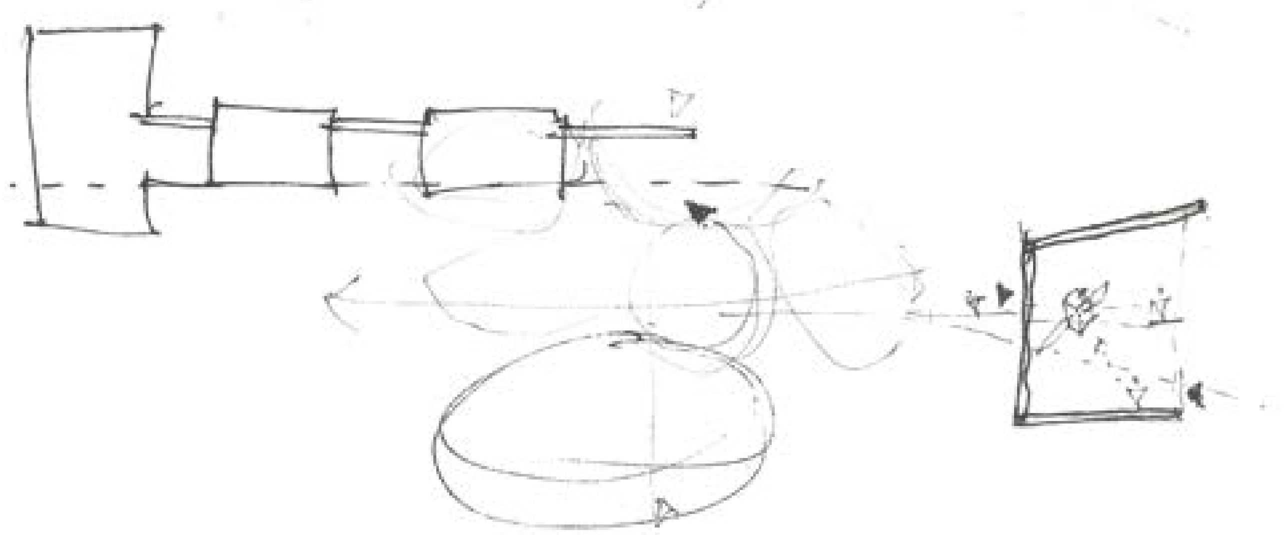
◄ This realisation meant that the layout of the scheme needed to change. In order to create a better connection between the exhibition spaces and the site, the mass of building needed to be fragmented. This would turn the covered space at the bottom of the exhibition hall into common space throughout the site which would improve the connection between this common space and the sky.



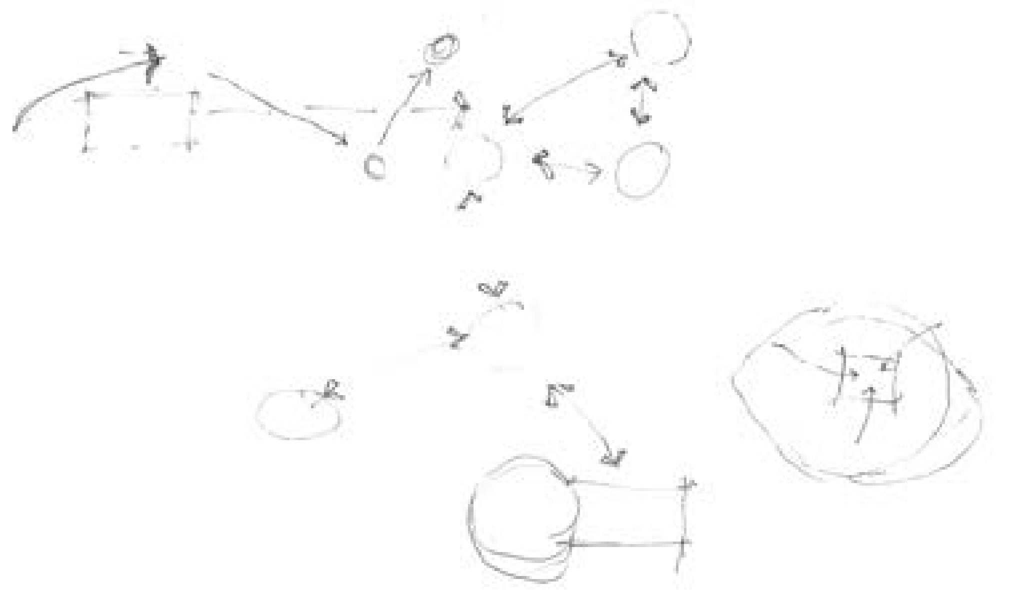
◄ Initially this fragmentation was minor, essentially taking the existing form and spreading the individual rooms but keeping the layout the same. This wouldn't necessarily change the path through the spaces, but would change the arrangement of the spaces.



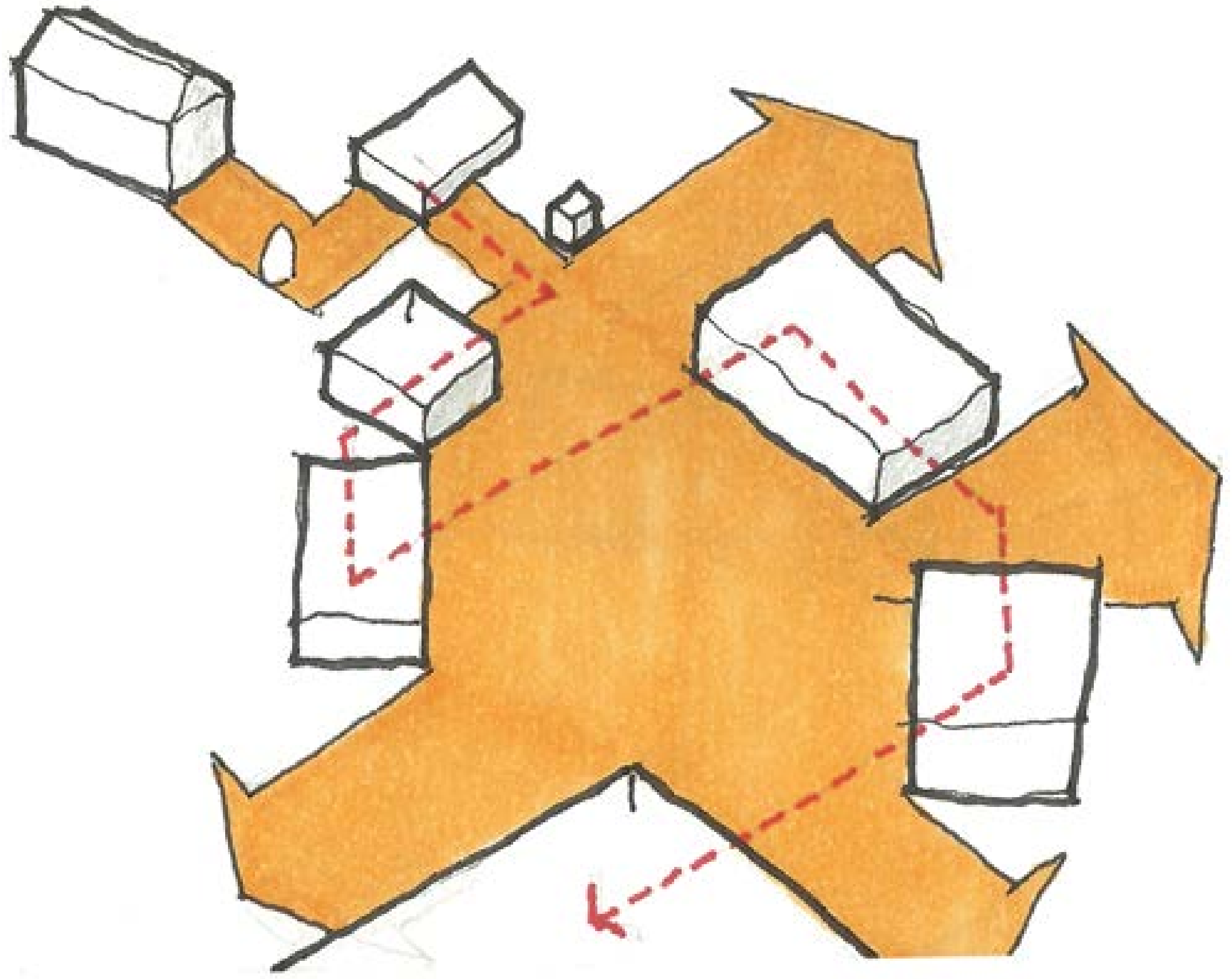
◄ More in line with the open-ended exhibition configuration posited by Dr Allen in chapter 2, the next stage of concept development saw the individual spaces begin to move apart, creating a more loosely defined path through the scheme and a more dynamic common space. However, the intended narrative woven through the scheme would be difficult to achieve with such a non-linear configuration



◄ Part of this stage of the concept development was the approach of designing the scheme to fit more carefully into the landscape. As opposed to the previous design revision which simply inserted its mass into the site and the landscape, the new design would need to find a method for sitting on the ridge: a mixture between sitting on top of and within the landscape.

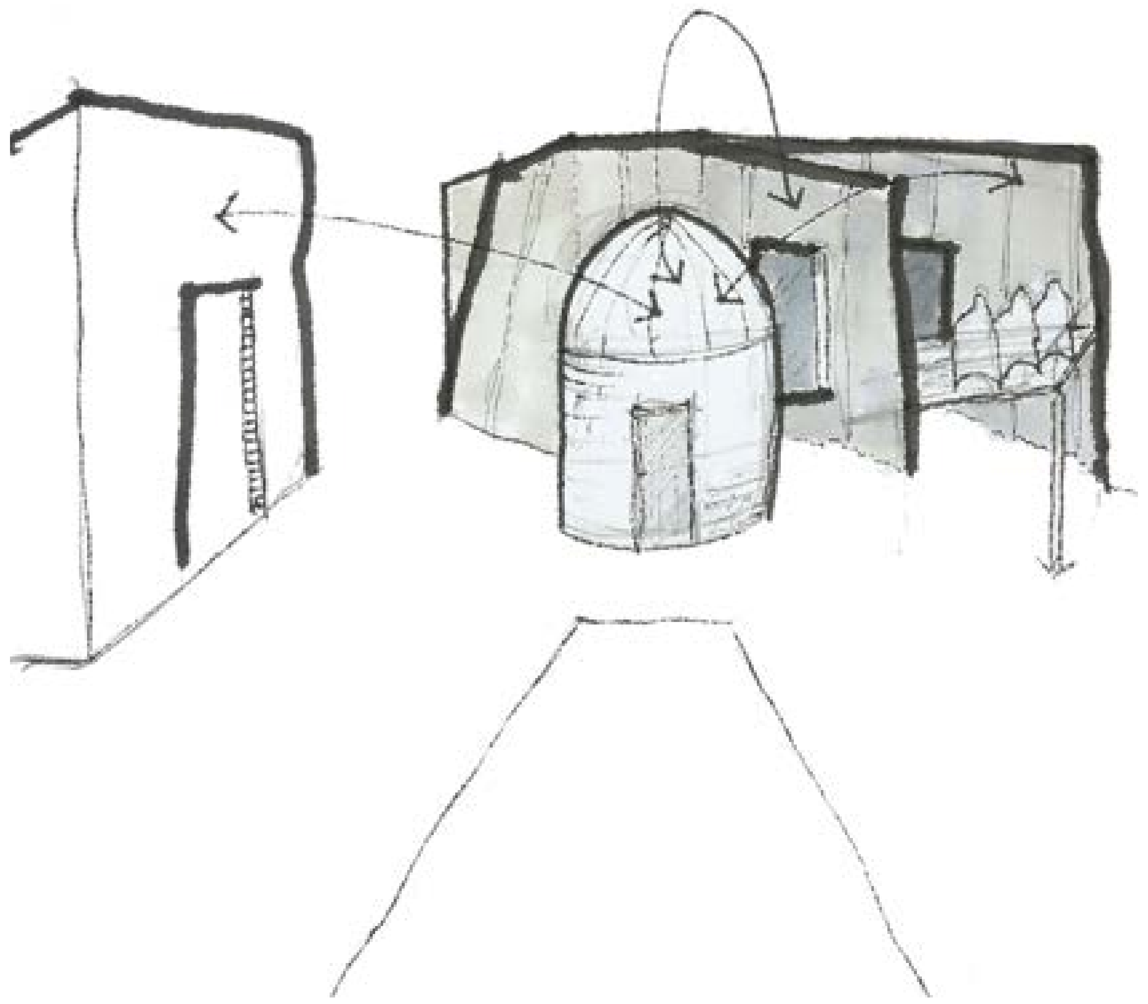


◄ A new configuration for the path through the site was conceived of and included a further separation of the individual exhibition halls and research labs. The in between spaces would form part of the exhibition and there would be an intended route through the scheme, but individuals would choose which direction to go. This is informed by Dr Allen's musings on whether or not a combination linear-open configuration for a museum would work better. This open scheme would also create a springboard for the architecture to become a tool for astronomy, in the spirit of ancient observatories studied in the theory chapter.



◄ This concept sketch essentially became the template for further design exploration. The arrangement of the spaces on the site were informed, largely, by the intended route through the site, which will be discussed further later in the chapter. The in between space of the scheme becomes an ethereal, but very important, aspect of the scheme. This space is what transforms the scheme from being a museum and visitor's centre into something that more closely resembles the celebration of mankind's history with astronomy.

CONCEPT SKETCHES AND DEVELOPMENT



◄ Once a general layout for the scheme had been decided, the specifics of the architecture were to be explored. At this point in the development of the scheme, this meant two explorations: material exploration and form exploration. Material-wise, the existing facilities on the site set a precedent for what to use. The buildings largely consist of brickwork; large sandstone rocks in the observatory, monument and Herbert Baker library; and the telescopes themselves have metal cladding in the domes. The metal cladding from the dome is what, at this stage, has informed the material used in the site. However, this material palette will be expanded upon in later revisions of the design.

The forms of the building were informed primarily by the movement through site and the connection of the spaces to the surrounding context, including historic buildings on site and the surrounding neighbourhoods. However, further development of these forms is required in order for them to adequately respond to space and astronomical events. This will be further developed in the final design revision.

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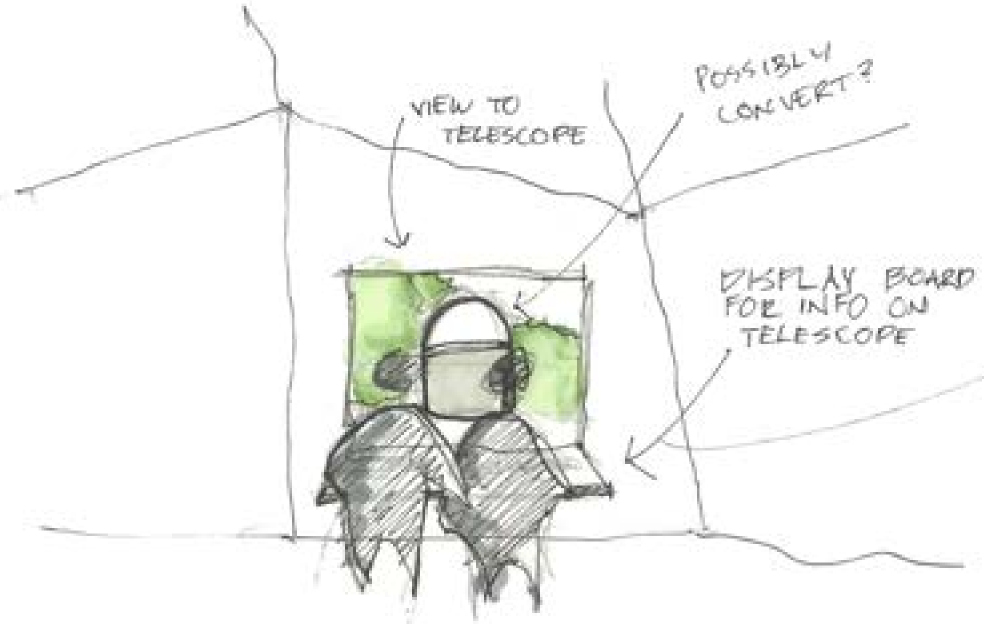
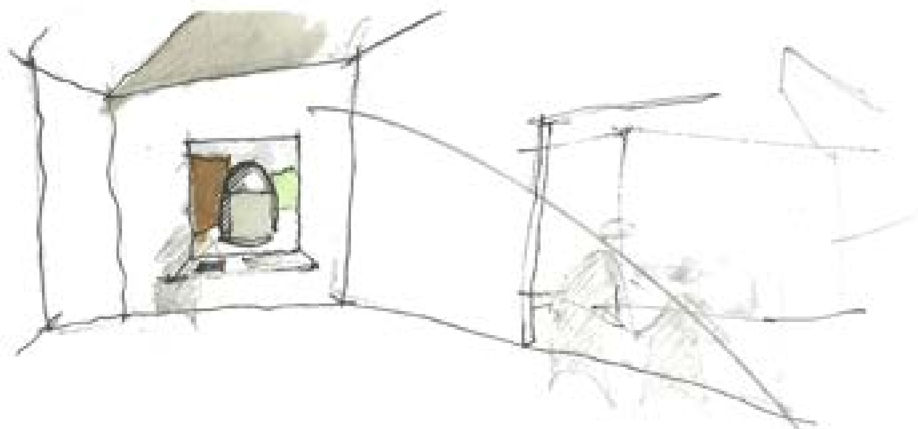
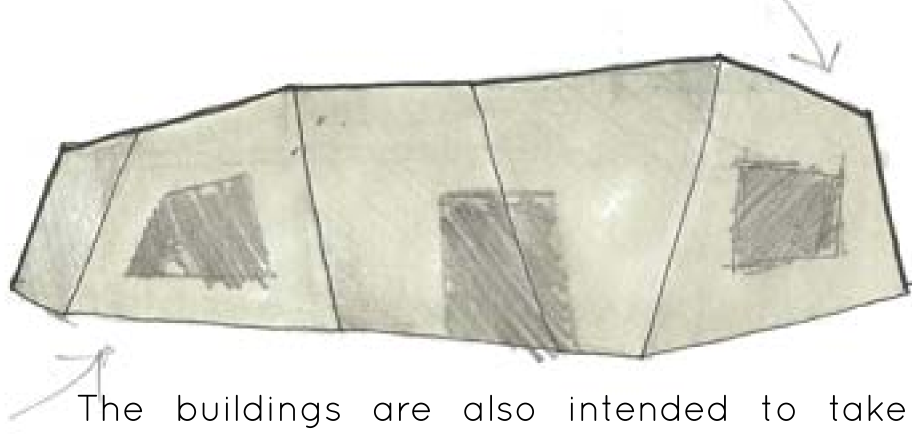
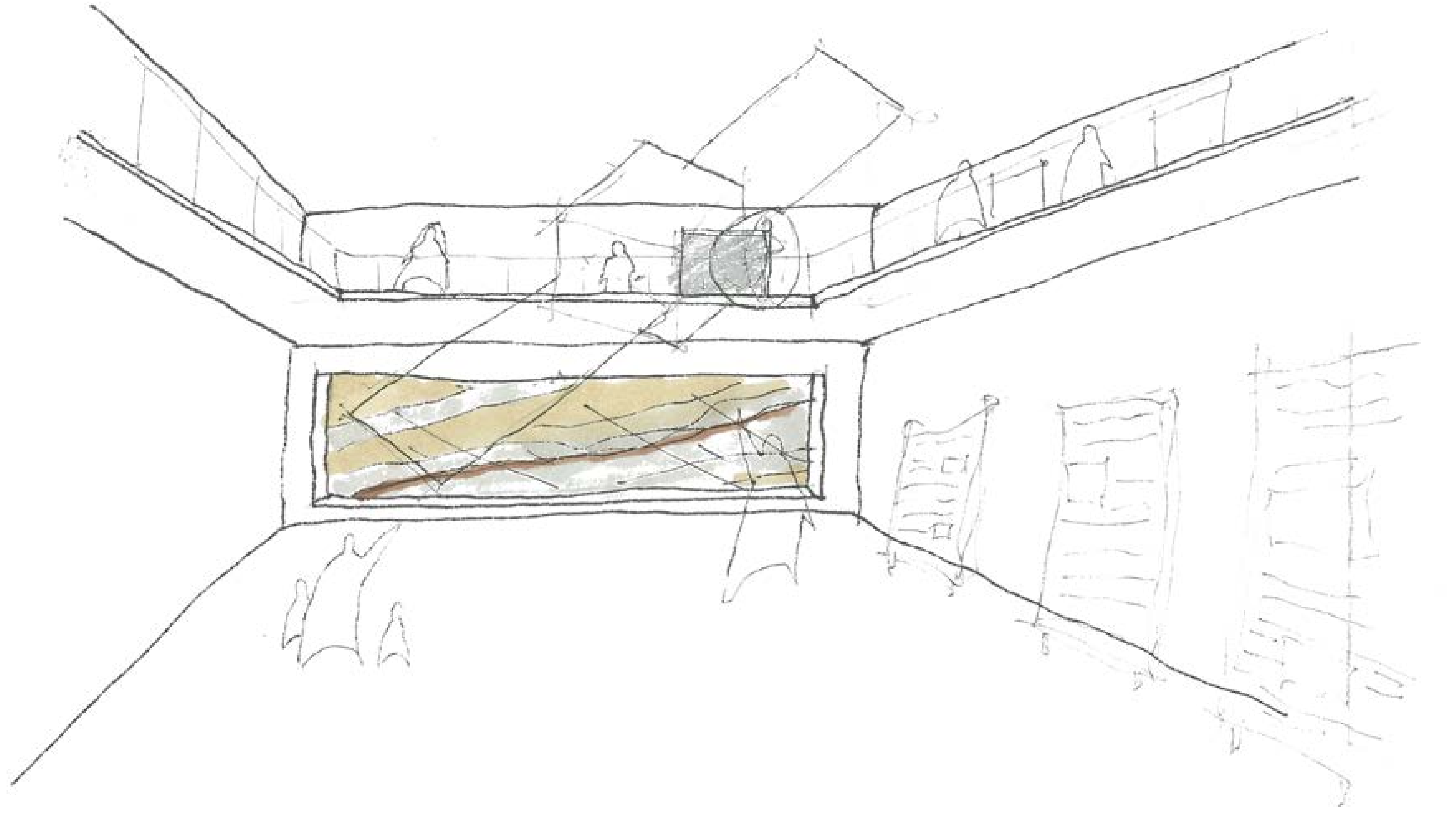




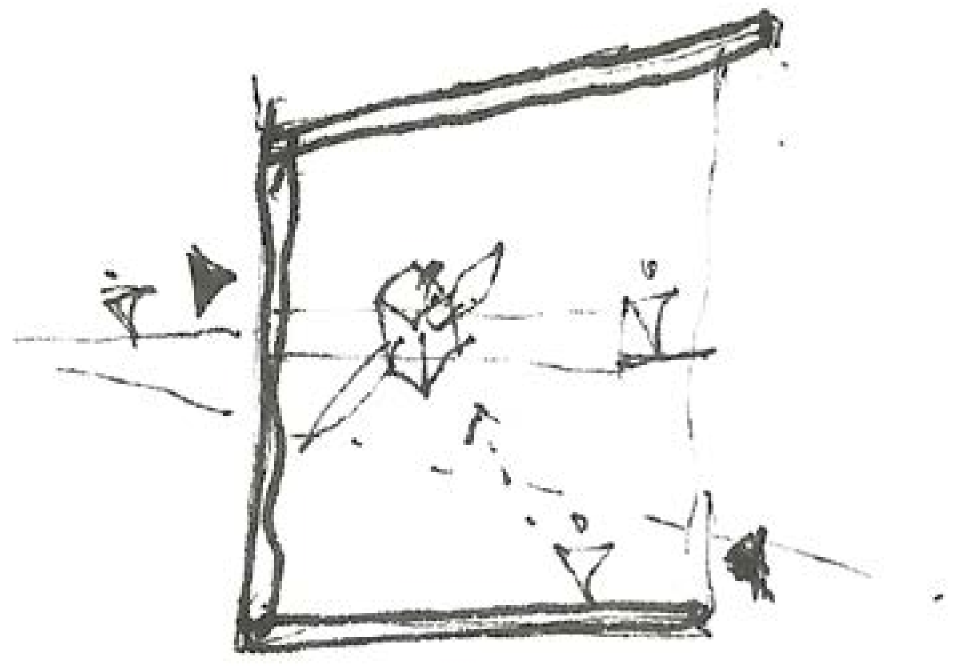


The buildings are also intended to take on a "geological" appearance, emulating the sandstone rocks protruding from the site. This could be further enhanced by an appropriate material choice and design which would take on properties similar to those of the rocks on site - for instance weathering and texture.

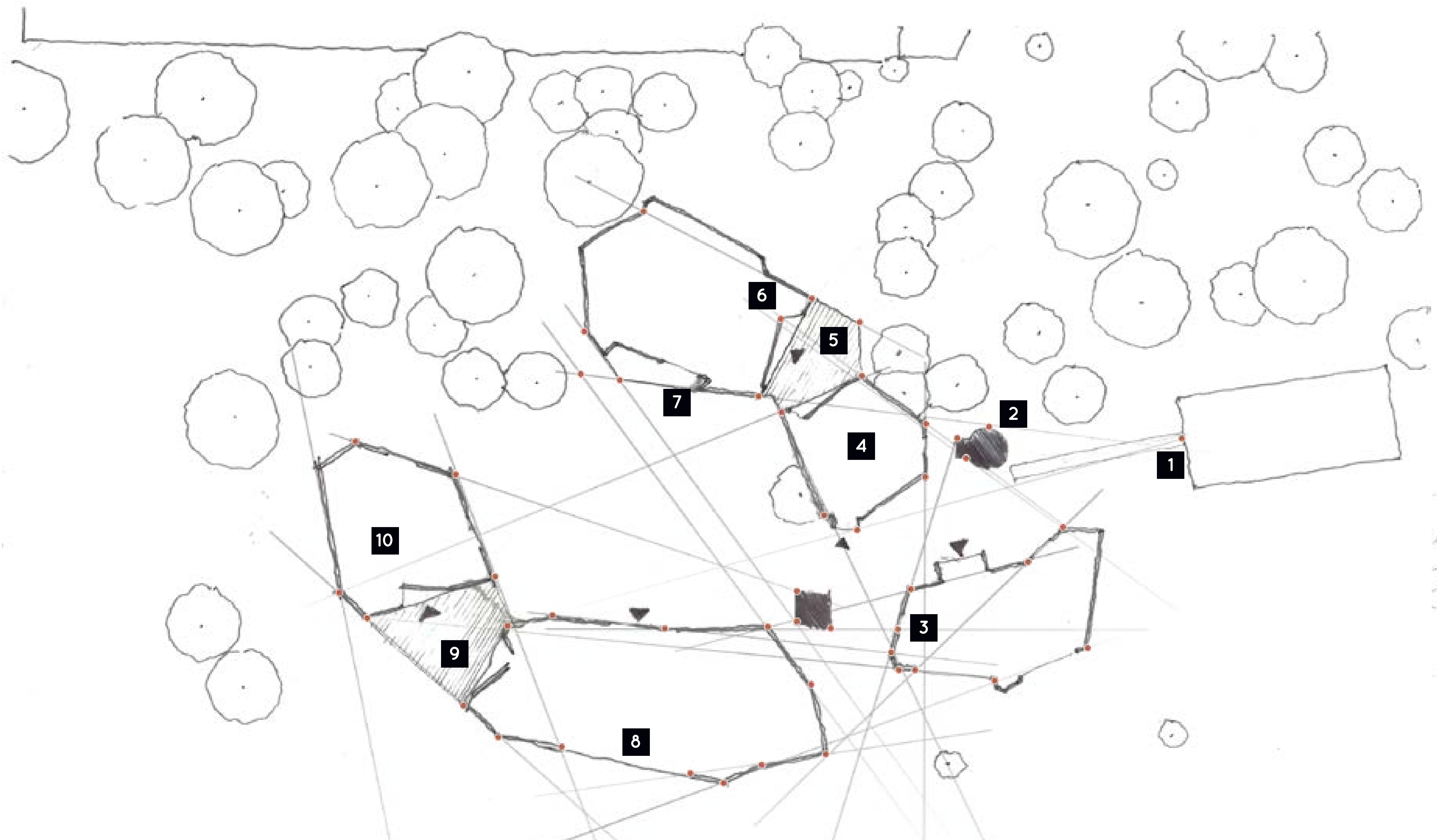


▲

Partially embedding the buildings in the site, as discussed on the previous page would provide an opportunity to celebrate the relationship between the earth and space. This relationship is evident in sites like Stonehenge and cave paintings of constellations. This hasn't been explored further but could provide an interesting addition to the site, especially because it aims to so closely link the Earth and space. Furthermore, the landscape is closely connected to the buildings on site: the observatory was chosen to be placed here because of the sites geological history, and the buildings on the site appear to use rocks that may have been taken from the site - although this can not be substantiated.



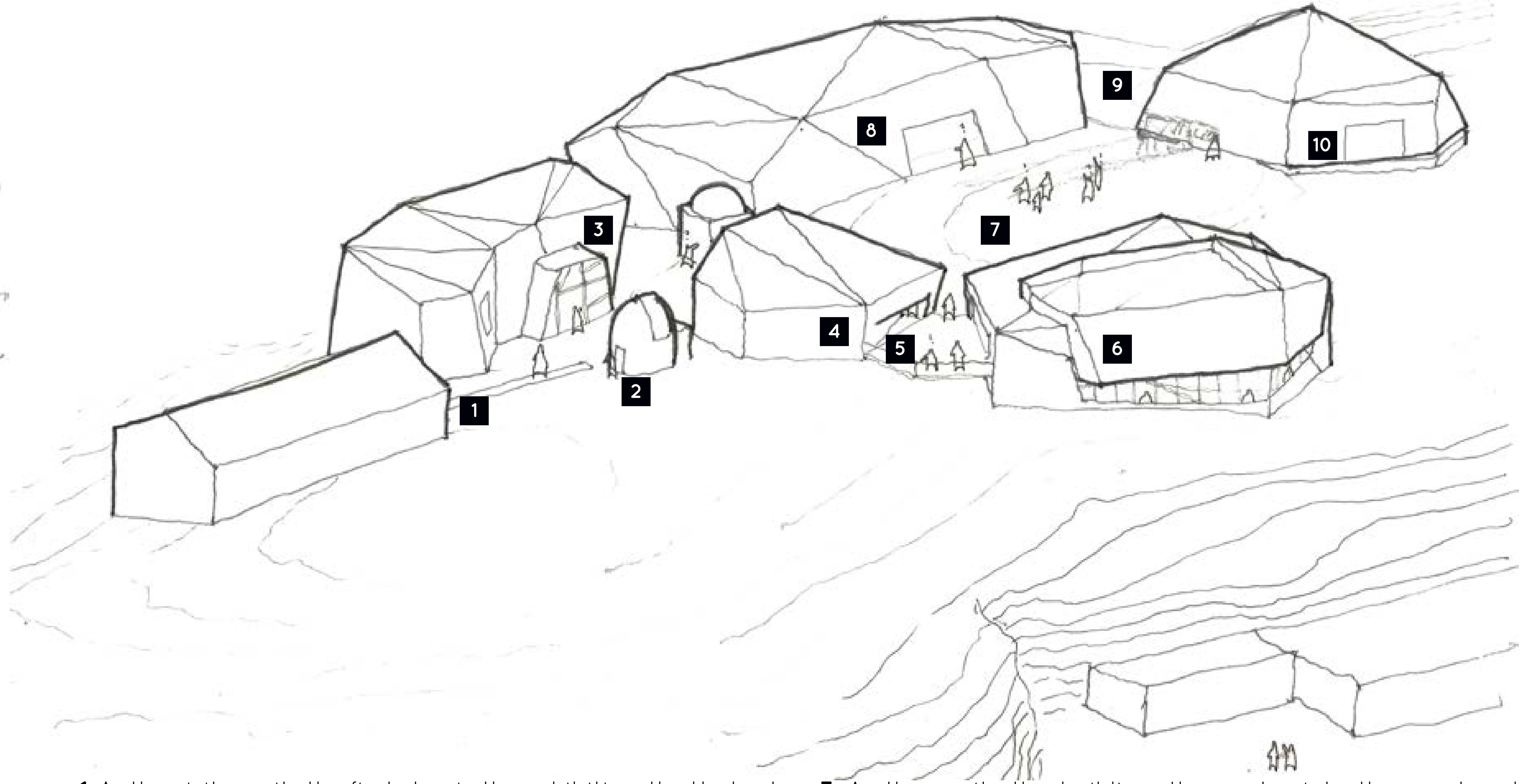
FORM FINDING



As stated previously, the forms of the buildings were decided primarily by the movement through the site. This initially was done by planning out the movement of people through the space, where their eyes would follow, where they would naturally walk, et cetera; this is explained on the facing page. This resulted in a simple plan that was then refined based on the possible spatial connections between the different forms. The refinement was done by looking for points that could be connected or emphasised (the orange dots on the plan) and then aligning them further, or modifying the geometry to conform to those alignments.

This then furthers one's experience as one navigates the scheme: as one moves through the site, different aspects of the building are revealed or hidden, turning the experience of the site into an adventure, of sorts. For instance, as one turns a corner the geometries of the buildings align, creating a spatial connection and therefore leading visitors on naturally; or ensuring that certain aspects of the site are hidden by the corner of a building until the final moment that someone rounds a corner. Moreover, this spatial connection ensures that as one moves through the scheme, the forms feel more homogeneous, rather than randomly fabricated. This exploration of form also ties closely into the design informants explored in the design charette, specifically the constellation abstraction and shadow study. As explored in the theory chapter, humankind's relationship with the constellations has been finding connections between seemingly unrelated elements, and the forms of the scheme were an extrapolation of this idea. This, however, may not be appropriate as a progenitor of the design form, as form finding should be further informed by other aspects. This process could be part of the form finding process, however should be considered secondary to other informants, something that will be explored further in the next revision of the design.

INTENDED MOVEMENT THROUGH SITE



1. As the visitor exits the first stop in the exhibition, the Herbert Baker library converted into a information centre, the first site is the telescope ahead. The visitor can just barely see the entrance to the first building, the History of the Area exhibit; however, it is possible to see between the buildings on the site and to Johannesburg skyline in the distance.

2. As the visitor reaches the first telescope and reads the information board, the most obvious next destination is the entrance to the first building on the left.

3. Once inside the building, there are windows that face both the first and second telescope with information boards. From the information board for the second telescope, the entrance to the second building is the obvious next step.

4. The next building, the How Satellites Work exhibit, has an entrance and an exit. Once the space has been explored, the visitor moves through the exit to the north and onto the viewing platform.

5. From the viewing platform they can see over Observatory and the eponymous observatory, as well as far into the distance, sometimes all the way to the Voortrekker monument.

6. The Large Technologies exhibition hall also has a very obvious entrance and exit, and once the space has been explored the visitor exits through the doors to the south.

7. As they exits the building, they enter into the courtyard proper. Directly across from the exited building is the interactive science museum, an obvious next step. However, if visitors are not interested in this space, the second viewing deck is just as obvious a destination, as by now it is framing the city to the south-west.

8. Once again, as the visitor enters this building, there is an obvious exit, the destination once the space has been explored.

9. This viewing deck allows for views of the Johannesburg skyline, and the door to the north of the deck is a natural next step in the progress through the site.

10. This room is dedicated to displaying and explaining CubeSats developed on site and in the rest of South Africa. Once this building has been explored, the exit to the north displays the research laboratory, the last stage in the exhibition. As the visitor exits this space, the research laboratory's entrance is obvious, inviting them in rather than trying to turn them away.

Note: While this is the route designed for visitors of the site, they are not limited to moving through the spaces in this way. The circulation spaces in the site are loosely defined and any deviation is allowed.

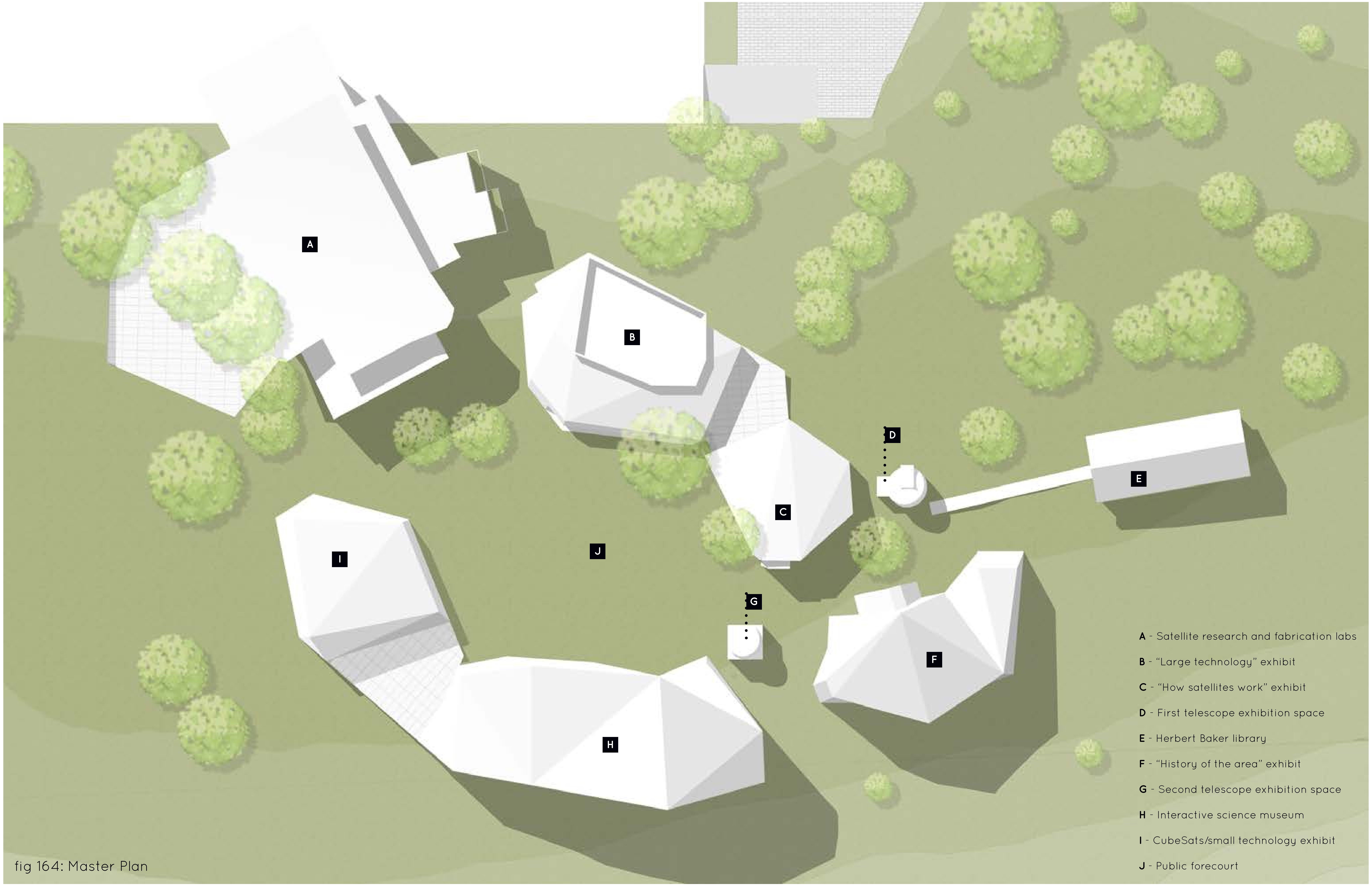


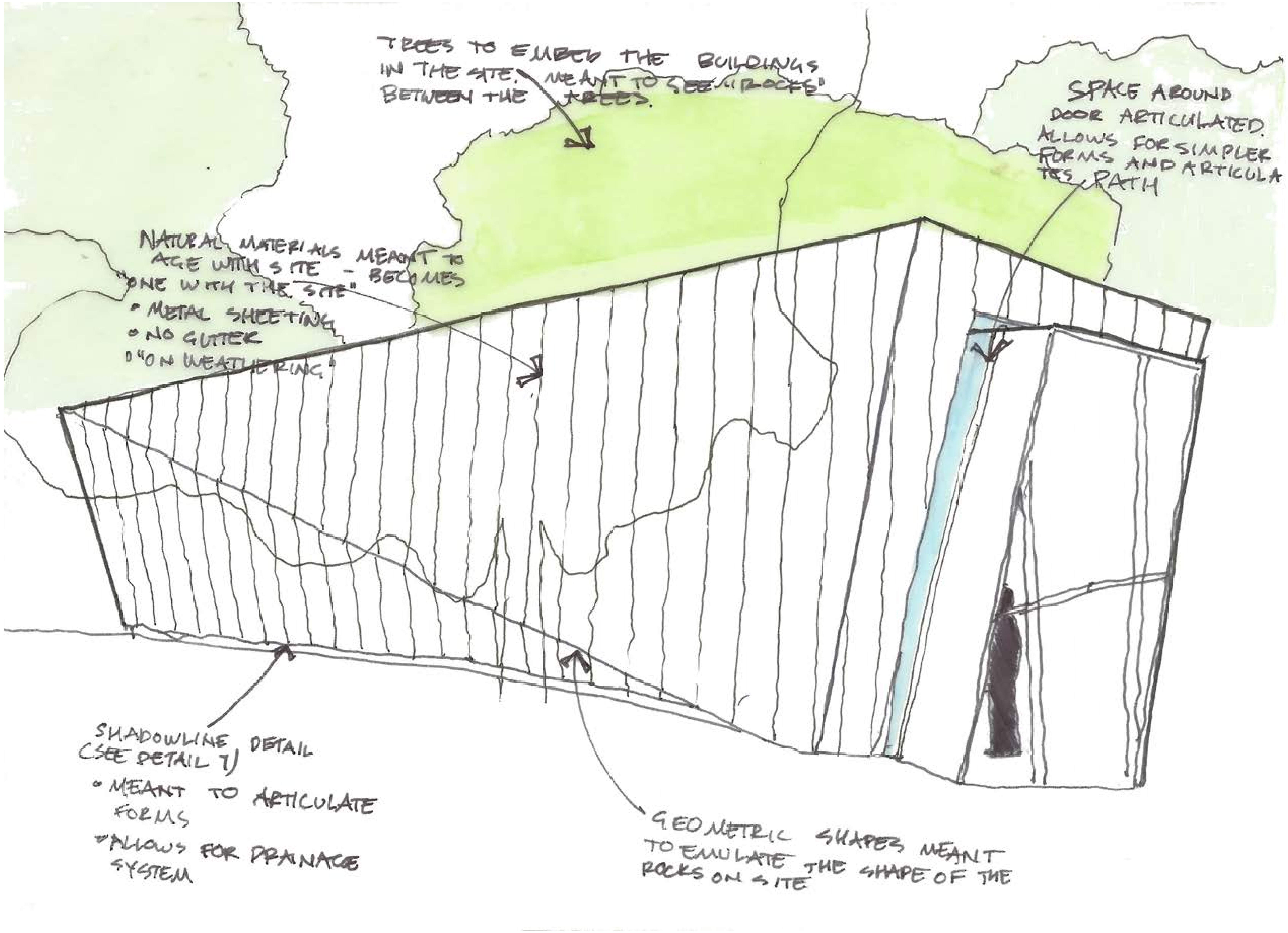
fig 164: Master Plan

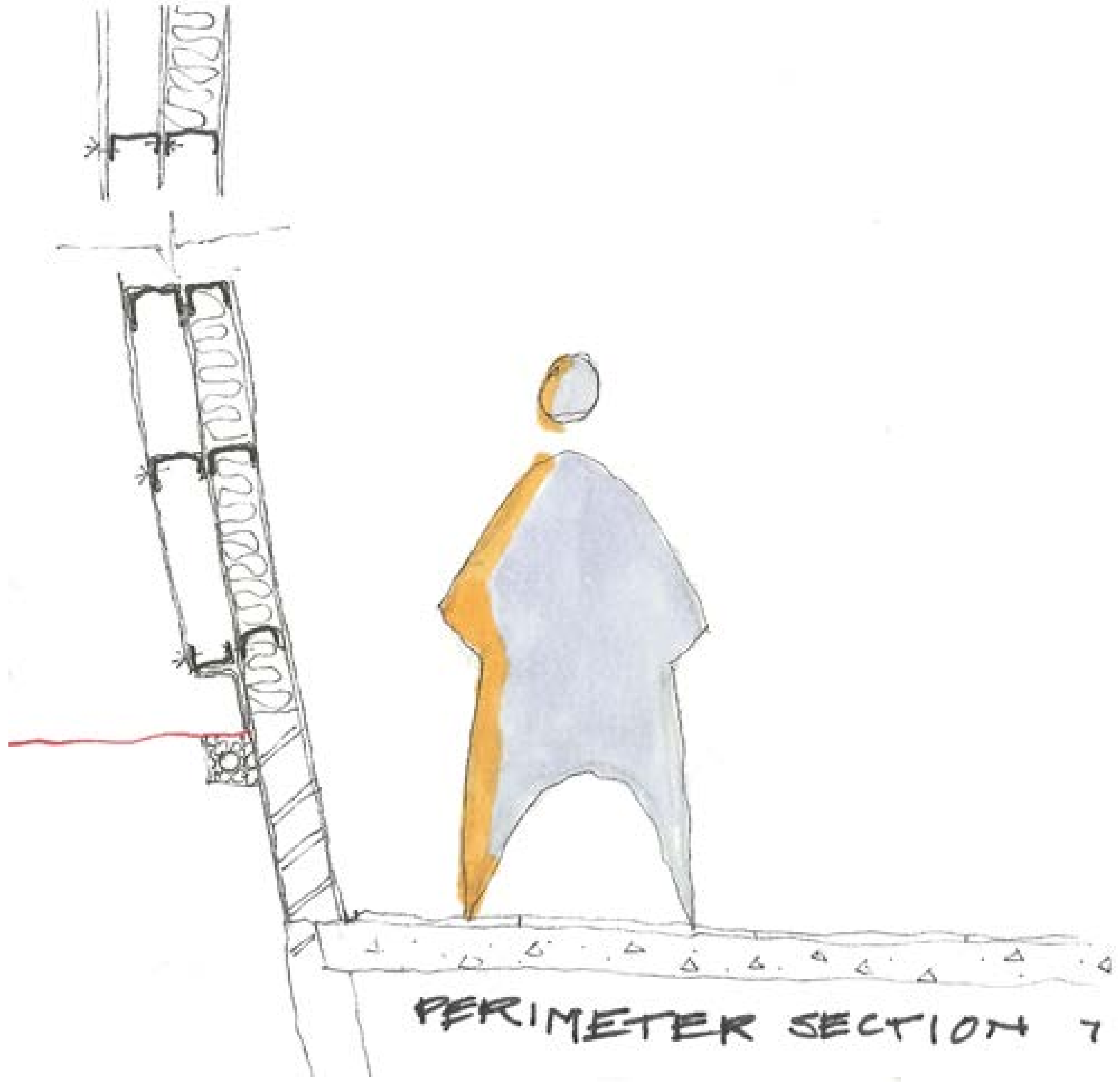
"HOW SATELLITES WORK" EXHIBITION HALL

The intended geometry of the buildings, while interesting, present a challenge in terms of their construction and detailing. One of the biggest challenges is the irregular forms of the buildings on the site: the buildings are meant to emulate the rocks on the site, seeming to protrude out of the ground. This led to several design decisions.

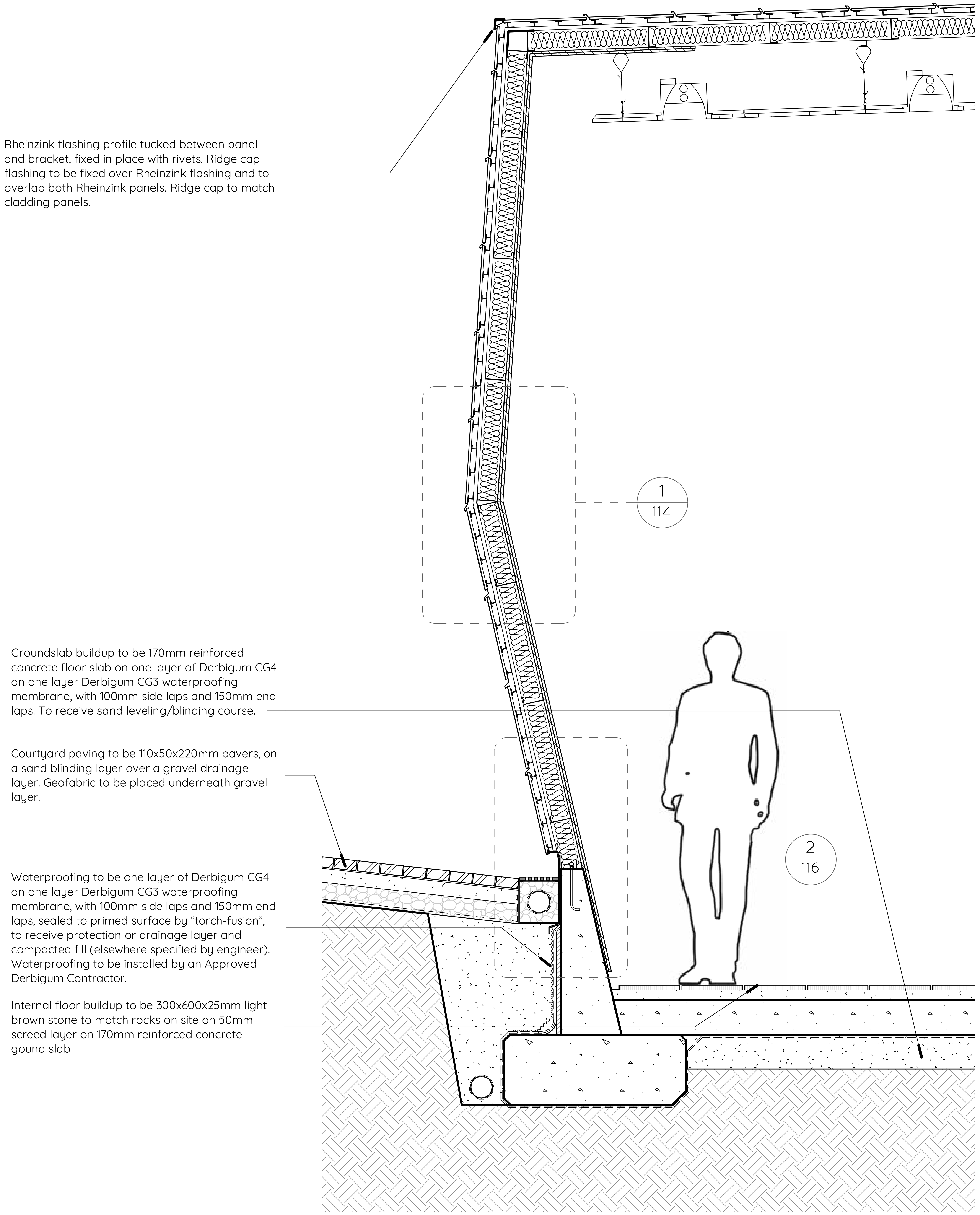
Firstly, the buildings are meant to appear geometric and "rock-like". This intended aesthetic led to the buildings' sloped walls and roofs, and the walls that seemingly blend into the roofs. This is problematic because it forgoes traditional building techniques whereby the roof is supported by walls. The response was to essentially create a frame with the intended geometry of the building and then simply to clad that frame in an appropriate material. While all the buildings are approached in this way, the chosen building, the "How Satellites Work" exhibition, exemplifies this aesthetic. The wall that forms part of the enclosure of the courtyard "splits" and is pulled back to create in interesting form. This interesting form is the reason this wall was chosen to be detailed on the proceeding pages.

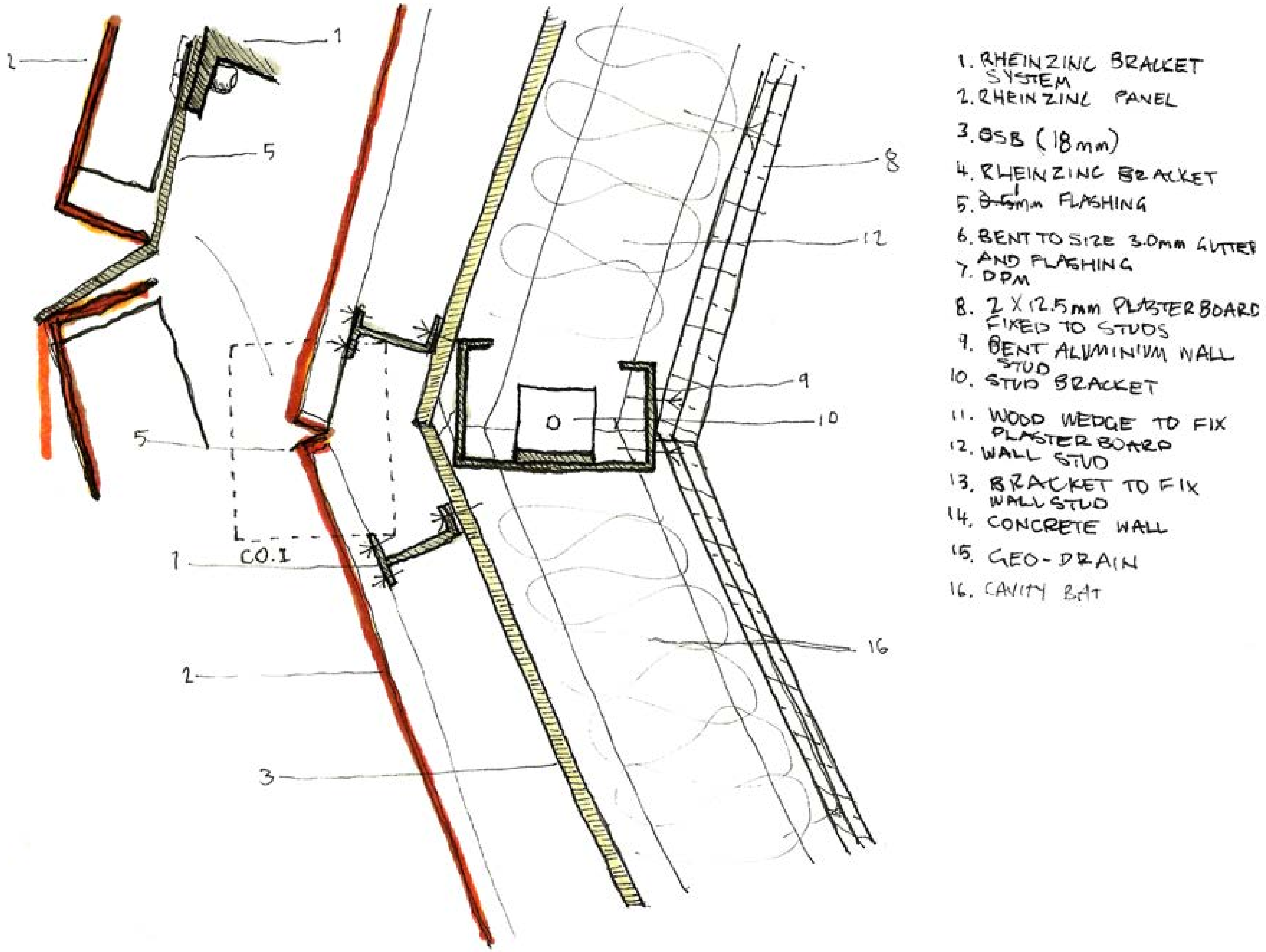
Secondly, the material chosen for the buildings also needed to relate to the design intent for the buildings on site. The buildings are meant to age with the site and with the scheme; they are meant to blend into the surroundings by taking on a patina that reflects the design intent for the building. Copper cladding was chosen for the buildings for this reason - it patinas over time and will eventually appear to be part of the site. The choice of cladding also presented a detailing challenge because of the niche use of copper cladding in South Africa. However, there are several companies with suitable materials and comprehensive guides and details on how these materials are to be used.



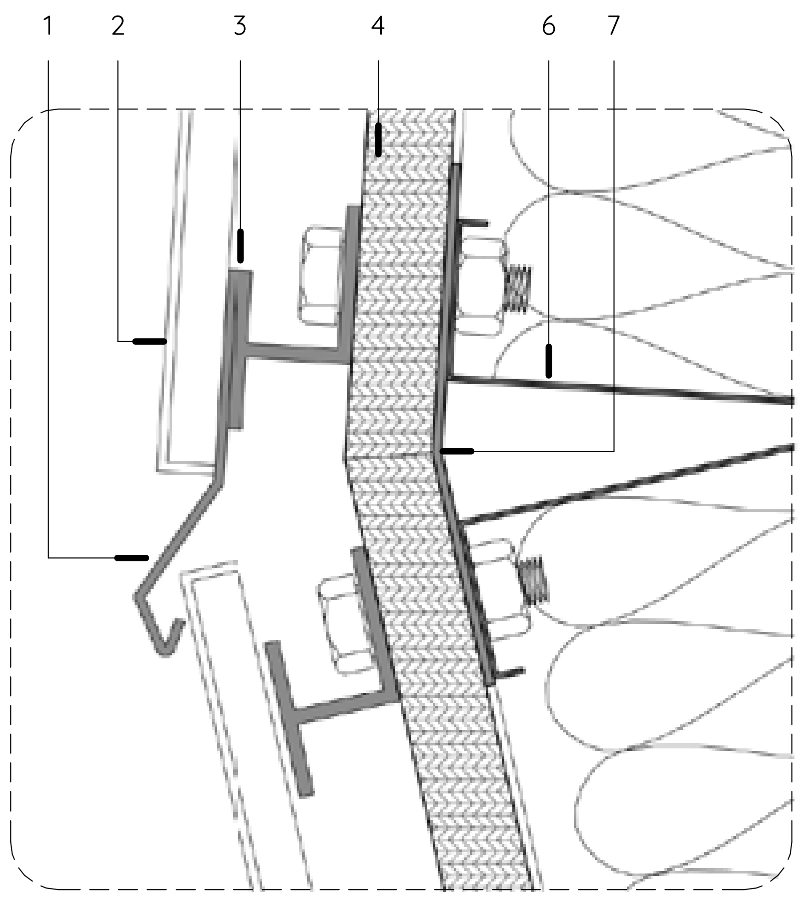

PERIMETER SECTION 7

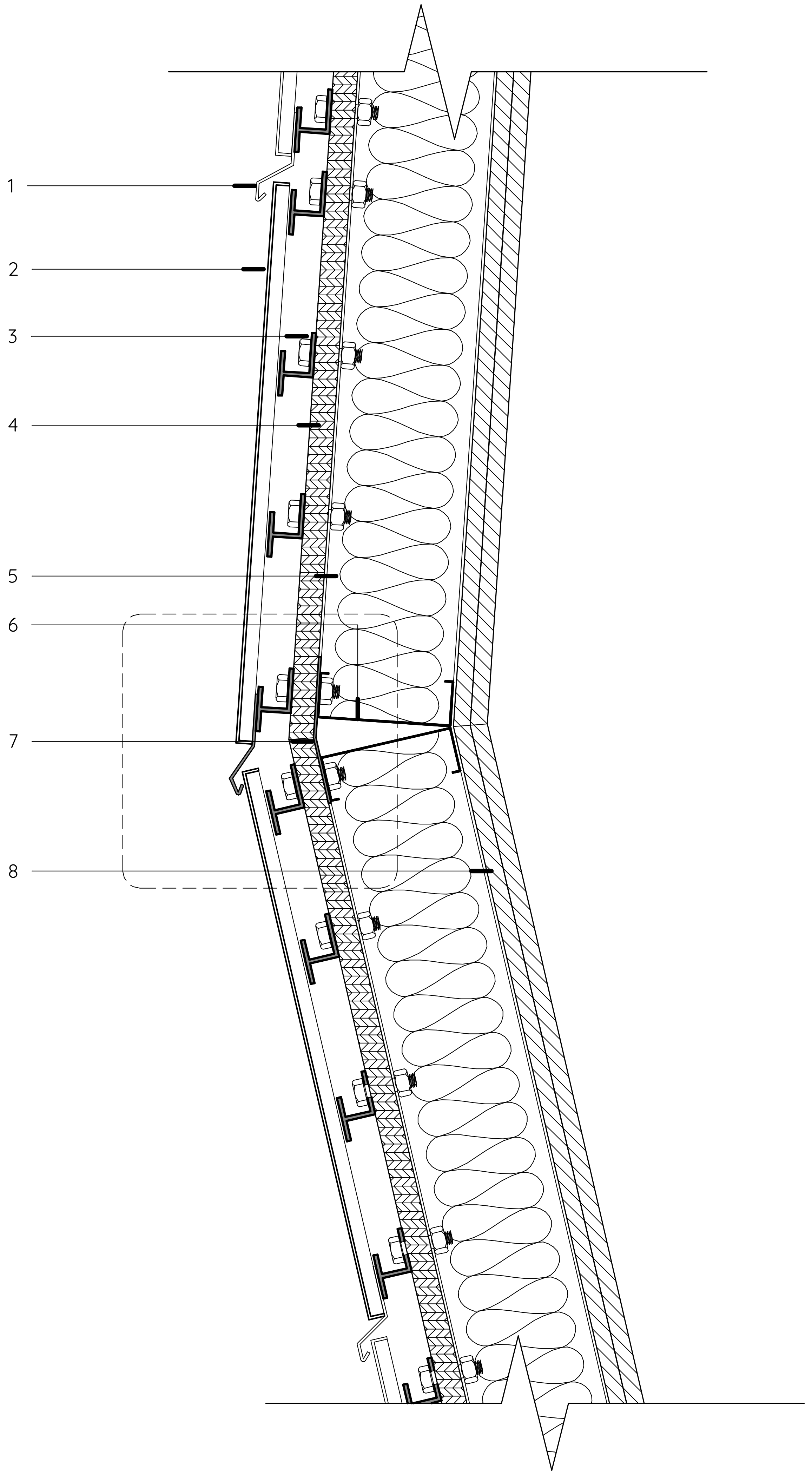

HOW DO THESE PARTS MEET?

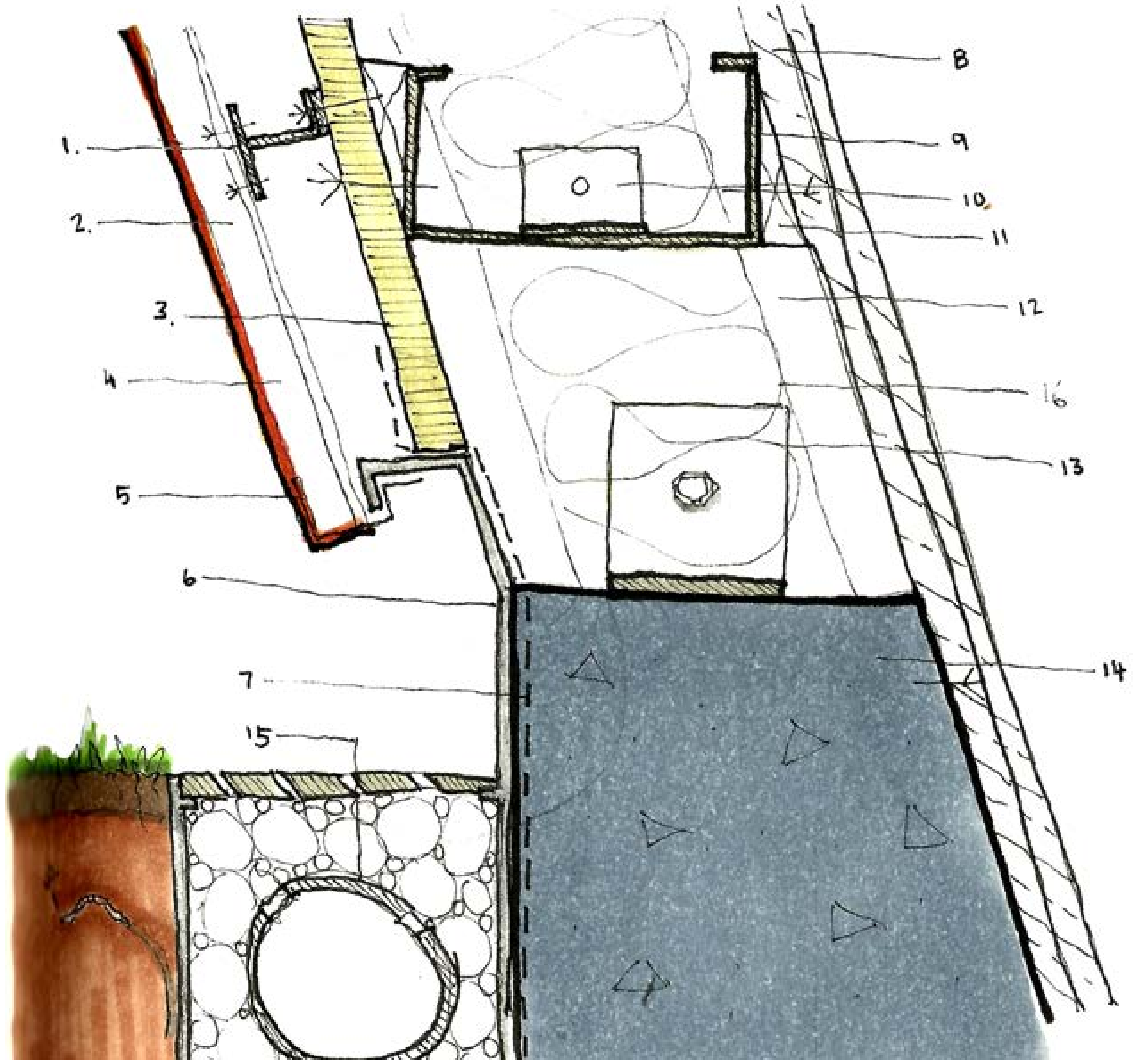

Rheinzink flashing profile tucked between panel and bracket, fixed in place with rivets. Ridge cap flashing to be fixed over Rheinzink flashing and to overlap both Rheinzink panels. Ridge cap to match cladding panels.
Groundslab buildup to be 170mm reinforced concrete floor slab on one layer of Derbigum CG4 on one layer Derbigum CG3 waterproofing membrane, with 100mm side laps and 150mm end laps. To receive sand leveling/blinding course.
Courtyard paving to be 110x50x220mm pavers, on a sand blinding layer over a gravel drainage layer. Geofabric to be placed underneath gravel layer.
Waterproofing to be one layer of Derbigum CG4 on one layer Derbigum CG3 waterproofing membrane, with 100mm side laps and 150mm end laps, sealed to primed surface by "torch-fusion", to receive protection or drainage layer and compacted fill (elsewhere specified by engineer). Waterproofing to be installed by an Approved Derbigum Contractor.
Internal floor buildup to be 300x600x25mm light brown stone to match rocks on site on 50mm screed layer on 170mm reinforced concrete gound slab
1
114
2
116



1. Rheinzink flashing profile tucked between panel and bracket, fixed in place with rivets
2. 1700x400x0.7mm Rheinzink-prepatina Copper cladding, fixed to substructure with blind rivets
3. Two-part Rheinzink bracket substructure, fixed to plywood substructure with Rheinzink recommended mechanical fasteners
4. 18mm oriented strand board, fixed to metal studs with M10 bolts protected with waterproofing membrane
5. 75mm Cavitybatt wall insulation
6. 100x30 galvanised steel wall stud, fixed at 600 centres
7. 60x60x3.0mm custom bent steel plate
8. Double skin 12.5mm plasterboard fixed to galvanised steel wall stud

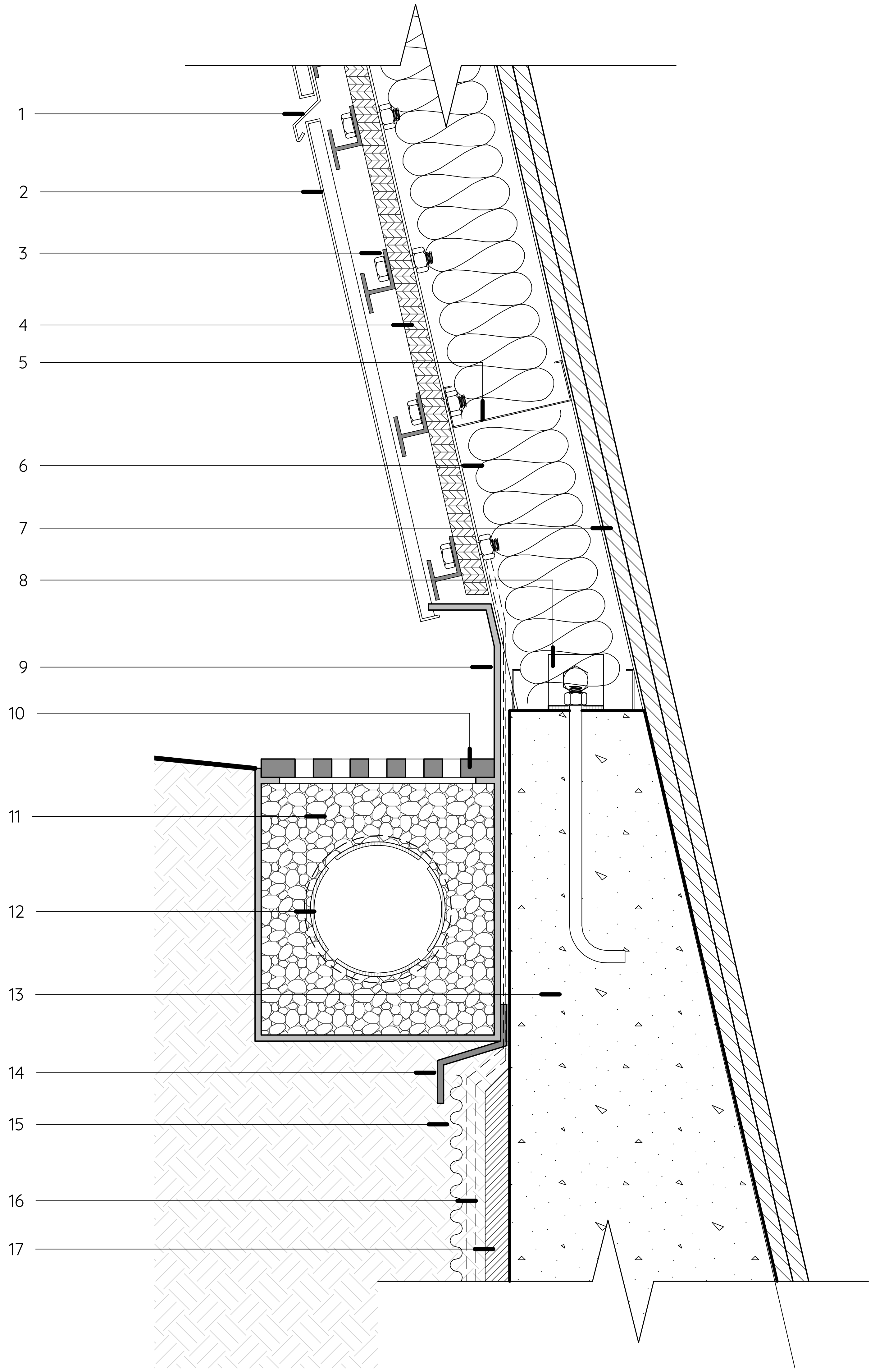






1. RHEINZINC BRACKET SYSTEM
2. RHEINZINC PANEL
3. OSB (18mm)
4. RHEINZINC BRACKET
5. ~~0.5~~mm FLASHING
6. BENT TO SIZE 3.0mm GUTTER AND FLASHING
7. DPM
8. 2 X 12.5mm PLASTERBOARD FIXED TO STUDS
9. BENT ALUMINIUM WALL STUD
10. STUD BRACKET
11. WOOD WEDGE TO FIX PLASTER BOARD
12. WALL STUD
13. BRACKET TO FIX WALL STUD
14. CONCRETE WALL
15. GEO-DRAIN
16. CAVITY BAT

1. Rheinzink flashing profile tucked between panel and bracket, fixed in place with rivets
2. 1700x400x0.7mm Rheinzink-prepatina Copper cladding, fixed to substructure with blind rivets
3. Two-part Rheinzink bracket substructure, fixed to plywood substructure with Rheinzink recommended mechanical fasteners
4. 18mm oriented strand board, fixed to metal studs with M10 bolts
5. 100x30 galvanised steel wall stud, fixed at 600 centres
6. 75mm Cavitybatt wall insulation
7. Double skin 12.5mm plasterboard fixed to galvanised steel wall stud
8. 45x45x3mm equal leg angle fixed to wall stud with M10 bolt and fixed to RC upstand beam with M10 anchor bolt
9. 3.0mm thick galvanised steel custom bent catchbox, 200x200mm drainage channel and 150mm built in flashing, tucked between OSB and cladding panel
10. Steel drainage channel grate
11. Gravel
12. 110mm perforated drainage pipe covered with geofabric
13. Reinforced concrete upstand beam
14. 3.0mm thick flashing to be tucked between drainage box and bitumen waterproofing membranes, fixed to drainage box with waterproof epoxy
15. Derbigum delta drainage sheet to be tucked underneath flashing, installed to manufacturer's specification
16. Water proofing to be one layer of Derbigum CG4 on one layer Derbigum CG3 waterproofing membrane, sealed to primed surface by "torch-fusion"
17. 20mm polystyrene protection layer fixed mechanically to concrete upstand beam



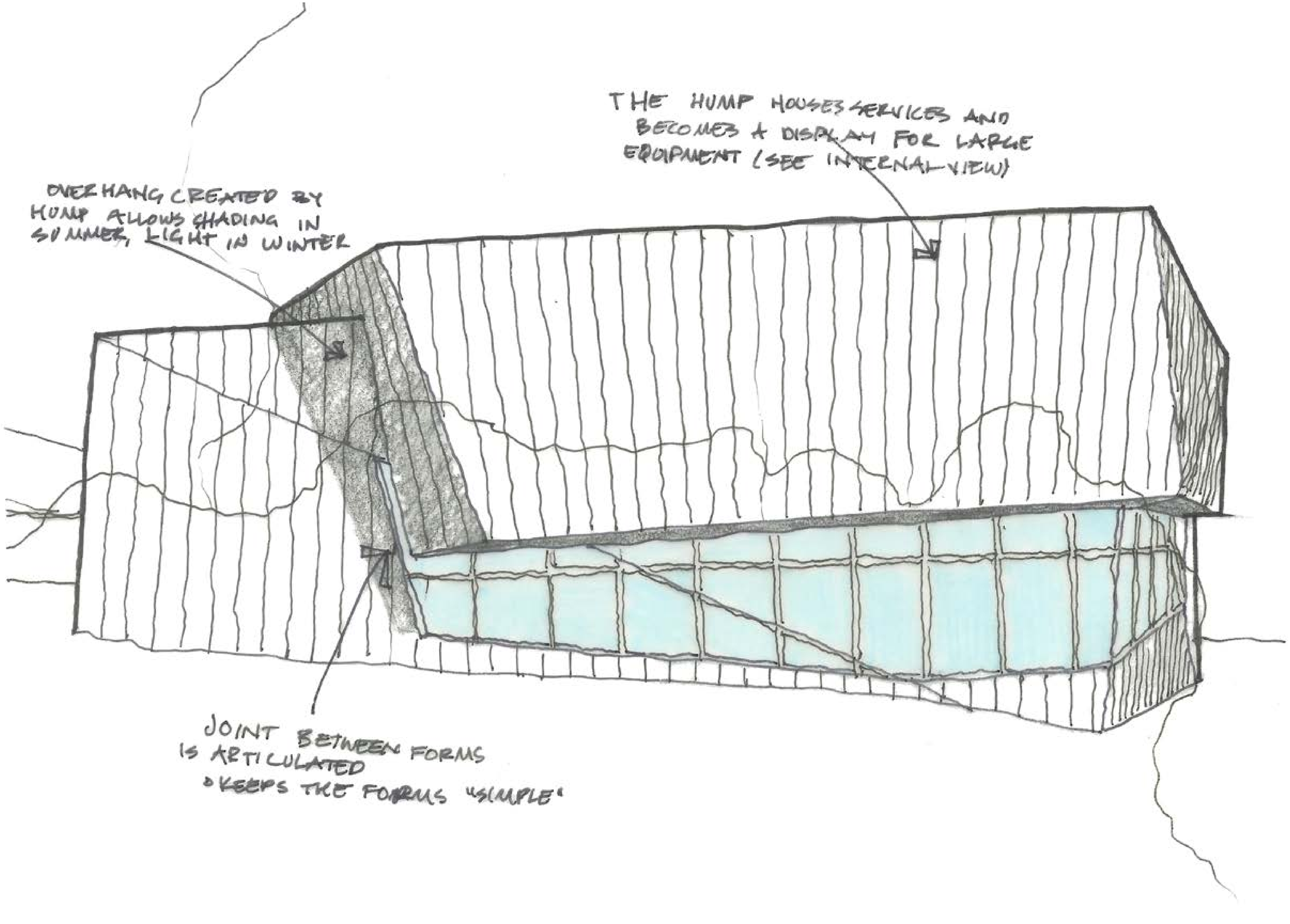
"LARGE OBJECT" EXHIBITION HALL

The second building that was looked at in terms of envelope design was the "large object" exhibition hall. The space itself is meant to house large pieces of technology from other institutions or industries, for instance displaying a large satellite or the piece of a rocket. This in itself already dictates a few considerations for the space. The larger design consideration is how visitors experience the space and how the circulation of the space works. From a construction point of view, there are other considerations, beside the overarching design intent for the space.

Firstly, the design of the space should facilitate a certain approach to experiencing the space. The design intent for the exhibition hall is that as one moves through the exhibition hall, the major piece of the exhibit is fully experienced. In the previous revision of the design, the voids created by the crossing of the bridges through the exhibition voids acted as the display spaces for the large technologies. As the visitor moved through the hall, the way that they experienced these pieces changed. This is the general design intent for this exhibition hall as well. However, the space is moved through once instead of the intermittent approach that the previous revision had. This is done by having a ramp that wraps around the space - as one moves through the space, one receives a 360 degree experience of the exhibition piece. This also means that the space should be a large volume, both to be able to house the exhibition piece and to allow the movement throughout the whole space with minimal visual interruptions. The approach to designing this exhibition experience should be very particular. Firstly, the space should be designed to be able to create an interesting form from the inside; rather than simple having a large cube that visitor's move around in, the space should feel more dynamic to create a less intimidating experience. Secondly, the large volume and the large hanging exhibition piece dictates that the approach to the construction of the space is sufficient in terms of structural integrity.

In addition to this design intent, the space should incorporate design elements from ancient astronomical observatories. For this building it means designing the space to incorporate design elements that respond to the sun in some way. This will be fully explored in the next revision of the design, however for this revision it simply meant exploring the possibility of influencing the light in the space through the incorporation of the large window and overhanging volume. The placement of the window also allows for views over the other buildings on the site and over the whole of Observatory without necessarily letting too much light into the space and making it uncomfortable. Furthermore, the pieces on display in the space may be sensitive to daylight and so the space should be able to let light in without the possibility of exposing the pieces to direct sunlight.

The realisation of these spaces in important and the proceeding pages are dedicated to the exploration of the construction of this space. The final revision of the design will see further exploration of the design of this space, with a similar approach in terms of the construction.



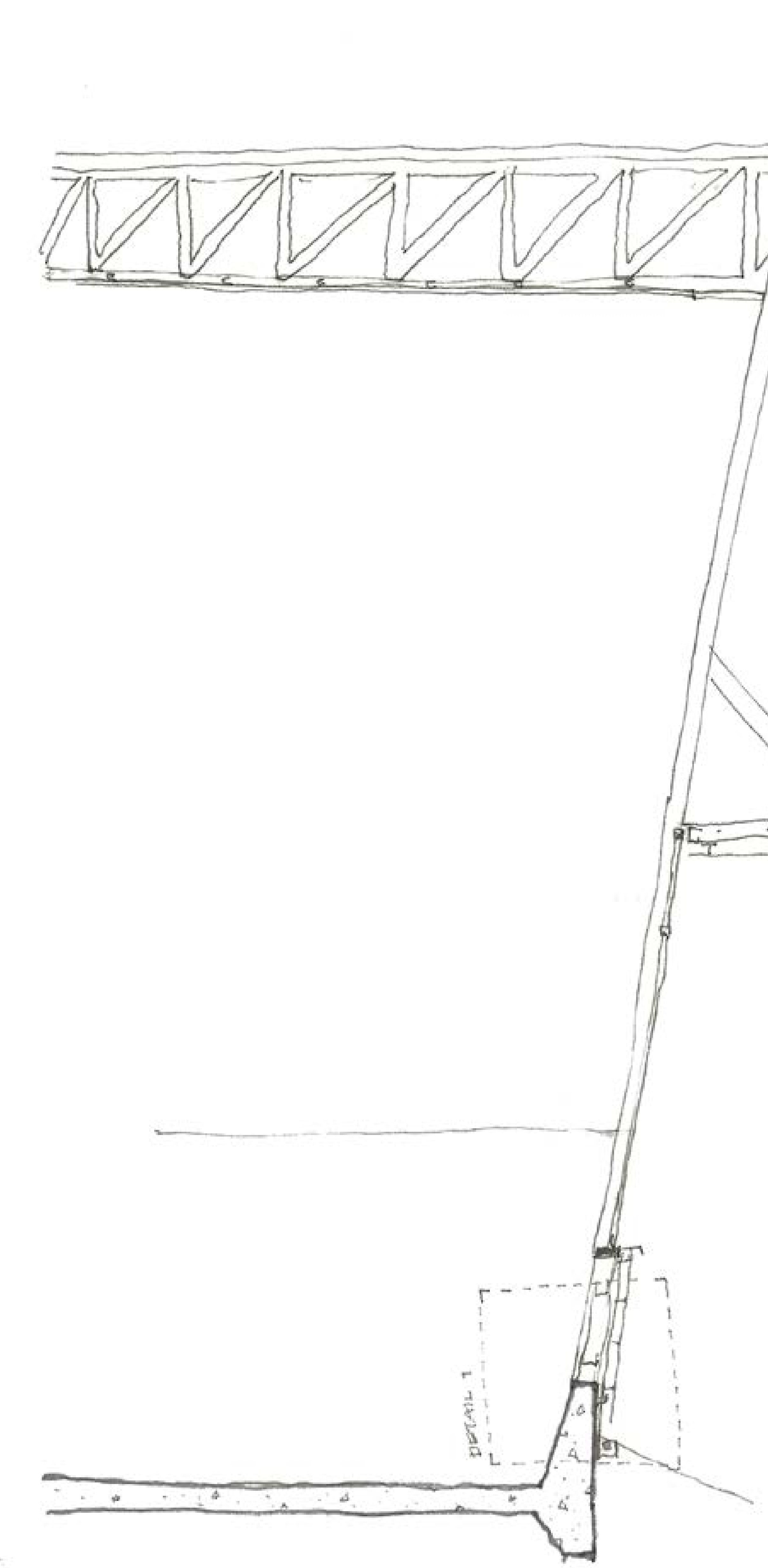
North-South Section during the day

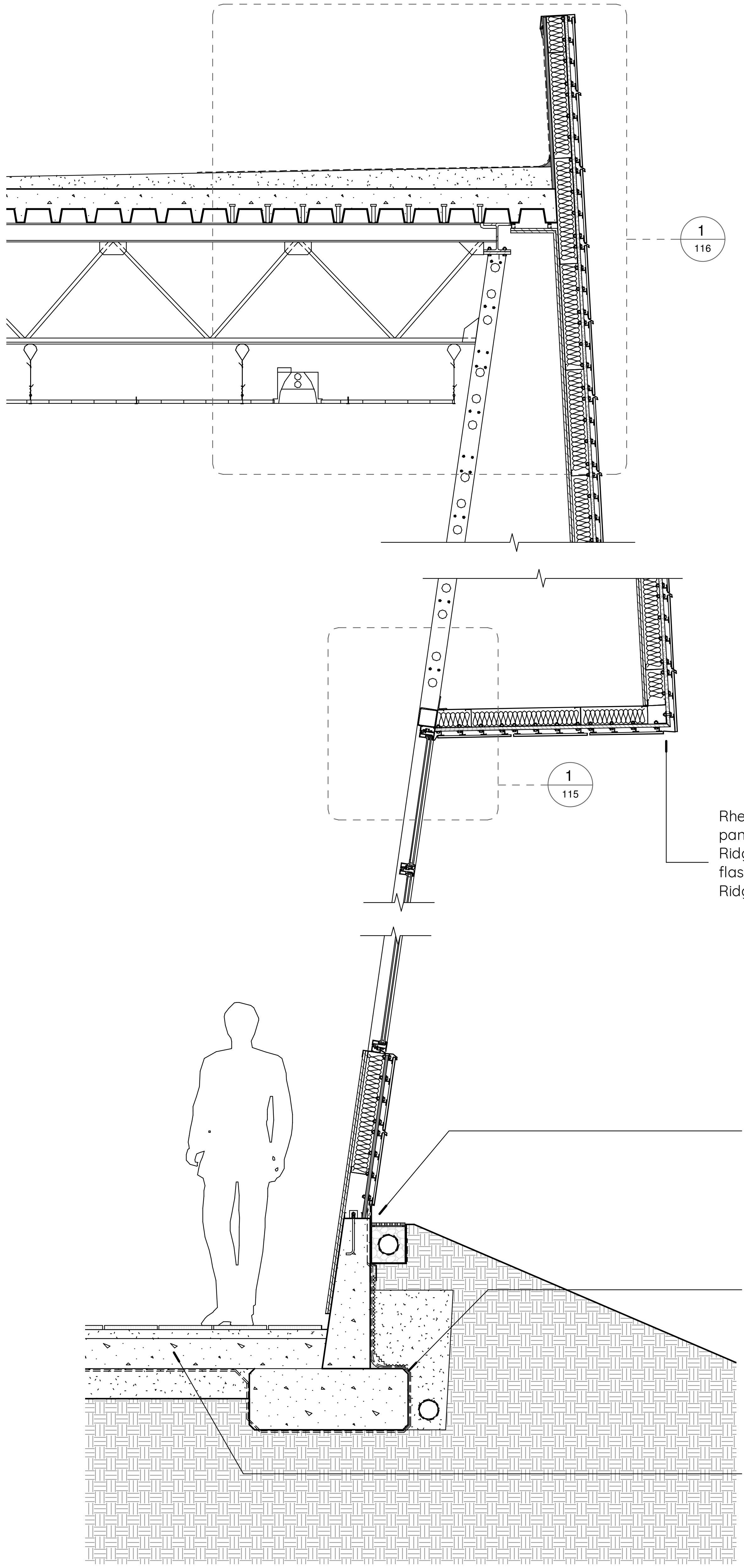
A - Satellite research and fabrication labs
B - "Large technology" exhibit
H - Interactive science museum
I - CubeSats/small technology exhibit
J - Public forecourt

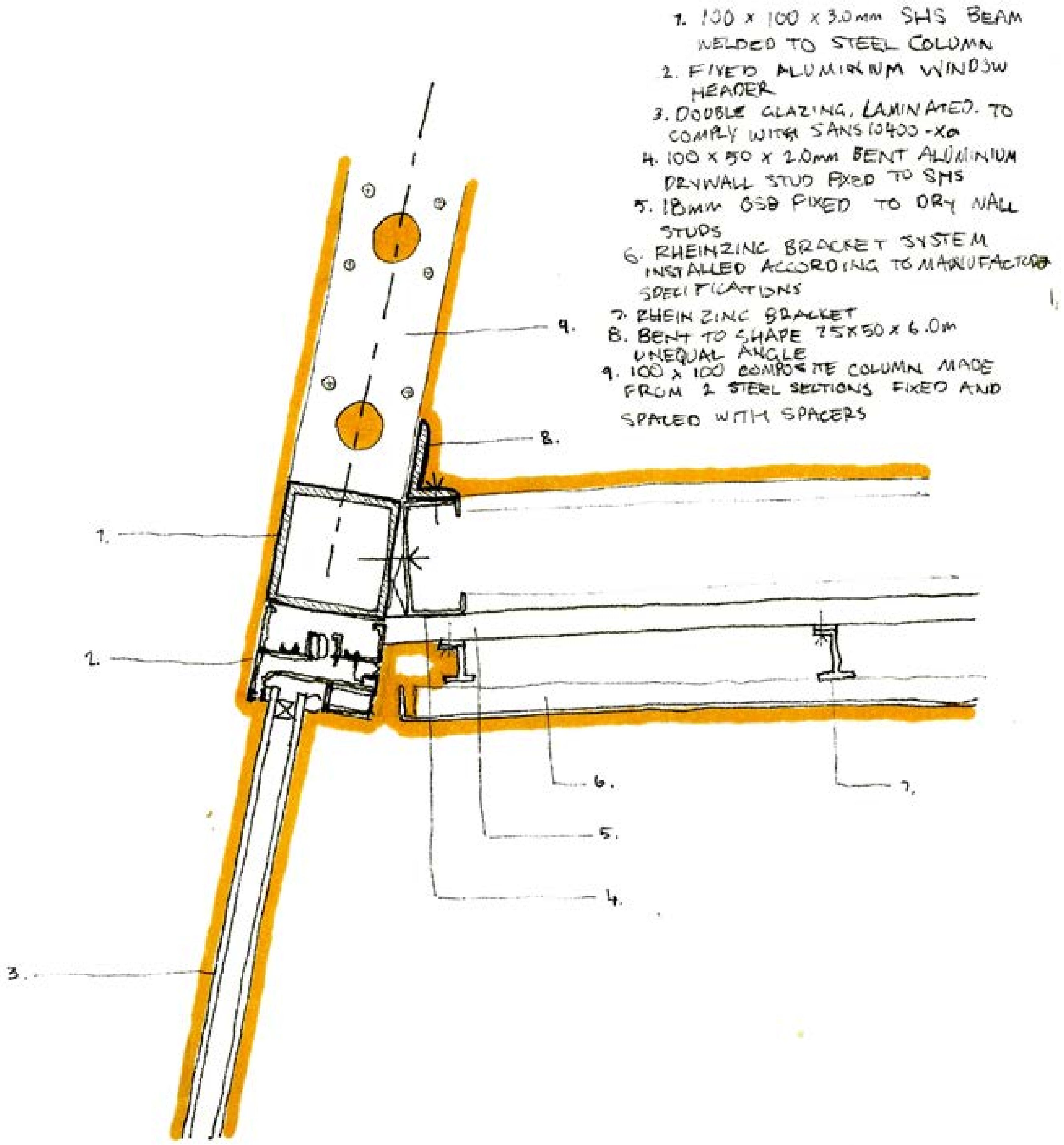
North-South Section at night
A - Satellite research and fabrication labs
B - "Large technology" exhibit
H - Interactive science museum
I - CubeSats/small technology exhibit
J - Public forecourt

▲
At night the interactive exhibition space should behave differently to how it does in the day. This may mean focusing more on interactive exhibition pieces that turn outward to the universe, for instance telescopes.

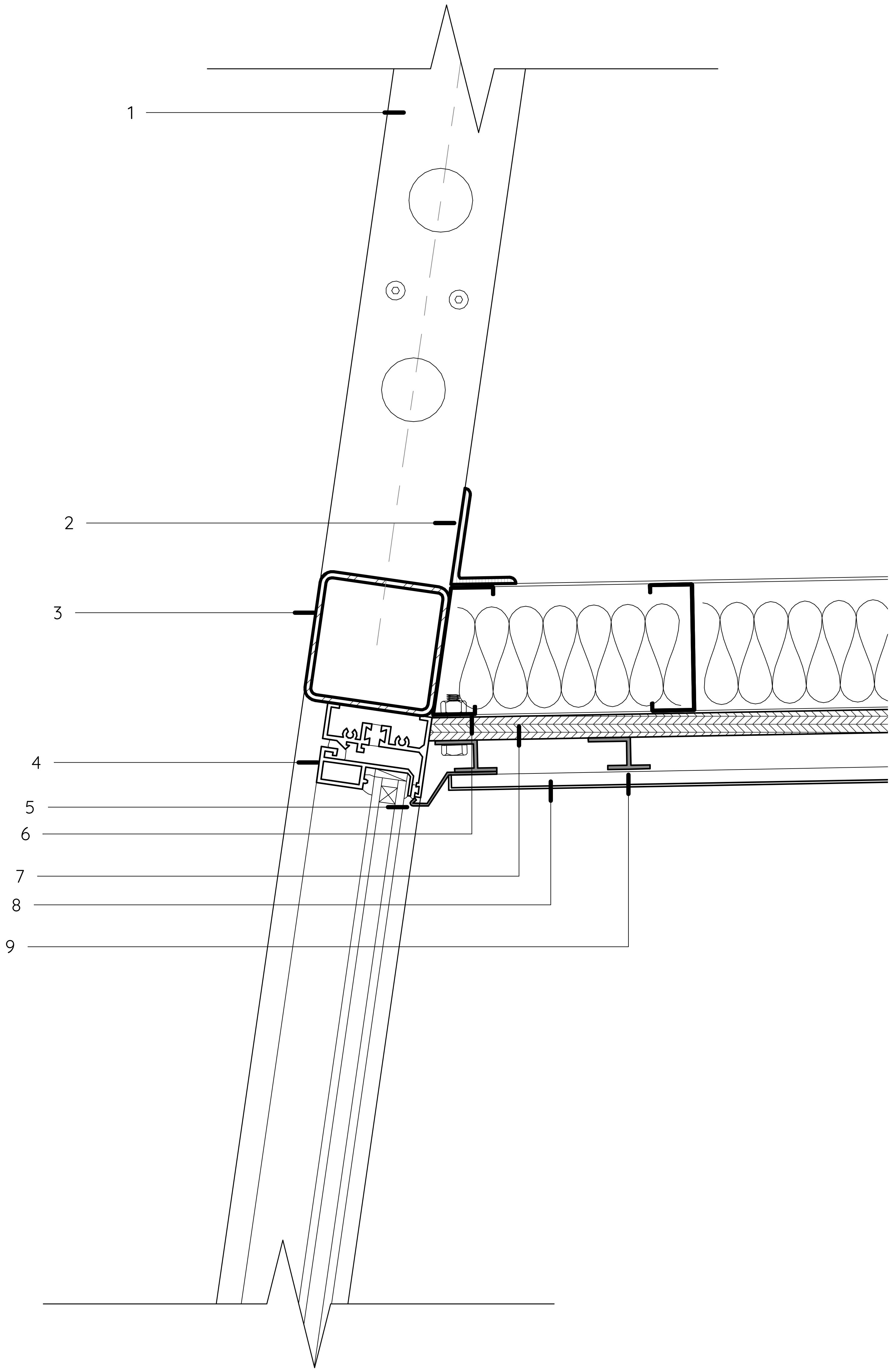
▲
At night, the public forecourt becomes a naked eye observatory. It allows visitors to have an unobscured experience of the sky. The design of the courtyard might also incorporate designs into the landscape to help recognise certain constellations, stars or planets.

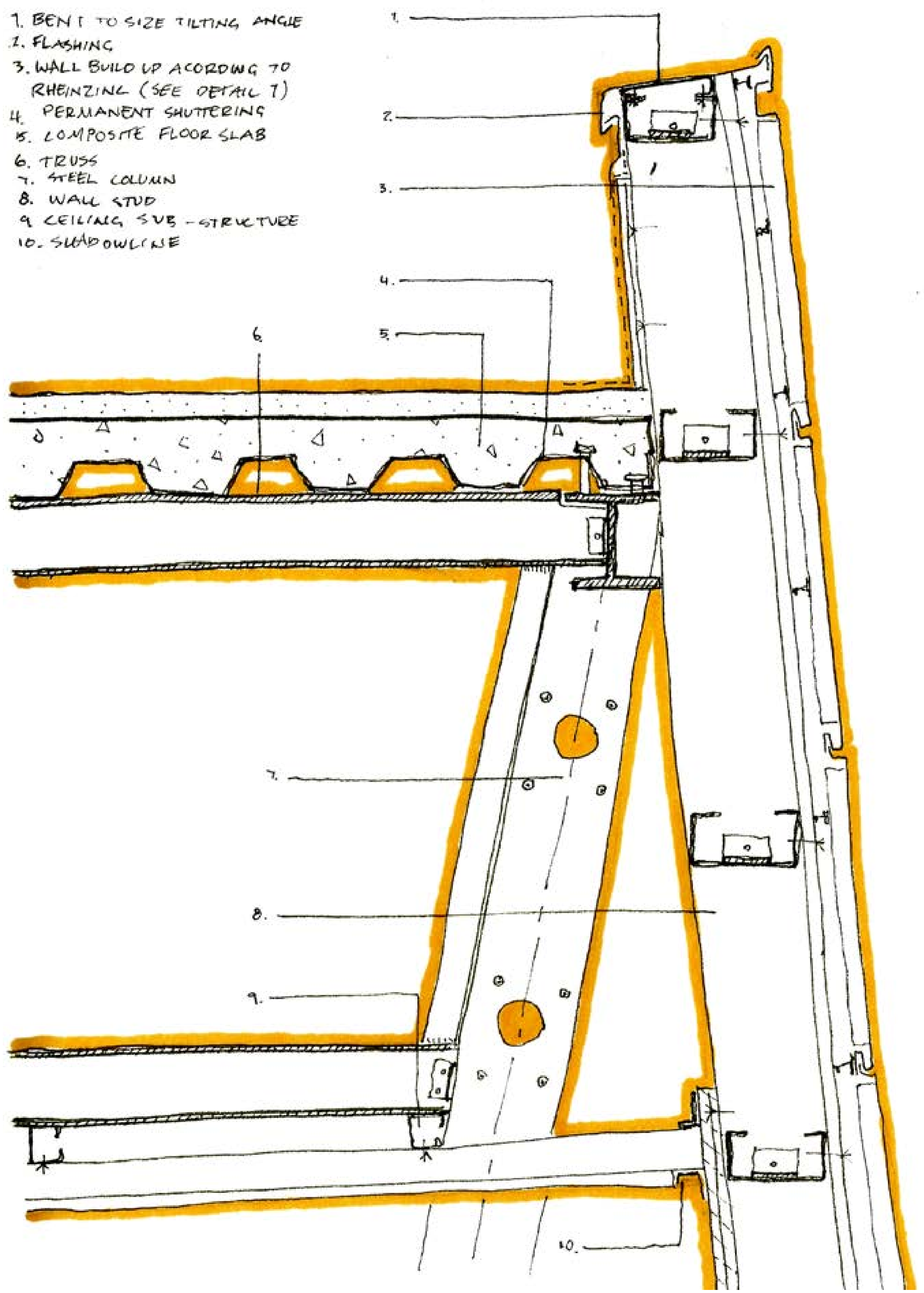



1
116
1
115
Rheinzink flashing profile tucked between panel and bracket, fixed in place with rivets. Ridge cap flashing to be fixed over Rheinzink flashing and to overlap both Rheinzink panels. Ridge cap to match cladding panels.
Wall and drainage buildup as per footing detail
Waterproofing to be one layer of Derbigum CG4 on one layer Derbigum CG3 waterproofing membrane, with 100mm side laps and 150mm end laps, sealed to primed surface by “torch-fusion”, to receive protection or drainage layer and compacted fill (elsewhere specified by engineer). Waterproofing to be installed by an Approved Derbigum Contractor.
Groundslab buildup to be 170mm reinforced concrete floor slab on one layer of Derbigum CG4 on one layer Derbigum CG3 waterproofing membrane, with 100mm side laps and 150mm end laps. To receive sand leveling/blinding course.

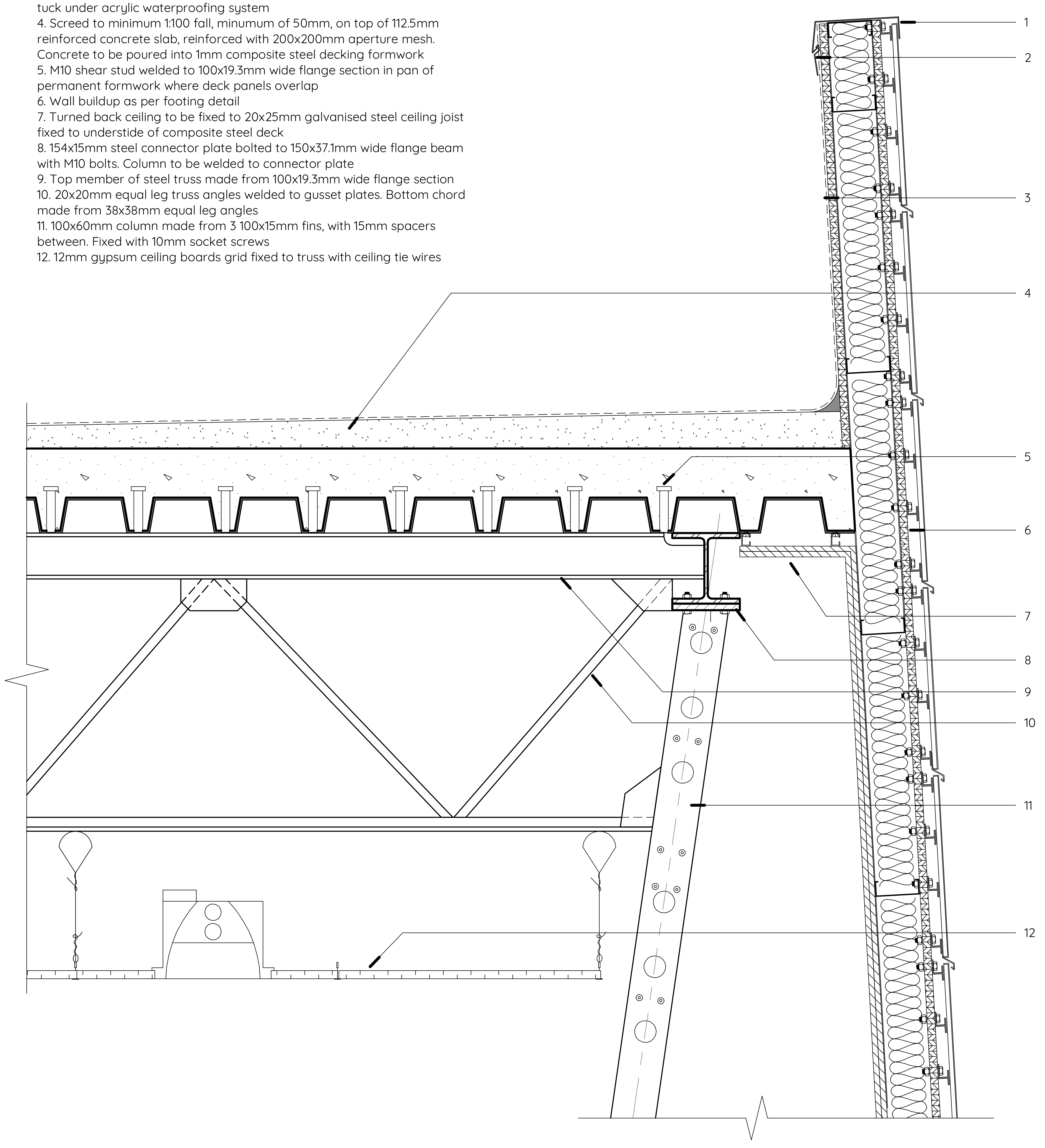


1. 100x60mm column made from 3 100x15mm fins, with 15mm spacers between. Fixed with 10mm socket screws
2. 76x51x4.8.0mm custom bent L-angle section, fixed to galvanised steel stud with blind rivets and welded to steel column
3. 101x101x4.8mm square hollow section beam, welded to steel column
4. 60x80mm fixed aluminium head
5. Rheinzink flashing profile tucked between panel and bracket, fixed in place with rivets and tucked under edge of aluminium window head
6. Custom bent 100x30mm galvanised steel wall stud, fixed to square hollow section with rivets
7. 18mm oriented strand board, fixed to metal studs with M10 bolts protected with waterproofing membrane
8. 1700x400x0.7mm Rheinzink-prepatina Copper cladding, fixed to substructure with blind rivets
9. Two-part Rheinzink bracket substructure, fixed to OSB substructure with Rheinzink recommended mechanical fasteners





1. Bent to shape 2mm parapet flashing, to match Rheinzink copper panels. Fixed to topmost galvanised steel wall stud with epoxy
2. 2mm galvanised steel counter flashing to be tucked underneath parapet flashing, fixed mechanically to OSB behind parapet flashing
3. Derbigum SP4 sealed to primed screen and turned up 100mm over fillet, to tuck under acrylic waterproofing system
4. Screed to minimum 1:100 fall, minumum of 50mm, on top of 112.5mm reinforced concrete slab, reinforced with 200x200mm aperture mesh. Concrete to be poured into 1mm composite steel decking formwork
5. M10 shear stud welded to 100x19.3mm wide flange section in pan of permanent formwork where deck panels overlap
6. Wall buildup as per footing detail
7. Turned back ceiling to be fixed to 20x25mm galvanised steel ceiling joist fixed to underside of composite steel deck
8. 154x15mm steel connector plate bolted to 150x37.1mm wide flange beam with M10 bolts. Column to be welded to connector plate
9. Top member of steel truss made from 100x19.3mm wide flange section
10. 20x20mm equal leg truss angles welded to gusset plates. Bottom chord made from 38x38mm equal leg angles
11. 100x60mm column made from 3 100x15mm fins, with 15mm spacers between. Fixed with 10mm socket screws
12. 12mm gypsum ceiling boards grid fixed to truss with ceiling tie wires



3 | final design

DESIGN DEVELOPMENT AND REFINEMENT

Although the overall scheme barely changed since the previous revision, the specifics of the forms has had major work. Among other things, the forms have become much more focused and specific to the spaces housed within. One of the criticisms leveled against the previous revision was that the geometry of the buildings seems to be somewhat random. This, the final revision, has used a more rational system for deciding fenestration, orientation of faces and angles of walls. Moreover, the landscaping for the scheme has had a major overhaul.

From an overall layout, the scheme has become a lot closer as the previous revision's courtyard was extremely wide for the usage of the space - more importantly, the connection between the sky and the architecture, expressed through sundial-like design, was lacking in the previous revision. One of the reasons for that was because of the vast space between the buildings- it was impossible for shadows to reach from one building to the next, making it difficult to frame the courtyard as a sundial.

The design of the exhibition space has also had a major overhaul; while it was roughly planned out previously, the final design presents a fully planned out and functional administration and research centre. Naturally, this required particular planning in order to achieve the level of functionality required to have the scheme function correctly. A consequence of moving the scheme around to reduce the size of the courtyard was that the potential connection between the existing learning centre and the new research centre was lost. Accommodation has been made to establish a certain connection between these elements, however this major connection has been compromised in order to strengthen other connections - the connection between the exhibition and the research centre.

One thing that was more heavily focused on for the final design solution was bringing the central concept into the design: the connection between architecture, space and the Earth. This concept informed the inclusion of accessible roofs (architecture as an extension of the landscape), the material choices (copper to age with the site), submerging certain spaces within the building underground (marrying landscape and architecture), focusing on landscaping (creating harmony between architecture and the Earth) and using the courtyard as a sundial (the expression of the effect the rest of the universe has on us through the lens of architecture).

Lastly, while the structural and tectonic development of the previous chapter is still relevant, and formed the basis of the technical solution provided in this chapter, it was not plausible enough for a final design solution. Therefore, the technical solution of this scheme has also been developed, although it did not need as much work as the overall design of the space.

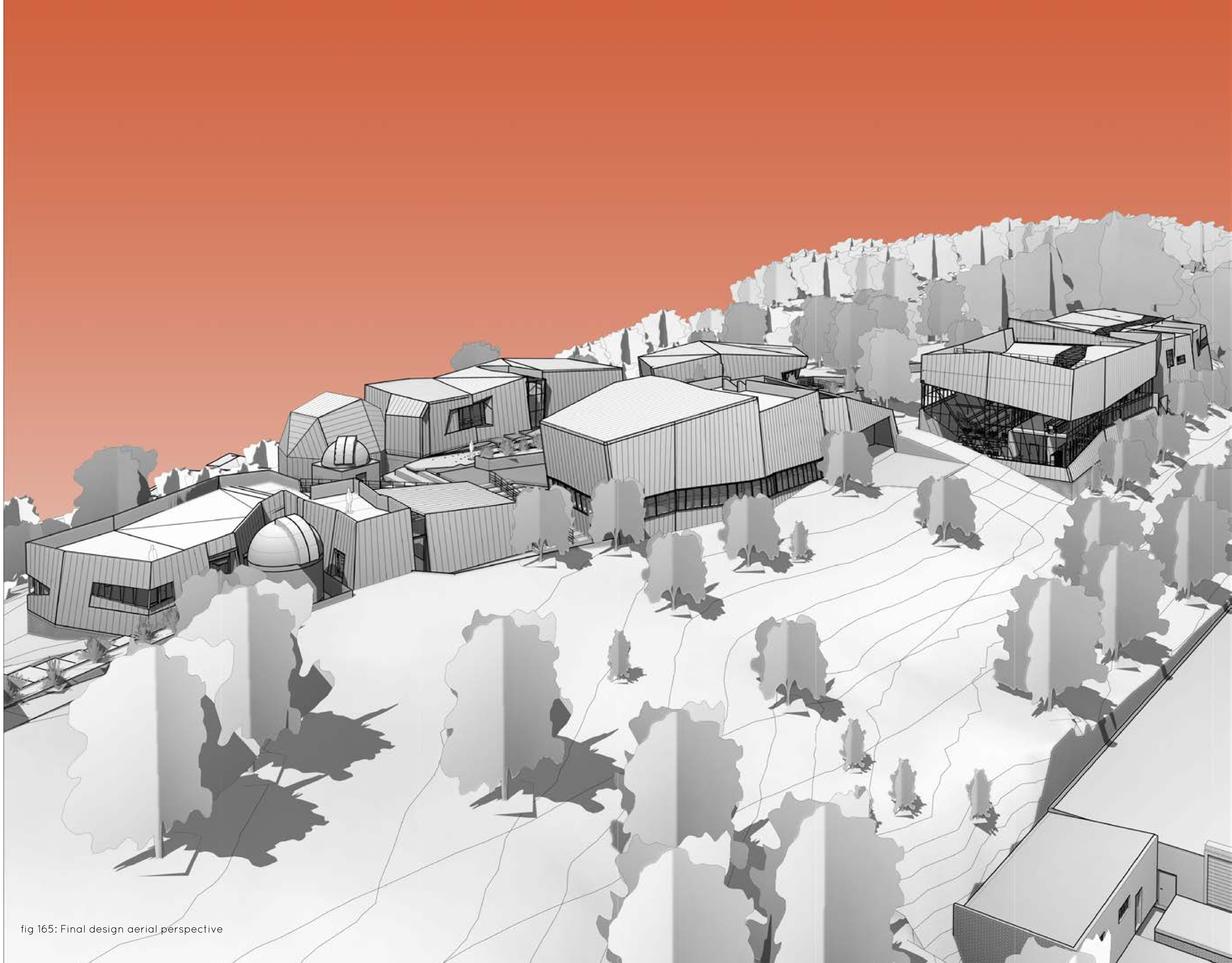


fig 165: Final design aerial perspective

Program

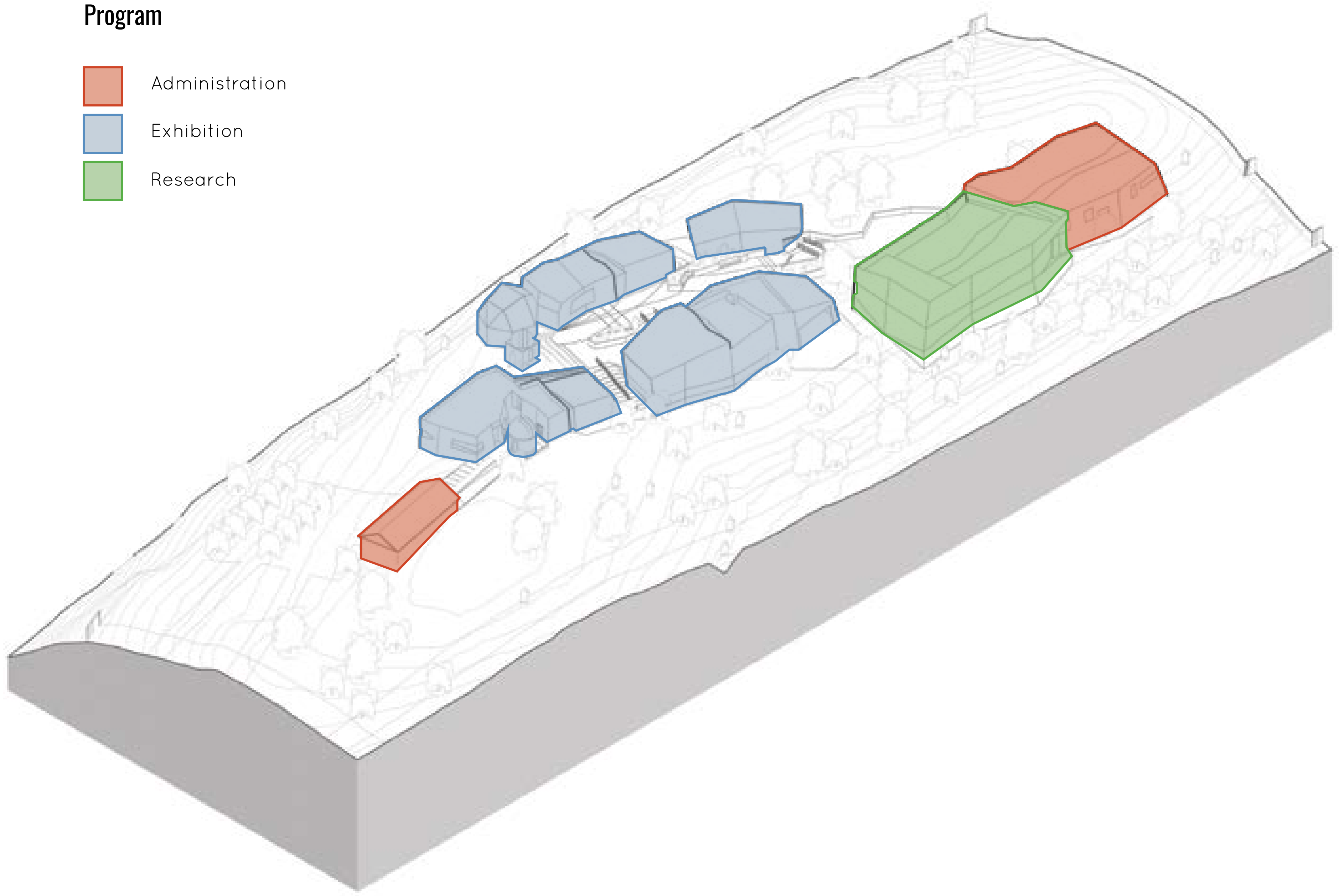


fig 166: Program diagram

Scheme narrative

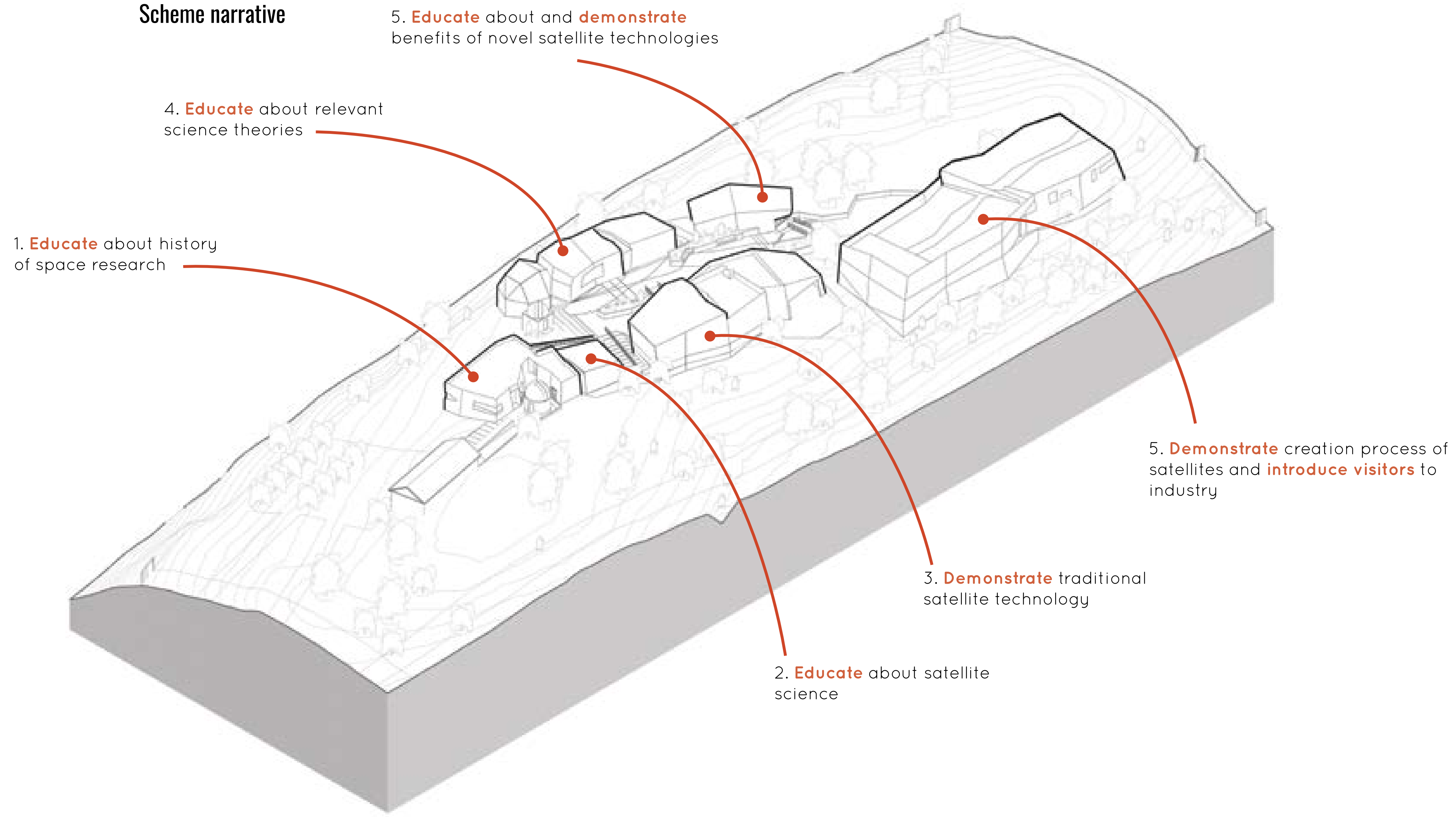


fig 168: Scheme narrative diagram

Circulation

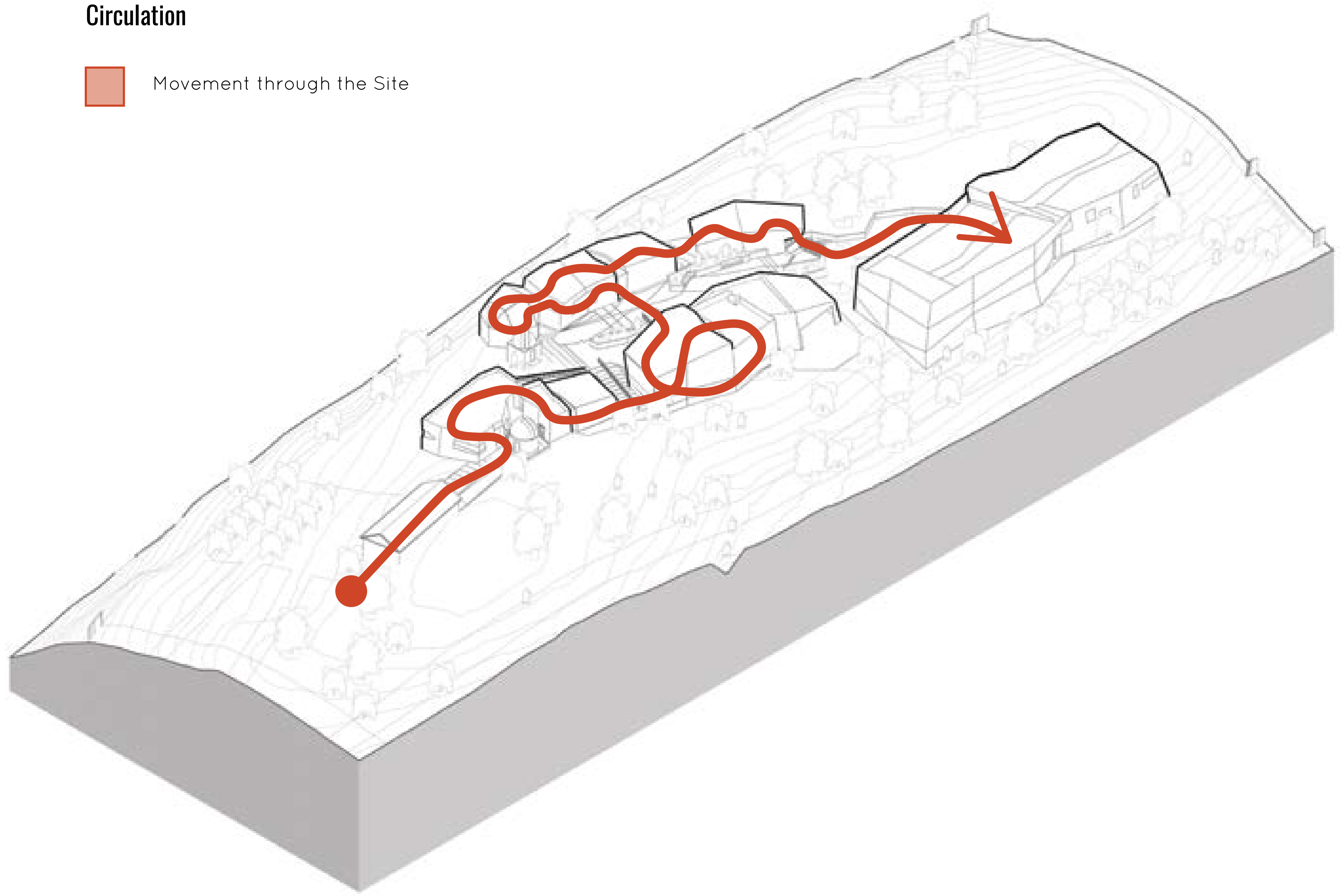


fig 167: Circulation diagram

Infastructure

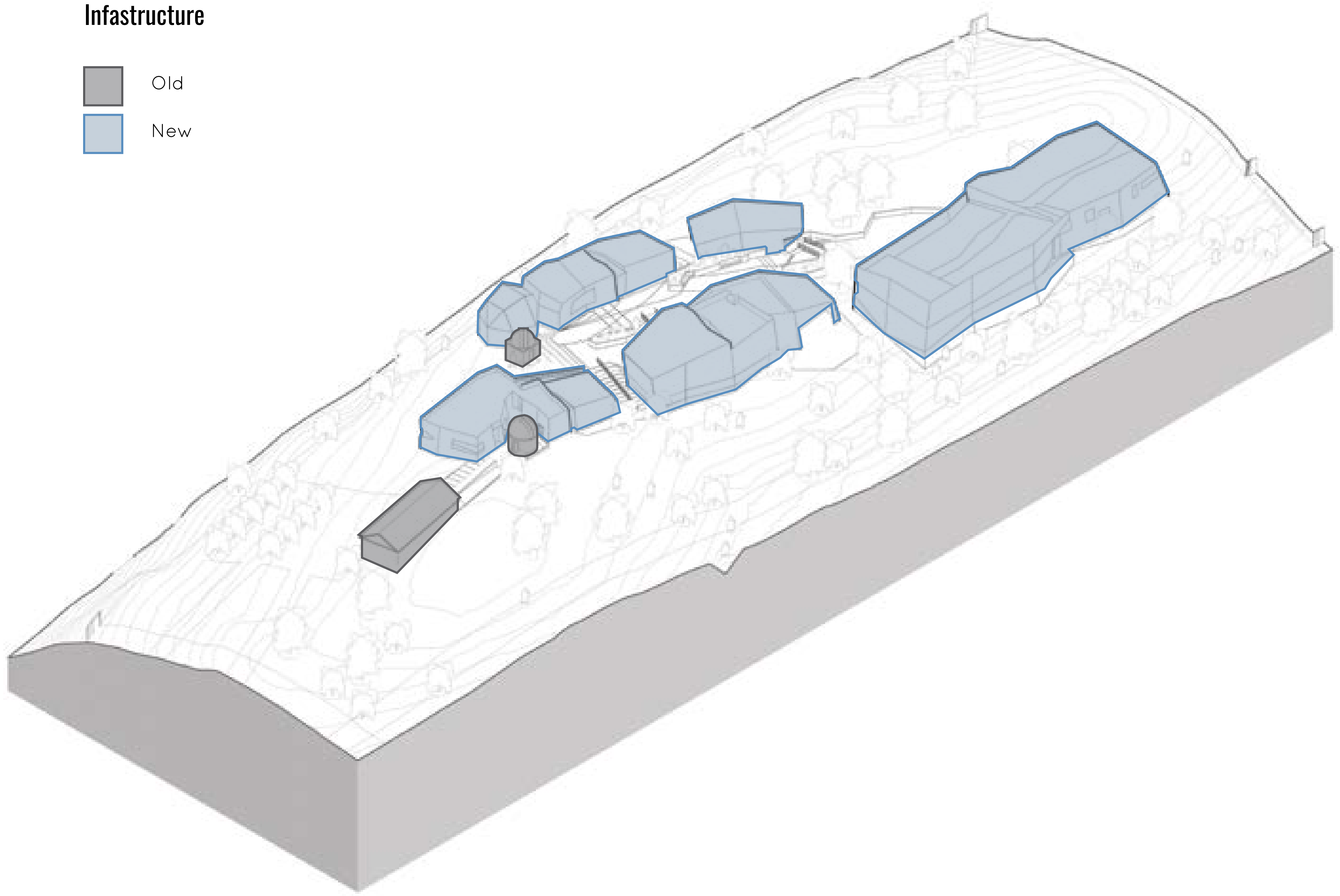


fig 169: Infrastructure diagram

Materiality

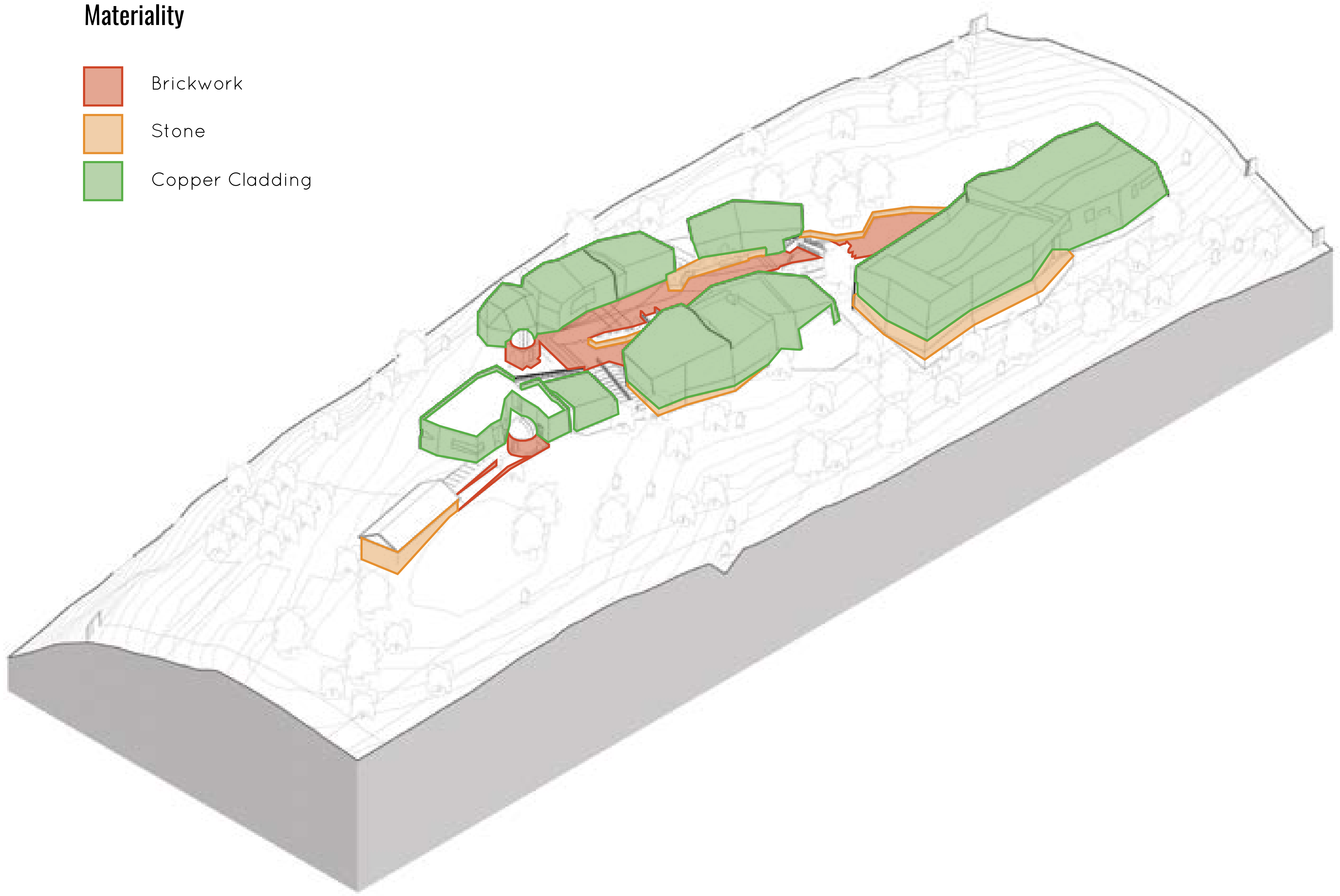


fig 170: Materiality diagram

Opening types

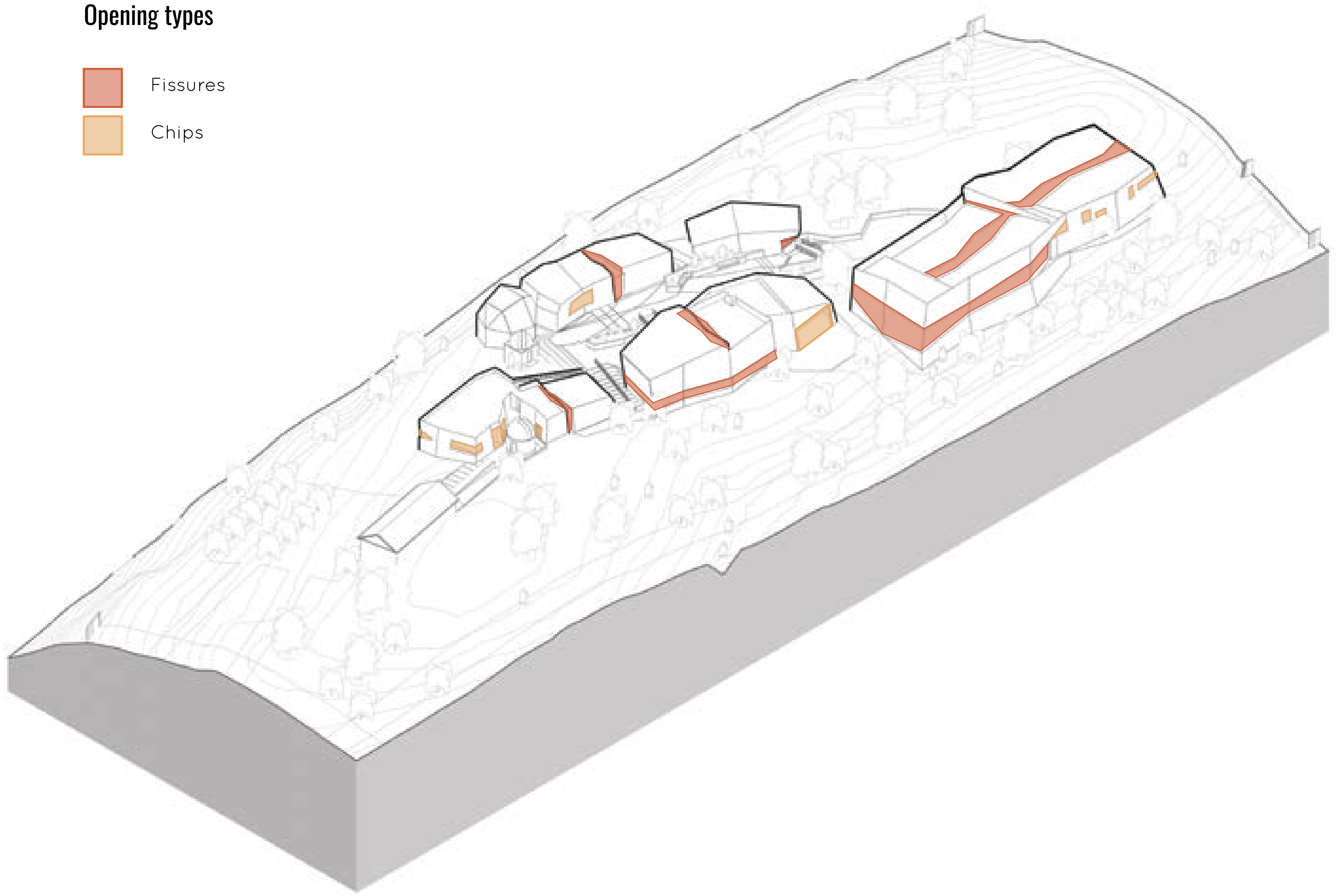


fig 171: Fenestration diagram

Facade informants

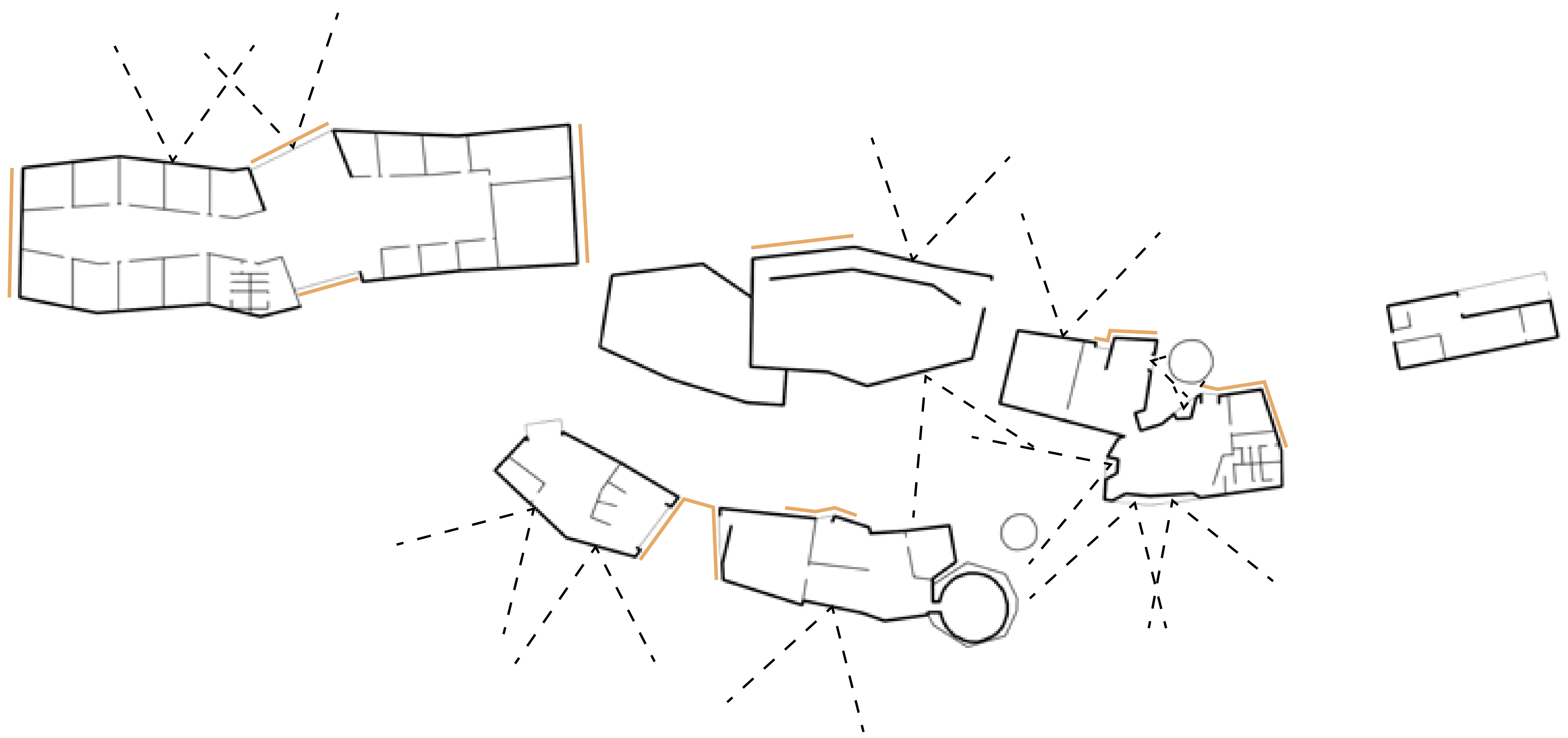


fig 172: Facade informants diagram

Public vs. Private

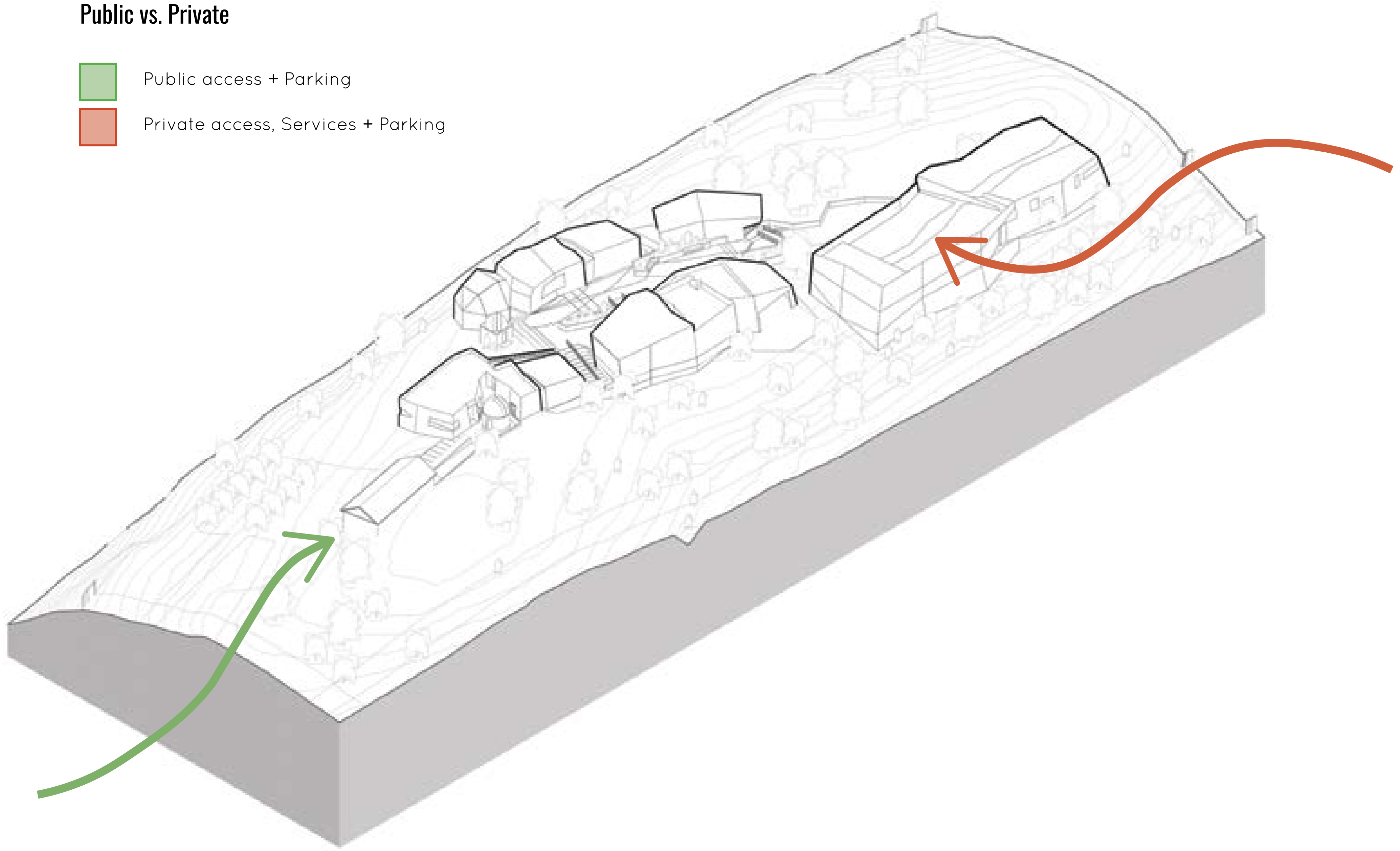


fig 173: Public vs. private diagram

SITE PLAN

Although the site was chosen very early in the course of the design for the Observatory Satellite Research, Development and Visitor's Centre, the specifics of the approach to the site changed throughout the course of the project.

Initially the approach to working with the site and the landscape was to dig the building directly into the side of the ridge; naturally, this was not the most subtle approach and was later changed to a more suitable approach: to gently place the buildings of the scheme on the top and sides of the ridge.

However, given the extreme topology of the site, this approach brought other complications - namely, how does one approach landscaping and circulation when the scheme is placed along the top and sides of a ridge. The suitable solution was, in some ways, a combination of the first two options: to scatter the buildings along the ridge, with some of them slightly sunken into the earth. The specifics of the inbetween sections (the courtyard and the landscaped circulation) were then simply solved with more thoughtful level changes, ramps and stairs. Overall, the landscaping follows the general contours of the ridge itself and the difference in levels is made up for in the circulation through the building, which itself is guided by the narrative of the scheme.

One thing that was never problematic was the amount of space on the site, as a lot of free space was one of the criteria of the site profile that led to the choice of site. This means that parking is available to everyone - private, public and existing parking that is used by staff that already use the site. One of the things that did become an issue was how busses were going to navigate the site. This was solved by creating a route that came in an existing entrance and left through an existing exit - this meant not having to provide turning space for a bus.

fig 174: Final site plan

MASTER PLAN (UPPER GROUND FLOOR)

A: Herbert Baker Library
1 - Entrance lobby
2 - Ticket booth
3 - Security office
4 - Exhibition shop
5 - Shop store
6 - Parking bays

B: History of Observatory Exhibition
7 - Small telescope exhibition
8 - Exhibition managers office
9 - Ablutions
10 - Exhibition floor
11 - Store room

C: Satellite Science Exhibition
12 - Exhibition floor
13 - Video exhibition
14 - Viewing platform

D: Large Tech Exhibition
15 - Viewing gallery
16 - Exhibition floor
17 - Exhibition workshop and delivery area

E: Astronomy Courtyard
18 - Ramp to rooftop
19 - Small telescope exhibition
20 - Human sundial
21 - Public courtyard

F: Interactive Science Exhibition
22 - Exhibition floor
23 - Exhibition manager's office
24 - Planetarium/observatory
25 - Solar system exhibition
26 - Viewing platform

G: Small Tech Exhibition
27 - Nanosatellite education exhibition
28 - Nanosatellite exhibition
29 - Store room

H: Research Centre and Administration
30 - Lobby
31 - Reception
32 - Ablutions
33 - Exhibition staff
34 - Marketing staff
35 - CFO office
36 - Meeting room
37 - Administration staff office
38 - Senior research coordinator office
39 - Staff room
40 - IT officer's office
41 - Senior researcher's office
42 - Assistant researcher's office
43 - Collaborative office space
44 - Lecture gallery viewing mezzanine
45 - Visiting researcher's office

fig 175: Final master plan (upper ground)

MASTER PLAN (LOWER GROUND FLOOR)

Research Centre and Administration
12 - Fabrication laboratory
13 - Airlock/air shower
14 - Female bunny suit changing room
15 - Male bunny suit changing room
16 - Locker room
17 - Researcher work stations
18 - Testing room
19 - Lecture gallery
20 - Viewing balcony
21 - Cafe
22 - Kitchen
23 - Male bathrooms
24 - Female bathrooms
25 - Preparation room for auditorium
26 - Auditorium

Large Tech Exhibition
1 - Entrance tunnel
2 - Exhibition floor
3 - Ablutions
4 - Exhibition manager's office
5 - Workshop access passage
6 - Tool storage
7 - Delivery officer's office
8 - Loading zone
9 - Workshop floor
10 - Machine room
11 - Exhibit storage

fig 176: Final master plan (lower ground)

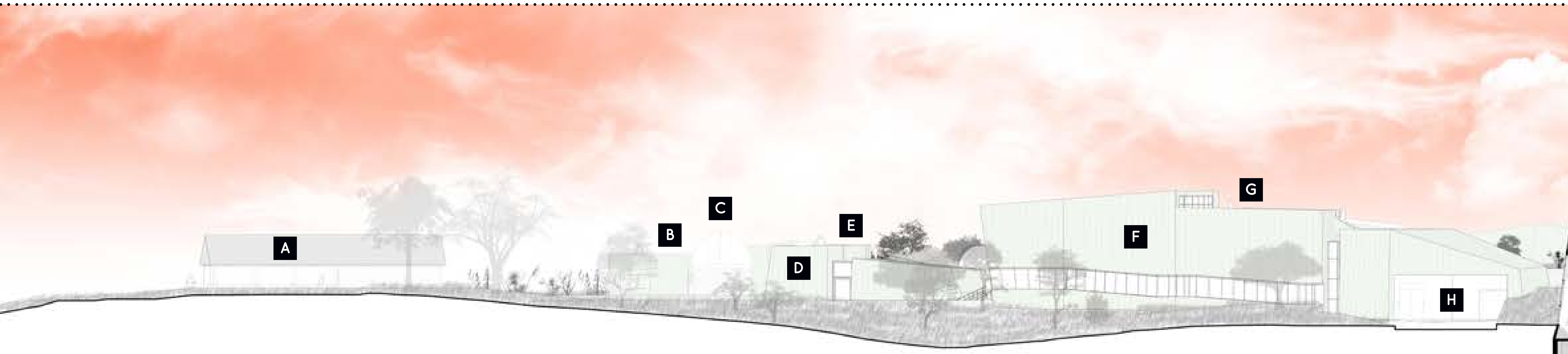
Long Astronomy Courtyard Section
A - Research and administration block
B - Accessible workshop roof
C - Large tech exhibition
D - History of observatory and satellite science accessible roof
E - Herbert Baker library/entrance lobby and parking

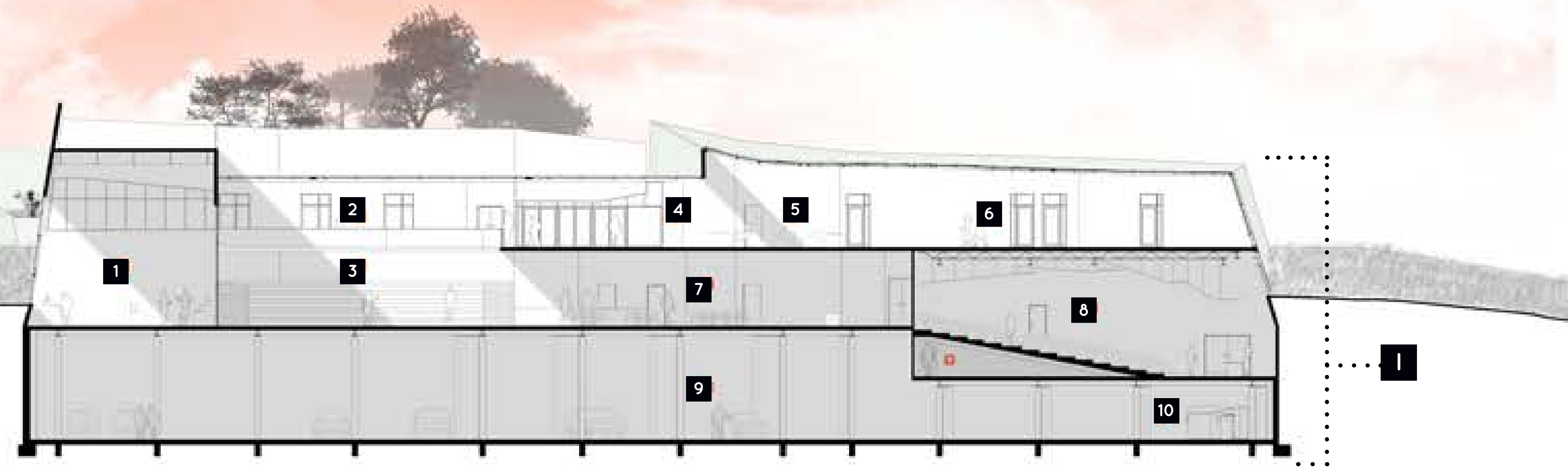
Although it is technically two floors, the research and administration block only stands one floor above the ground line on the south side. This is done by partially submerging the building beneath the floor and achieves a more uniform profile and elevation for the scheme.

The landscaping for the site ensures that the buildings read as more formal architecture from the centre of the scheme. However, the same buildings appear, from the outside of the scheme, to be more "one with the Earth" as the formal landscaping cannot be seen and the buildings are lost amongst the trees.

The astronomy courtyard is intended to be used by visitors to achieve a more personal connection with the sky - either during the day or at night. Elements of the landscaping align with the sun on significant days, encouraging people to question their own connection to the sun and surrounding universe.

fig 177: Long astronomy courtyard section





Although the inner courtyard is hard-surfaced and more formal, the outer edges of the scheme appear to be lost in the trees. As the copper facade patinas, the scheme will appear to age along with the rest of the site. These two decisions are an expression of the concept of marrying architecture, space and the Earth.

Long research and administration section
A - Herbert Baker library/entrance lobby
B - History of Observatory exhibition
C - Small satellite exhibition
D - Satellite science exhibition
E - Accessible roof/viewing platform
F - Large Tech exhibition
G - Accessible roof/viewing platform
H - Workshop
I - Research and administration block

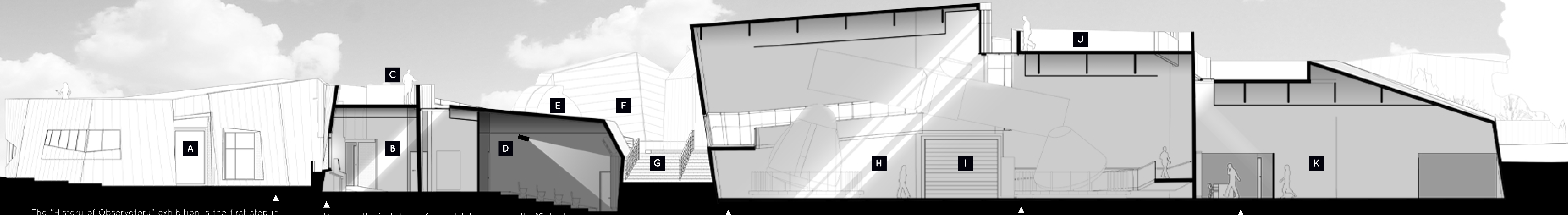
fig 178: Long research and administration section

Research and Administration Block Section
1 - Satellite fabrication labs
2 - Researcher's office and mezzanine
3 - Lecture gallery
4 - Lobby
5 - Reception
6 - Administration offices
7 - Cafe
8 - Auditorium
9 - Private parking garage
10 - Refuse area

As mentioned previously, the research and administration block is partially submerged to allow the profile of the site to be more uniform. The spaces that are underground require less sunlight and so it is less problematic if their south side doesn't have windows.

East-West Section During the Day

A - "History of Observatory" Exhibition
B - "Satellite Science" Exhibition
C - Rooftop viewing platform
D - Video exhibition theatre
E - Existing telescope
F - Interactive science exhibition
G - Access to astronomy courtyard
H - "Large Tech" exhibition hall
I - Access to workshop
J - Rooftop viewing platform
K - Workshop



The "History of Observatory" exhibition is the first step in the narrative journey of the site. This is to teach people, early in the journey, the direct correlation between space research and technological development and the socio-economic benefits.

Much like the first stage of the exhibition journey, the "Satellite Science" exhibition is meant to teach visitors the basics of the science used when launching satellites into space.

The roofs of some of the buildings are walkable. This is an expression of the concept that the architecture is meant to be an extension of the landscape itself. Naturally, the walkable roofs also provide viewing platforms over the surrounding area.

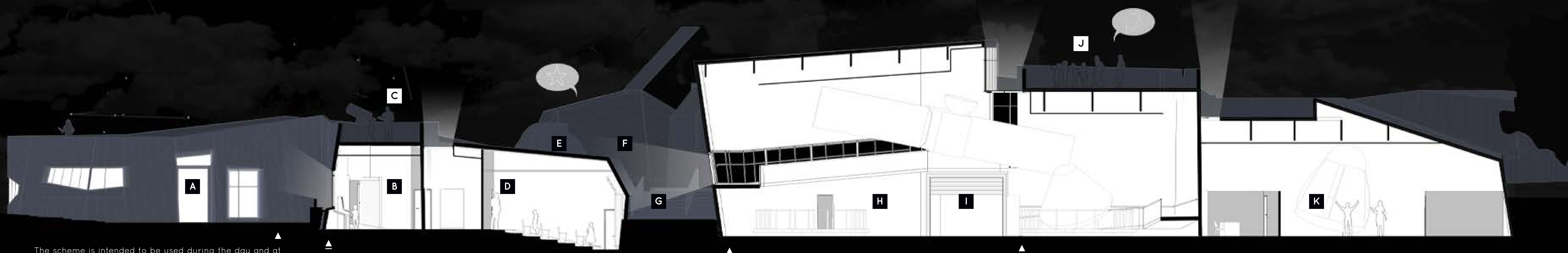
The "Large Tech" exhibition hall houses examples of traditional satellites. The exhibition pieces form a base of knowledge for both the benefits and drawbacks of satellites, typically conventional ones. As the exhibition pieces are large and take up much of the space, visitors get to experience a 360° view of the pieces as they move around the spaces via the ramps.

Once again, the walkable roof becomes an extension of the landscape and allows visitors a different view over the landscape. The viewing platform also looks down into the exhibition hall, offering one last look at the exhibition pieces from an unusual angle.

The private workshop allows the creation of set pieces and exhibition accessories throughout the scheme. It is accessed from a private road and has no direct connection to the public.

fig 179: East-west section through exhibits during the day

East-West Section During the Day
A - "History of Observatory" Exhibition
B - "Satellite Science" Exhibition
C - Rooftop viewing platform
D - Video exhibition theatre
E - Existing telescope
F - Interactive science exhibition
G - Access to astronomy courtyard
H - "Large Tech" exhibition hall
I - Access to workshop
J - Rooftop viewing platform
K - Workshop



▲ The scheme is intended to be used during the day and at night, particularly on certain days of the year. As one can see satellites during the night, the continuation of teaching during the night can be extremely informative.

▲ As the roofs are intended to be used during the night as well as during the day, these spaces can be very valuable as teaching spaces as well; possibly even being used by casual astronomers who already use the site during certain nights of the year.

▲ As people will be using the site during much of the day and night, it becomes hard to service the exhibition spaces. However, on nights when it is less busy or on nights when there are no events planned for the evening time, the spaces can be serviced by the workshop.

▲ Rooftop spaces can be valuable learning spaces - particularly those roofs with unobstructed skies or with a lot of space where groups can gather.

fig 180: East-west section through exhibits during at night

TECHNICAL EXPLORATION

One of the challenges of designing a building with a geological nature such as this, is that the structure and tectonics are more complex. This meant creating a system that could both accommodate for irregular forms as well as achieve the appropriate architectural language.

Early on in the development of the project, as far back as the previous revision of this scheme, a structure and tectonic solution was decided upon. However, for the final design submission the technical solution needed to be developed fully. This not only meant designing the details of the structure and tectonics, but also more fully fleshing out the structure for the rest of the site - this will be expanded upon further into this chapter.

Structurally and tectonically, the solution that was decided upon consisted of a shell made from steel members and then copper cladding around the outside of the shell and plasterboard on the inside of these shells. This solution allowed for a thinner shell, allowing for a closer relationship between the outside (landscape and sky) and the inside.

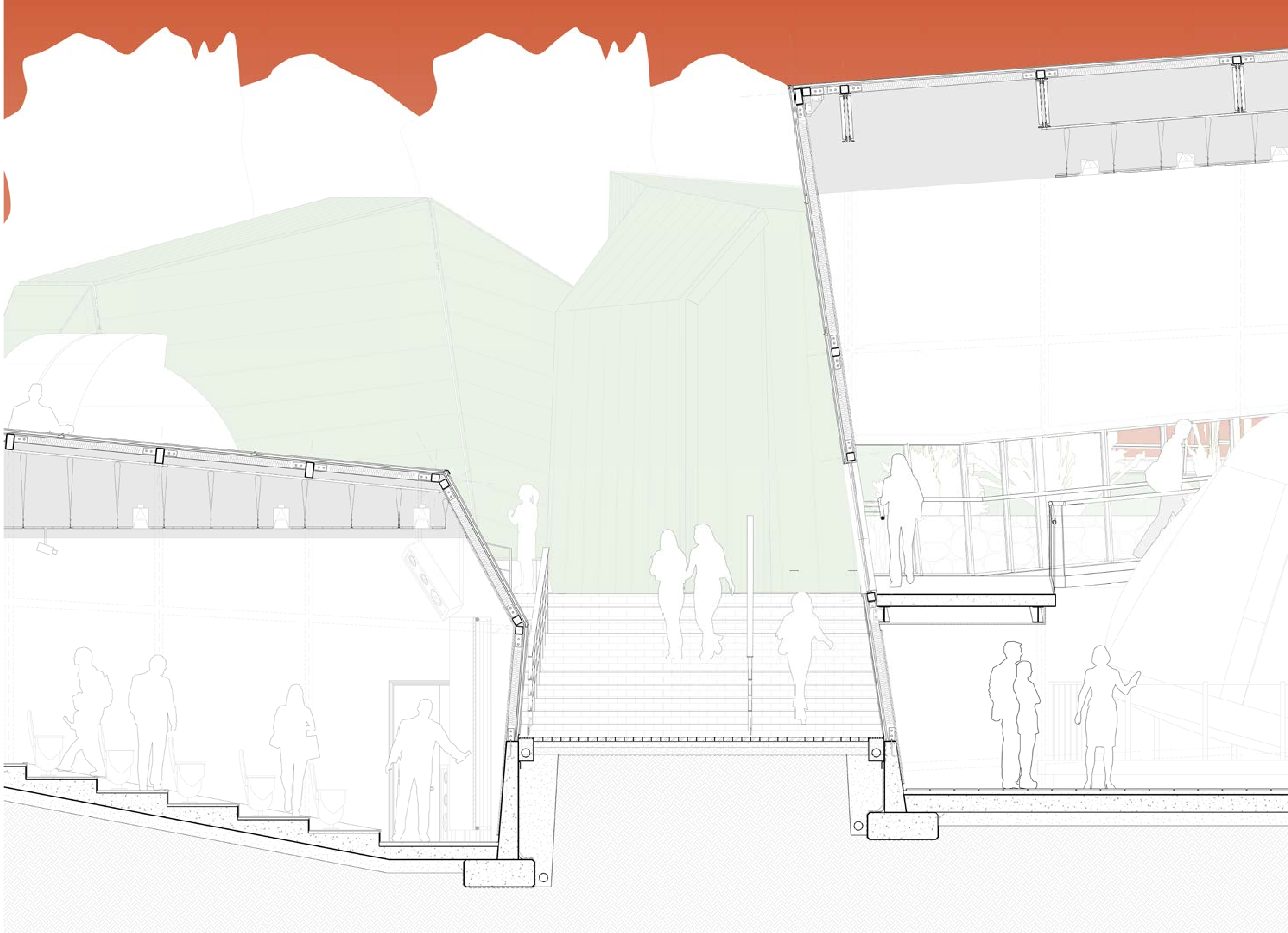


fig 181: Perimeter section through video and large tech exhibitions

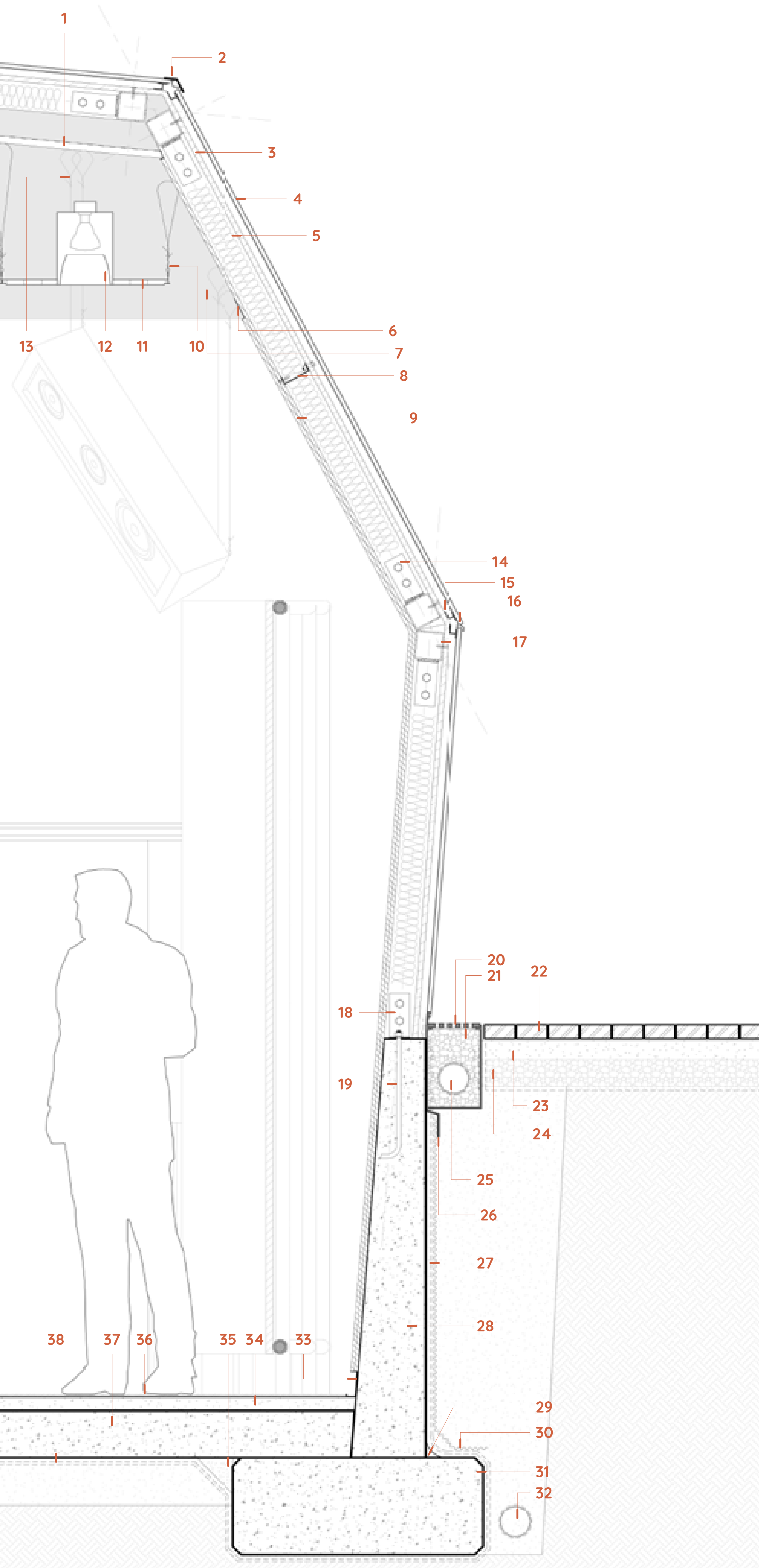


fig 182: "How Satellites Work" Exhibition Hall Perimeter Section

"How Satellites Work" Exhibition Hall Perimeter Section

1. 25 x 25mm galvanised steel ceiling grid structure fixed to U/S of 100 x 200mm RHS beam with rivets
2. Rheinzink flashing profile tucked between panel and bracket, fixed in place with rivets. Ridge cap flashing to be fixed over Rheinzink flashing and to overlap both Rheinzink panels. Ridge cap to match cladding panels.
3. 18mm oriented strand board, fixed to 100 x 100mm SHS members with self-tapping screws and fixed to galvanised steel runner channels with M10 bolts
4. 1700 x 400 x 0.7mm Rheinzink-prepatina copper cladding, fixed to substructure with blind rivets as per manufacturer specification
5. 75mm Cavitybatt wall insulation
6. 80 x 12.5mm anodised aluminium trim expoxied to second plasterboard skin
7. Exposed plasterboard skin to be skimmed and painted dark grey
8. 100 x 31mm galvanised steel runner channel sub-structure fixed to 100 x 100mm SHS with rivets
9. Double skin 12.5mm plasterboard fixed to galvanised steel runner channel at 600 centres. Skimmed and painted white
10. Suspension wires to suspend T-ceiling grid from ceiling grid structure 4000mm above FFL of landing
11. 1200 x 600 x 19mm acoustic ceiling tiles with tegular edge dropped into ceiling grid
12. 200mm recessed can downlight fitted into 1200 x 600 x 19mm ceiling tile
13. Suspension wired to suspend sound equipment from ceiling grid or from 100 x 100mm SHS members
14. 165 x 165 x 6.0mm L-angle bolted to vertical and horizontal 100 x 100mm SHS members with 16M bolts. Vertical and horizontal members to be welded together
15. Two-part Rheinzink bracket substructure, fixed to OSB substructure with Rheinzink recommended mechanical fasteners
16. Rheinzink flashing profile tucked between panel and bracket, fixed in place with rivets
17. 100 x 100 x 4.8mm SHS members
18. 165 x 165 x 6.0mm L-angle bolted to vertical 100 x 100mm SHS member with 16M bolts. L-angle to be fixed to reinforced concrete upstand beam with M16 anchor bolt
19. M16 anchor bolt to be cast into reinforced concrete upstand beam
20. Steel drainage channel gate
21. Gravel
22. 50 x 110 x 220mm brick pavers
23. Sand blinding layer
24. Gravel drainage layer
25. 110mm perforated drainage pipe covered with geofabric
26. 3.0mm thick flashing to be tucked between 200 x 300mm drainage channel and bitument waterproofing membranes, fixed to drainage channel with waterproof epoxy. Drainage channel to include 150mm built in flashing, tucked between cladding panel and OSB substructure
27. Waterproofing to be one layer of Derbigum CG4 on one later Derbigum CG3 waterproofing membrane, sealed to primed surface by torch-fusion
28. 1500mm high reinforced concrete upstand beam
29. 75 x 75mm chamfer to protect waterproofing and drainage sheet
30. Derbigum delta drainage sheet to be tucked underneath flashing, installed to manufacturer's specification
31. 900 x 350mm reinforced concrete strip footing
32. 110mm perforated drainage piped covered with geofabric
33. Anodised aluminium shadownline trim to be epoxied to reinforced concrete upstand beam
34. 25mm screed layer
35. 130 x 130mm chamfer to protect waterproofing
36. 10mm grey carpet to be fixed to 25mm screed layer
37. 170mm reinforced concrete groundslab
38. One layer of Derbigum CG4 on one layer of Derbigum CG3 waterproofing membrane, with 100mm side laps and 150mm end laps. To receive sand leveling/ blinding course

"Large Tech" Exhibition Hall Perimeter Detail

1. 100 x 100 x 4.8mm SHS primary beam painted black
2. 100 x 100 x 4.8mm SHS secondary beam painted black
3. 1700 x 400 x 0.7mm Rheinzink-prepatina copper cladding, fixed to substructure with blind rivets as per manufacturer specification
4. 18mm oriented strand board, fixed to 100 x 100mm SHS members with self-tapping screws and fixed to galvanised steel runner channels with M10 bolts
5. M16 nut to be countersunk into 18mm oriented strand board to allow for placement of cladding system
6. Two-part Rheinzink bracket substructure, fixed to OSB substructure with Rheinzink recommended mechanical fasteners
7. Rheinzink flashing profile to be tucked underneath overhead Rheinzink panel and to overlap Rheinzink panel below. Flashing to be fixed to both panels with rivets
8. Ridge cap flashing to be fixed over Rheinzink flashing and to overlap both Rheinzink panels. Ridge cap to match cladding panels
9. M16 bolts to fix 100 x 200 x 4.8mm RHS to primary 100 x 100 x 4.8mm SHS members and to secondary 100 x 100 x 4.8 SHS members via L-angle bracket
10. Anodised aluminium trim fixed to RHS with epoxy. Trim to be painted black
11. 100 x 200 x 4.8 RHS ridge beam
12. 12.5mm plasterboard to be skimmed and painted dark grey. Fixed to galvanised steel runner channel at 600 centres
13. 100 x 31mm galvanised steel runner channel substructure foxed to 100 x 100 SHS with rivets
14. M10 bolt to fix 18mm OSB to galvanised steel runner channel
15. Flat head screw to fix plasterboard to galvanised steel channel. Skimmed and painted over
16. 100 x 100 x 4.8mm SHS structure beyond
17. 12.5mm plasterboard to be skimmed and painted dark grey. Fixed to galvanised steel runner channel at 600 centres
18. 8mm gusset plate to be welded to 100 x 100 x 4.8mm SHS beams and columns. Gusset plate to be painted black
19. Weld
20. M16 bolt used to fix primary and secondary 100 x 100 SHS members via L-angle bracket
21. 75mm Cavitybatt insulation
22. 165 x 165 x 6.0mm L-angle bolted to primary and secondary 100 x 100mm SHS members and M16 bolts. Primary and secondary members to be welded together
23. 64 x 64 x 6.4mm equal leg angles to form top and bottom chords of joist girder. Welded to girder webs
24. Joist girder webs made from 64 x 64 x 6.4mm steel equal leg angles
25. Double skin 12.5mm plasterboard fixed to galvanised steel runner channel at 600 centres. Skimmed and painted white
26. 100 x 100 x 4.8mm SHS beam beyond as window lintel
27. Aluminium brake closure trim
28. 120 x 30mm aluminium storefront head mullion
29. Double glazed window panel
30. Sealent bead
31. Weep-hole for counter flashing to be at 300mm centres
32. Counter flashing to tuck behind vapour barrier and above Rheinzink panel. To be fixed to 100 x 100 x 4.8mm SHS with self tapping screw
33. Self tapping screw to fix closure trim and counterflashing to 100 x 100 x 4.8mm
34. Weather barrier to fixed to back of 18mm oriented strand board
35. 50mmØ bar used as handrail, fixed to SHS columns with 10mmØ steel pins. Handrail to be painted dark grey
36. 10mmØ steel pins welded to handrail and SHS columns. Pins to be painted dark grey

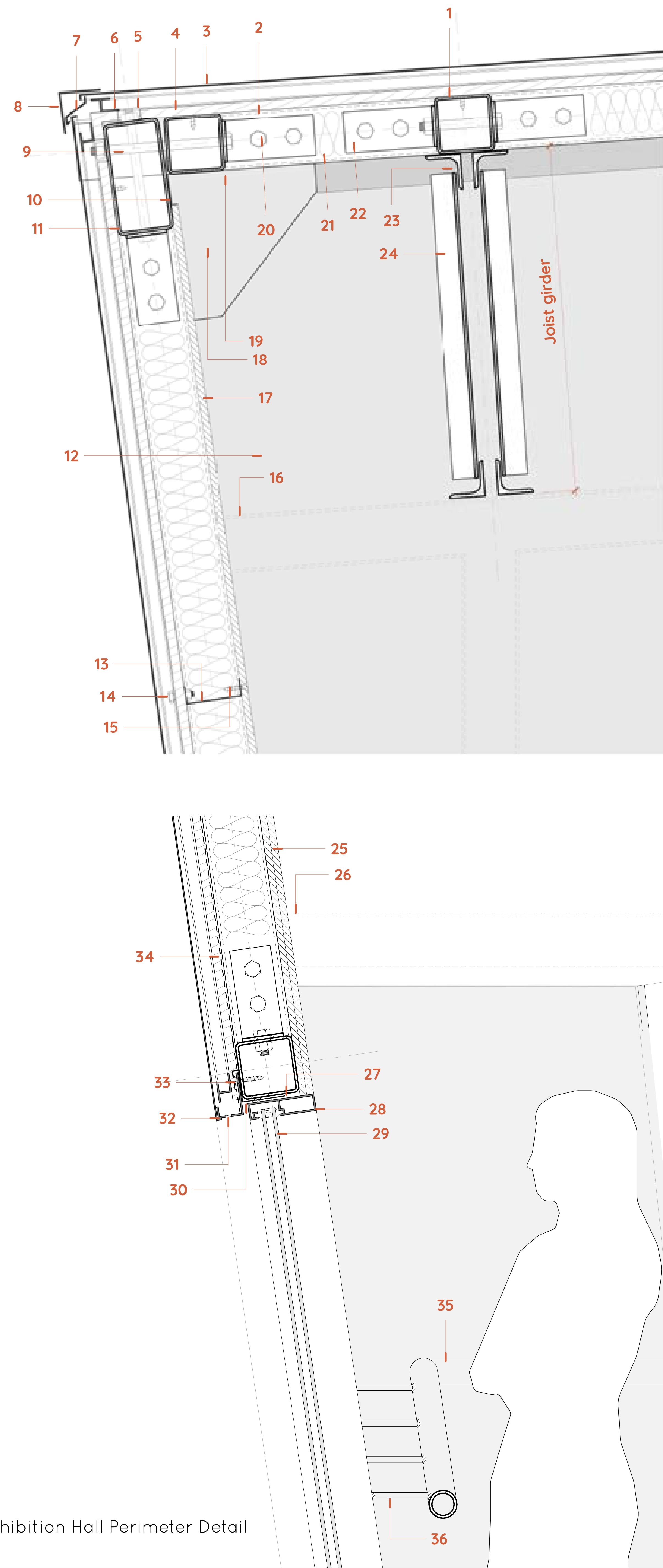


fig 183: "Large Tech" Exhibition Hall Perimeter Detail

TECTONIC EXPLORATION

As mentioned previously, a problem with choosing to design such geological forms was figuring out the specifics of how to get the forms to work plausibly from a structural and tectonic point of view.

Structurally, the solution was to create a shell from 100x100x4.8mm square hollow sections, spaced about 3000mm apart vertically and 2000mm apart horizontally - demonstrated in C. This would form a strong enough shell for a cladding to be attached. This also freed up the facades to tie in more closely to the central design concept - to marry architecture, the sky and the Earth. Structurally, some spaces were more demanding than others - specifically the large tech exhibit and the workshop spaces. In these spaces, trusses were used (B) to provide better support in the event that something would be hung from the roof.

The facade itself (A), or rather the cladding used over the structural shell, is made up, primarily, from copper cladding. As stated previously, this was to allow the buildings to patina with age and add depth to the connection between the architecture and the site.

The shell is made from vertical 100x100x 4.8mm steel hollow members spaced at 2000mm c/c (2) and fixed to horizontal 100x100x4.8mm steel hollow members spaced at 3000m c/c (5); they're fixed to each other firstly by being bolted (4) to 100x100x4.8mm equal leg angles (3) and then welded together. The internal cladding is two layers of 12.5mm gypsum plasterboard (1), which is fixed to galvanised steel runner channels and then skimmed and painted - different spaces have different treatments for the walls, depending on the specific usage of the space. The white walls were intended to keep the interior simple in order to turn the focus on to the exhibits. The external facade is made up of the standing seam copper cladding (9) which is fixed to mechanically to a 25mm sub-structure (8) which in turn is fixed mechanically to 18mm oriented strand board (6). In between the OSB and the sub-structure is a vapour barrier (7) to ensure that the interior is kept moisture free, specifically closer to the ground and near to the edges of the forms.

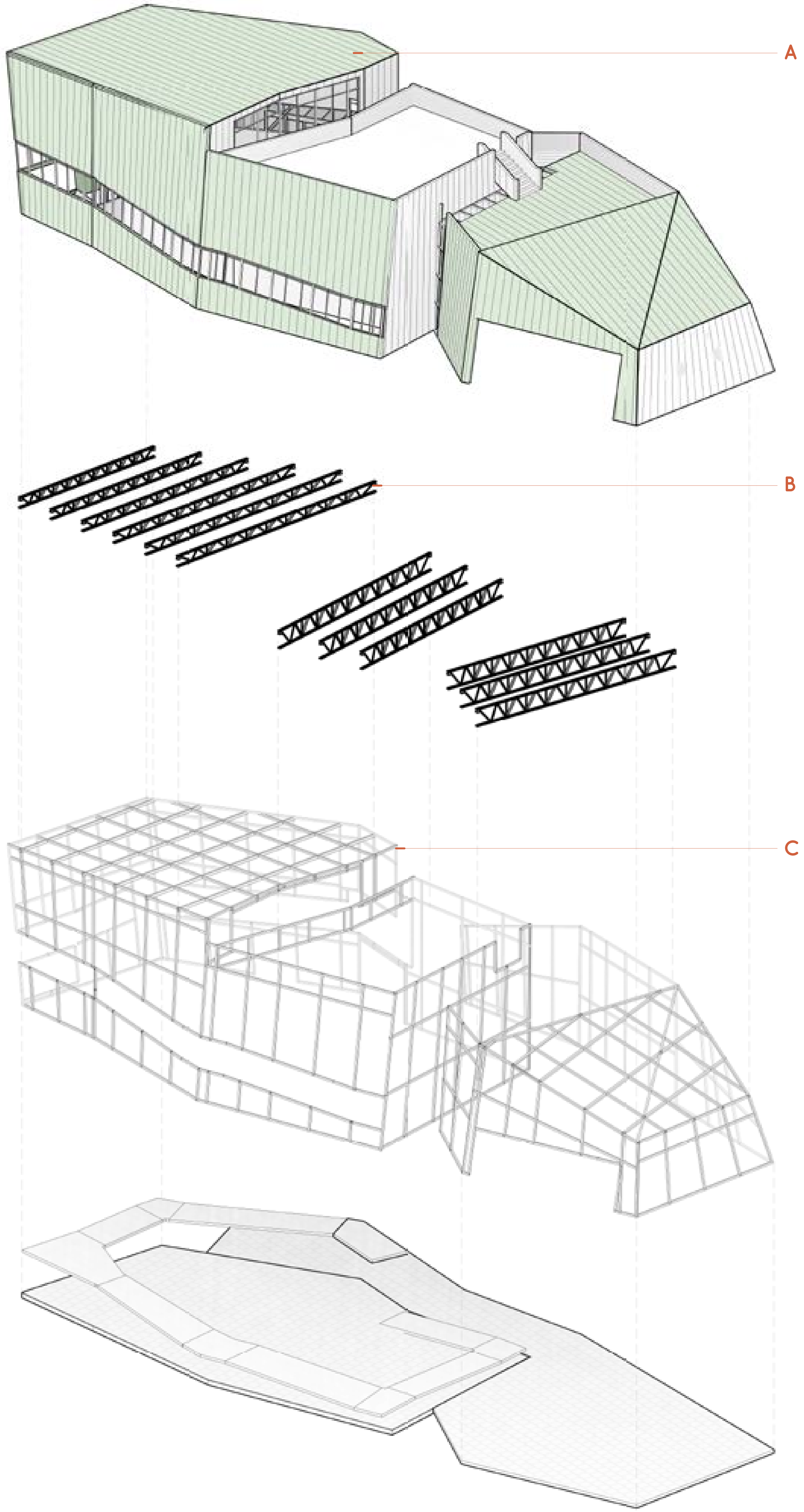


fig 184: Exploded structure and tectonics axonometric

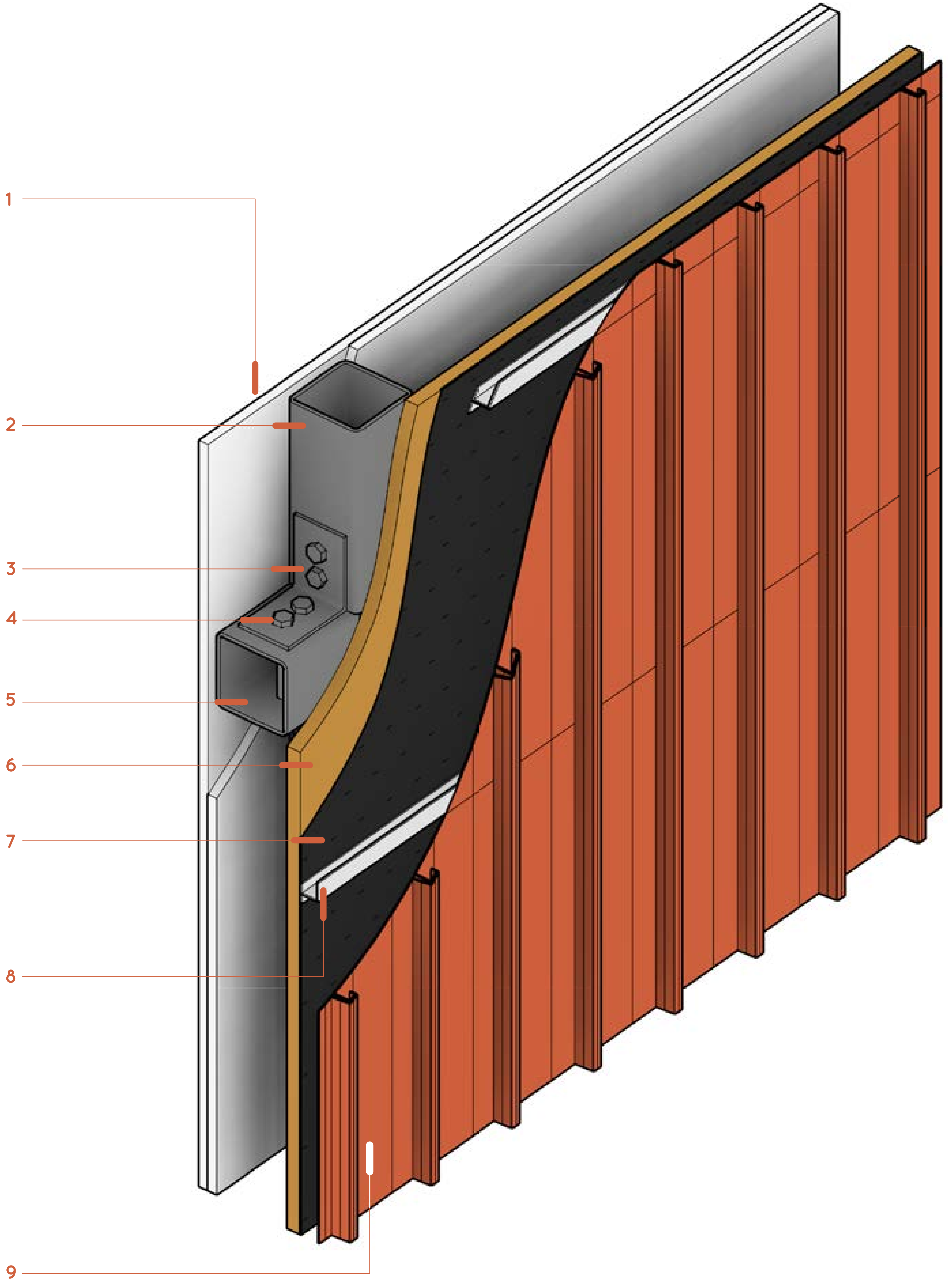
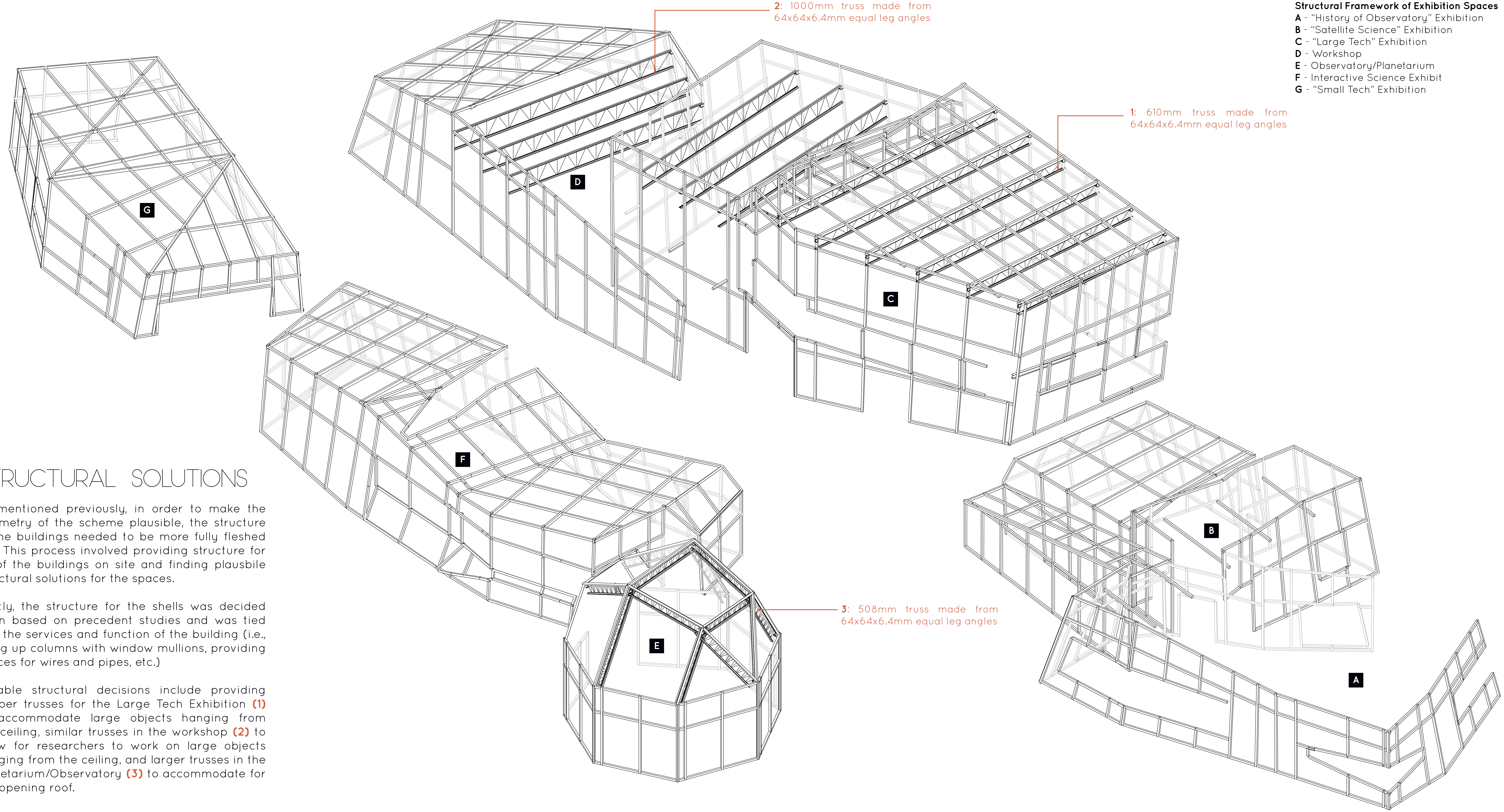


fig 185: Wall tectonic cut-away axonometric



STRUCTURAL SOLUTIONS

As mentioned previously, in order to make the geometry of the scheme plausible, the structure of the buildings needed to be more fully fleshed out. This process involved providing structure for all of the buildings on site and finding plausbile structural solutions for the spaces.

Firstly, the structure for the shells was decided upon based on precedent studies and was tied into the services and function of the building (i.e., lining up columns with window mullions, providing spaces for wires and pipes, etc.)

Notable structural decisions include providing deeper trusses for the Large Tech Exhibition **(1)** to accommodate large objects hanging from the ceiling, similar trusses in the workshop **(2)** to allow for researchers to work on large objects hanging from the ceiling, and larger trusses in the Planetarium/Observatory **(3)** to accommodate for the opening roof.

fig 186: Full scheme structural axonometric

fig 187: Astronomy courtyard render

fig 188: Large tech exhibition render

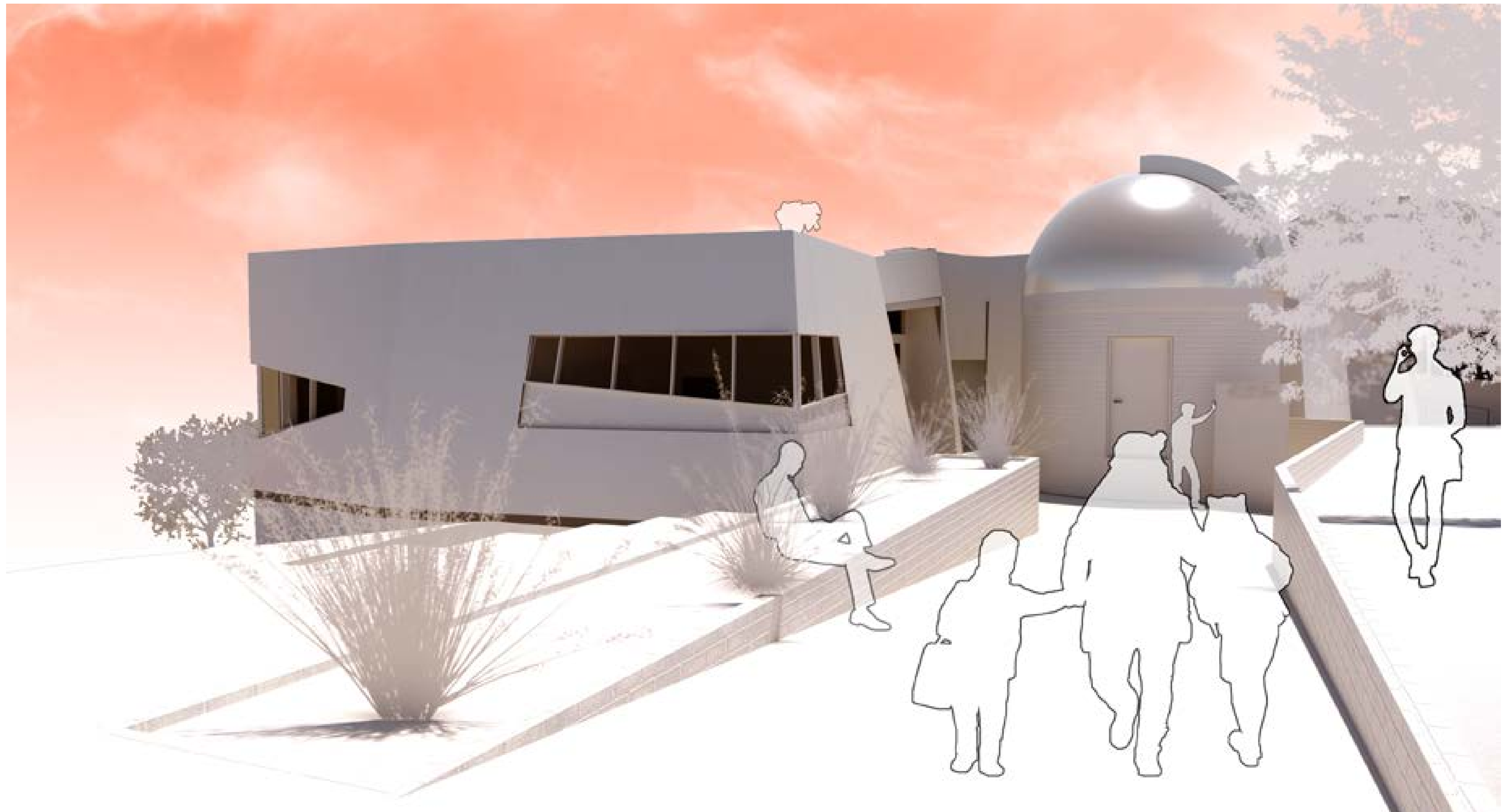


fig 189: Small telescope / entrance ramp white render

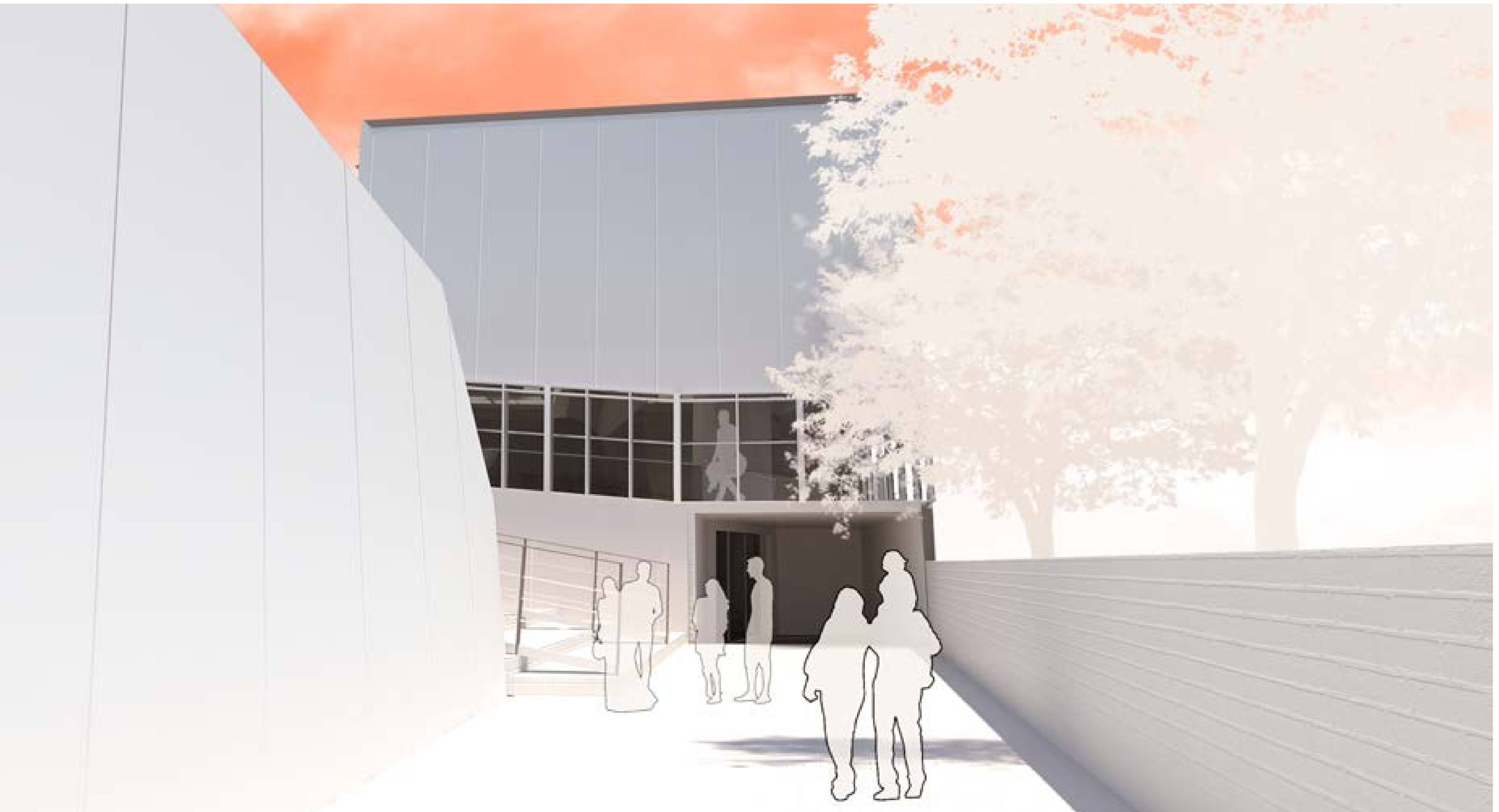


fig 191: External walkway / viewing deck white render

fig 190: History of Observatory exhibition white render

fig 192: Staircase leading to astronomy courtyard white render

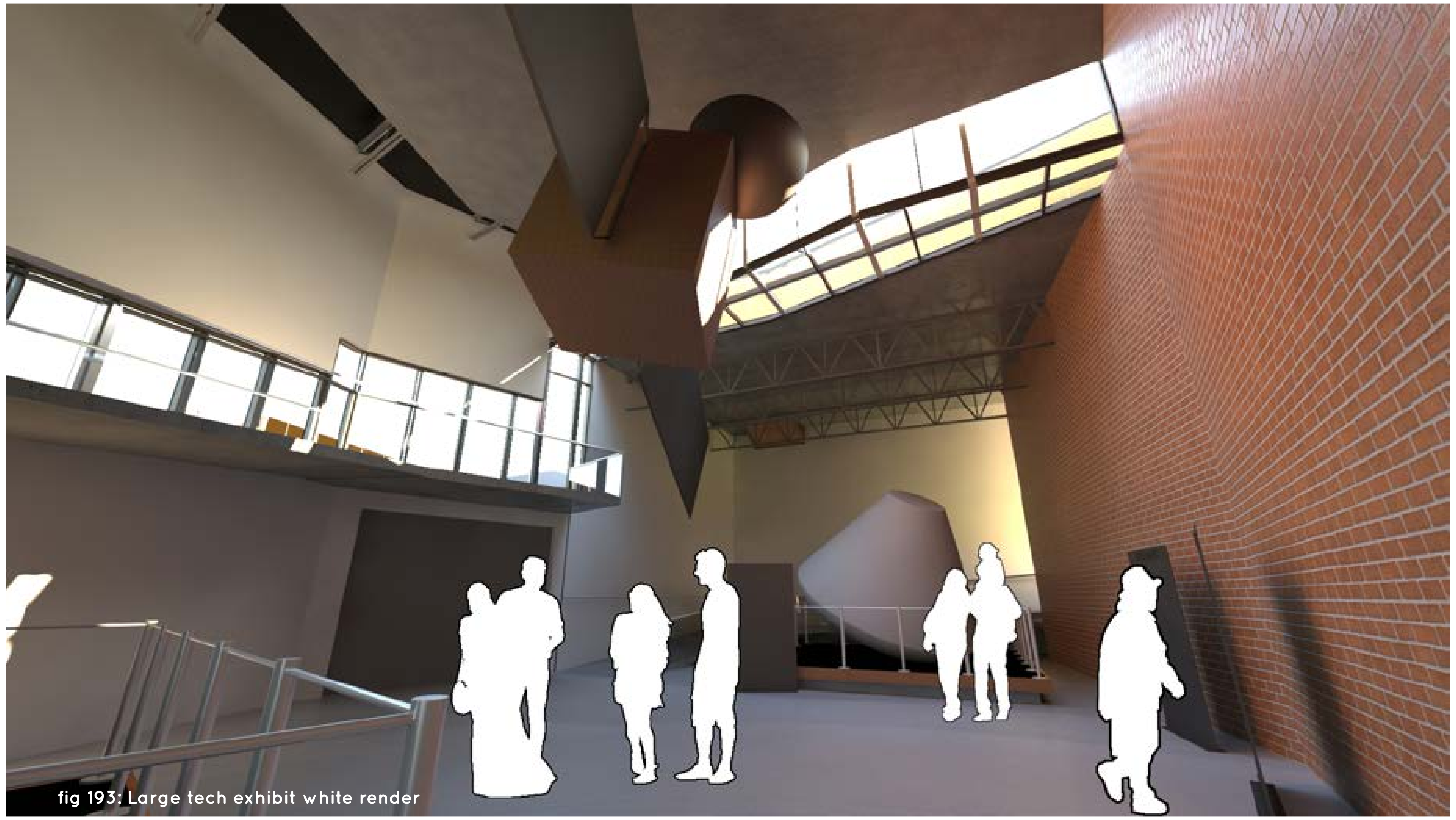


fig 193: Large tech exhibit white render

fig 195: Exterior research and administration block white render

fig 194: Astronomy courtyard white render

fig 196: Interior research and administration block white re

7 / 7 References

"The greatest part of a writer's time is spent in reading, in order to write: a man will turn over half a library to make one book."

- Samuel Johnson

fig 197: SpaceX Dragon Capsule (Pixabay, 2018)

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LIST OF FIGURES

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