EXPLORING OPPORTUNITIES FOR 3D PRINTING CONSTRUCTION IN EMERGING CONTEXTS:

THROUGH THE DESIGN OF A VOCATIONAL TRAINING COLLEGE IN PHILIPPI

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2022

Supervisor: Michael Louw
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to the original Architect,
who created us to create

PLAGIARISM DECLARATION

Marie Snyman

SNYMAR020

APG5079W

Declaration

I know that plagiarism is wrong. Plagiarism is to use another's work and pretend that it is one's own.

I have used the ...Harvard... convention for citation and referencing. Each contribution to, and quotation in, this ....dissertation... from the work(s) of other people has been attributed and has been cited and referenced.

This essay/report/project/... dissertation .. is my own work.

I have not allowed, and will not allow anyone, to copy my work with the intention of passing it off as his or her own work.

Signature ___Signed by candidate___

Date ____11-09-2022______________________

ETHICS APPROVAL

PRE-SCREENING QUESTIONNAIRE OUTCOME LETTER

STU-EBE-2022-PSQ000039

2022/08/08

Dear Marie Snyman,

Your Ethics pre-screening questionnaire (PSQ) has been evaluated by your departmental ethics representative. Based on the information supplied in your PSQ, it has been determined that you do not need to make a full ethics application for the research project in question.

You may proceed with your research project titled:

Employing 3D Printing technology in the local construction industry; implications and benefits of introducing the revolutionary technology in developing cities like Philippi.

Please note that should aspect(s) of your current project change, you should submit a new PSQ in order to determine whether the changed aspects increase the ethical risks of your project. It may be the case that project changes could require a full ethics application and review process.

Regards,

Faculty Research Ethics Committee

PREFACE

For my 11th birthday, my parents bought me one very long rope, a little bucket, and two pulleys. That summer I tried out every imaginable combination of the two-pulley system to hoist up and lower my bucket at all the different angles and heights. I was fascinated by this simple trick that saved me all the trouble of climbing down and up again to get what I needed. Ever since, I've honed an admiration for mankind's ability to invent tools and techniques that save time, energy, and resources. Maybe I should have studied to become an engineer... but I fell in love with architecture, because it goes beyond the practical and masterfully employs technology to create spaces and experiences that are not only rational and functional but also beautiful. So, I set out at the start of this year to really gain a deep understanding and appreciation of the intricate and ancient connection that exists between building technology and architecture.

As we are entering yet another industrial revolution, the development of new technologies is triggering major changes in the field of construction, and architecture must change with it. What Antonio Sant'Elia proclaimed in his futurist manifesto nearly a hundred years ago, is as true now as it was then; *"that just as the ancients drew their inspiration from natural elements, we – the materially and spiritually artificial – must find our inspiration in the new mechanical world we have created,* ***and our architecture must be its most beautiful expression, its most complete synthesis, its most effective integration."***

ACKNOWLEDGEMENTS

Thank you to my supervisor Michael Louw, your guidance and insights throughout the year. Special thanks to John from the workshop for the encouragement and technical support I needed to experiment with clay printing.

Thank you to my family for always asking questions and sharing in my excitement. But most of all… thank you to my parents. For teaching me how to ***see**, **think**, and* ***understand**. And for every cent spent on my dreams, and every second spent listening to them.*

Dankie span.

CONTENTS

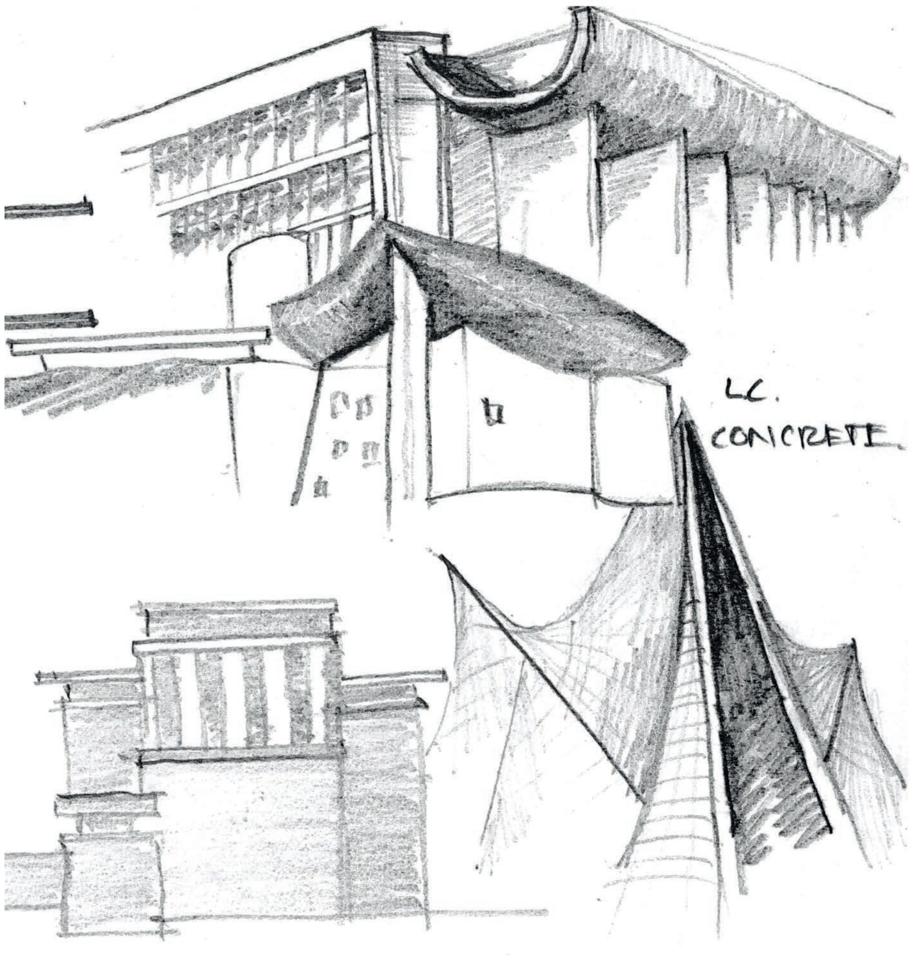


FIG 1

INTRODUCTION

Architects create designs in a conceptual world that is to be built in a physical world which is governed by completely different constraints, tools, and materials. There is therefore a very direct and intricate relationship between the design of a building and the methods used to construct it. On the one hand, architects can modify and manipulate construction to achieve a particular effect. A notion exploited by designers like Venturi of the Post-Modern movement. On the other hand, the rationale of the constructional technique can be seen as the generator which influences the design solution. In reality most solutions are a particular mix of the two going back and forth in a loop throughout the design process.

To make this more complicated, new technologies, materials, software, and construction methods are continuously introduced to the field of construction and architecture. This leads to continuous shifts in the fundamental principles and processes that facilitate architectural design and making. And the rate at which these new technologies are introduced will only increase. Forecasters like Ray Kurtzweil are predicting that we will see the same total industry growth of the last 100 years happen in the next decade. We could raise the question of whether this is a problem or an opportunity? As architects we can actively facilitate these changes, so they happen in a social and environmentally sustainable manner and solve more problems than they create.

Part of facilitating the changes is understanding them. In an attempt to do so, this dissertation investigates the topsy-turvy relationship between construction and design in a context of regular technological innovation. Architects must continuously update their knowledge of the world where construction takes place in order to design for the new possibilities it presents. This has never been more crucial than now when we find ourselves in an age that sees developments and breakthroughs happen at an unprecedented scale and velocity. Therefore, the investigation sets out to understand how this construction-design feedback loop works when it comes to 3D printing construction - one of the more recent additions to the construction industry. What forms and aesthetics are inherent within, and generated by this construction method that is fundamentally different from its predecessors? And, importantly, what are the opportunities and implications of introducing 3D printing construction in the local industry and South African context?

The dissertation aims to first establish what the current relationship between design and construction is, secondly to paint a clearer picture of the kind of future that could be made possible with the help of new tools like 3D printing, and lastly to take a stab at creating such a future in the form of a design proposal. Consequently, the paper is set out in three parts: Part 1 & 2 investigate theoretical and technical aspects while part 3 shows how these could be applied in a speculative design proposal. Essentially, where we are , where we want to be, and how to get there.

There is a very ancient and direct relationship between the design of a building and the methods used to construct it.

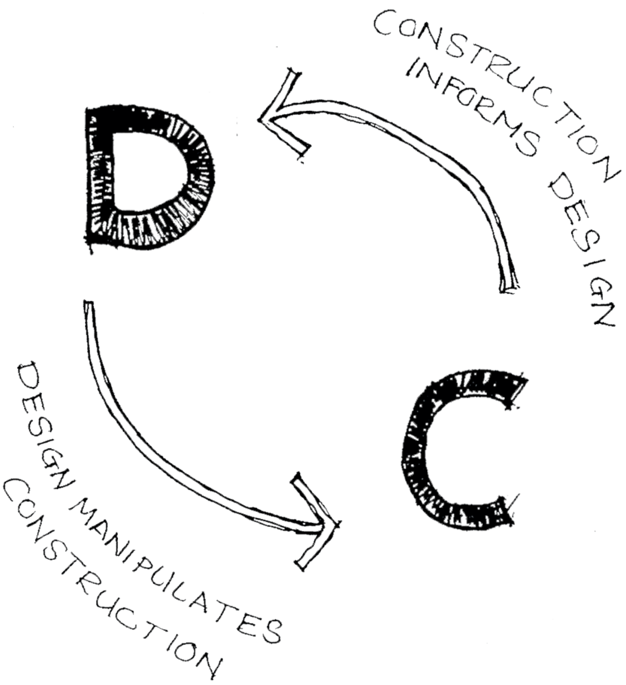

D
C
CONSTRUCTION INFORMS DESIGN
DESIGN MANIPULATES CONSTRUCTION

FIG 2

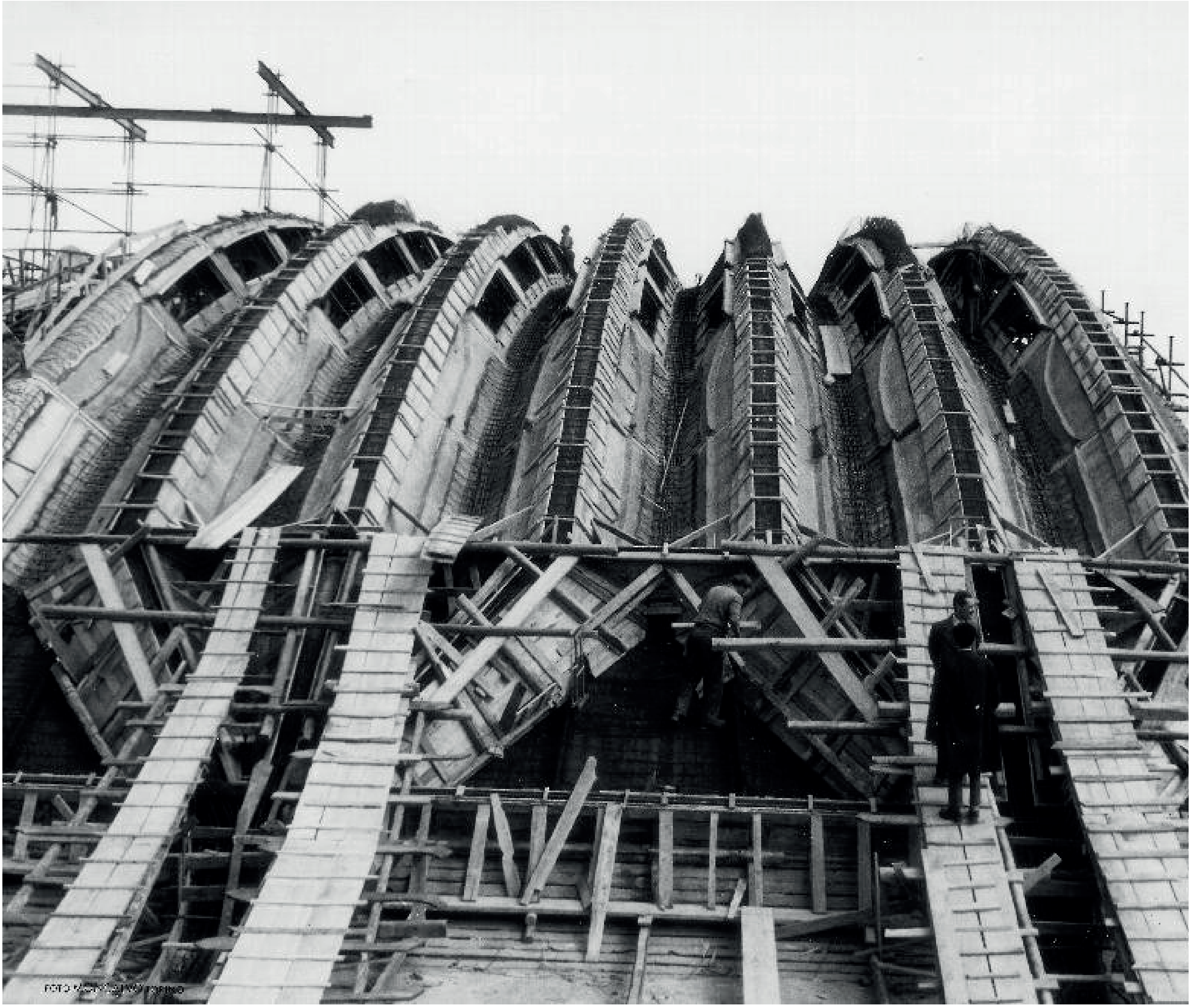


FIG 3 Construction of Turin Exhibition hall by Pier Luigi Nervi, 1948.

"Construction gathers in a unique synthesis the elements of manual labour, industrial organization, scientific theory, aesthetic sensibility and great economic interest...

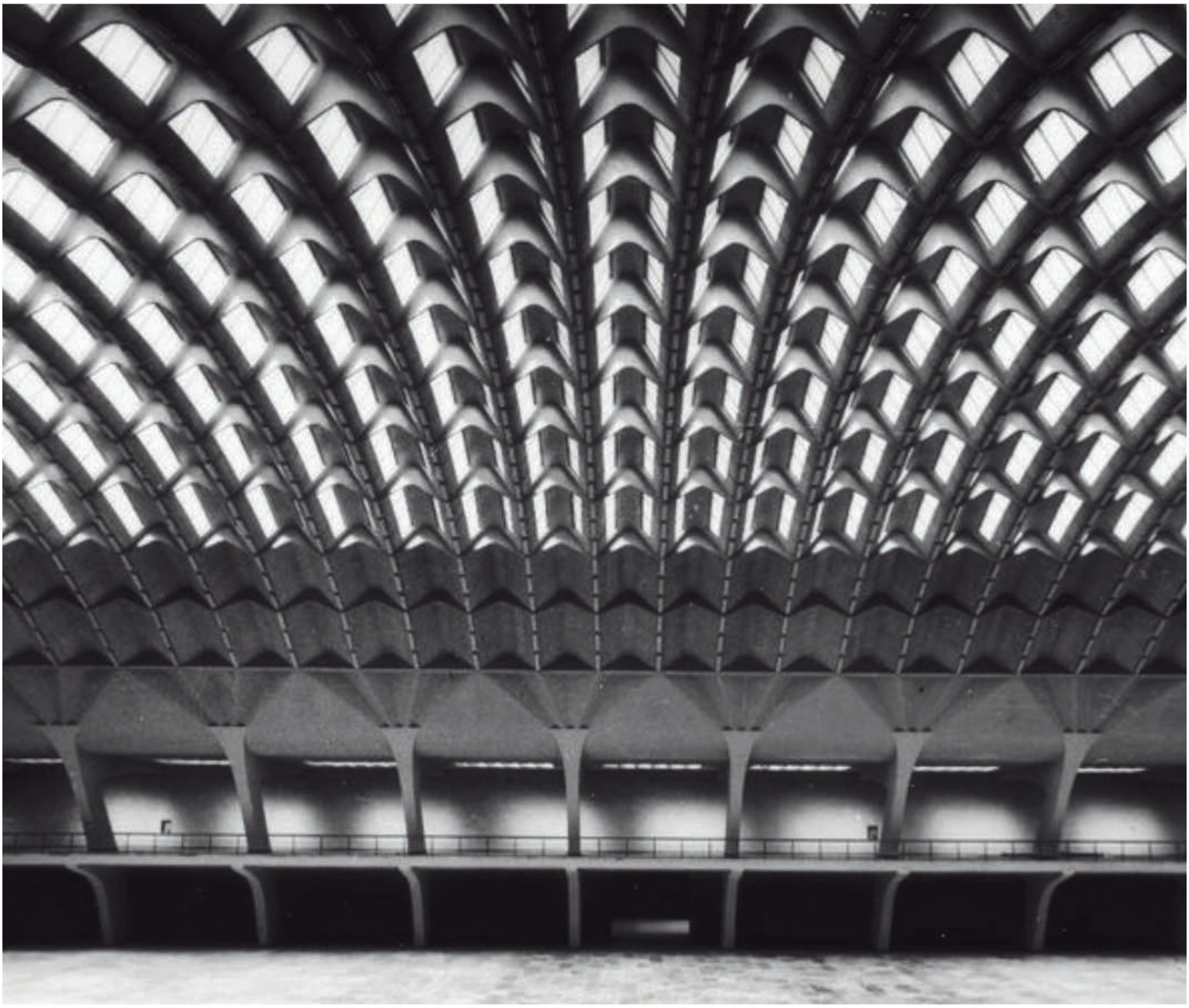


FIG 4 **Inside the exhibition hall after completion**

... It creates our physical
environment, and this exercises
a silent but deep educational
influence on each one of us."

- Pier Luigi Nervi, Structural Engineer

PART 1

CONSTRUCTION & DESIGN

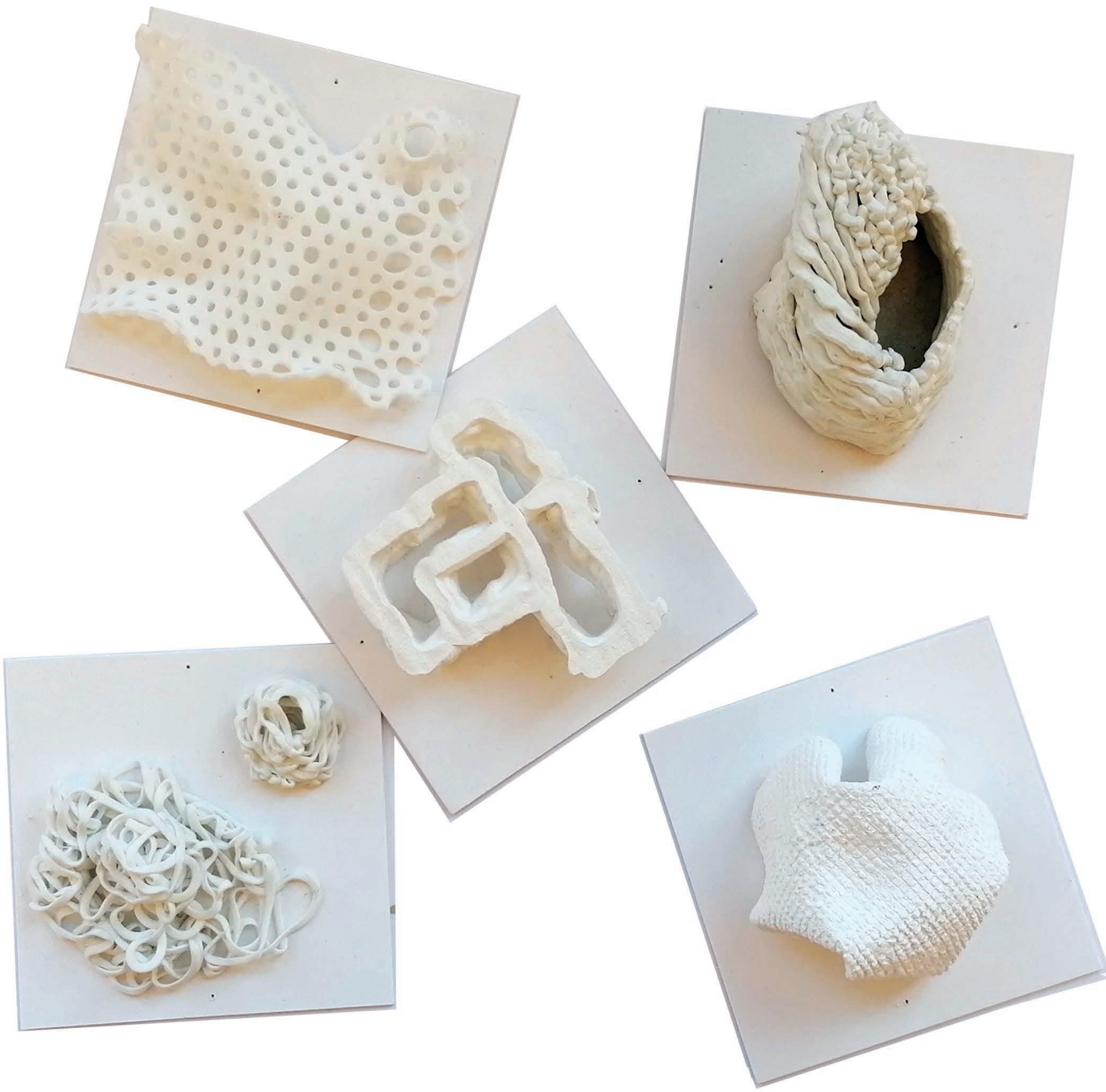


FIG 5

Looking at the design-construction feedback loop, how it influences architecture, and what changes we can expect in the near future.

CONSTRUCTION + DESIGN WORLDS

Part 1 of the paper serves as a theoretical foundation and investigates the relationship between the possibilities and constraints of the construction industry and the principles and decisions inherent to the architectural design process. The 'construction-design-relationship' is investigated further by doing a broad historical overview of construction and design trends and what changes we can expect in the near future.

Goodman's (1976) theory of allographic and auto-graphic art forms serve as a useful starting point to explain the nature of architectural design. He calls auto-graphic those arts, like painting and sculpture, which depend upon the direct contact of the author for their authenticity. Whereas allographic arts are those capable of being reproduced at a distance from the author at a later stage by means of notation. With these arts, the work exists in many copies and can be produced without the direct intervention of the author (Goodman, 1976). We might consider architecture as an allographic form of art because architects produce drawings or models with depictions and instructions about the design so it can be constructed by a second party on a physical site at a later stage.

The idea of design happening in one place while construction happens in another is reinforced by the work of William Mitchell. In his book 'The Logic of Architecture', Mitchell (1995) gives a detailed outline of the entire architectural design process from organizing the smallest primitives to later establishing architectural types and styles. He identifies what he calls the 'Design World' on the one hand and the 'Construction World' on the other:

DESIGN WORLDS

Design worlds consist of all the tools and mediums designers use while they design. Similar to how critical language consists of words (verbal tokens) strung together to form sentences, so design worlds are populated by graphic tokens arranged to form intricate compositions. Tokens such as points, lines and shapes can be added, deleted, or manipulated to form two- or three-dimensional arrangements (Mitchell, 1990). Procedures exist to relate the properties and relations of these graphic tokens to the larger world. In this sense, the design world depicts possibilities of the 'real world'. Designers can establish different Design Worlds through their choices of media, instruments, and primitives (Mitchell, 1990). For example, Euclidean design worlds are governed by straight lines and arcs that might be arranged at different angles. Just as a designer making a model with cardboard pieces works with tokens of shape and planes. Fast forward to today where digital design software creates unimaginably complicated design worlds of various relations between points, shapes, folds, and textures that relate back to thousands of computational tables in database systems.

CONSTRUCTION WORLDS

Mitchell (1990) refers to the 'real-world' as the construction world. This is our physical world where building sites, components and materials exist. In essence, because architectural designs intend to change the real world, the design worlds architects work in, depict different possible configurations of components and materials in the construction world.

(Caption) It is important to note that many states of the construction world will have the same depiction in the design world (see fig. 10) (Mitchell, 1990).

Both the components in construction and design worlds are tools at the architect's disposal. Tools such as models, drawings, and generative design software are used to portray ideas in the design world. While in the construction world tools such as structural elements, materials, and robots are used to make buildings. Architects have to master the skill of continually jumping between thinking in the one world and then the other.

It is important to use design tools and mediums that are similar to those that will be used to construct the building in real life. To create a design world that more accurately represents the desired construction world. For example, using 3D printing to make exploration models for a house that will be 3D printed on-site.

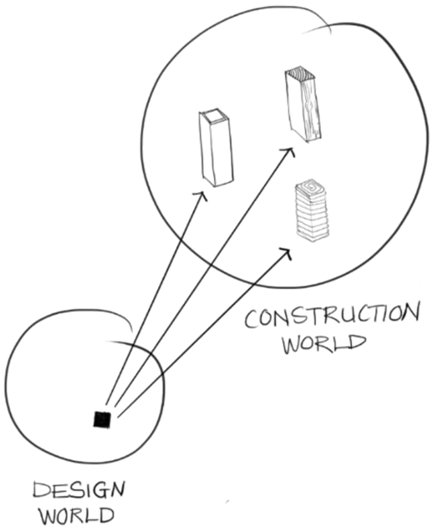


FIG 6

Many states of the construction world will have the same depiction in the design world (Mitchell, 1990). A column drawn on a plan might have several different options of realization in construction.

The Overlap

Historically the designer and the constructor of a building were the same person and the interaction between the emotional and physical requirements of the building was natural. There was no clear distinction between the two worlds. However, in modern times there has been a separation of the two with a team of individuals acting as engineers, contractors, builders, and architects as design consultants. Construction and design have become a two-way process.

But more recently the lines between design and making in construction are again starting to blur. With the recent introduction of Computer-aided design (CAD) and Computer-aided making (CAM) to the construction industry, architects and craftsmen again have more direct control over the construction of the structures designed.

CAM methods like 3D printing, reconnect the designer to the material and the machine (Rael & San Fratello, 2018). It is even possible for the architect to create new materials and software that pave the way to intimate relationships between traditionally separate fields of visualization, structural design, budgeting, and construction (Rael & San Fratello, 2018). Designers can again become the craftsmen themselves instead of handing the design over to be built by a 3rd party. When architects become more involved in the production of construction elements, they close the gap between design and construction. Blurring the lines between design and making, between the architect and the builder, or even the user and builder can open new possibilities for the built environment.

Knowledge of the one world informs the decisions made in the other. In other words, the better designers understand the technology, the better they can design for it. And the more contractors and technicians know about design the more they can develop the technology to achieve what the designers dream up.

The structural capacities of steel and reinforced concrete introduced new rules and possibilities in the construction world

FIG 7+8

The architects of Emerging Objects were directly involved with the printed of these mud huts in Mexico. There were no 3rd party contractors that needed to read their plans and build the structures.It was created directly from the architects models, blurring the lines between designer and builder.

Knowing the construction world

New materials and methods are continuously introduced in the world of construction that invalidate previous restrictions by establishing new ways of making that were not previously possible. When evaluating the value of a design, critics require a good knowledge of the new realities of the construction world. For example, a designer cannot critique a design for an in-situ 3D printed building, if they don't have sufficient knowledge of the capabilities and restrictions of the method of in-situ 3D printing. This is echoed by Michael Arbib (2015) as he investigates the technological environments that allow humans to develop constructions in fresh and surprising ways. He says the following about the architect's own knowledge of these environments:

"The architect's design must incorporate a deep understanding of the skills of the builder and the artisan (which, these days, may themselves be rapidly changing in tandem with new technologies)—of what different forms of construction might achieve.

This, no less than ideas about how the building is to be used and what aesthetic statement it is to make, will contribute to rendering the design so explicit that the actual construction process can begin"

(Robinson et al., 2015, p. 89).

THE POINT IS...

it's crucial to the architectural design process to know and understand the construction world

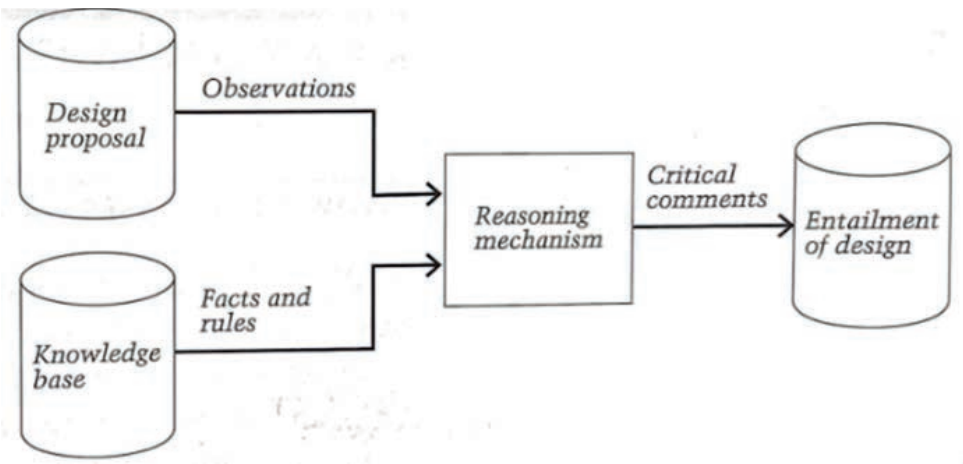


FIG 9

A good knowledge base about the facts and rules of a particular construction world is essential to design for that world (Mitchell, 1990).

INFLUENCE OF TECHNOLIGICAL INNOVATIONS ON ARCHITECTURE

To better understand the relationship between the development of construction techniques and architectural design, I started looking at the recent history of the construction industry in the form of a time line. I began by plotting out mayor technological innovations and the subsequent architectural principles and styles that followed out of it.

Time line

The pre-industrial period saw a slow but relentless refinement of load -bearing masonry systems. This was an **evolutionary** process that changed the architectural grammar from small, dark, thick-walled buildings of the Saxon churches, to the lofty, vast structural brick domes of 15th century Italy (Strike, 1991.pg 5).

However, from the 18th century changes in construction technology happened a lot quicker and triggered of the accurately called industrial **revolution**. It was not until the effects of the first industrial revolution began to show in buildings and landscapes of the early nineteenth century that criticism of the effect that construction was having on people's taste began to emerge (Strike, 1991). Since then, we have seen three more technological revolutions, each bringing more and faster change than the one before. With architecture simultaneously being influenced by and pushing innovation.

In the 1890s reinforced concrete became widely adopted as a mainstream method in construction (Champ, 2021). During the 20 or 30 years that followed we see the rise of the Modern movement in architecture. In his manifesto of 1914, Antonio Sant'Elia provokingly suggests that the construction materials and scientific concepts of the time are completely incompatible with the disciplines of historical styles (Sant'Elia, 1914). He says that because architects tried to use 'the superb grace of steel' and 'delicacy of reinforced concrete' to obtain the bulkiness of the arch and marble, the 'fashionable' buildings of the time had grotesque appearances (Sant'Elia, 1914). The Modern movement de-emphasized the long tectonic tradition of detailed joints expressing the transfer of loads and replaced it with the standardized connection (Bañón & Raspall, 2021). Because the technological innovations of the day opened new possibilities, the new style disregarded the monumental, static, and heavy to introduce a taste for the practical, light and swift (Sant'Elia, 1914).

Le Corbusier designed the Dom-Ino house the same year as Antonio's manifesto, and also proposed that architects adopt a functional articulation and specializations of components as an aesthetic principle (Mitchell, 1990). The structural capacities of steel and reinforced concrete introduced new rules and possibilities to the construction world and changed the functions of components. Because of the new possibilities, modern architects also completely changed how they design.

For example, interior walls and façades no longer had a structural function, their only function was to divide space and could now do that freely. This is demonstrated by Le Corbusier's five points on Modern architecture where he separates structure from plan (Mitchell, 1990). It is worth pointing out that it wasn't until the 1930's that reinforced concrete was used to construct thin curved shell roofs with large spans. It took more than 40 years after the commercialization of reinforced concrete for architects and engineers to fully exploit the potential of these revolutionary technologies.

The timeline on the next page shows the link that exists between the initial invention and development of key construction technologies, and the architectural styles that followed out of it. During the 2nd industrial revolution, the production of affordable steel and later reinforced concrete heavily influenced the architectural designs that followed during the age of Modernism. It also shows the current state of the construction industry and the developments that occurred in the last two decade.s These included revolutionary technologies such as 3D printing, highly engineered concrete mixes, plastic, and parametric design software. All of these heavily influence our design processes and the full impact they have on the architectural languages and styles of our day has yet to be discovered.

The structural capacities of steel and reinforced concrete introduced new rules and possibilities in the construction worlds Modern architects operated in and changed the functions of components.

FIG 10

The small, dark and thick architectural grammar buildings of the Saxon churches

FIG 11

A language of lofty, vast structural brick domes of 15th century Italian cathedrals

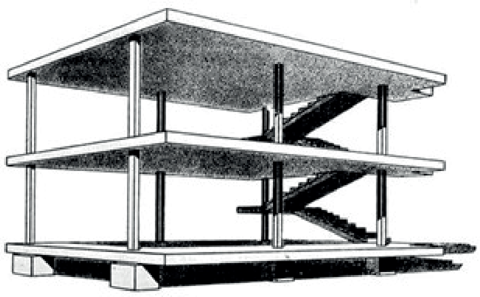


FIG 12

The 1914 Dom-Ino house illustrates how technological innovation (reinforced concrete frames) introduced new design 'rules' by allowing for free plans and facades.

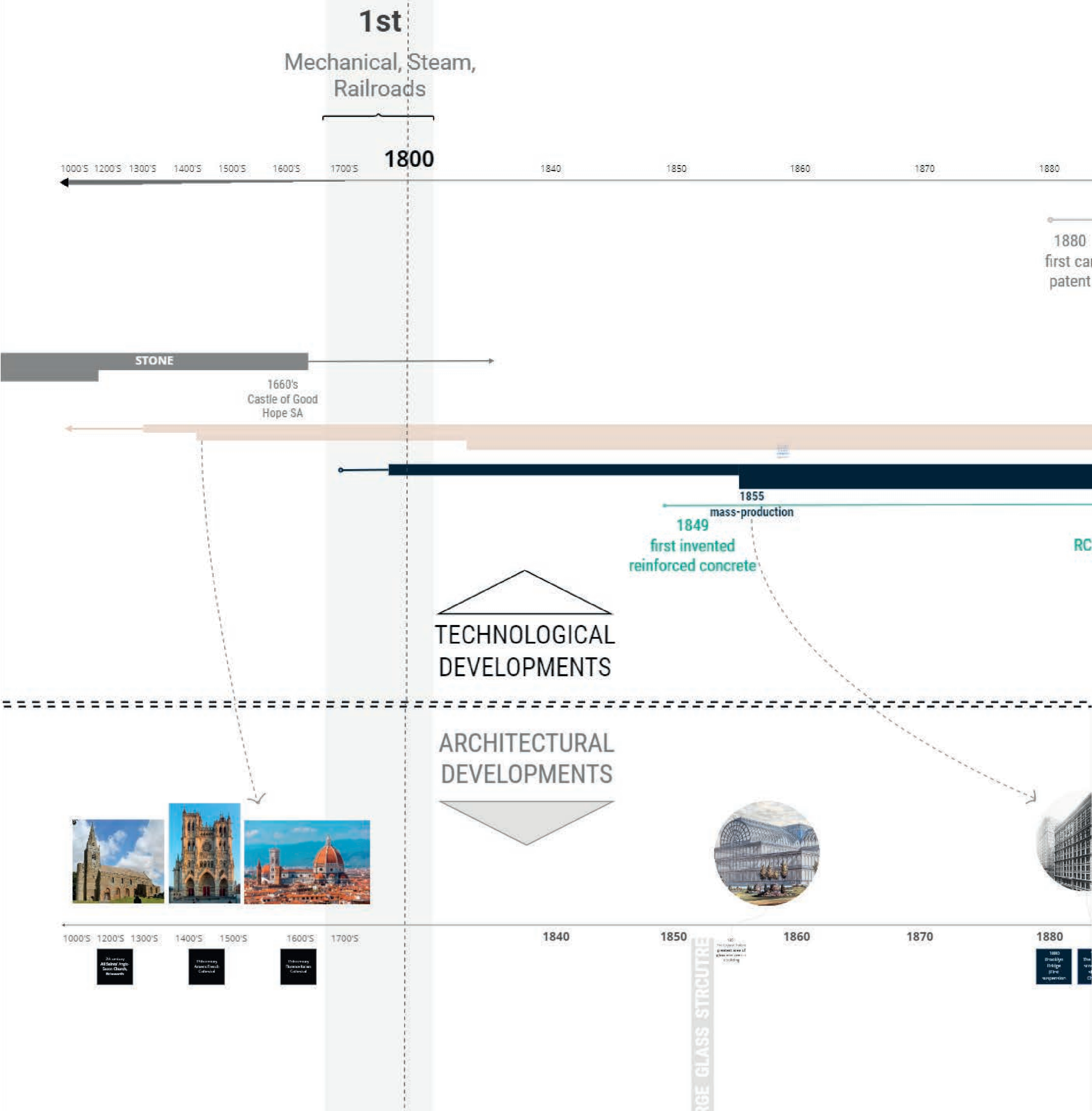
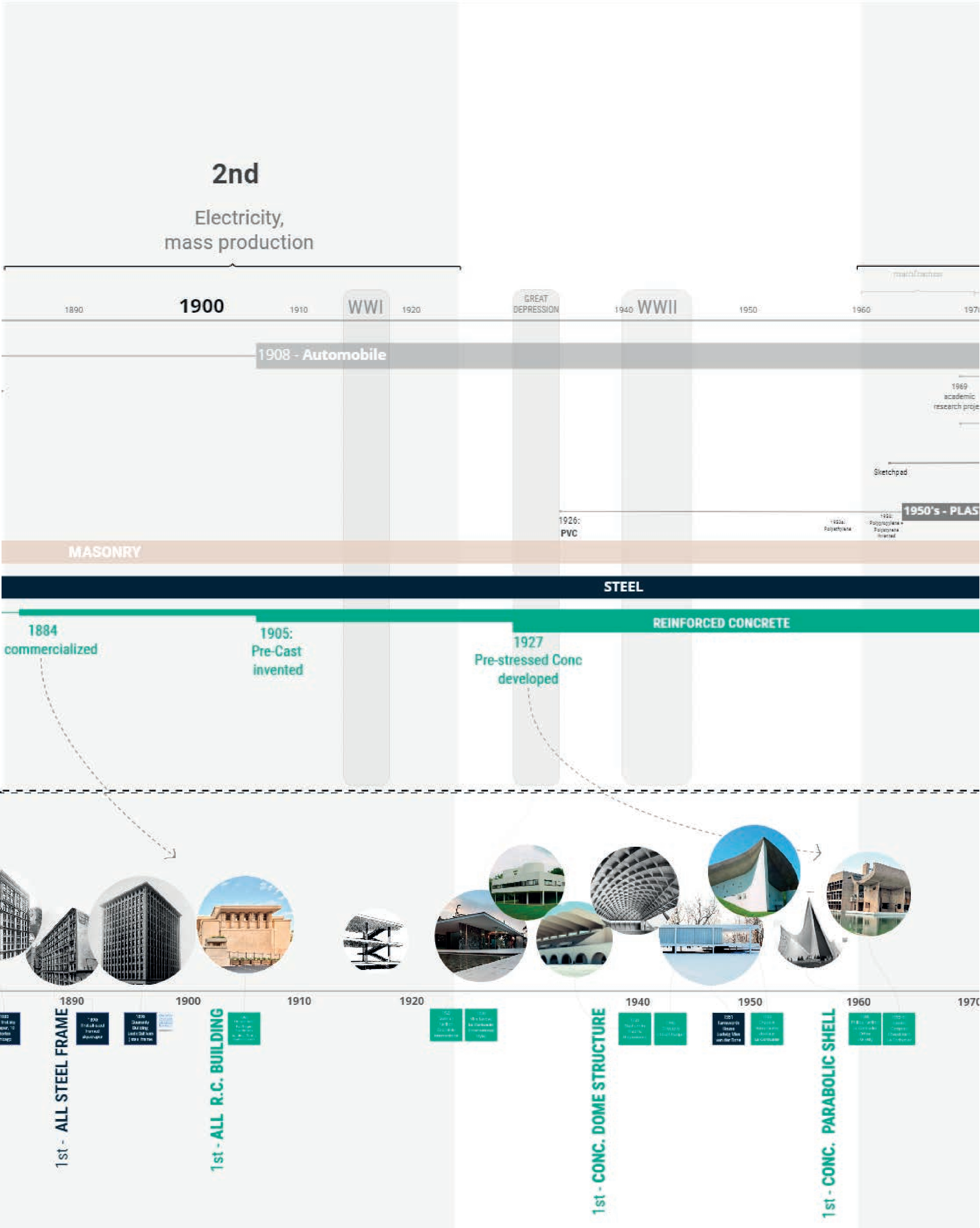


FIG 13

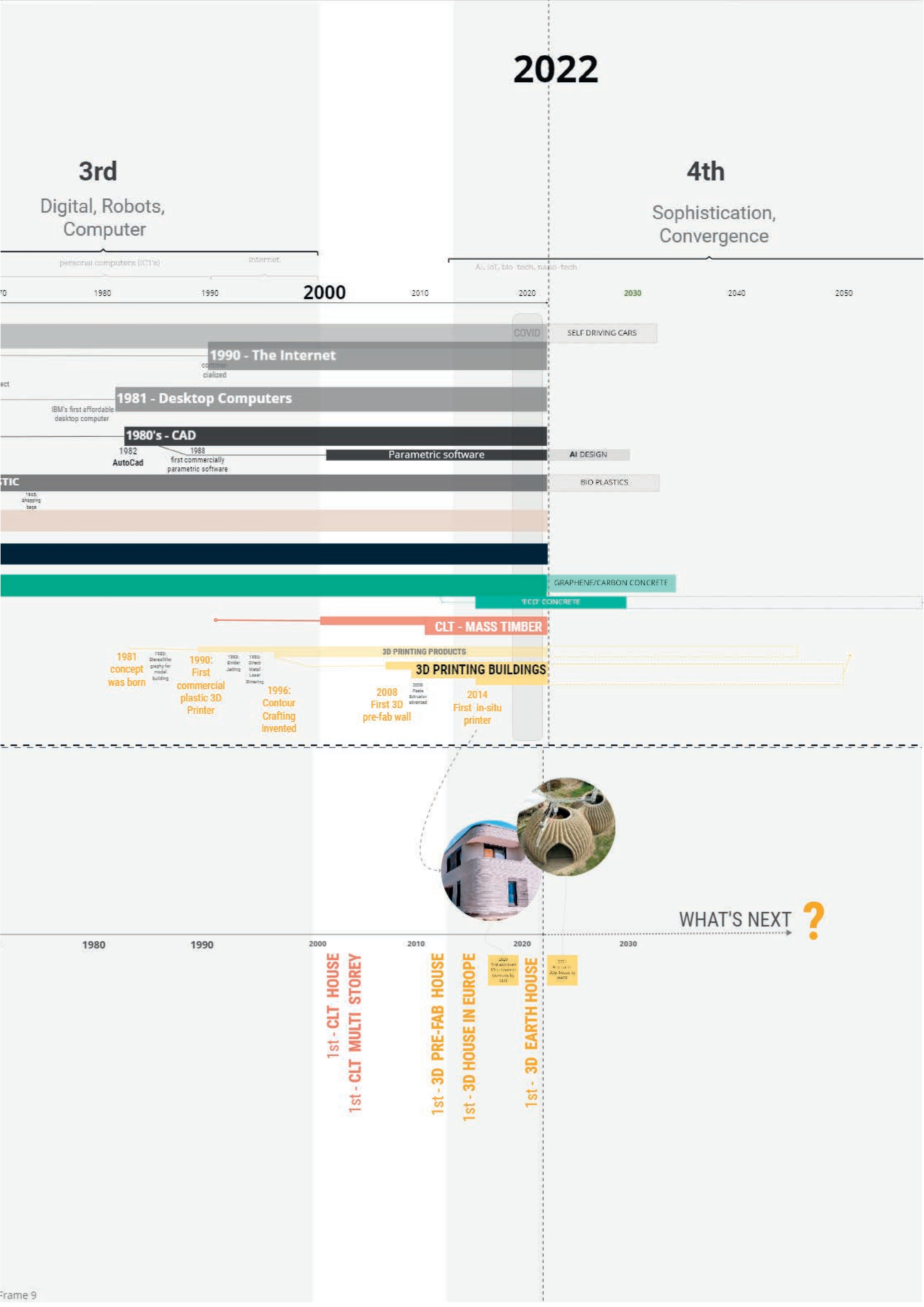
By Author, 2022

Timeline showing the relationship between technological developments and development in the field of architecture.

Note that it took almost 30 years for the effect of mass produced steel and reinforced concrete to show in the architectural styles of the day.



2nd
Electricity,
mass production
1890
1900
1910
WWI
1920
GREAT DEPRESSION
1940
WWII
1950
1960
1908 - Automobile
1969 academic research proje
Sketchpad
1926: PVC
1950's - PLAST
MASONRY
STEEL
REINFORCED CONCRETE
1884 commercialized
1905: Pre-Cast invented
1927 Pre-stressed Conc developed
1890
1900
1910
1920
1940
1950
1960
1970
1st - ALL STEEL FRAME
1st - ALL R.C. BUILDING
1st - CONC. DOME STRUCTURE
1st - CONC. PARABOLIC SHELL


2022
3rd
Digital, Robots, Computer
personal computers (ICT's)
internet
4th
Sophistication, Convergence
AI, IoT, bio-tech, nano-tech
1980
1990
2000
2010
2020
2030
2040
2050
COVID
SELF DRIVING CARS
1990 - The Internet
cialized
1981 - Desktop Computers
IBM's first affordable desktop computer
1980's - CAD
1982 AutoCad
1988 first commercially parametric software
Parametric software
AI DESIGN
BIO PLASTICS
GRAPHENE/CARBON CONCRETE
'ECO' CONCRETE
CLT - MASS TIMBER
3D PRINTING PRODUCTS
3D PRINTING BUILDINGS
1981 concept was born
1990: First commercial plastic 3D Printer
1996: Contour Crafting invented
2008 First 3D pre-fab wall
2014 First in-situ printer
WHAT'S NEXT ?
1980
1990
2000
2010
2020
2030
1st - CLT HOUSE
1st - CLT MULTI STOREY
1st - 3D PRE-FAB HOUSE
1st - 3D HOUSE IN EUROPE
1st - 3D EARTH HOUSE
Frame 9

The changing 'rules' of Design

As new materials and methods of assembly gradually integrate into the building industry, the architect is provided with an extended range of solutions, a greater number of design options. Mitchell (1990) introduces the idea of design 'rules' that govern any architectural language. He describes these as the designer's knowledge of formal and functional characteristics of elements in the construction world to suggest appropriate choices to serve functional and architectural purposes. Designers both apply and make these design 'rules', in much the same way courts both apply and construct a country's law by considering specific contexts of application. He refers to the example of flying buttresses. The strict Greek classical language does not create a context in which flying buttresses serve a structural purpose. The big windows and weightless language of Gothic architecture, however, create a demand for something like a flying buttress to resist lateral thrusts (Mitchell, 1990).

Mitchell (1990) describes the rules of architectural languages as;

FIG 14

Gothic language with flying buttresses

"...not just arbitrary restrictions on the application of shape operators. They are, more positively, expressions of knowledge about how to make available objects appropriately serve a purpose in building"
(Mitchell, 1990, p.236)

Where there are severe technological restrictions, as in ancient Greek society, architectural vocabularies tend to be relatively small and stable. But where construction worlds are technologically advanced, it becomes possible for architectural vocabularies to grow large. The industrial revolution, in particular, brought about an enormous expansion of architectural vocabulary as new materials and processes became available.' (Mitchell, 1990, p. 220)

When designing the built environment, architects continuously look back to learn from the past. Precedent studies form a fundamental part of the profession. However, these examples we seek to learn from were built

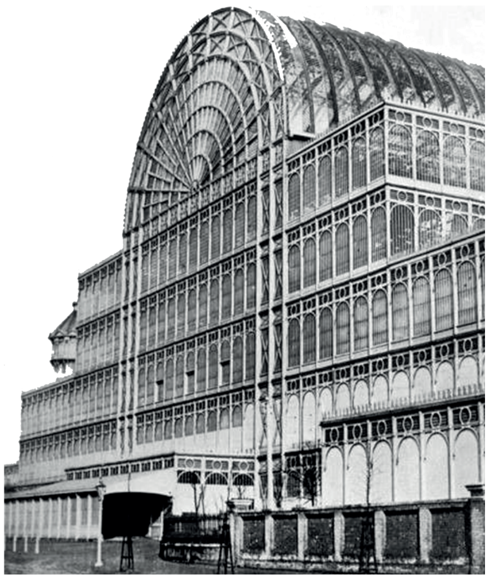


FIG 15

Crystal Palace built in 1851 to showcase examples of glass and steel technology developed in the industrial revolution using the available technologies of the time and were subsequently restricted by the 'rules' of now outdated construction worlds. As the capabilities of construction methods and materials develop, we should be wary not to restrict our conceptual thinking to the constraints of the older methods while designing for the possibilities of today. Rather our conceptual idea of the construction, spatial and material possibilities of our time should reign and be transferred into the designs of today and tomorrow.

The structural capacities of steel and reinforced concrete introduced new rules and possibilities in the construction worlds

FIG 16

The first 3D printed house in Germany in 2020, illustrates how a new curved architectural vocabulary is formed because of the particular construction method used.

FIG 17

The first ever house printed with earth by WASP architects demonstrates how the architectural language can be a direct product of the construction methods used.

Riding the next wave of innovation

There have been several technological revolutions in recent history, each ignited by a combination of two or three individual revolutionary technologies followed by later incremental innovations. The wave we are currently in will be pioneered by innovations such as biotech, nano-tech, and new materials. In the field of architecture, I would add to this list; the development of sustainable construction materials (renewable or low-carbon), robot- and computer-aided construction methods, and computer-automated design software.

We are currently in an age of major change and big global shifts in terms of technology. Economist Klaus Schwab (2017) mentions inventions like AI, robotics, the internet of things, 3D printing, and energy storage to paint a picture of the massive scale, scope and complexity to fully grasp the speed and breadth of the new revolution. In the very first sentence of his book, Schwab (2017) says the most important challenge we face today is how to '*understand and **shape** the new technology revolution*.' He emphasizes that it is our responsibility to facilitate the change to benefit all. As creators of space, architects shape our built environment and share in this responsibility. Carlota Perez echoes this when she says that people often think the future is something that happens to us when in reality it is something we create (Perez, 2021).

Like the Modernists, there is maybe again a need to completely break from the past, and the consequent design thinking patterns, to be able to fully embrace the opportunities of new construction methods and materials. We might want to ask; **how will the language and processes of architecture change this time around? We are moving towards a paradigm sh**ift in architecture as we enter the age of digital fabrication, heavily engineered materials, and computers leading design. An age of intelligent architecture. What Antonio said more than a 100 years ago, might again ring true today:

"Our lives have been enriched by elements the possibility of whose existence the ancients did not even suspect". (Sant'Elia, 1914, p. 2)

If we can learn anything from the historical development of construction technology and architecture, it is this; it will take some time after initial technological breakthroughs (like 3D printing) before the 'Le Corbusiers' of our time, design this century's 'Domino House' that celebrates the birth of a new era in architecture. But if it is true that the rate of development is accelerating, and that the technological revolution we are in now will develop ten times faster than the previous one, architecture will also need to adapt faster than it did in the past. To reach the Sustainable Development Goals (SDGs) in 2030, the built environment cannot afford to take almost four decades to fully embrace new technologies as it did in the past. But as we can see from the case of 3D printing in architecture, styles are rapid-

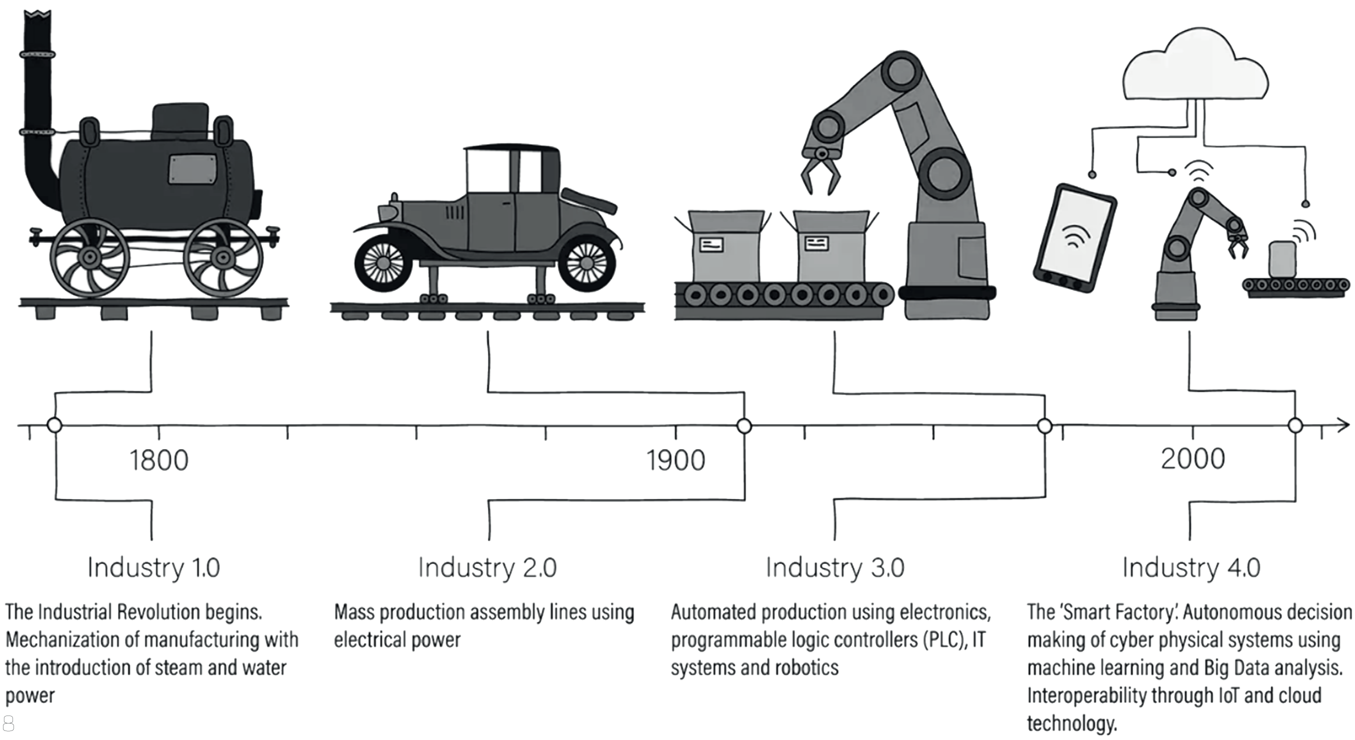


FIG 18

Time line of the four industrial revolutions ly evolving as industry leaders refine their processes. And we will see the field gain even more momentum as the first in-situ printers are commercialized and introduced to the market.

How will the language and processes of architecture change this time around?

THE POINT IS...

architecture changes when construction technology does

...

the rate of change will only increase

...

the local industry has to start adopting the new methods of making

PART 2

A FUTURE WITH 3D PRINTING CONSTRUCTION

FIG 20
By Author
Small experimental objects
3D printed with clay

Getting to know a new construction world with 3D printing in it.

SIMULATING THE METHOD ON A SMALLER SCALE

Investing in a clay 3D printer

In the six years of studying and working as an architect, I have never had to design something to be built by a 3D printer. My thought patterns are wired to consider the capabilities of stacked bricks or the spans of concrete beams while I design. Very soon in the process of researching 3D printing as a construction method, I realized that I don't have a natural sense of what the technology can and can't do like I do with brick or cast concrete.

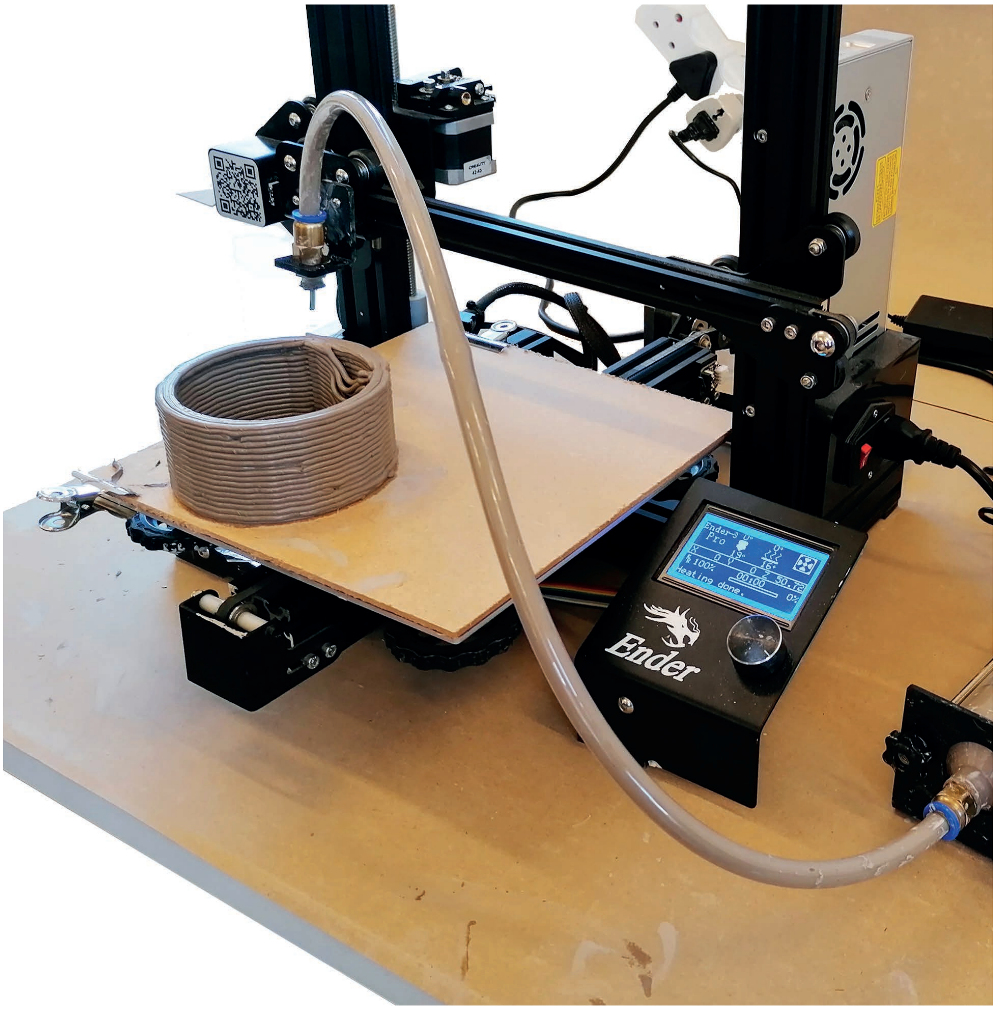
In an attempt to really understand the inherent principles and to gain a more intuitive feeling for the capabilities and limitations of the technology, I started looking at the ways I could mimic the way the big concrete printers work on a smaller scale. A clay 3D printer proved to be the best way of simulating a concrete printer since it also works by extruding a wet paste that needs time to set before it becomes structural.
However, the University did not have these facilities, as all the 3D printers in the department can only print with plastic and a very small scale. Therefore, I decided to invest in a ceramic 3D printer kit for myself better understand how the technology would work on a large scale on a real construction site.

The set-up comprises of an Ender 3 plastic printer that we have access to in our studio, that has been upgraded with a ceramic upgrade kit. The components of the kit is described on the next page.

This exercise has proved to be a vital part of my process of getting to know the capabilities and limitations of the technology. I have only been using the printer since the beginning of August, but even just experimenting and playing with it these last five weeks has given me a greater and more intuitive understanding of the inherent workings of the technology than the entire years' worth of desktop research has. I have mostly been struggling to get it to work and print the kind of forms I want, but even this has given me a great deal of insight into the challenges one would face printing with concrete on a construction site.
Thus far, I have only printed a hand full of experiments, none of which are really architectural components, but I look forward to exploring

FIG 21

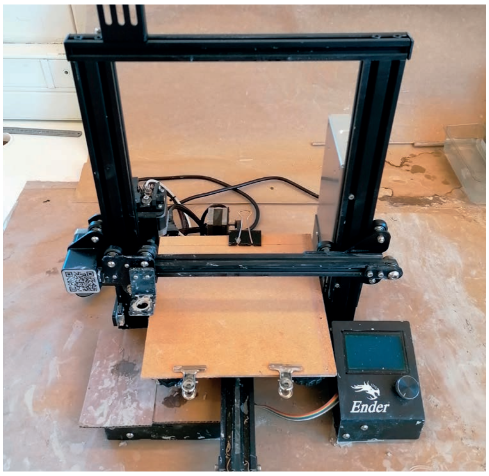
My clay 3D printer set-up in studio. An Ender 3 Creality plastic printer adapted with a ceramic upgrade kit from Eazao



Clay printer components

FIG 22-28

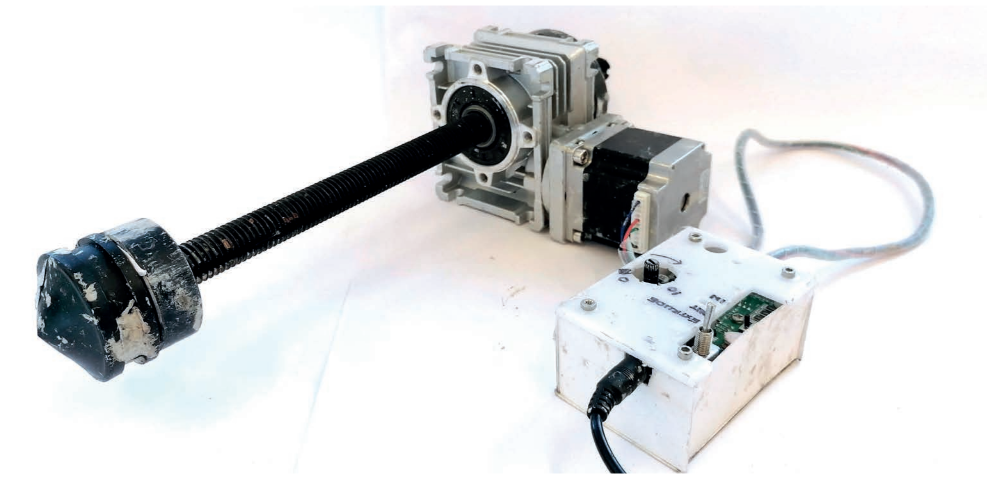
By Author



Ender 3 Creality base and frame

PVC plastic cartridge cylinder where the clay is loaded into.

PVC hose that connects the cylinder to the nozzel mounted on the printer.

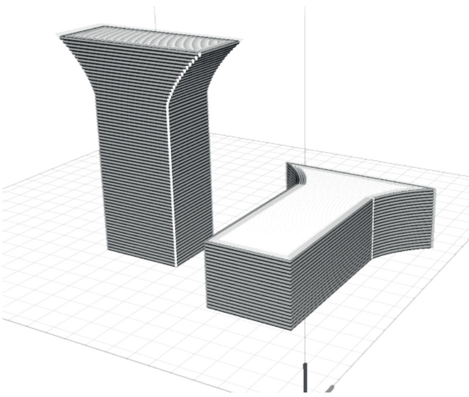


Motor and screw to push the clay through the cartridge cylinder into the connected hose.

Control box to operate the motor and regulate the speed of the extrusion

Example of materials to print with, including paper mache

Nozzels of sizes ranging from 2mm to 0.5mm



Cura Slicer software to prepare digital models for printing

How the small printer simulates real-world printing

FIG 29

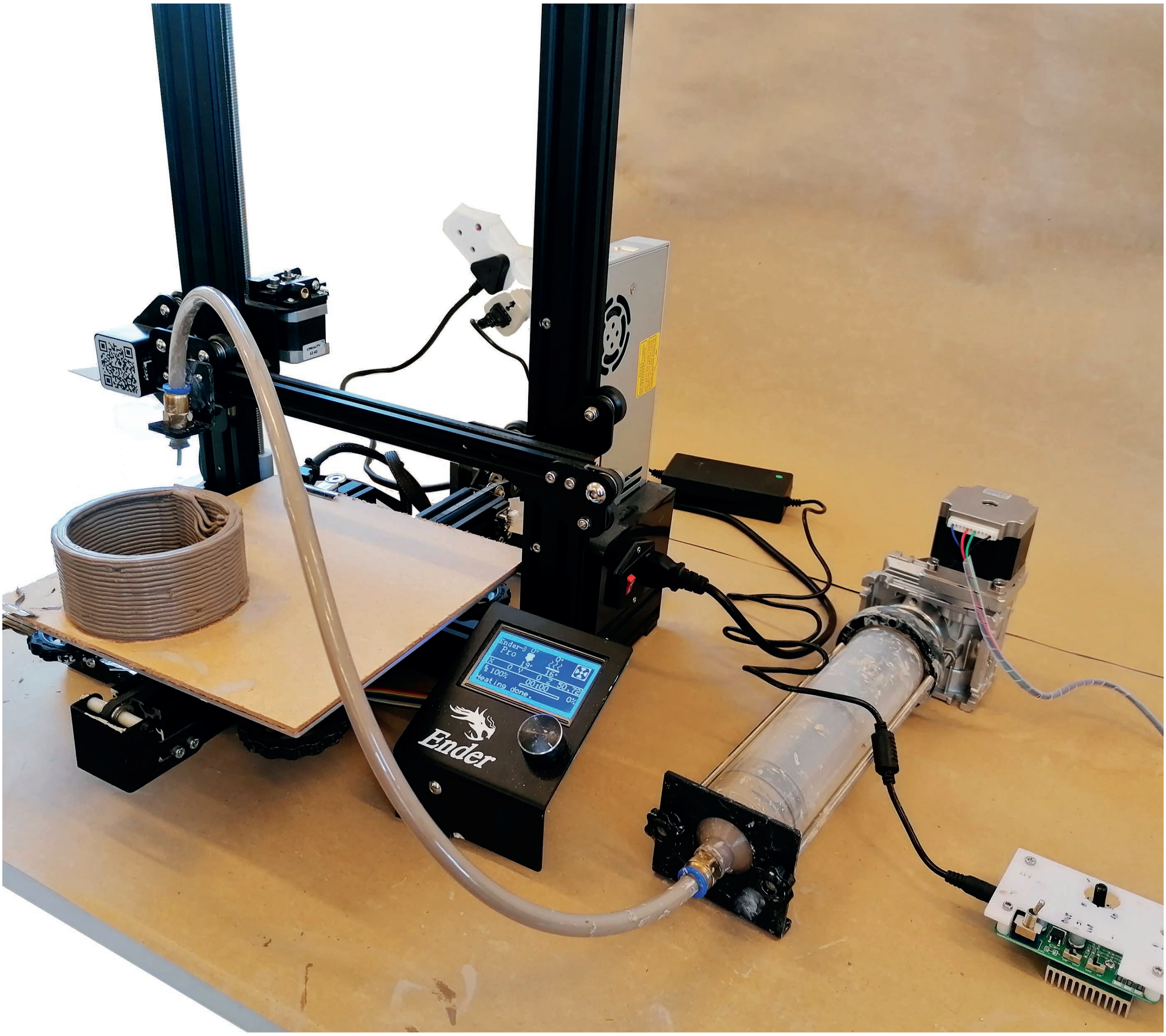
A robotic arm with a print radius of 3m. It is manufactured by CyBe, a company in The Netherlands, and is the same model the University of Johannesburg recently bought for their housing prototype project.

A LARGE SCALE CONCRETE PRINTER

FIG 30

My small scale print set-up in the studio as explained above

(B) SMALL SCALE CLAY PRINTER



LARGE SCALE CONCRETE PRINTER

A

FIG 31-33

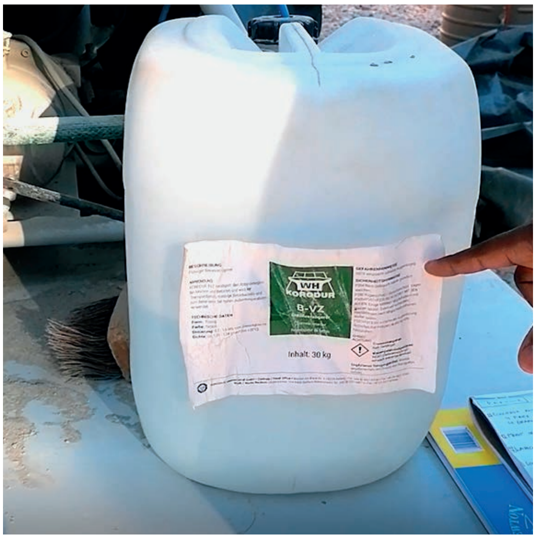
Photos taken at UJ printed house project site by other (2022)

NOZZLE SIZE:

The CyBe printer has a nozzle size of 2mm and prints layers that are 3mm high

MATERIAL:

Special concrete mix supplied by CyBe

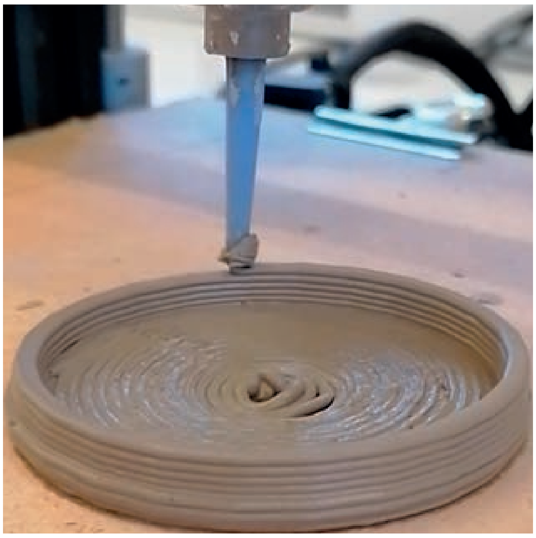


ADDITIVES:

The additives used by the UJ team to either slow down or speed up the rate at which the concrete sets/dries

Ⓑ SMALL SCALE CLAY PRINTER

FIG 34-36
Photos taken in studio by Author (2022)



NOZZLE SIZE:

The clay printer's nozzle sizes range from 0.5mm to 3mm and can print in layers from 2mm to 1mm high

MATERIAL:

I use normal clay available at the local pottery store and recycled paper for the paper mache mix

ADDITIVES:

Additives I use for my experiments. Glue added to reinforce the paper mache mix and Sodium Silicate to make the clay mix more runny so it goes through the nozzle

UNDERSTANDING 3D PRINTING CONSTRUCTION

From the time line in the previous section, it is clear that large scale 3D printing is reaching a point of maturity and commercialization. The technology is already influencing architecture in major ways. Part 2 of the document will tackle the question of how this technology will change design. And investigate how this technology can be employed to save time and cost when building essential infrastructure in South Africa. Internationally the industry is already moving in the direction of 3D printing construction. I am therefore looking at how we can accelerate the process of adopting the new method in our local industry.

I started my quest to understand this technology because I believe it is an extremely useful and effect technology that can have considerable value in our local context.

3D printing construction works on fundamentally different principles compared to today's mainstream methods like masonry and formwork concrete construction. I am sure you have all seen the hundreds of YouTube videos of entire houses being printed with concrete within days. Although this method can be very effective and applicable in certain cases, the technology has so much more to offer than in-situ printed walls. In this section, I set out to understand where the value of this unique construction method lies.

Since the initial invention of 3D Printing technology in the 1980s, it has sparked innovation in many industries such as medicine, food, and aerospace engineering to name but a few. Unsurprisingly, the building industry has adopted this technique and aims to apply it on a larger scale. This way of manufacturing is growing by 33% a year and is starting to cover all sectors of the industry (Bañón & Raspall, 2021).

In the last decade, construction industry leaders have started to employ the technology in three ways (see image below):

Firstly, elements are being printed off-site to be assembled on-site (Pre-Print); secondly, large 3D printers are used on-site to print structures in-situ, and lastly, the technology is being used to print construction apparatus and devices such as formwork, casting moulds or scale models.

3D printing construction works on fundamentally different principles compared to today's mainstream methods

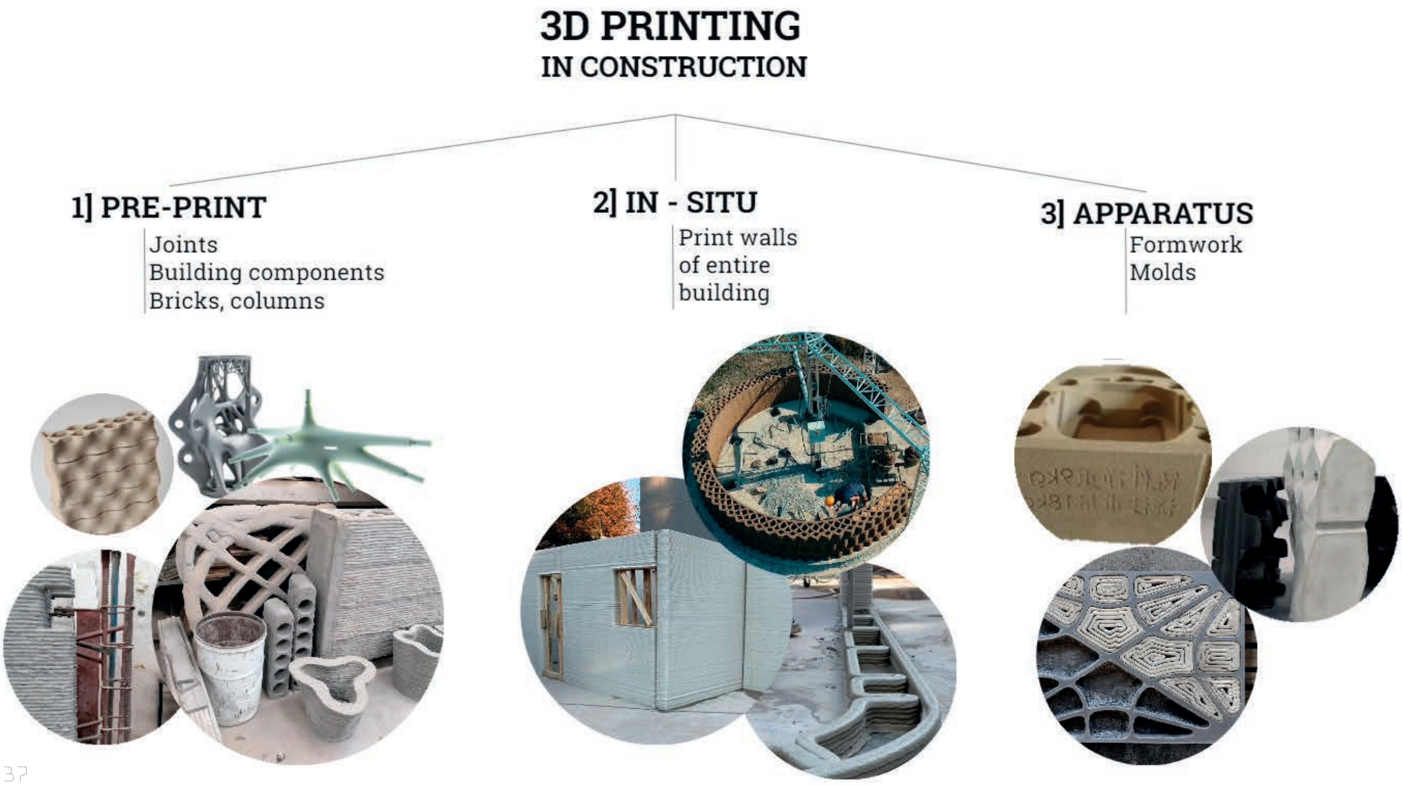
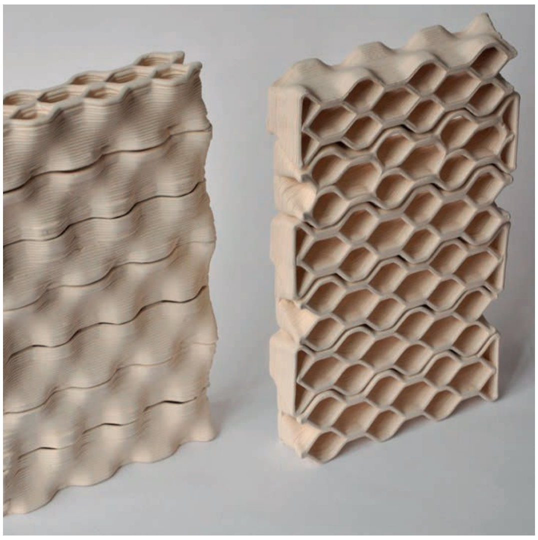
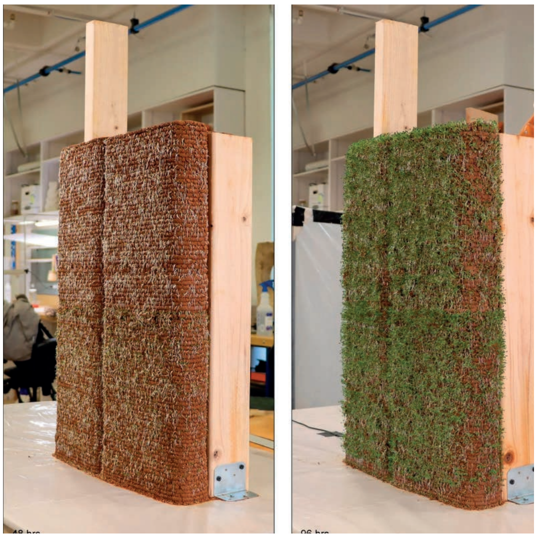


FIG 37

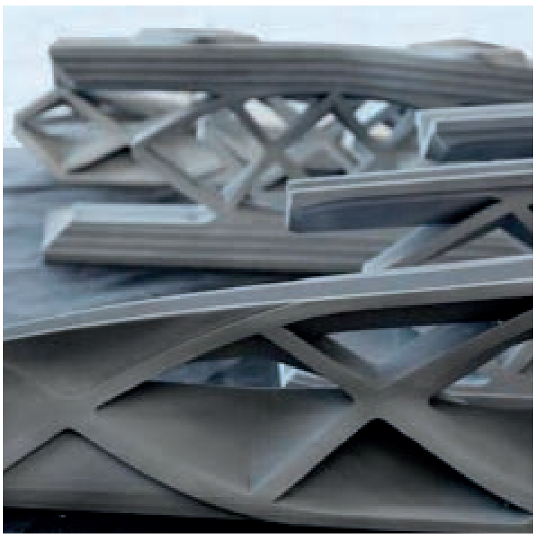
3D printing constrcution technology can be devided roughly into three main catagories.



3D printing does not only have to be used for in-situ construction. It can be employed to print complex elements that can be easily assembled
FIG 38



3D printing can be used with a wide range of materials including natural living materials.
FIG 39

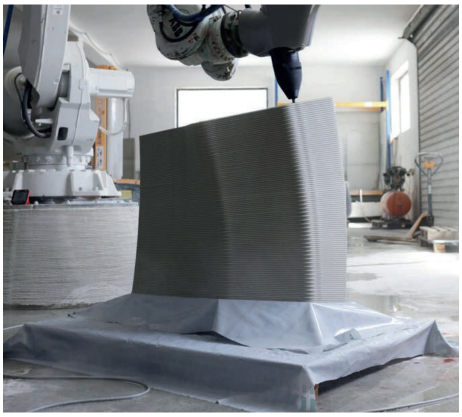


3D printing goes hand in hand with structurally optimized designs as it can easily print very complex forms like this beam that can be disassembled.
FIG 40

Introducing New Design Opportunities

3D Printing technologies bring to the design table; endless variety, intricacy, and complexity at no extra cost. It also introduces new materials and shapes that were previously only possible in nature. This allows for a new conception of architecture with vast new design possibilities. The 3D Printer is not just a technology, but a paradigm shift. It will ultimately change the way architects think and design as they evolve with the technology.

As there is no apparent penalty for intricacy, designers are freed from the fabrication constraints of cost and time which allows them to explore ornamental dimensions of architecture (Bañón & Raspall, 2021). With the help of parametric design software forms can be printed that are not only structurally logical but aesthetic as well. Structural and decorative per-



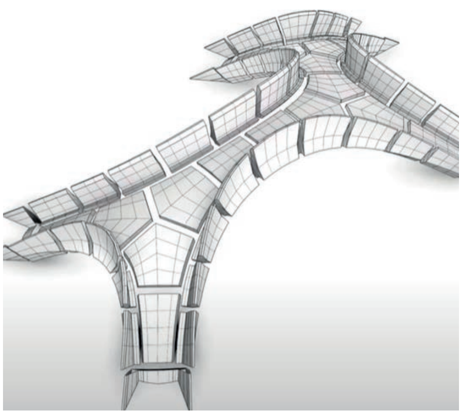


FIG 41-42

More than 30 bespoke concrete members printed off site and assembled using a temporary timber frame and dry stack method.

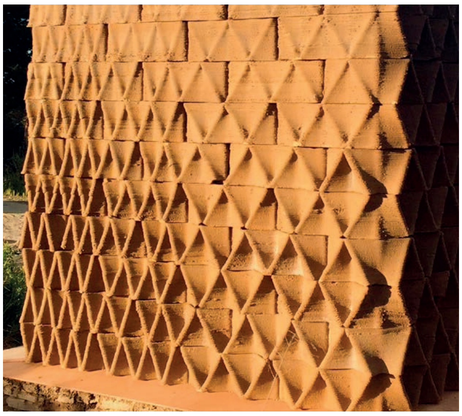


FIG 43-44

Expressive wall and stair members printed using earth and clay by WASP and IAAC

REDUCED TOLERANCE

Unlike traditional methods of form work and cast concrete, less and less tolerance is needed to achieve the desired accuracy between the design platform and the machine that makes the members. The improvements in digital fabrication reduce the tolerance required during construction to almost zero (Stott Rory, 2014) This means less is wasted and architects can design increasingly precise components.

MASS CUSTOMIZATION

Digital fabrication methods such as CNC and 3D printing technologies have made mass customization a physical reality. A variety of building elements has become free because it costs the same to make many different versions as it would to make all the elements exactly the same (Stott Rory, 2014).This makes way for an architectural language that is no longer a characterised by the broad-brush-stroke approach to fabrication.

EXPRESSIONIST TRENDS

The use of parametric design and the matching CAM (computer aided making) devices, simplify the creation of complicated curvilinear surfaces and highly articulated free forms to such an extent that it is no harder to make than traditional orthogonal forms. This paves the way for an architecture that can deal with curvature, fluidity, and disorder (Bañón & Raspall, 2021). Complexity in architecture is no longer a constraint but an opportunity (see fig. 22 & 23). In the South African context it opens the door for the incorporation of traditional patterns and textures in the actual structure of a building.

"Maybe there is, indeed, something fundamental about the old vocabularies. But maybe...instead, these will eventually be seen as conventions established by a particular set of now-obsolete technological capabilities"

(Mitchell, 1998, p. 212).

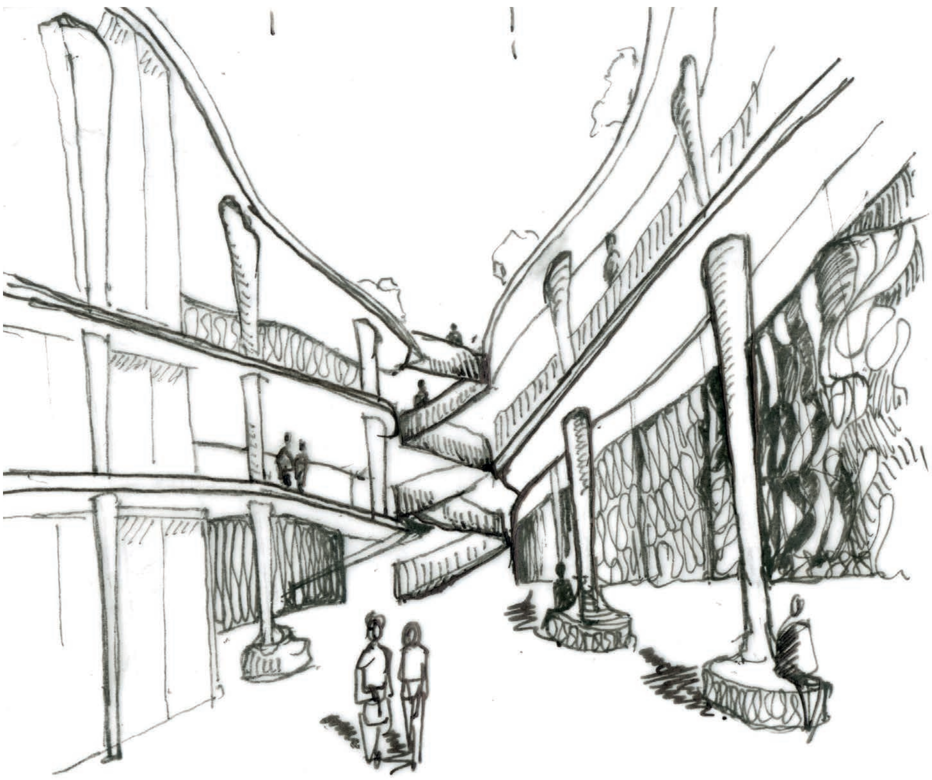


FIG 45

Exploring the expressive value of the technology through spatial design

...continued

STRUCTURALLY OPTIMIZED

Live feedback from software that provides structural and energy use information directly within parametric models enables designers to design optimal forms very early in the design phase already (Bañón & Raspall, 2021). This validates the design's structural integrity in real-time to produce refined forms with optimal structural and energy performance while retaining a sense of simple lightness. The unusual level of feedback during the design process is very beneficial, as sometimes small design decisions can have a large impact on cost and structure (Bañón & Raspall, 2021)

COMPATIBLE

Because 3D printed objects have the advantage of accuracy and customized free form, it can very easily be used with standard, of-the-shelf building components (see image...). Steel, clay bricks, pre-cast and in-situ concrete all still have their parts to play in the construction worlds of the 21st century. It is by strategically combining the advantages of these and the new methods of construction, that we will find optimal solutions. 3D printing has very specific things it excels at and should be used to perform these functions where it is most useful, not to be overused or forced in places where another technique might work better.

Although this new method of making works by a different set of 'rules' and has the potential to revolutionize how buildings are made, many consultants in the construction industry have yet to realize its potential and adapt their designs accordingly. The buildings in figures on the next page were all constructed using concrete 3D printing technology, however, it is by no means apparent from their appearance or the architectural language of the buildings.

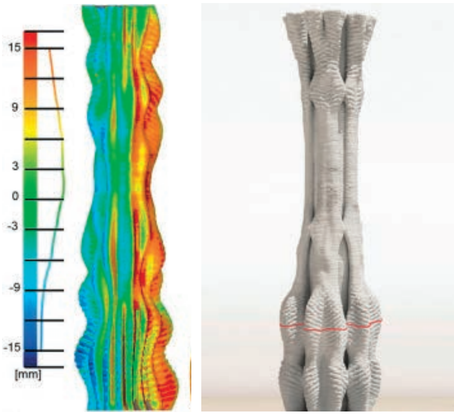


FIG 46

FEM (Finite Element Method) analysis of the force distribution through structural components is used to structurally optomize designs. 3D printers have no difficulty in printing these complex forms.

FIG 47

Structurally optimized beams printed using the minimum material required.

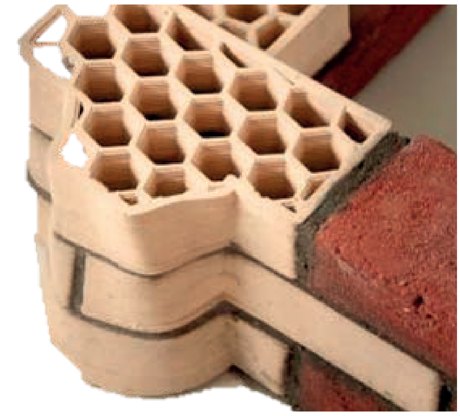


FIG 48

Masonry units are 3D printed and baked. The units have custom (made-to-order) geometries designed to perform certain functions and used with traditional bricks.

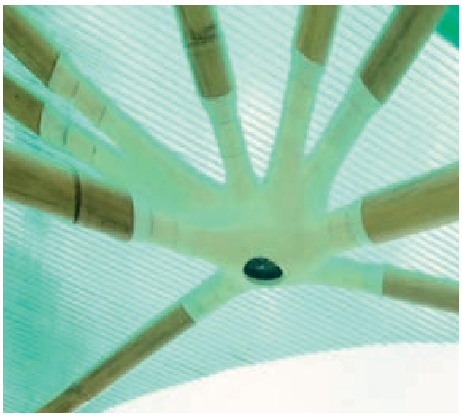


FIG 49

The Sombra Verde bamboo canopy by AirLab is made from 36 bespoke 3D printed nodes used to connect standard local bamboo members.

A house completed this year by Habitat for Humanity in Virginia, USA. It is the world’s first 3D-printed owner-occupied house. However one would never guess that when considering the buildings appearance.
FIG 50

...many consultants in the construction industry have yet to realize the technology’s potential and adapt their designs accordingly.

A 1,100 m² mansion was completed in 2015 by WinSun in China. Pre-printed wall panels and on-site assembly methods were used to construct it. Even though printing wall panels makes a wide range of forms and pattern possible, they still opted for a conventional aesthetic.
FIG 51

The same company built this 6 storey appartment block by assembling preprinted wall panels, but also failed to take full advantage of the technology's capabilities
FIG 52

Limitations of 3D printing construction:

1

FIG 53

Dealing with the concrete slurry that drips before and after every print. It fills almost two wheel barrows.

DRIPPING

To keep the concrete mix from drying in the printer, the entire system is rinsed out with water after every print. This means that before and after every print the printer drips a slurry of diluted concrete. This mix is too weak to print with and must be removed with wheel barrows. Some contractors find a way to recycle the material but otherwise it is written off as waste.

2

FIG 54

Testing concrete mixes to increase its structural capacity while it is still wet so higher prints can be achieved

MATERIAL DEVELOPMENT

The development of structural but printable materials are probably the most difficult and expensive part of 3D printing construction. You need exactly the right mix of concrete, water, and catalysts or retarders to ensure the filament keeps its form when printed. This often requires a very skilled person to be actively involved with the printing on site.

3

FIG 55

Often entire building footprints are covered during printing to protect the wet prints and machines.

SENSITIVE TO WEATHER CHANGES

Like with other concrete construction methods, 3D printed concrete is sensitive to moisture and temperature changes. However, with 3D printing, layers of wet concrete are added on top of each other. Therefore the concrete must dry quicker but not too quick. This is done by regulation the concrete mix with additives throughout the print. The method is thus more precise and sensitive to drastic weather changes. Some contractors opt for a plastic cover over the printing area to protect the machines and wet prints.

The development of structural but printable materials are probably the most difficult and expensive part of 3D printing construction.

...vs. my experience with the clay printer:

Similar to the concrete printers, a small amount of clay is wasted before and after every print because the clay must start extruding before the robot starts moving. This becomes an issue when prints need to be neat.
FIG 56

Checking the consistency on the clay to see if it will keep its form when printed but is still soft enough to go through the nozzle.
FIG 57

Attempts to develop a paper mache mix that could mimic non structural materials like the examples where they print with earth.
FIG 58

...continued

4

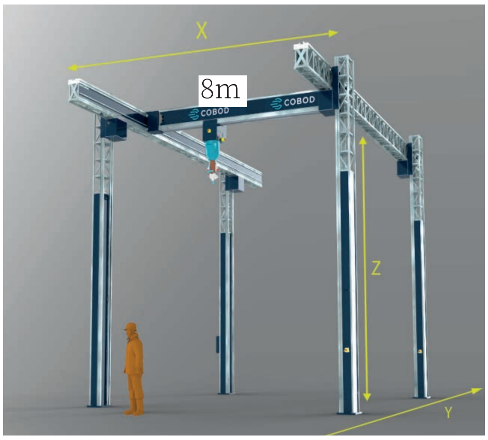


FIG 59

A typical Gantry-system printer with a printing area of 8 x 10 meters.

FIG 60

The robotic arm printer used by the UJ team to print the first prototype house has print reach of 3m in all directions.

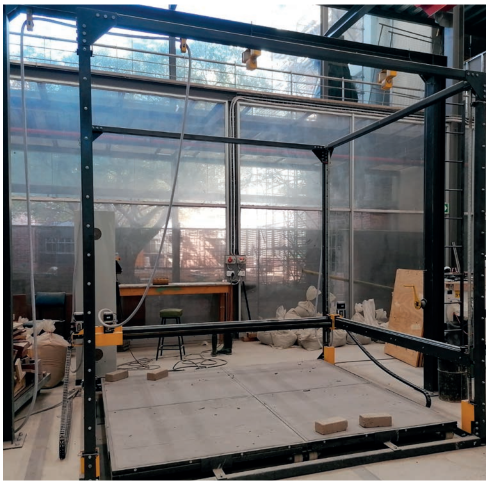


FIG 61

The Gantry system at the University of Stellenbosh has a print area of 2 x 2 meters.

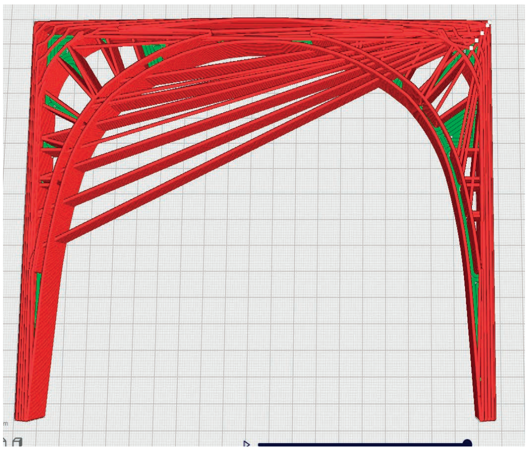
CONSTRAINTS OF PRODUCTION

The size of 3D printed building parts is limited to the size of the printers used. The reach of 3D printers can range anything from the 1m radius's of small robotic arms to the 8m stretches of large gantry systems. Although the fabrication method restricts the design in some respects it also presents opportunities for easier assembly and disassembly of printed building parts.

For instance, the University of Johannesburg recently bought a printer with a print reach of 3m in the x,y, and z axis. They therefore printed a prototype house in 13 separate wall sections instead of the entire house as a whole.

The reach of 3D printers can range anything from the 1m radius's of small robotic arms to the 10m stretches of large gantry systems.

...other issues I experienced when printing with clay

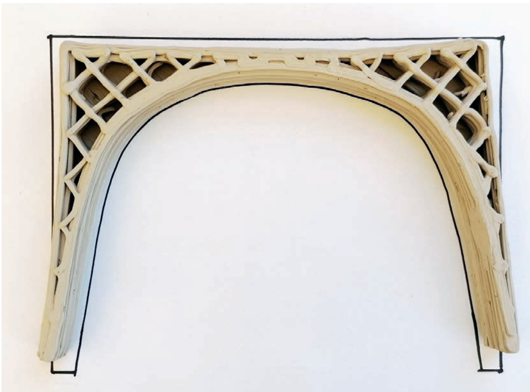


EXTRUDES WHILE TRAVELING

Because the extrusion of clay cant be temporarily paused or reversed like when printing with plastic, the clay is always being released even when the printer is only traveling from one point to the next and not supposed to print.

The first image shows how this looks in the slicer software. The second shows what it results in when it is printed.

FIG 62 + 63



SHRINKAGE

This hollow arch was printed with Air-drying clay and a 2mm nozzle using the slicer software's default infill pattern.

However, the clay skrinked about 12 % and deformed slightly. The drawn lines indicate the original shape. This could become an issue when models need to accurate and the shrinkage will need to be acounted for when modelling

FIG 64 + 65

VALUE OF THE TECHNOLOGY IN SOUTH AFRICA

1 EFFECTIVE

After the initial capital investment of buying a printer, 3D printing a building (or parts thereof) saves construction time and cost. Walls, columns, and beams can be erected in a fraction of the time it would take conventional methods. It also saves time and cost in terms of transport, because most of the parts are manufactured on site.

3D printing creates the opportunity to make multi-functional building components because it can reach a level of detail and complexity not previously possible with cast concrete and masonry methods. This often means killing two birds with one stone, again saving time and cost.

But the technology's most productive feature, by far, is being able to create form without formwork. It is a well-known fact that formwork is responsible for about 40-50 % of the total project time and cost of concrete construction projects. Therefore, by eliminating just this part of construction the entire process can be much more time- and cost-effective. This makes projects much more feasible, especially in struggling economies like South Africa where construction is often too expensive.

Lastly, locally there is a big supply of unskilled or semi-skilled labour that can be employed to assemble very complex building components using very simple methods of stacking. It is thus worth looking at methods of assembly for 3D printed parts. Smaller manageable parts could be printed on or near the building site to be stacked by local workers.

2 SUSTAINABLE

3D printing uses less material by printing only what is essential for structural stability. Unlike formwork concrete, it is easy and free to print members hollow or with multiple small holes. Designers can, therefore, use parametric software to design forms that use the minimum required material.

WASTE: The process also creates less waste. If the 'dripping slurry' mentioned earlier is properly recycled, there is much less waste created with printing when compared to the heaps of rubble we see on conventional construction sites. Other environmental factors include the lower $C0^2$ emissions from having to transport less components and materials to and from the site.

MATERIALS: One of the biggest opportunities for the technology in South Africa lies in the fact that almost any material can become a construction material. 3D printing makes it much easier to use 'green' and local materials. This can range from non-structural, natural materials like mud or hemp, to materials like recycled Fly-ash or concrete. Designers all around the world have been experimenting with printing materials like old coffee, recycled plastic, earth, clay, and sawdust. All of which we have a lot of in South Africa. 3D printing gives us the opportunity to not only keep these from ending up in landfills but to use them as an affordable construction material.

3 VERSATILE

SCALE: The principles used to 3D print concrete on a large scale applies universally across all scales of printing. The skills and knowledge of construction printing are directly transferable to other manufacturing industries like furniture or pottery.

MATERIAL: The same tube and robotic arm used to print concrete today can print clay or paper pulp or hemp tomorrow. This means for the price of one machine you get the manufacturing capabilities of a dozen. Each material will require a bit of experimentation to get a mix that works, but with hundreds of sources available on the topic, craftspeople can easily innovate and create their own range of materials.

LOCATION: Becasue the smaller printer are portable, it can easily be transported on the back of a truck to the next construction site. Even the bigger gantry systems only take a day to disassemble and move. This means what would have been trucks full of scaffolding, formwork, mixers, wheel barrows and shovels can now essentially be transported in one container in the form of a 3D printer.

I'm imagining a future where an entrepreneur can sell furniture or planter boxes they made using the exact same skills they learned on the construction site but on a smaller scale and using different locally available materials.

But the technology's most productive feature, by far, is being able to create form without formwork.

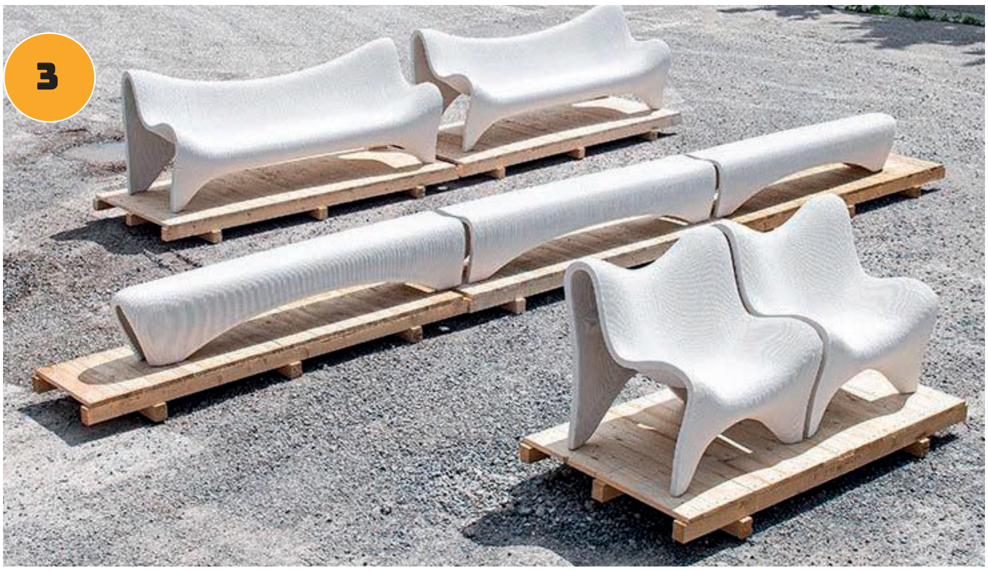
FIG 67

'House Zero' printed by ICON

Smaller, manageable, non-load-bearing parts could be printed on site and stacked by local workers.

FIG 68

Earth blocks printed by to be build walls on site



The same robot used to print a concrete wall today can print a clay or hemp bench tomorrow. This means for the price of one machine you get the manufacturing capabilities of a dozen.

FIG 69

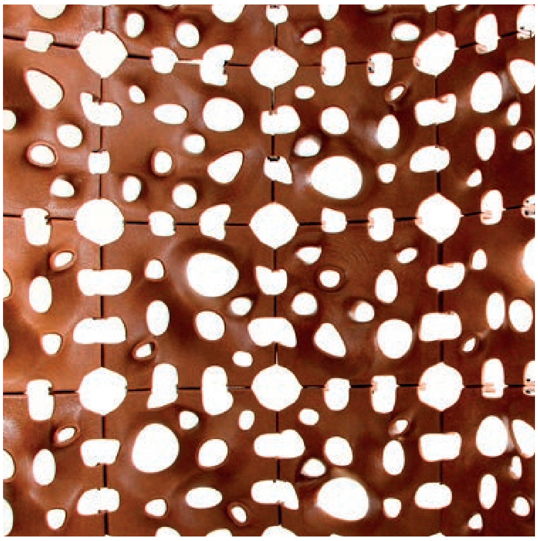
Concrete 3D printing used to make furniture

Exploring different materials

"Architects can use 3D printing to become material morphologists; it is a medium that ascribes value to design. Materials go in—and a product comes out.

The driving factor in that process is design, which, as the research scientist Andreas Bastian points out, integrates both quantitative and qualitative information, turning raw material into a valuable and meaningful object."

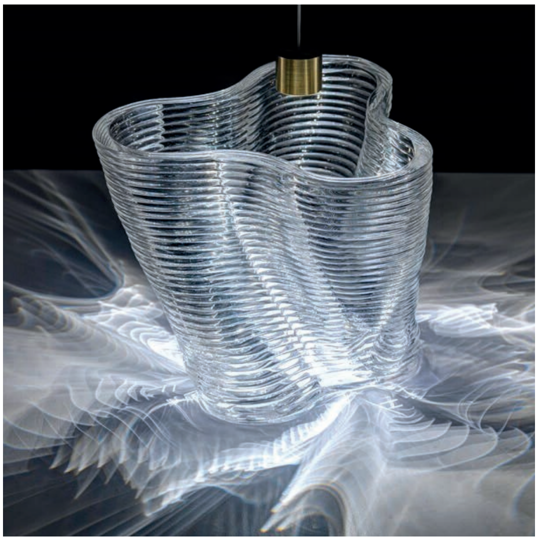
(Rael & San Fratello, 2018, p.14)



SAWDUST FIG 70

SALT FIG 71

COFFEE FIG 72



GLASS FIG 73

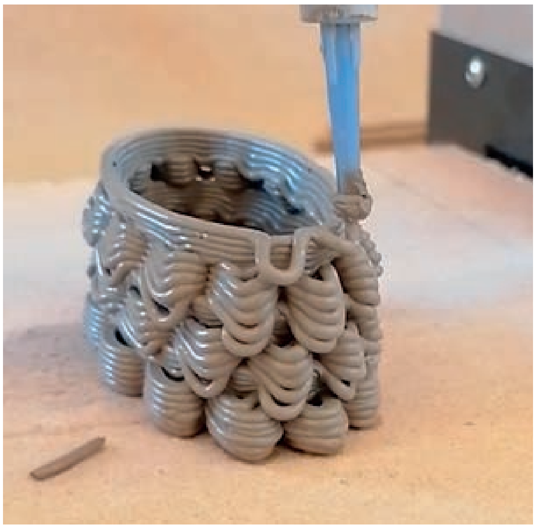
EARTH FIG 74

PAPER PULP FIG 75

Exploring printing patterns

The print in this picture fell over when it reached 8cm because the clay was too wet.

FIG 76



The object was then scaled down to about 5 x 4cm and then successfully reprinted. It took about 15mins.

FIG 76 +77

A 5cm radius bowl that
took 20 mins to print

FIG 78

CHALLENGES OF ADOPTING 3DP IN SOUTH AFRICA

IMPLICATIONS

1. It requires a different skill set than what workforce currently has
2. The machines and matrials are currently very expensive
3. There exists no building regulations for it
4. While it could create new jobs, it might reduce overall jobs in the construction industry
5. Capital flows out of the country as machines and materials are imported and maintenance can't be done locally

South Africa still has a long way to go in terms of adopting the technology. The local construction industry is still in the experimental phase and the technology is still far from reaching maturity and becoming affordable when we look at the current cost of printers and materials. However, on a university level a lot of investment has already gone into the development of the technology. The University of Stellenbosch is currently working towards developing their own printers and materials and are experimenting with printed concrete columns. On the other hand, the University of Johannesburg printed South Africa's first ever prototype house this year (see fig). The robotic arm and printer parts were imported from the Netherlands. It is a good capital investment because this one printer can be used to print hundreds more houses. However, the special concrete mortar mix they used to print with is almost four times more expensive per bag than normal local cement, making the entire project very expensive. It will take a great deal of material development and innovation before projects like this become feasible and a realistic alternative for low-cost housing and other concrete construction projects. Even though this new construction tool is not affordable in South Africa yet, I believe as architects we can in the meantime contribute to the process of innovation and development through speculative design.

The nature of technological development

The development of technologies like 3D printing happens in three parts; A) software and hardware technology development, B) material development, and C) design development. In the case of 3D printing the technology is there. The robots and software can already do more than we know. It is in developing the materials and design that the answers lie. With this project, I hope to push the design part of the equation by looking at the kind of structures and forms we can create with 3D printing. If, say, the structures I design are only 80% achievable, the other 20% will hopefully soon be made possible by the further development of high-performance materials such as fiberglass or graphene-infused concrete. These materials are far form only speculative but are currently being tested in labs around the world like MIT.

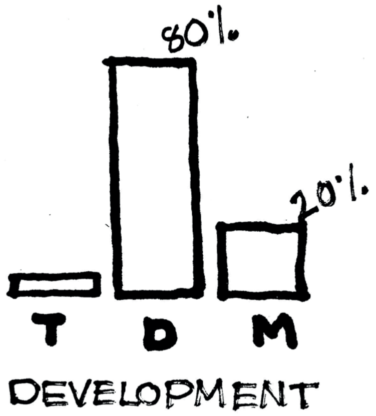


FIG 29

Technology development
Design development
Material development

Why design for tools we don't have yet?

It is the nature of technology to mature and become widely affordable even though it seems unlikely at first. People said flying in planes will never be affordable enough to become a mainstream transport option and today commercial flights are part of our daily lives. The New York Times called the automobile impractical and said the price will never be sufficiently low to make them as popular as bicycles. And just like these, 3D printers and their materials will become affordable and part of mainstream manufacturing.

Every year South Africa has to deal with a massive backlog in essential infrastructure development. However, the current mainstream methods of construction are not cost or time efficient enough to deliver on these shortages. In-situ concrete and brick construction take time, leave room for error, and is wasteful. Prefabrication and systems of on-site assembly are more efficient and are subsequently mainstream methods in Europe, China, and the West. 3D printing combines the customization of in-situ methods with the speed and accuracy of pre-fab manufacturing to take efficiency to the next level.

Decisions of industry leaders and entrepreneurs are not only guided by breakthroughs and inventions but also affect the course of innovation (Perez, 2009). In other words, architectural design is not only to be steered by, but can also steer construction innovation to some extent. Architects have the ability to paint a picture of a different future that can be achieved and shift the current focus accordingly. In this case, by designing forms and structures that are just out of reach, it forces technological and material development to catch up and make it possible.

This design dissertation tries to imagine what a South African city like Philippi could look like in a future where 3D printing is an affordable and highly integrated technology. How can we create the built environment differently with a new tool at our disposal?

In other words, architectural design is not only to be steered by, but can also steer construction innovation

THE POINT IS...

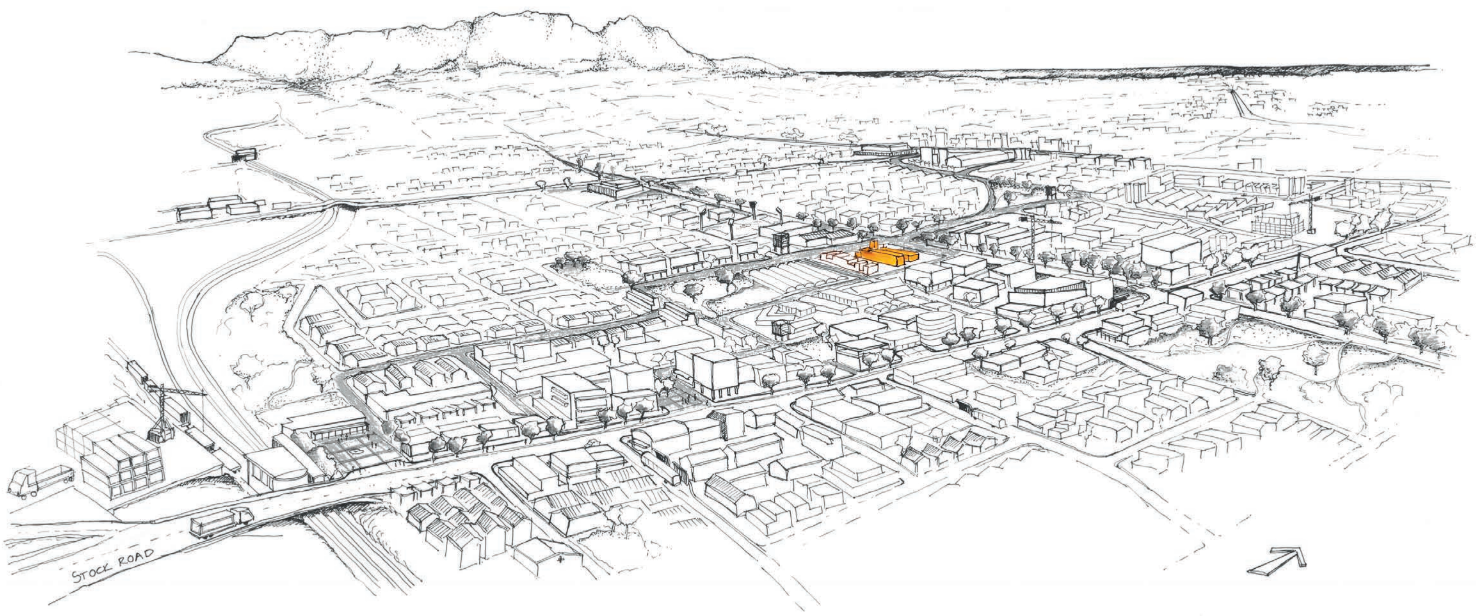
large scale 3D printing is not feasible in SA yet

...

but there is value in designing for tools of the near future in an attempt to push innovation in the local industry

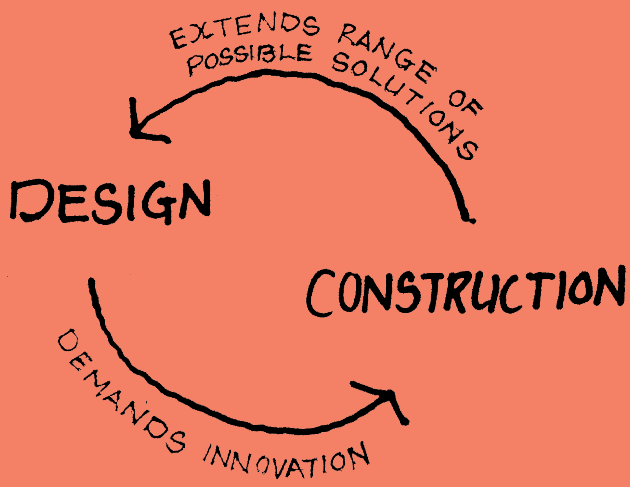
PART 3
DESIGN PROPOSAL

A] ANALYSIS
B] DESIGN DEVELOPMENT
C] CONSTRUCTION



Imagined future
of Philippi

FIG 81



About Philippi and introducing 3D printing to the local context

A] ANALYSIS

LOCALITY

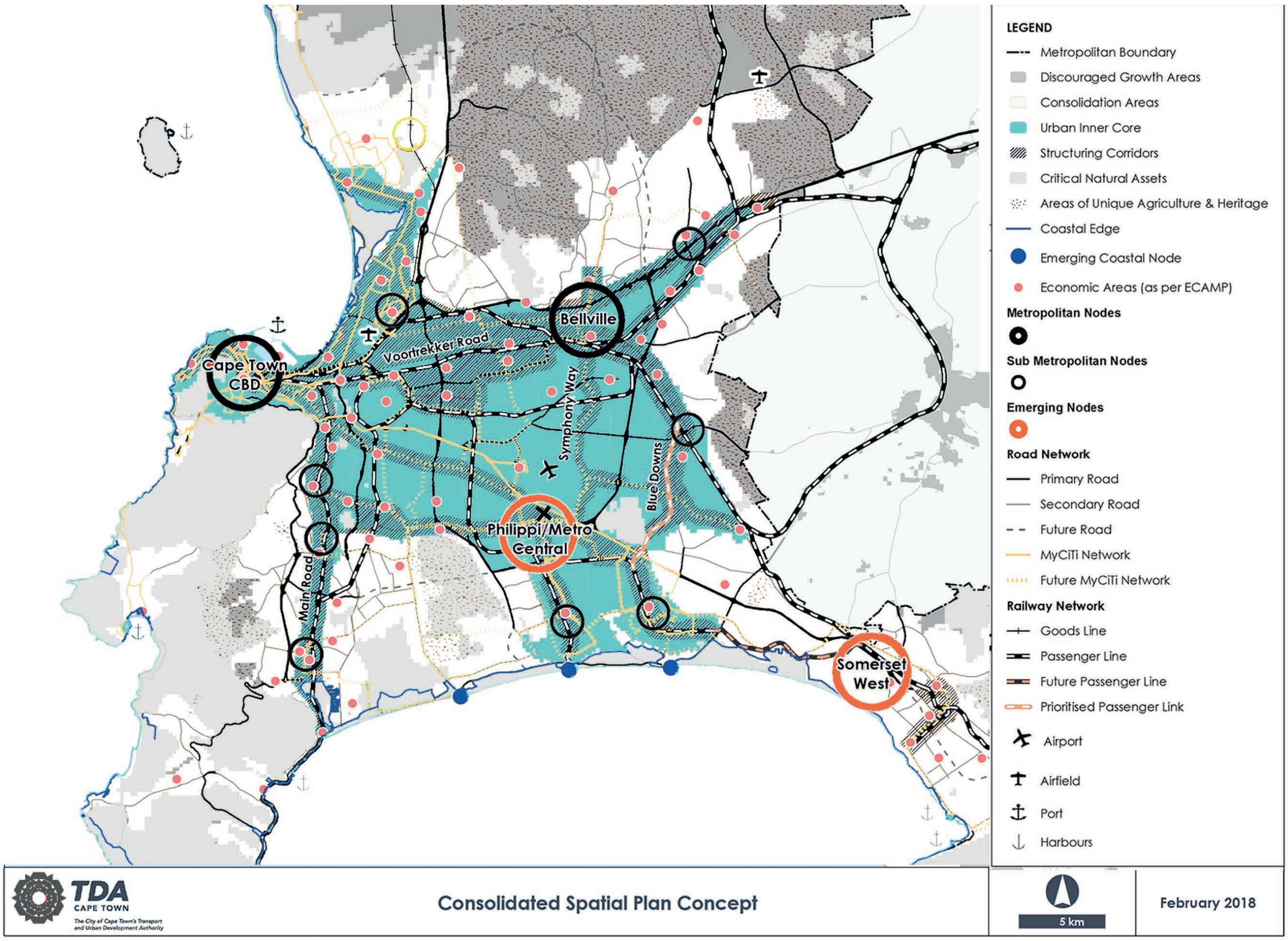
Why Philippi?

To explore the potential and limitations of 3D printing construction in a local context, I decided to design a Technical Vocational Educational and Training (TVET) facility in Philippi, Cape Town. Philippi has been identified in the City of Cape Town's municipal development framework as a new metropolitan node in addition to the three existing nodes in Cape Town CBD, Bellville, and Somerset West.

Once I plotted all the existing TVET colleges and universities (in orange on the image to the right) in Cape Town it was obvious that there is a lack of tertiary skills training in Philippi. The area deals with huge unemployment numbers and there is thus a need under young residents to gain practical skills they can use to get sustainable job opportunities.

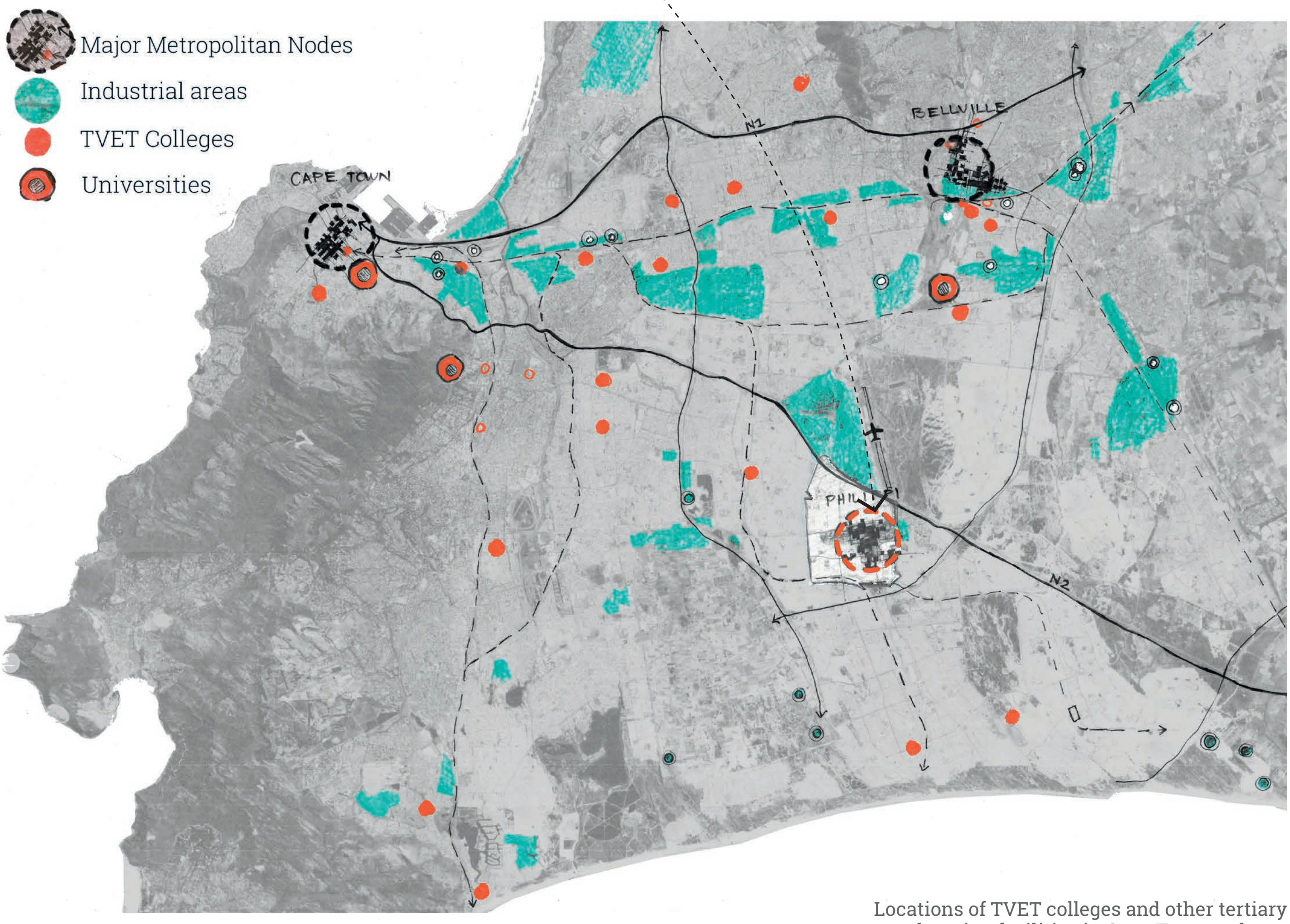
After learning more about existing economies and industries in Philippi it was evident that there is already an established industrial area and general culture of craft and manufacturing. Philippi is, therefore, a good location for a school that provides a platform for emerging manufacturers to be educated in a form of accredited vocational training.

The new Philippi node is also very accessible as it sits at the centre of the other three nodes and right next to two mayor vehicular routes (N2 and M5), the airport, and multiple railway stations. The new proposed TVET college will therefore be easily accessible not only to the residents but also to the surrounding areas like Khayelitsha, Delft and Mitchells Plain.



Consolidated Spatial plan concept by the City of Cape Town showing existing and planned metropolitan nodes

FIG 82



Locations of TVET colleges and other tertiary education facilities in Cape Town and surrounds, as well as established industrial areas

FIG 83

POA - Philippi Opportunity Area

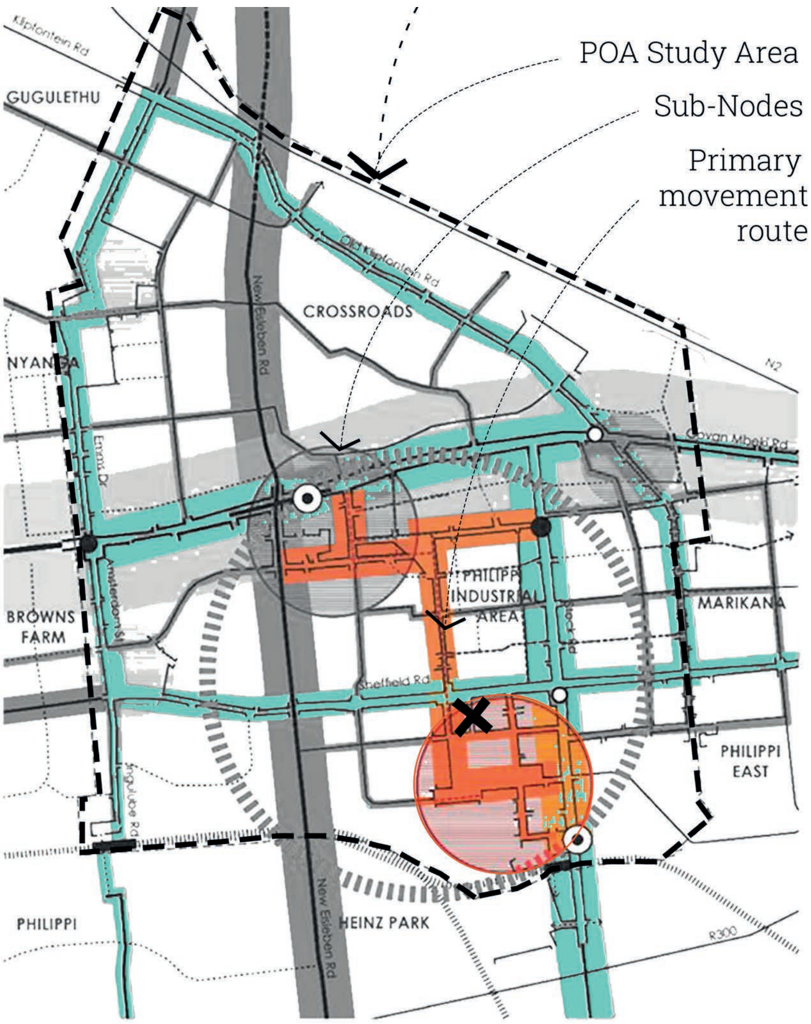
In their Spatial Development Framework, the City identified what they call the Philippi Opportunity Area (POA). Within the larger Philippi this area has the most community and commercial activity and therefor potential for development. The idea is to invest in this area first as a catalyst and study the outcomes for future interventions in surrounding areas.

Within the POA area there exist two sub-nodes and a primary movement route that links them. This route is completely pedestrian focused and it is about a 10 min walk from the one node to the next. My design proposal is situated on this pedestrian linking route in the second node closer to the industrial area and Stock Road train station.

A zoomed in area plan of the two nodes and linking route. The proposed site is indicated.

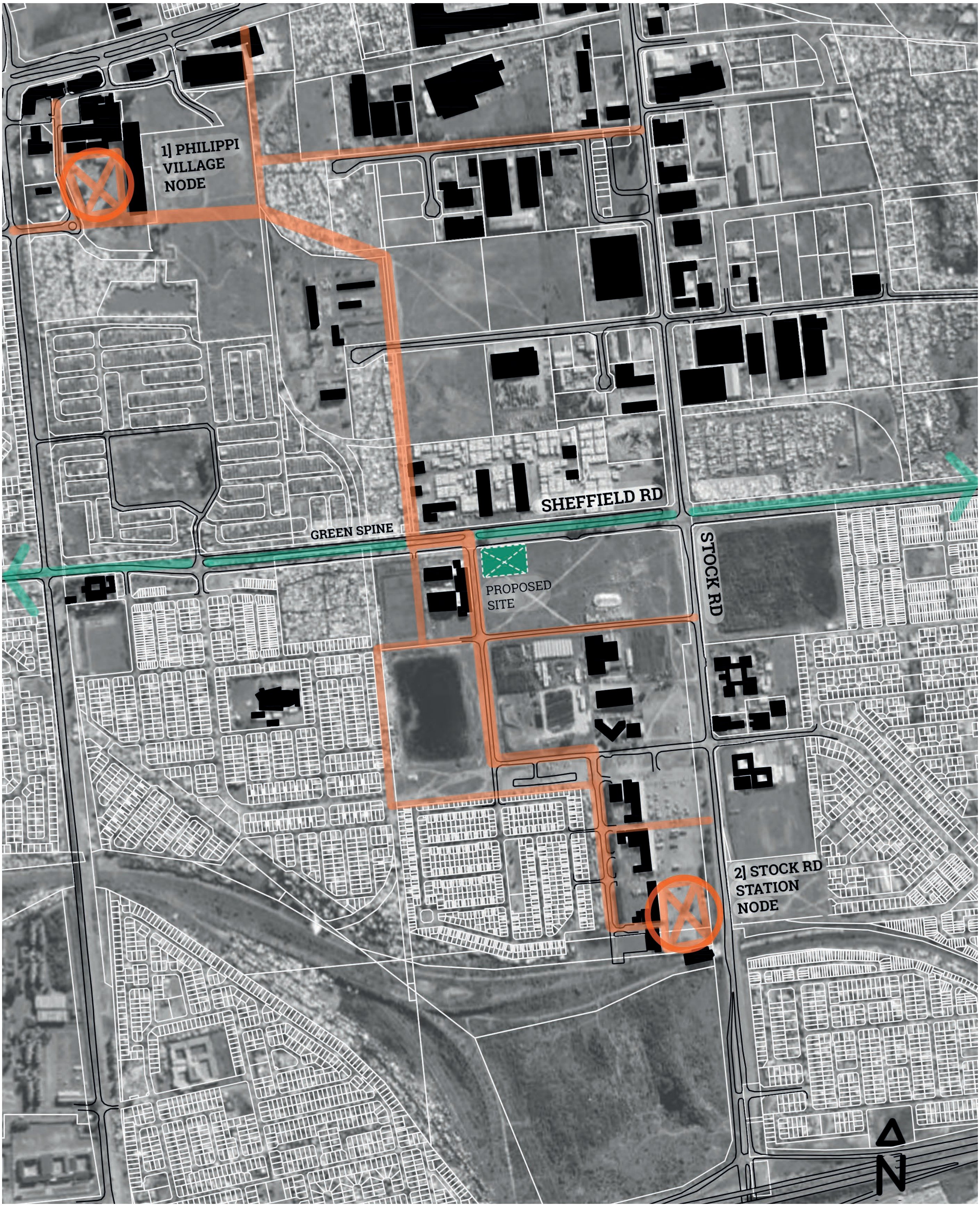
FIG 85

POA area in white



Location of the two sub-nodes in the POA, as well as the main pedestrian route marked in orange linking them

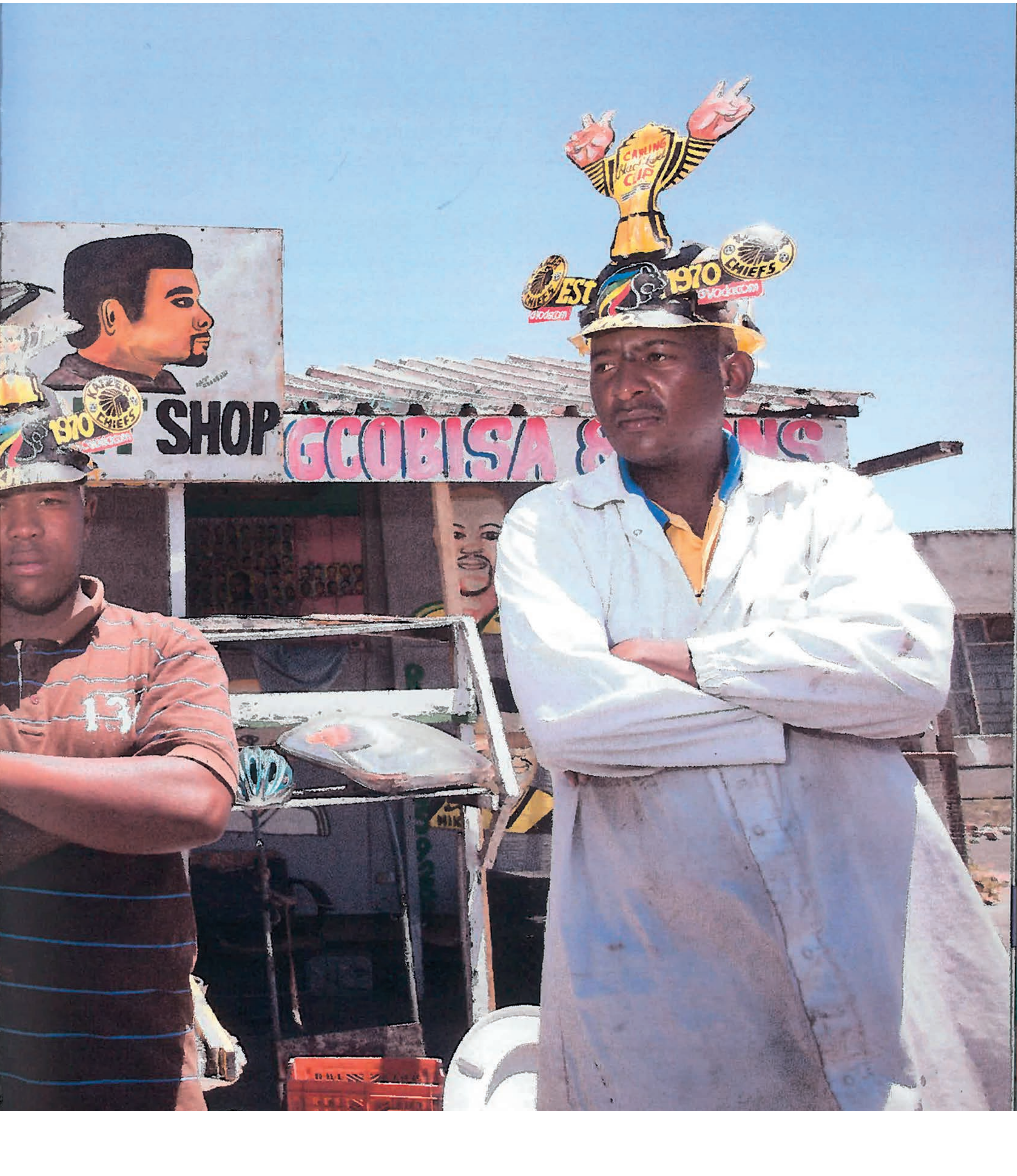
FIG 84


1] PHILIPPI VILLAGE NODE
SHEFFIELD RD
GREEN SPINE
STOCK RD
PROPOSED SITE
2] STOCK RD STATION NODE
N

Philippi has big culture of craft and making

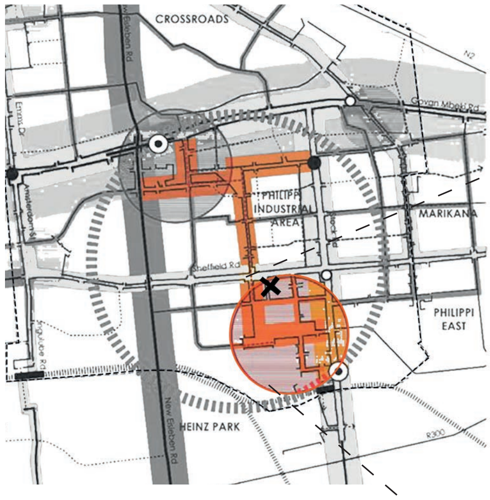
FIG 86

Philippi book


SHOP
GCOBISA
1970
CHIEFS
EST
1970
CHIEFS

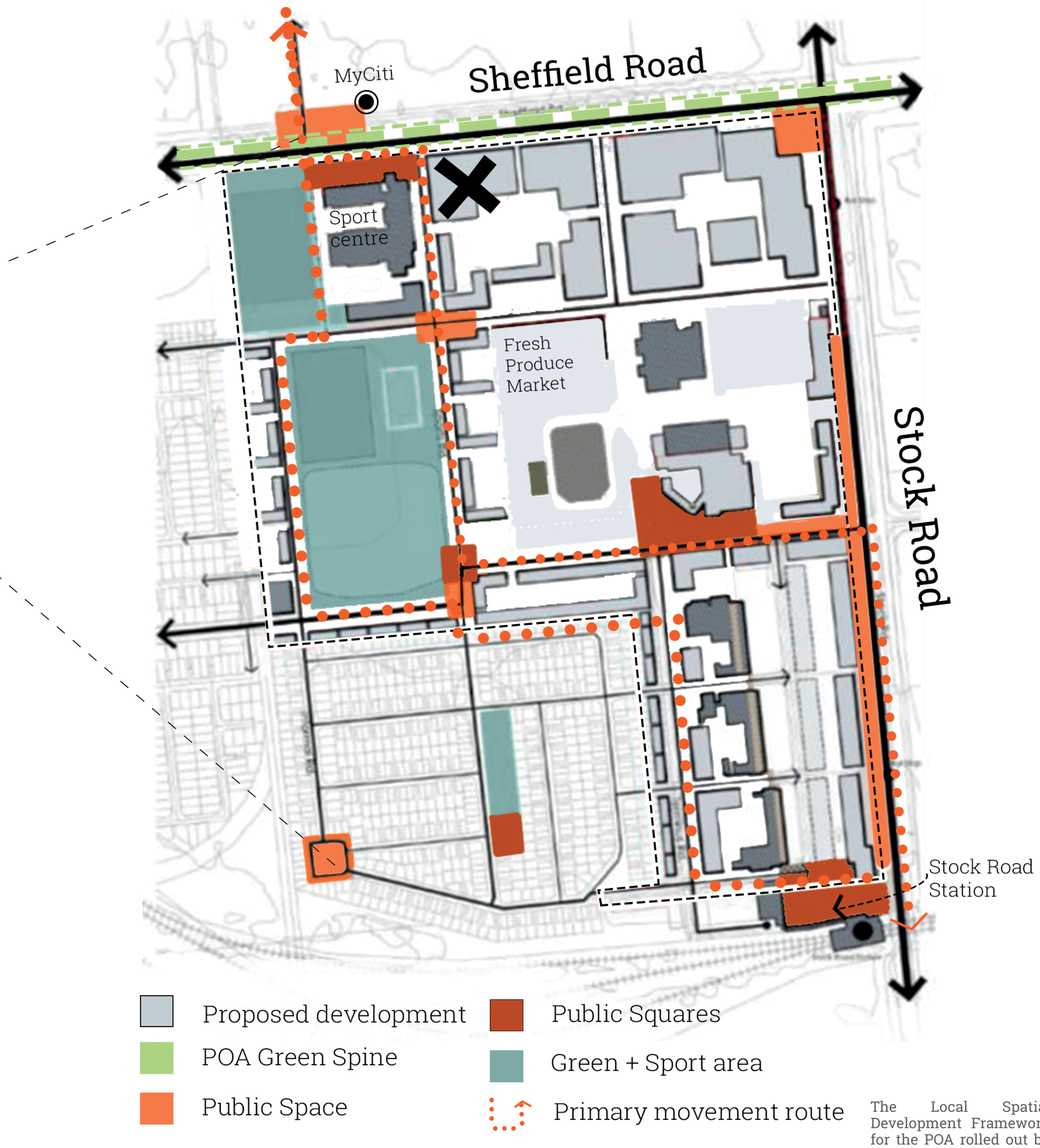
Local Spatial Development Framework

The City did a future urban plan proposal for the POA that introduce a green spine in Sheffield road as well as multiple sports spaces and public squares along the pedestrian route linking the two sub-nodes. The proposed site is located on Sheffield Road on the pedestrian route and opposite an existing sport centre. The site is opposite a future my MyCiti bus stop and 3 min walk from the Stock road Station. It is also on the same street as multiple other civic and institutional functions such as the iTemba community centre that is also involved with vocational skills training programs.



Stock Road Station at the centre of the second node

FIG 87



The Local Spatial Development Framework for the POA rolled out by the City in 2022

FIG 88

URBAN + SITE ANALYSIS

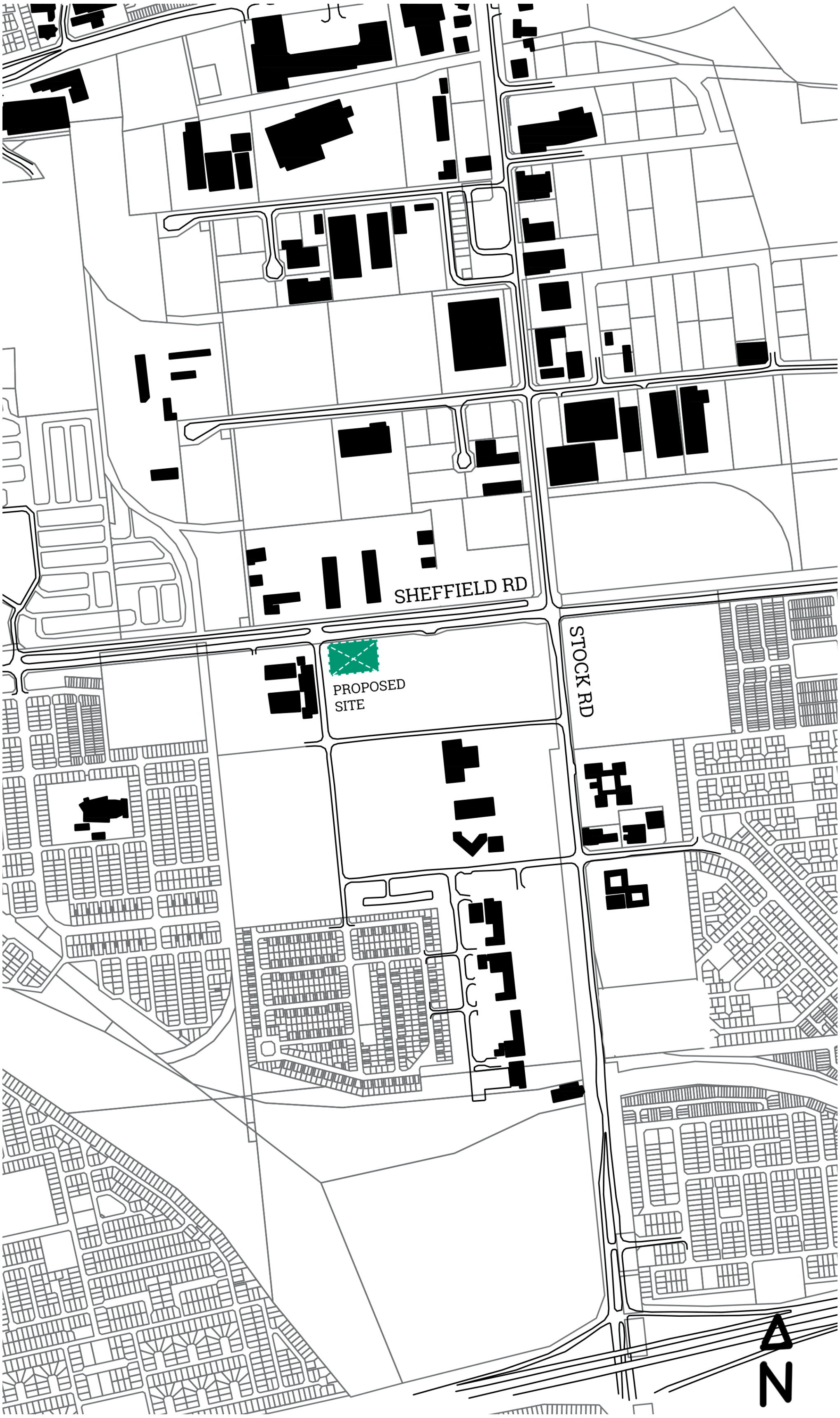
Existing Urban Fabric

Although this area in Philippi has been identified as a new mayor metropolitan node, it is still far from reaching the desired density and diversity. Large plots of open land stretches between the one neighbourhood and the next and while larger buildings are far apart instead of being clustered around transport intersections that would make it easier to walk from the one to the other. Important civic and commercial buildings are set back from the street, sometimes creating 15m gaps between the entrance to the street. This and other poor planning strategies has led to Philippi streets with high crime rates and unauthorized squatter settlements.

In the drawing below you can see how the few open plots of land in the established Belville node compare to the vast stretches of open land in the Philippi node. Hence the enormous need for cost and time effective mixed-used developments to house and cater for the ever-growing population. The proposed site is located on one of these open plots aims to act as a precedent to establish a new urban development pattern.

Existing urban fabric compared to that of the Belville metropolitan node - developments are few and far between. The orange mass is the entire footprint of the University of Cape Town Upper Campus, for a sense of scale

FIG 89

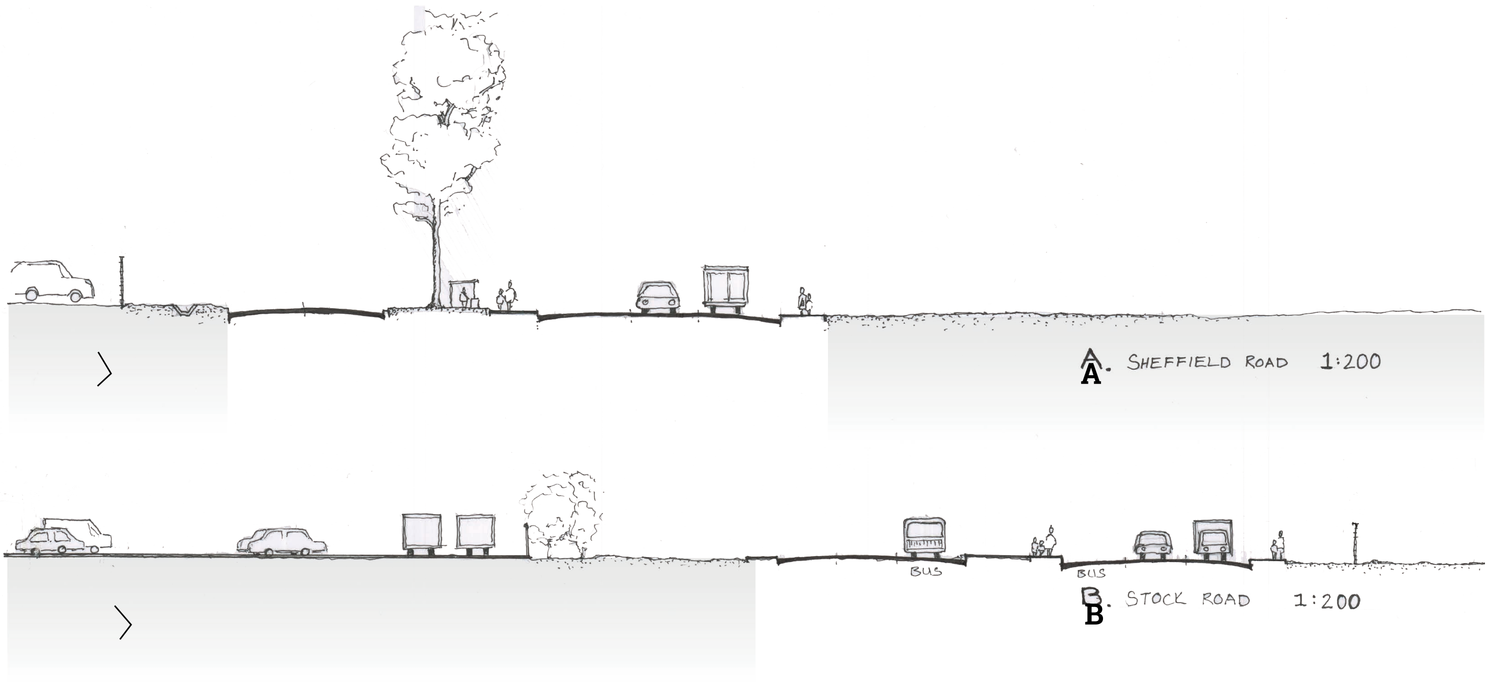


Showing the proposed site in relation to the streches of un-developed land

FIG 90

A 1:1000 context model showing the existing urban fabric and highlighting poor planning decisions

FIG 91



Street sections showing poor edge conditions and urban layouts
FIG 92

Existing street conditions on Stock and Sheffield Road - undesirable street edge conditions
FIG 93


4654
Golden Arrow
The Bus For Us

Development Guidelines

To deal with the shortcomings of the current urban conditions mentioned in the previous section, the City outlined new development guidelines in their Spatial Development Framework. These include guides such as 0m building lines and three or four storey mixed-used developments with a special focus on public street interfaces.

To summarize , the new guidelines have five main objectives or principle it tries to promote in the development of the new Philippi node. These are to densify existing developed areas, diversify developments to have residential and commercial space, focus on transport for the pedestrian, and to create a sense of place or identity in Philippi. There is already an existing culture of making and selling, agriculture, and industrial manufacturing. With the design proposal I hope to add to this a culture of tertiary skills training. A place where young people entering the work force can come to gain useful modern skills for the next industrial revolution. And a culture of innovation in the manufacturing and construction industry.

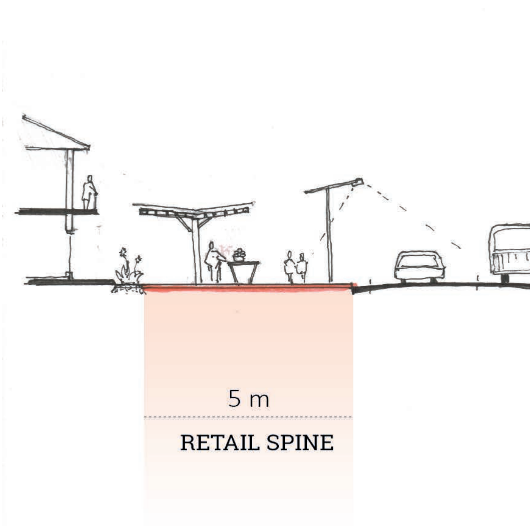
PRICIPLES

1. DENSIFICATION
2. MIXED-USE
3. TRANSIT ORIENTATED
4. RESIDENTIALLY LEAD
5. CREATE IDENTITY

DEVELOPMENT GUIDELINES

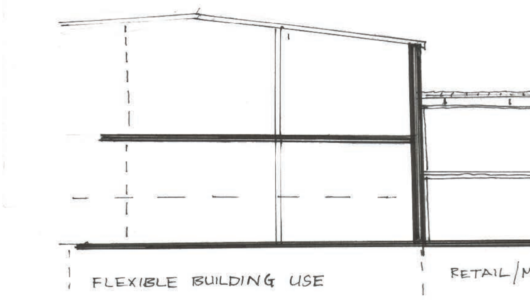
SHEFFIELD ROAD:

1. Become a new lower-order mobility route
2. Green spine connecting green open space
3. Activity corridor
4. Multi-purpose green infrastructure
5. Active Ground Floors
6. Street facing development
7. Pedestrian-friendly (accessible from sidewalk)



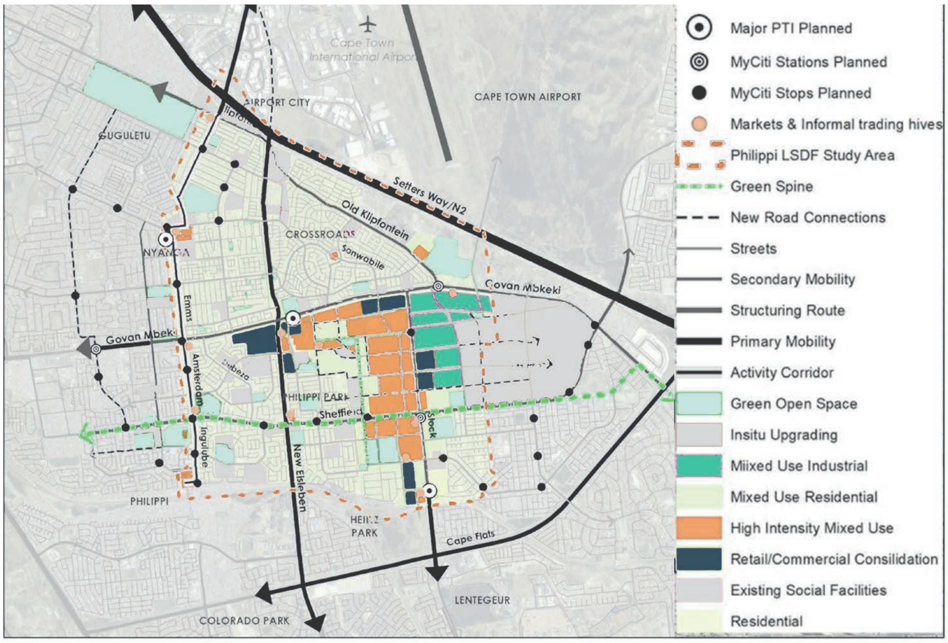
STOCK ROAD:

1. Become new Town Centre
2. Limit vehicle access points (NMT)
3. Support informal markets
4. 0m Building lines
5. 150 du/ha density
6. Building heights of 4 storeys
7. Allow for land use to change (regenerative)



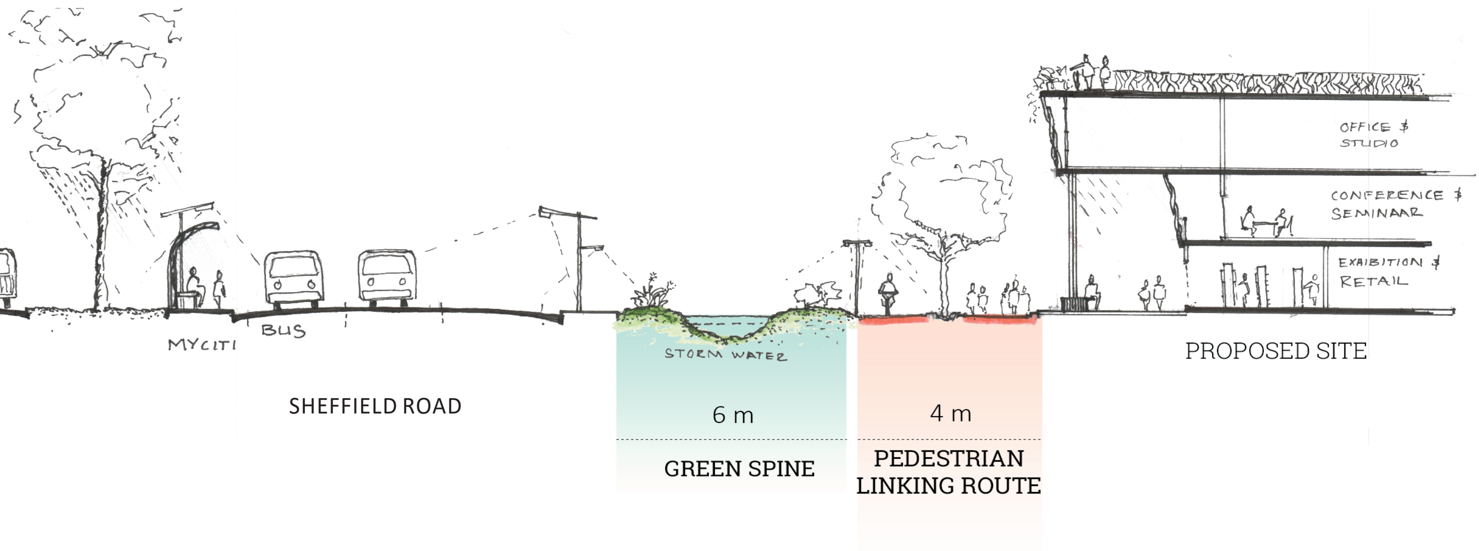
Future development plans rolled out by the City in 2022. The orange indicates High intensity Mixed used developments

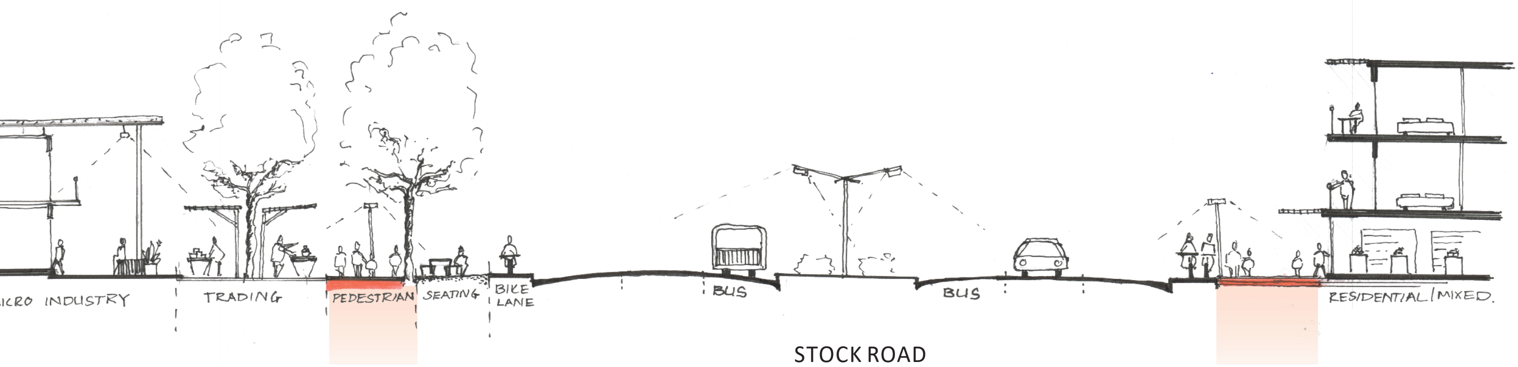
FIG 94

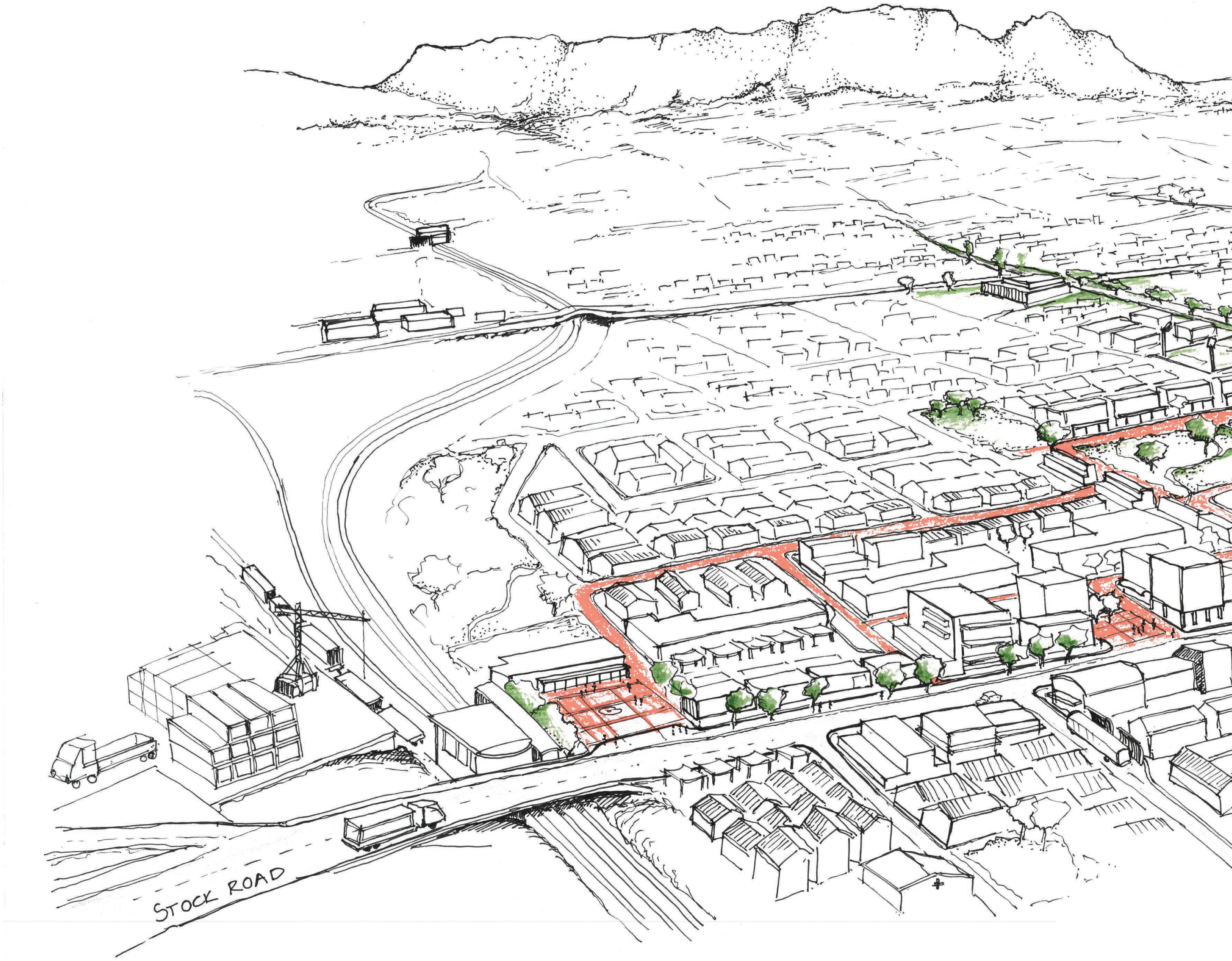


Sections showing proposed street conditions for Sheffield and Stock road according to the development guidelines.

FIG 95



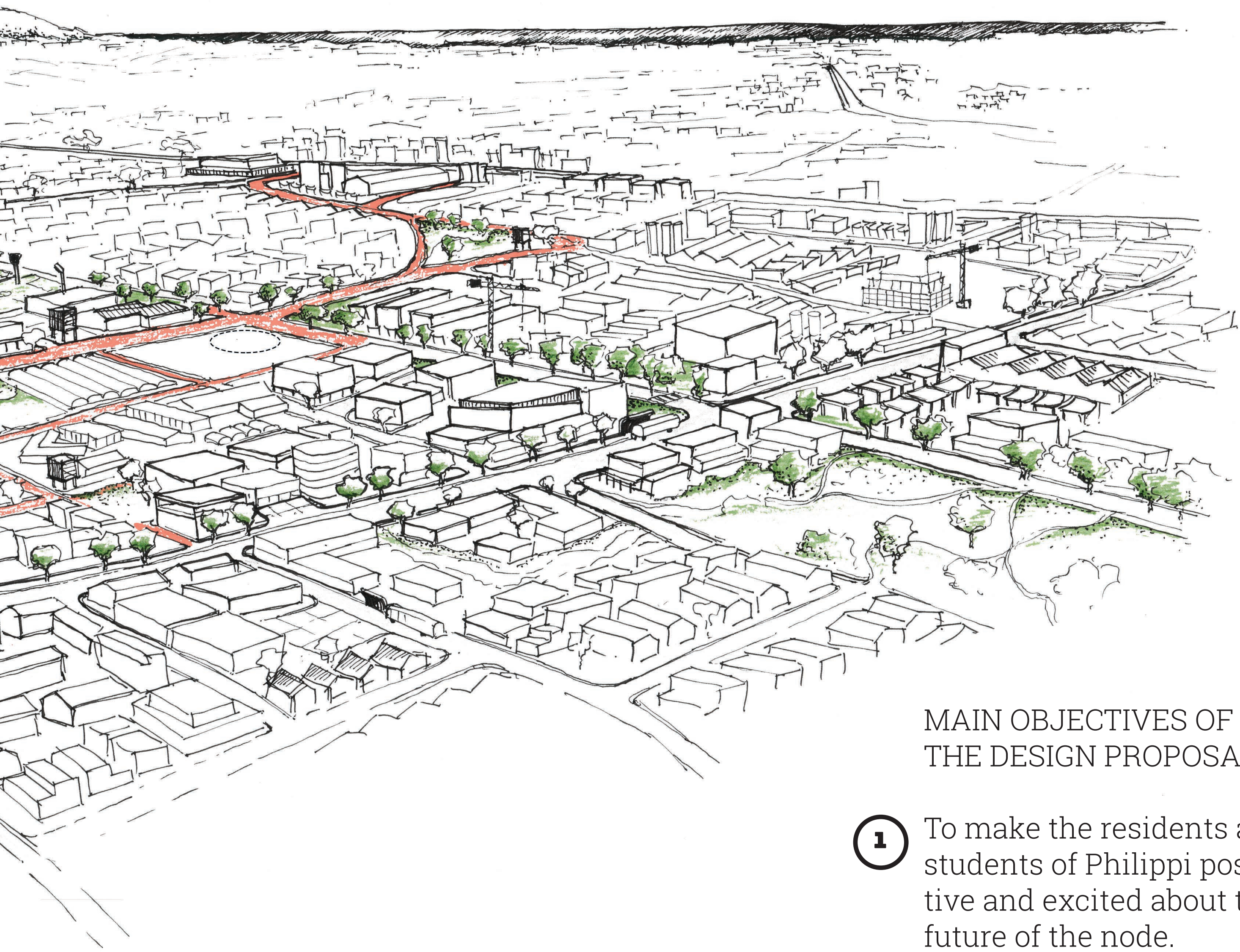




The city did extensive research in the area and my design proposal will therefore build on their development frameworks.

An imagined future of the Stock road node in Philippi. The site is located on the pedestrian linking route, indicated in orange, and proposed green spine.

FIG 96



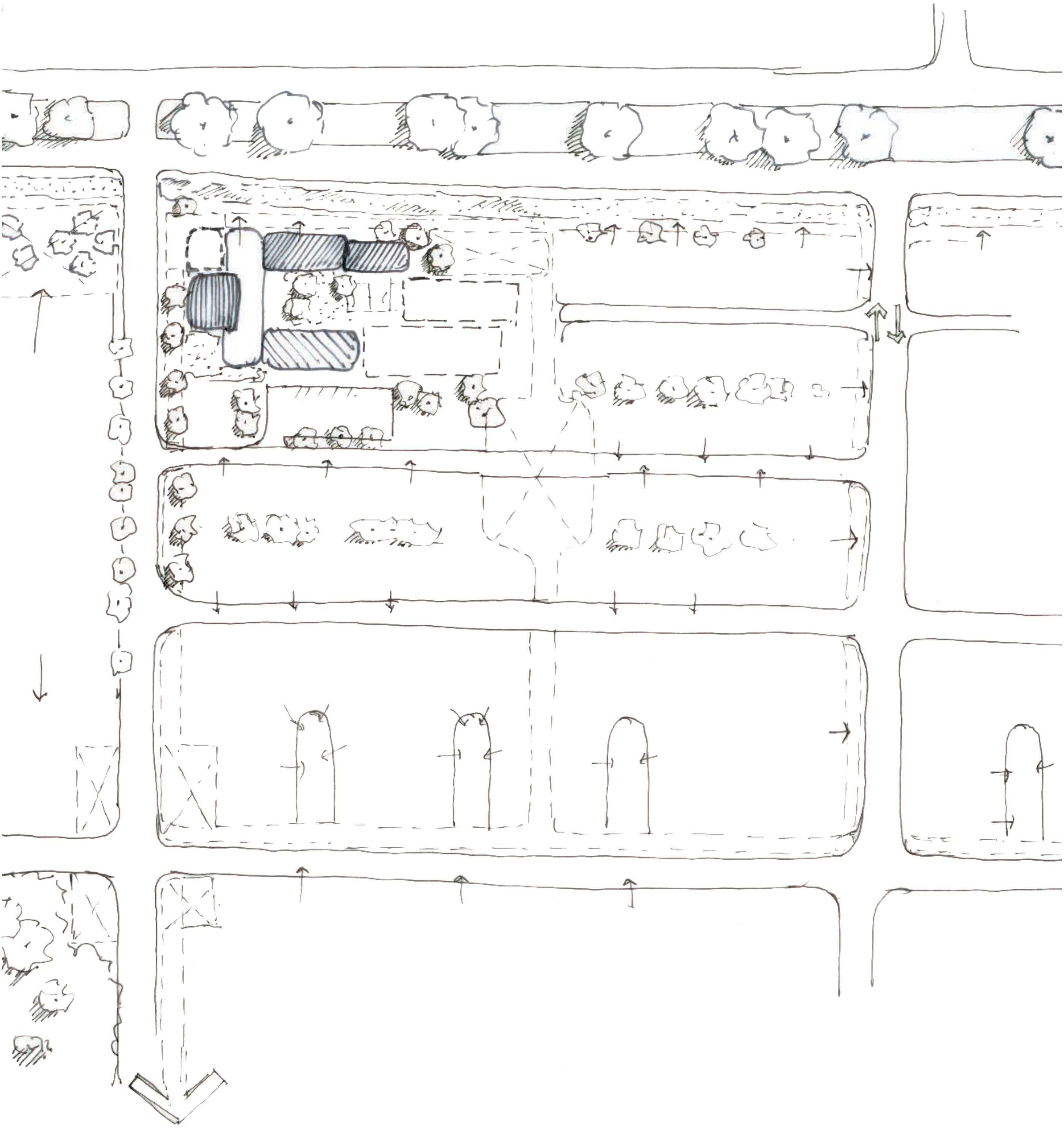
MAIN OBJECTIVES OF THE DESIGN PROPOSAL

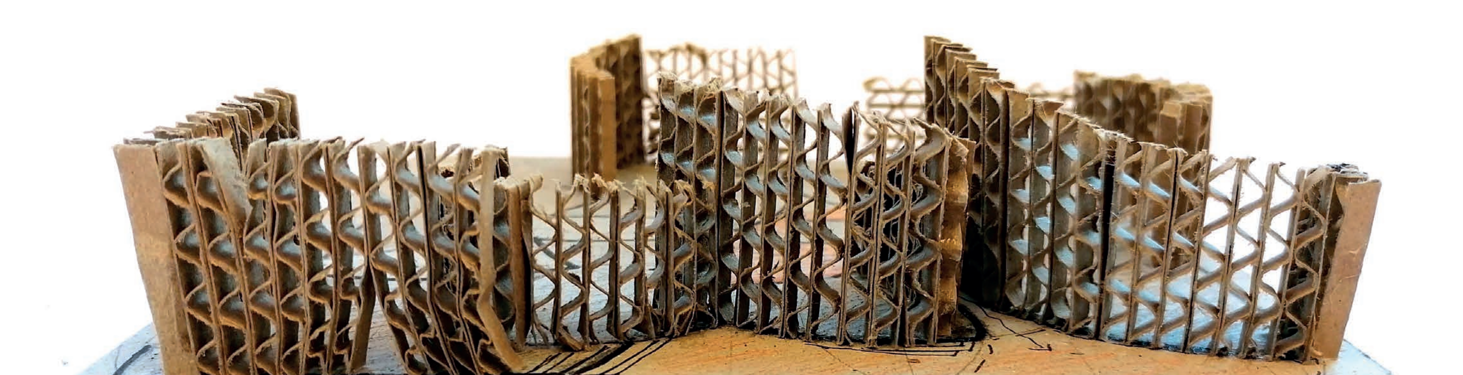
1. To make the residents and students of Philippi positive and excited about the future of the node.

2. Act as a catalyst to start the process of becoming this node by establishing a pattern of well-designed urban spaces

3. Demonstrate the value 3D printing can have for the area and educate on how to best employ the technology.

B] DESIGN DEVELOPMENT





PROGRAM

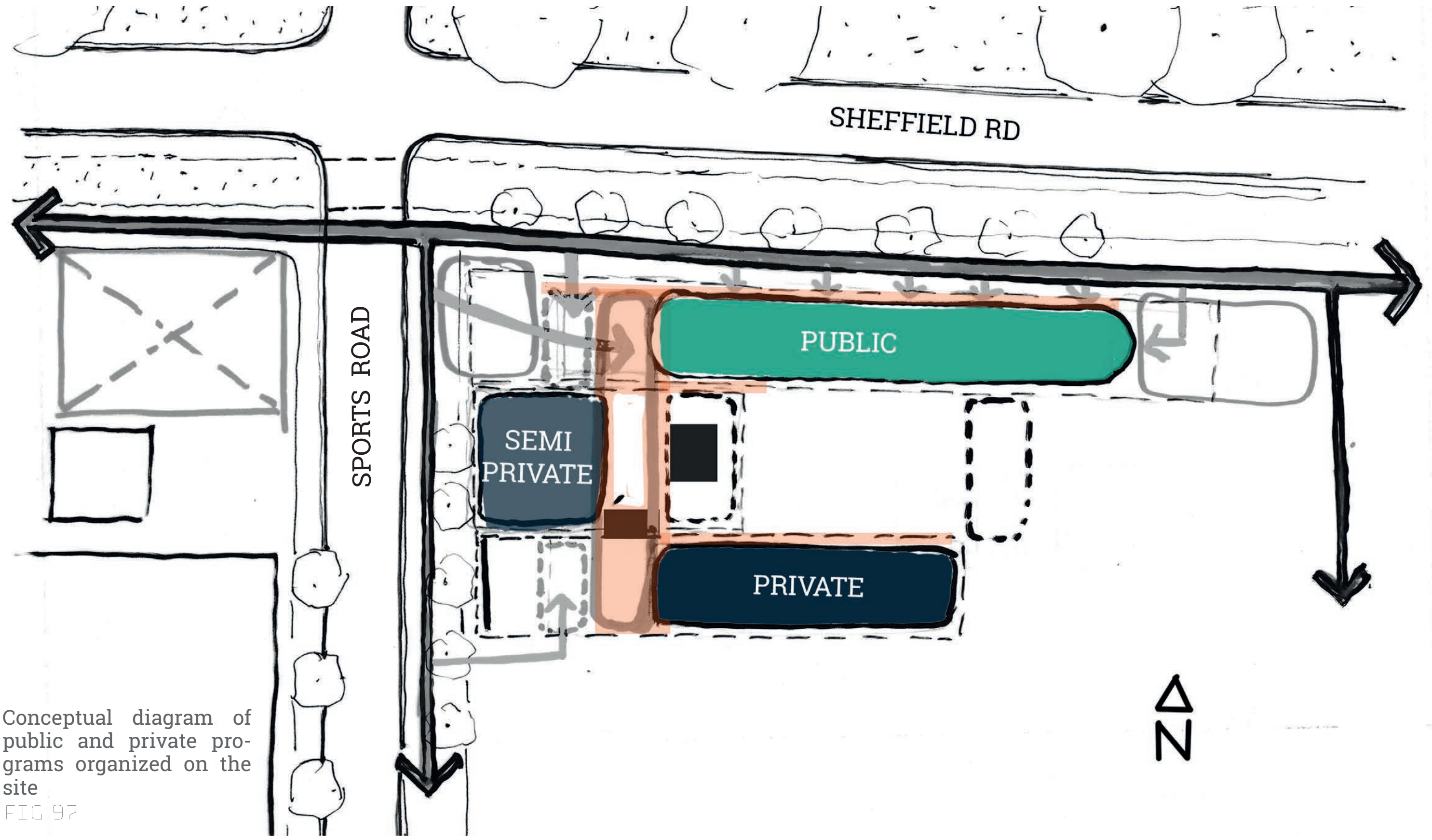
The new TVET college's main objective will be to educate and promote the use of 3D printing and other 4th industrial revolution (IR) manufacturing technologies. The school building, workshops and public facilities are not only built using 3D printing construction but also train locals in the craft to give them useful and modern skills that will soon be in high demand as the technology matures in the future to become a mainstream fabrication method, internationally and in South Africa.

In addition to the college facilities the development will host 3D printing research labs and a range of workshops, as well as showrooms and exhibition spaces for visiting stakeholders and the public. This is to educate on and demonstrate the value and benefits the technology holds for a developing node like Philippi. And as part of City's plan to activate street edges with mixed used developments, the ground floor of the North wing, on Sheffield rd. facing the green spine, will provide retail space for local entrepreneurs and business owners.

The daily use, output, and the construction of the building itself, are all working towards the main function of the building that is to further the advancement of the local construction industry in the age of another industrial revolution. **In other words, the ever-growing, ever-changing building houses a three-fold program of teaching, production and experimentation.**

The north wing houses the public programs such as retail on the ground level and auditoriums and temporary living units for visiting researchers on the higher levels. The South wing houses the private programs like offices and studios for the students and staff of the college. And in the middle linking the two is the semi-private workshop spaces with large windows to allow the public a glimpse of the making and learning happening in the school. A circulation core and semi-private courtyard for the students and researchers link the three sections. This allows the different wings to function separately while also allowing for easy collaboration, as both the research and student departments will make use of the workshops.

...a three-fold program of teaching, production and experimentation.



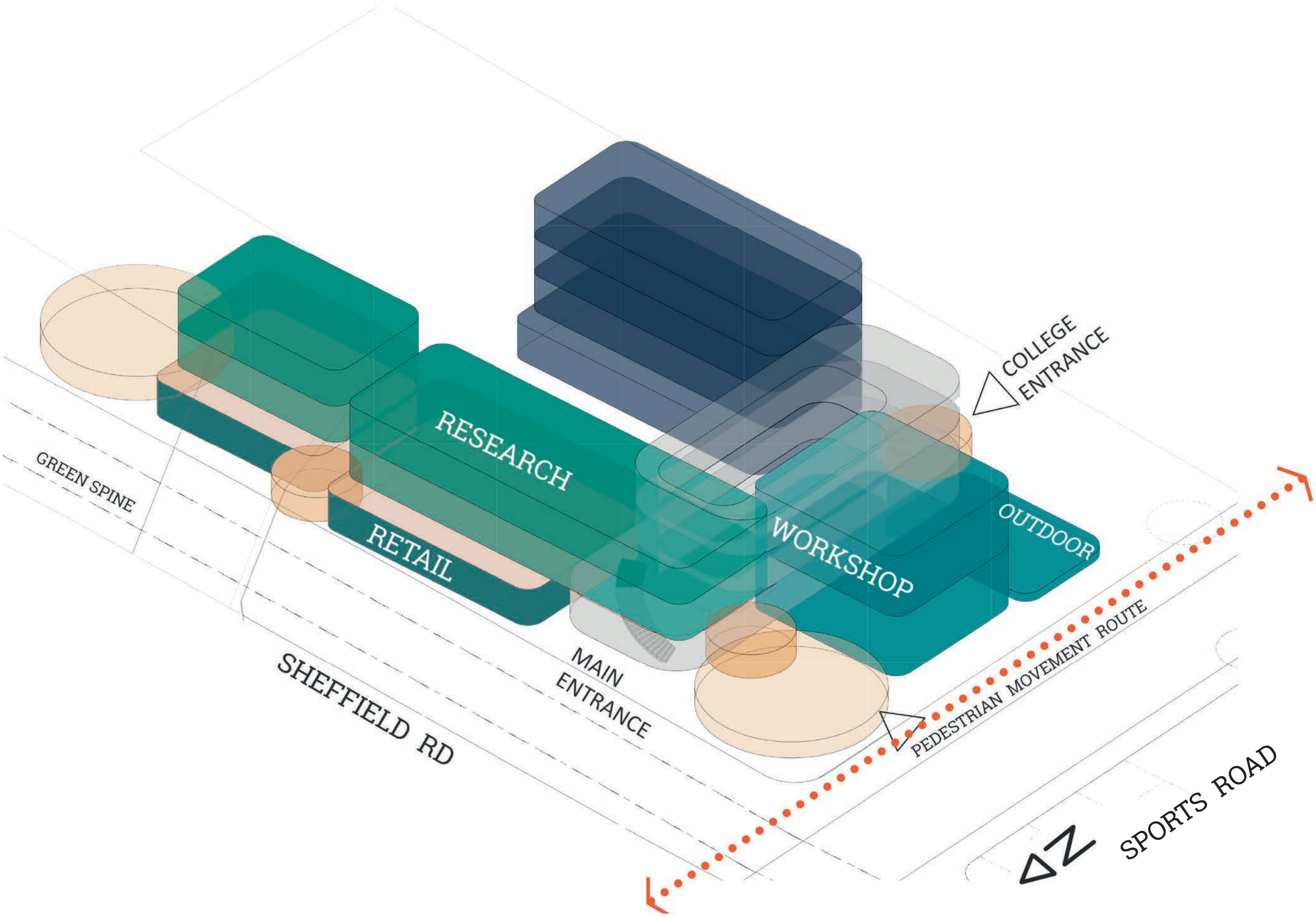
Conceptual diagram of public and private programs organized on the site
FIG 97

A **BUILDING** THAT MAKES...

BUILDINGS

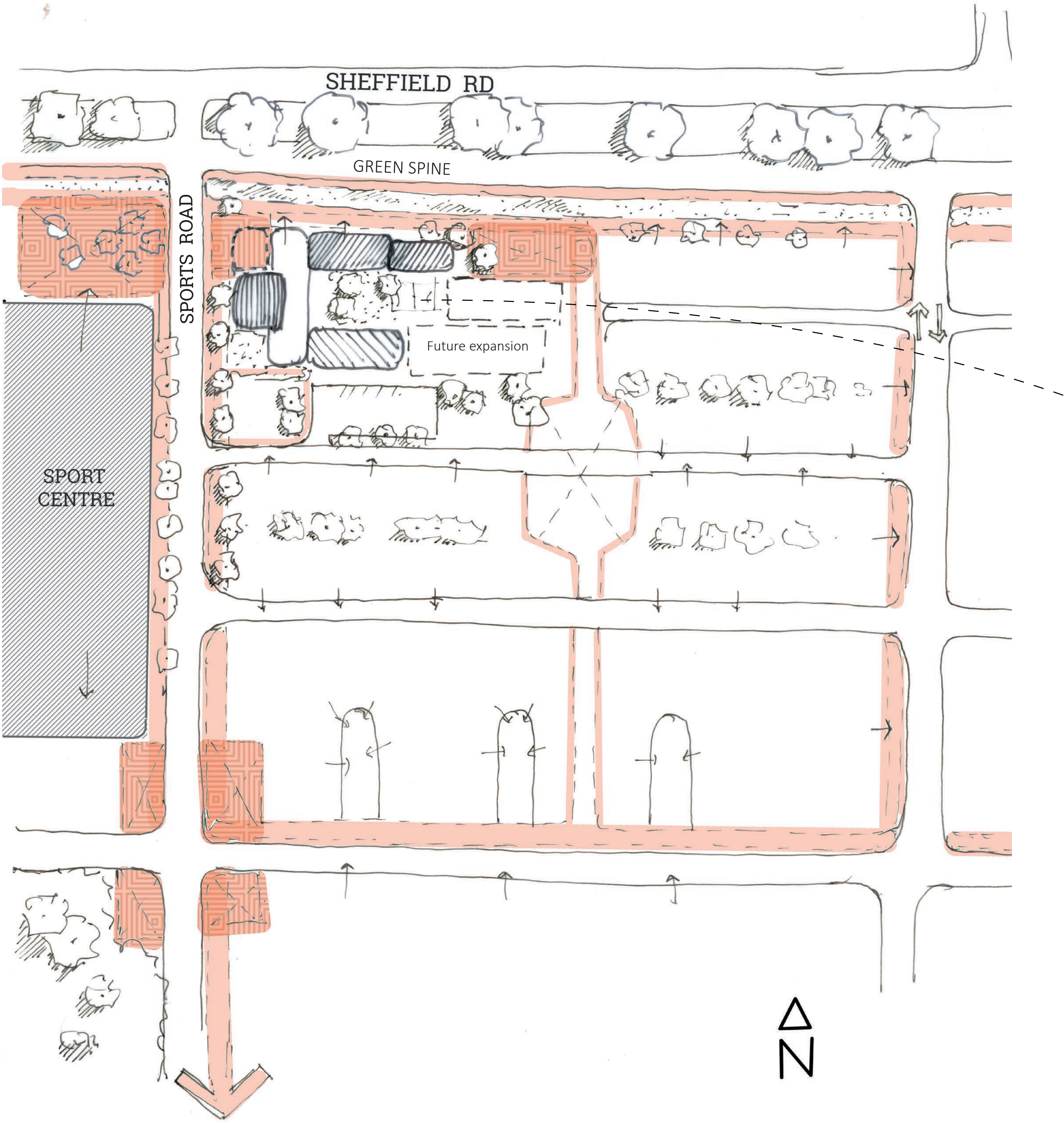
and...

BUILDERS



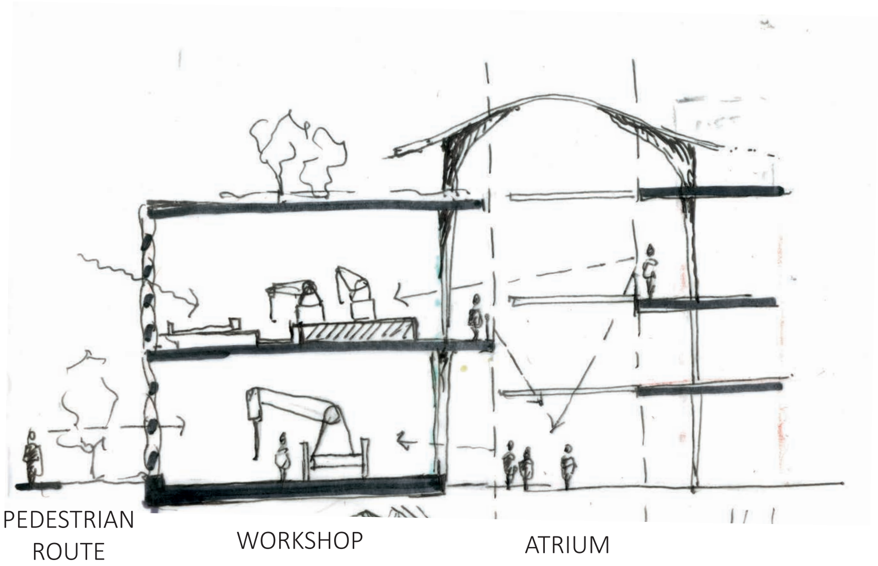
Conceptual massing diagram explaining where the different programs are housed. The ground level remaining mostly publicly accessible
FIG 98

URBAN RESPONSE



The urban scale drawing shows where the building is situated in relation to Sheffield road and the green spine as well as the existing sport centre to the left. Note the public corner that is created by the setback of the west wing of the building. This public square ties in with the rest of the pedestrian network between the two sub-nodes.

FIG 99

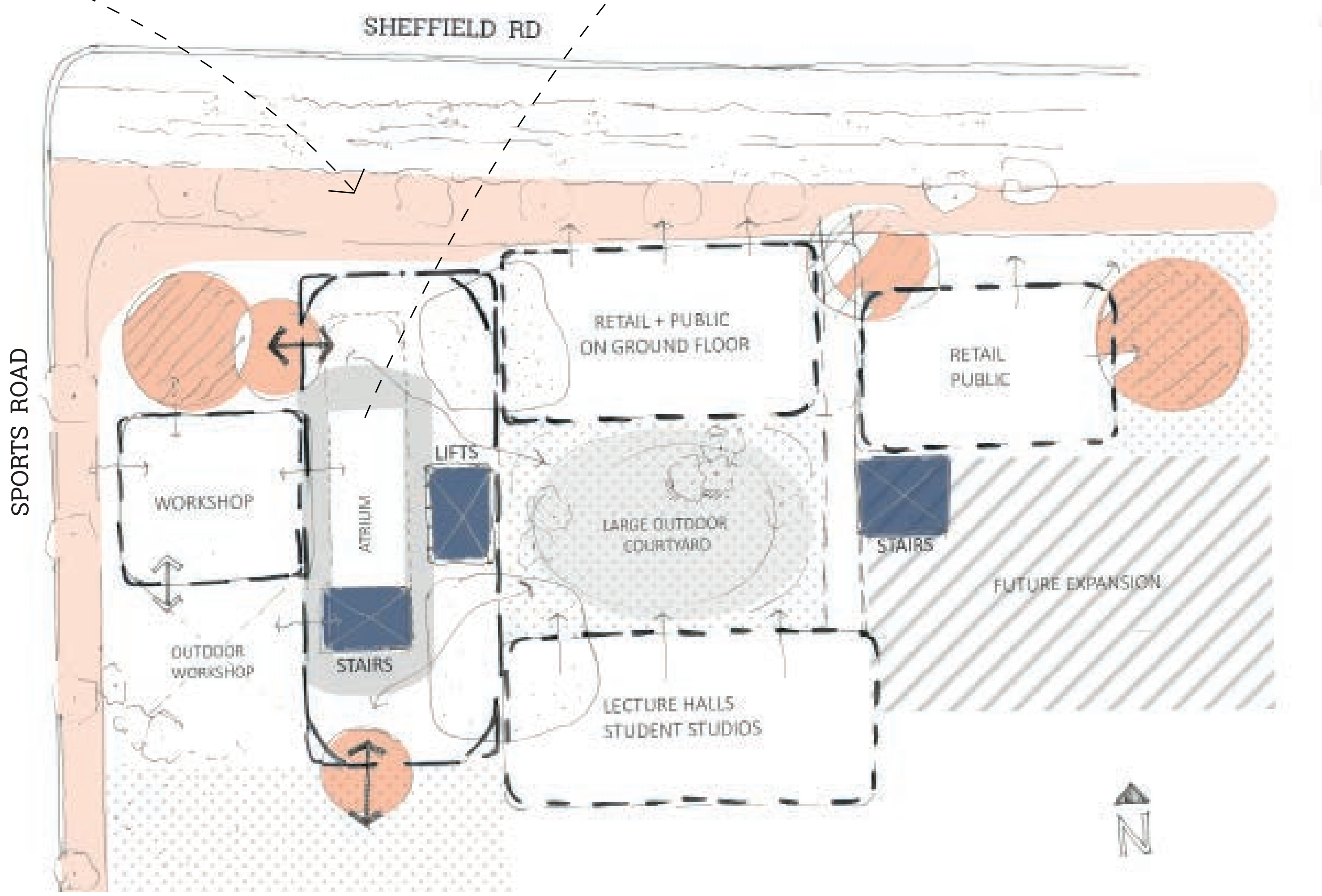


Conceptual section of the atrium in the main circulation core. The idea is that the workshop is visible both from the public spaces in the builing and the side walk.

FIG 101

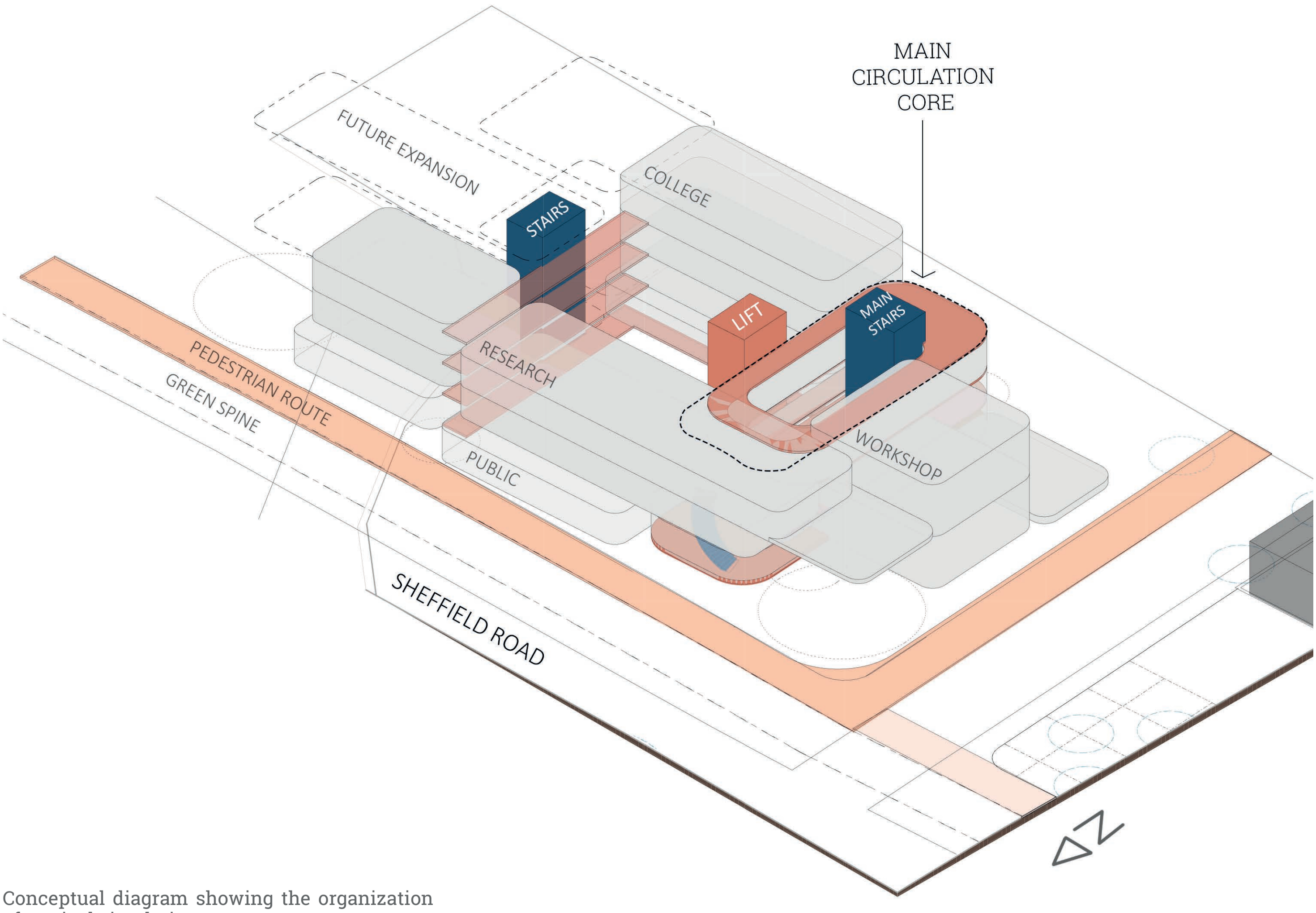
A zoomed in drawing of the different sections and programs of the building and how it relates to the street. Note the main entrance is more public while the South entrance to the college facilities is more private and set back from the street.

FIG 100



CIRCULATION

The three main programs of the building are all organized around a main circulation core. The atrium in the core also acts an event space with the main staircase on the one end. A second stair case links the North and South wing of the building and could in future become a secondary circulation core when the collage expands.



Conceptual diagram showing the organization of vertical circulation.

FIG 102

C] CONSTRUCTION

3D PRINTED STRUCTURE

Most of the 3D printed projects of the last couple of years are single-storey houses (see fig. 103) as the technology naturally lends itself towards constructing load bearing walls. Although 3D printing works exceptionally well in constructing this typology, it means a lot more concrete is used for the walls creating a larger carbon footprint. In South Africa we have optimized the system of load bearing brick walls and could rather then continue using that system for small projects like a single house. However, when we start to consider other typologies such as multi-storey, mixed-used buildings that often require free façades and higher floor to ceiling heights, the mainstream method of in-situ cast concrete and infill bricks is still very time consuming, leaves room for human error, and limiting in terms of structure.

I have therefore started exploring other ways 3D printing can be employed in terms of structure to make the construction of larger buildings more time and cost effective in our local context.

Column & Beam systems

My initial inclination when first attempting to use 3D printing to construct a multi-storey building, was to still use a column-and-beam system but with very bespoke printed members that use less material and allows for easy connection and assembly.

However, this seemed to not be the most effective way to employ 3D printing as the columns would still need reinforcement and in-situ concrete for extra strength (see fig 105). Essentially these columns would just be very advanced 3D printed permanent formwork. Although this would already be a huge advantage as formwork usually makes up for almost half of the construction time and cost. Another issue would be the reinforcement bars in the columns because they limit the printing to small sections as the robots can't print around it (see fig. 107).

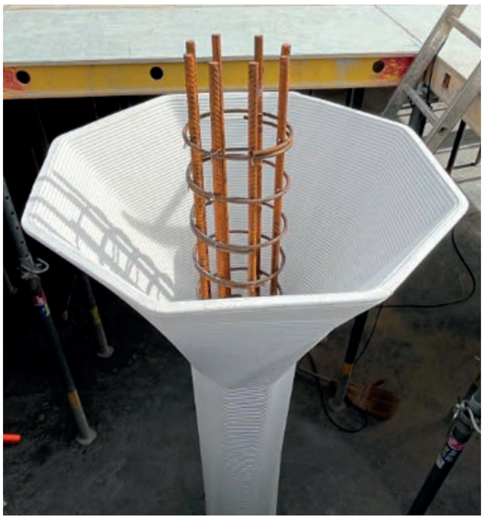
The next step was to look at how else this technology might be employed in making the structure of a building in order to hopefully replace the in-situ concrete column-and-beam system that is currently so time consuming and wasteful. I started to look at how columns and beams could rather be printed as a single structural member (see fig. 104c) after realising the inherent issues with printing the members separately and having to connect them with reinforcement and more concrete. However, this method would still require large sections of formwork or printed temporary support material to keep the overhangs in place while it sets (see fig 104c).

To overcome this, I began looking at the principle of ***print-orientation***, one of the most important aspects of 3D printing. Print-orientation in 3D printing construction will be discussed in depth in the next section.

...exploring other ways 3D printing can be employed in terms of structure to make the construction of larger buildings more time and cost effective in our local context.

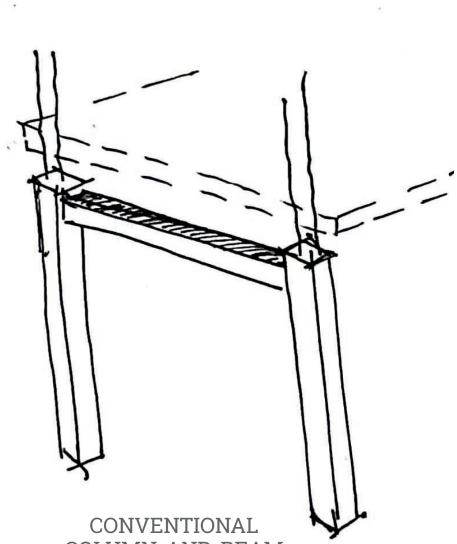
ICON's 3D printed homes in Texas, USA, are examples of the typical load-bearing wall typology 3D printer constractors opt for.

FIG 103



These diagrams show the progression of a conventional column-and-beam system to one that has been 3D printed. The last drawing shows a single 3D printed structural member.
However this method still has many of the same limitations as the conventional system, like requiring formwork, and is therfore not the best way to employ the technology.

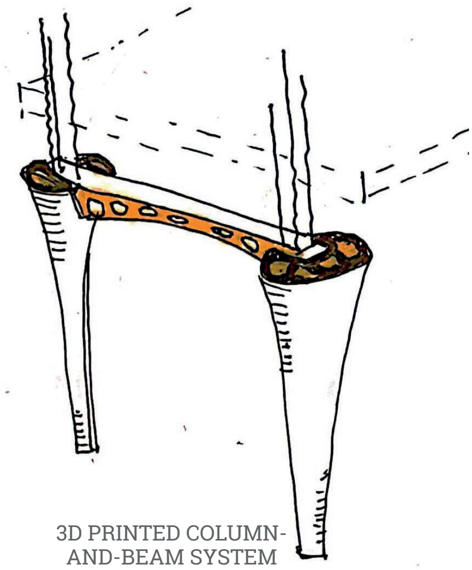
FIG 104



CONVENTIONAL COLUMN-AND-BEAM SYSTEM

These printed columns act as permanent formwork. Steel reinforcements are cast in place to connect the columns to the floor slab and deal with any tension the member might experience. This method has many limitations and does not do the potential of 3D printing construction justice.

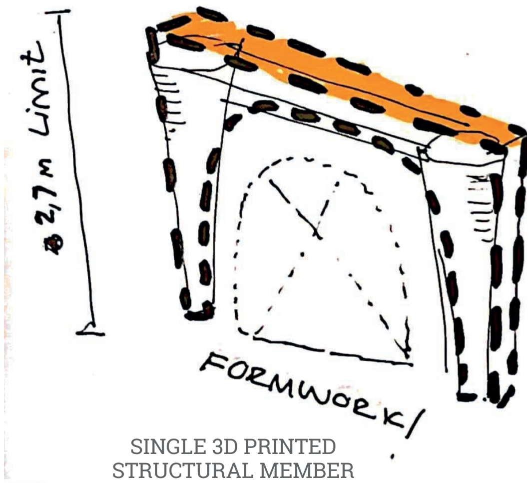
FIG 105 +106



3D PRINTED COLUMN-AND-BEAM SYSTEM

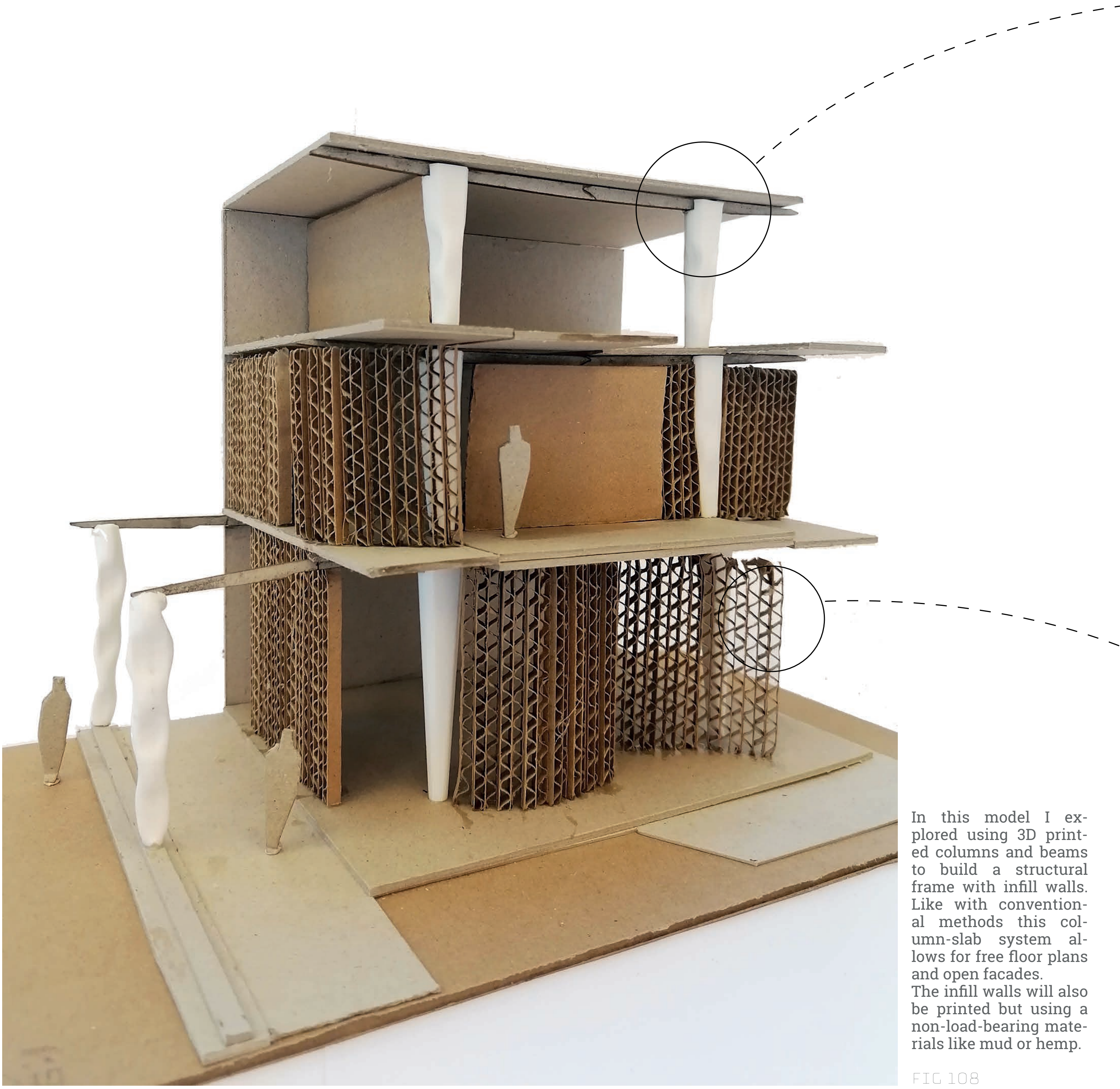
The same method as above is used for this multi-storey building by WinSun. Only here the shells of the columns were printed in sections as the printer can not print around the re-bar

FIG 107



SINGLE 3D PRINTED STRUCTURAL MEMBER

Column & Beam concept model

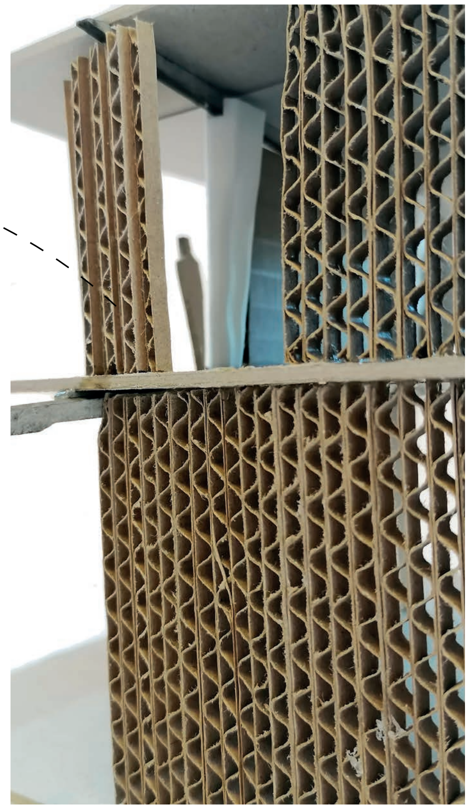


In this model I explored using 3D printed columns and beams to build a structural frame with infill walls. Like with conventional methods this column-slab system allows for free floor plans and open facades.
The infill walls will also be printed but using a non-load-bearing materials like mud or hemp.

FIG 108

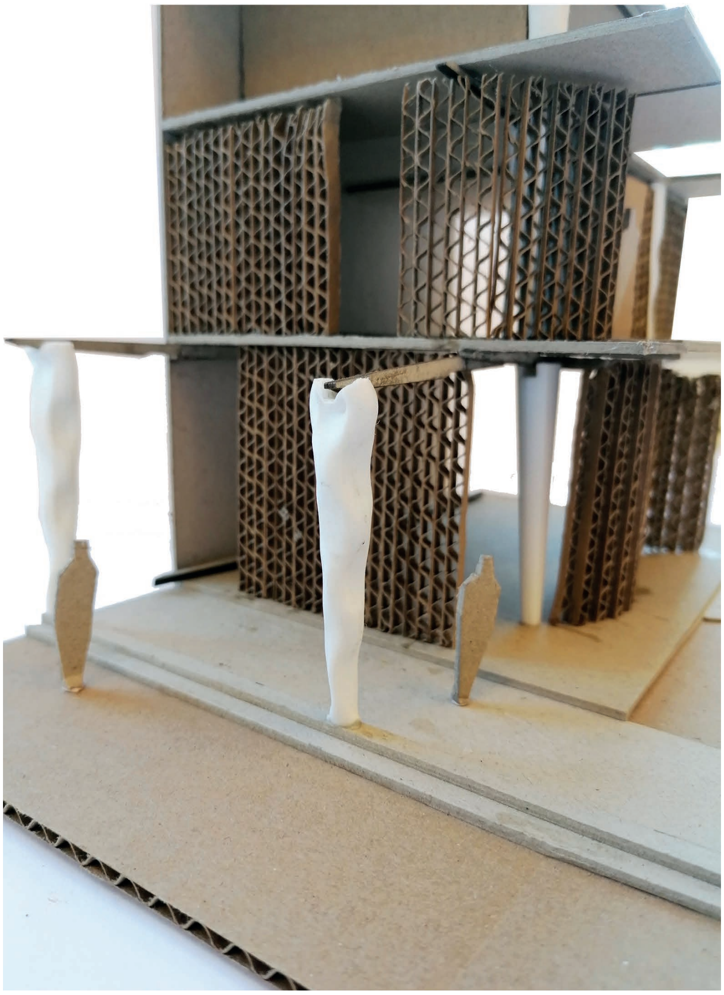
I experimented with printing the top half of a column on a scale of 1:20 with clay.
3D printing allows for more complex forms without any extra time or cost, so I tried to take advantage of this and designed the column head to easily accommodate the beam that would also be 3D printed in future. This also makes disassembly of the members easier .

FIG 109 +110



The infill walls could be printed with non-structural materials like hemp or recycled plastic. Because of the expressive nature of 3D printing the façades could be printed with al kinds of patterns and gaps to allow ventilation and sunlight where required.

FIG 111+112



PRINT ORIENTATION

The direction of the printed layers, or print-orientation, is an important aspect of 3D printing construction as the printer member behaves differently depending on how the layers bind or fail to bind each other.

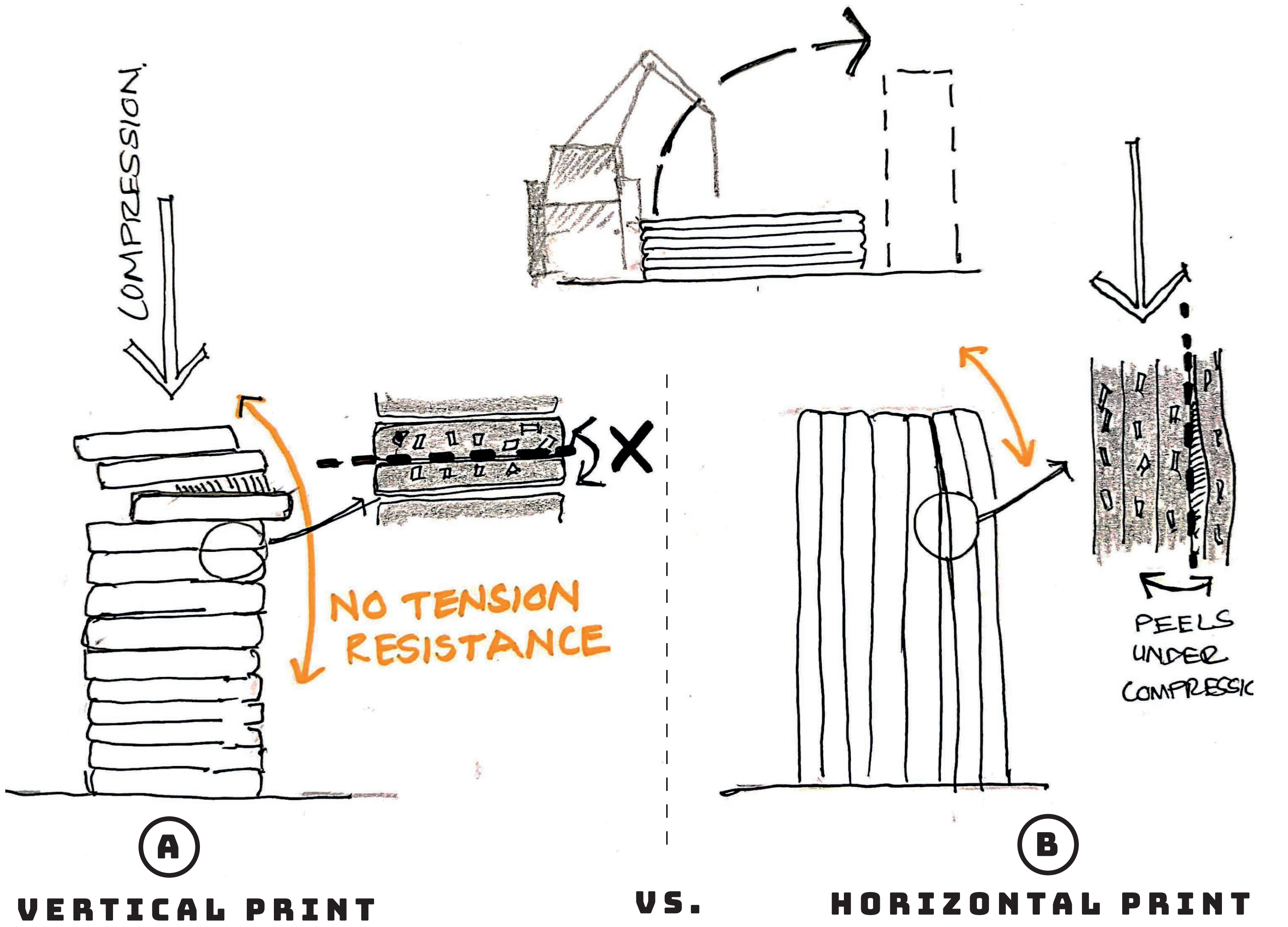
(A) In the drawing below the member on the left it is printed vertically like can be seen in all the photos on the previous two pages. This orientation works great under compression, but once it experiences any tension the layers start flaking as there is no bond between them. Hence the need for the steel reinforcements. The concrete layers also have to dry quite quickly in order to achieve printed heights of 2.7m and more, otherwise the wet concrete buckles under the weight of the new wet layers above.

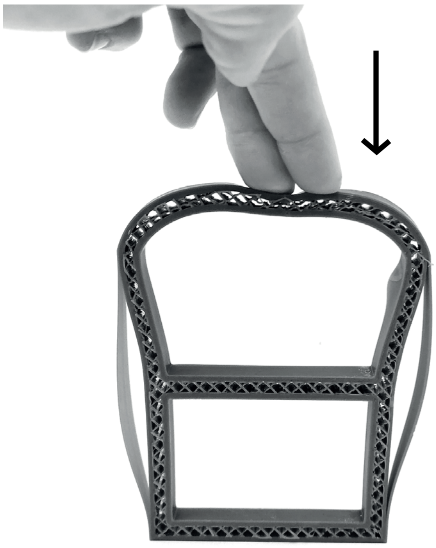
(B) The member on the right it is printed horizontally and tilted upright after it has dried. This has several advantages. First, a stronger bond can form vertically which can better handle stress, especially if there are reinforcement fibres in the concrete mix. Secondly, it enables us to make taller members without having to print that high. In this case, the width of the member determines the maximum print height which means it rarely needs to go higher than 0.5m -1m. This is a huge advantage because the concrete can stay wetter for longer and gain strength while it cures. Lastly, it would be much easier to print large openings in wall panels for instance, again without the use of any formwork.

Industry leaders have developed a technique called 'beading' to prevent layers from sliding off each other (see figs. 115 + 116). This technique can be used in vertical or horizontal prints to enhance the structural performance of the members.

Explaining the advantages and disadvantages of horizontal vs vertical print orientations

FIG 113



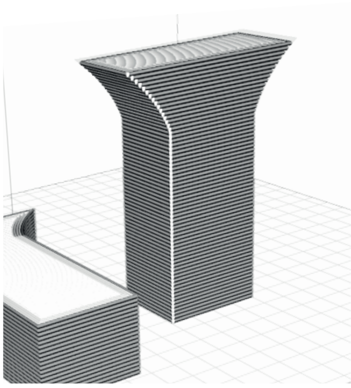


Investigating how printed layers behave when a force is applied. In this case the outer layers did not properly bind and started to tear off.
FIG 114

The 'beading' technique used by WinSun to prevent the separate printed layers from sliding off each other when under compression.
FIG 115

The beading technique used by Emerging Objects in their hut project in Mexico where they exclusively print with the local mud.
FIG 116

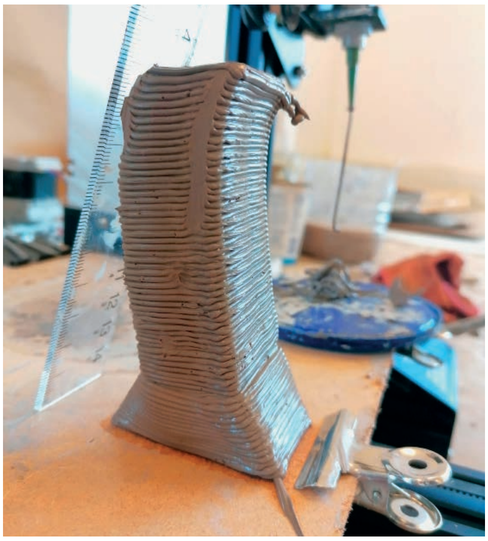
Print orientation experiment



Direction of layers set vertically in Cura slicer software.

Model size: 5 x 10 cm
Hollow: yes
Infill: Default pattern
Nozzle size: 1.5mm
Printing time: 25 mins

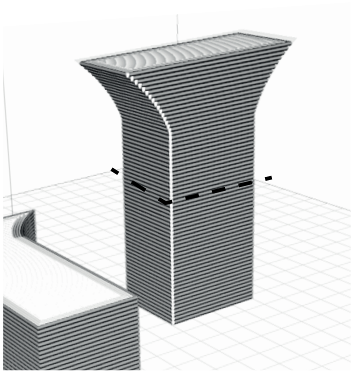
1
VERTICAL PRINT



For the first part of the experiment the object was printed vertically. However, it started to fall over when it reached 8 cm. The wet clay of the first couple of layers was not stable enough to carry the load of the layers above. Resulting in the object being deformed and not reaching the full height of 10cm

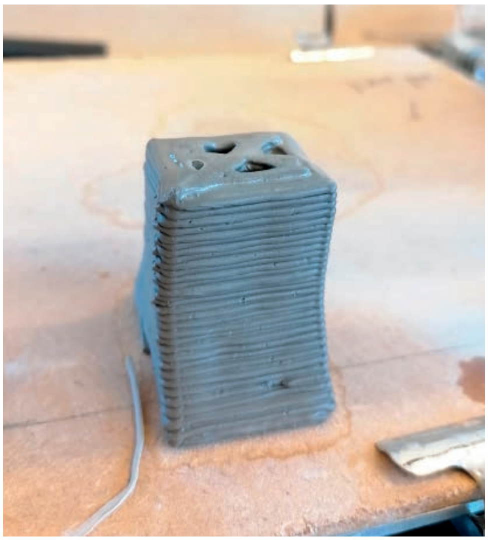
FIG 117-119

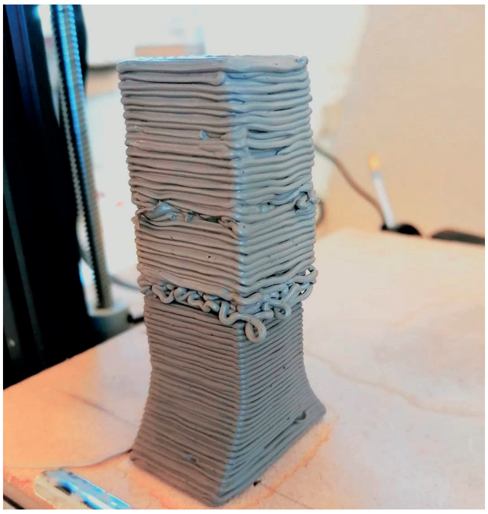
2
PHASED PRINTING



Direction of layers set vertically in Cura slicer software.

Model size: 5 x 10 cm
Hollow: yes
Infill: Default pattern
Nozzle size: 1.5 mm
Printing time: 13 min + 24h drying period + 15 min





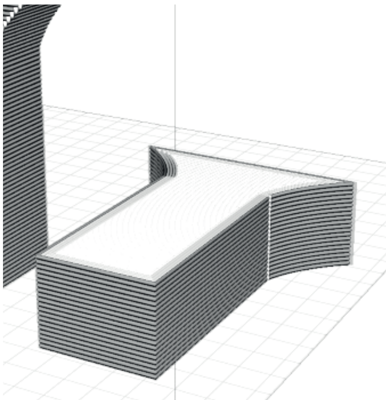
For the second part of the experiment the 1st half of the object was printed and left to dry for 24 hours before printing the 2nd half. Even though the object did not start to fall over like in part 1, it proved to be very tricky to get the two halves to bind. This resulted in it breaking in half after it dried. The total final height being 9cm instead of 10cm.

Phasing the printing of structures is something the industry is exploring, as printing with wet concrete has the same challenge of not being stable enough when it reaches a certain critical print height.

FIG 120-122

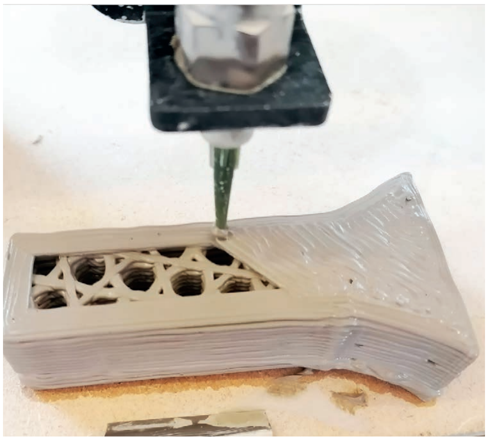
3

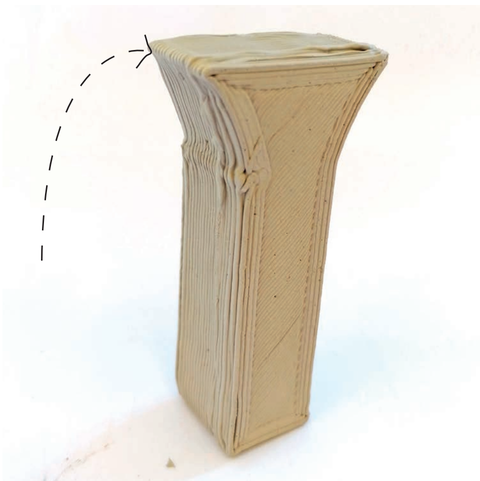
HORIZONTAL PRINT



Direction of layers set horizontally in Cura slicer software.

Model size: 10 x 5 cm
Hollow: yes
Infill: Default pattern
Nozzle size: 1.5 mm
Printing time: 20 min





For the 3rd part of the experiment the object was printed horizontally on its side with the layers running the length of the object. After it dried it was tilted upright and proved to have the best form out of all 3 experiments. The height was the closest to the 10cm of the original model.

FIG 123-125

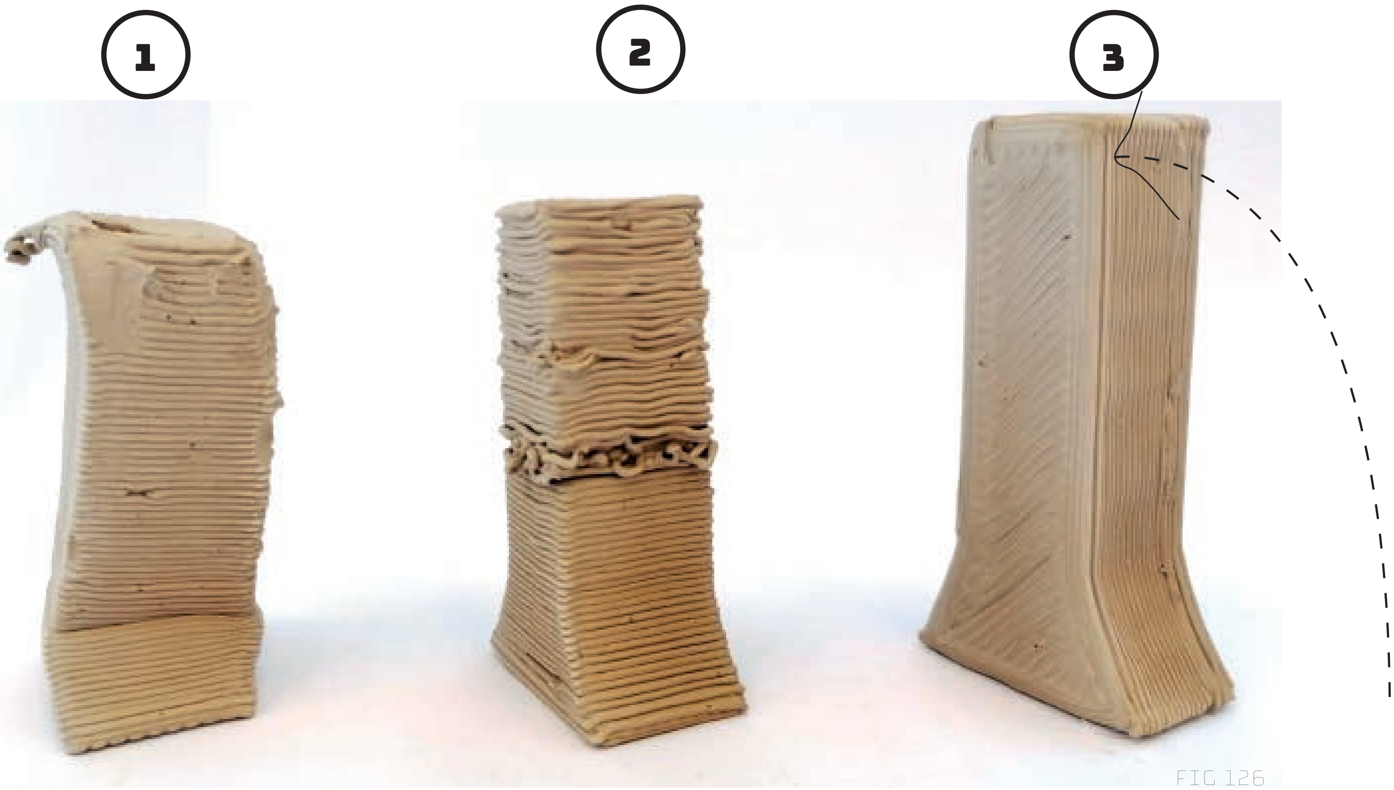
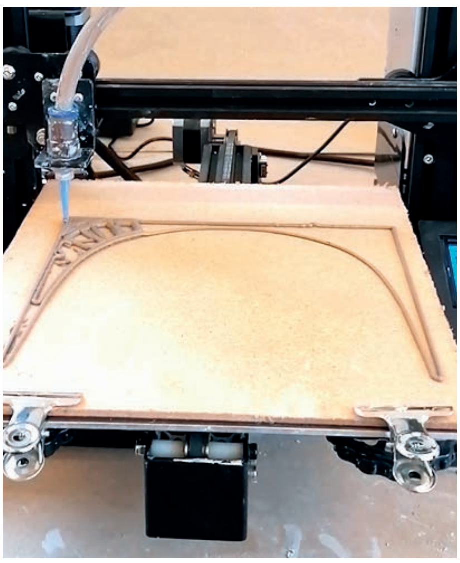


FIG 126

CONCLUSION:
The 3rd object printed horizontally and then tilted upright proved to have the best form and structural stability.



NEXT STEP:
Building on this conclusion, I began to explore how structural frame mebers might be printed using this tilt-up method. This idea is explored further in the next section.

This 1:20 model tests the concept of a strcutural arch printed horizontally to be tilted up and form part of a series of strcutural frames in a building.

FIG 127-129

PHASED CONSTRUCTION

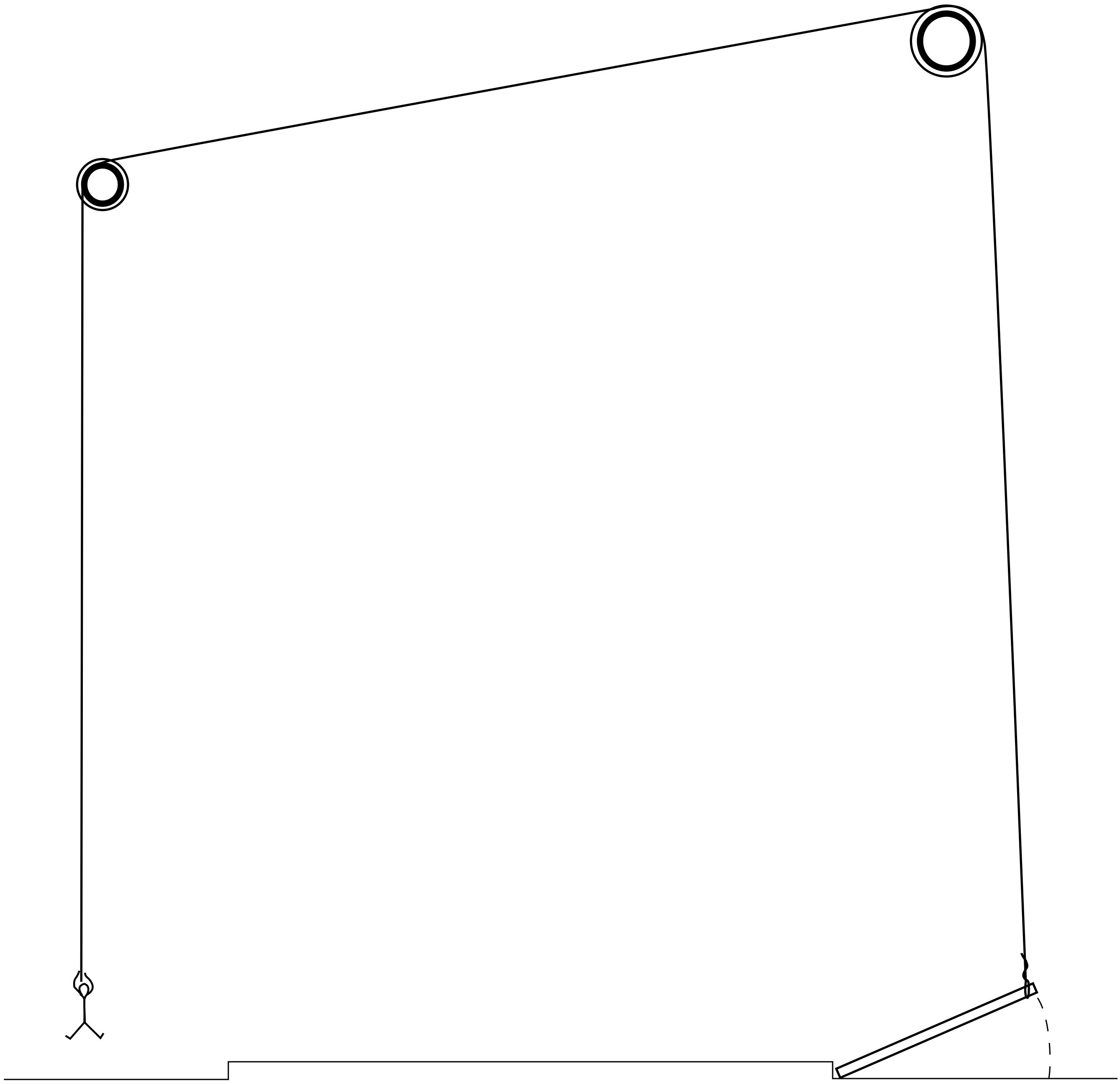
I propose that the building be constructed in phases in order to grow with the technology as it develops over the next few decades. As 3D printing technology matures, people and industries will innovate to find more and more new ways to use the technology. Because the school places emphasis on experimentation and production in addition to teaching, it is important to test the new techniques of making taught and theorized over by students and staff. And what better way to explore these methods than building the school building itself. As a result, the method used to build the first section of the school might be very different from the methods used later after some innovation and discovery occurred in the field.

As the technology is still very new to the South African context, there are currently only a hand full of people that know how to use the construction method. **This means the team to build the first section of the school would also have to be its first students.** Starting with a single workshop-lab and a couple of offices the first student and teachers can grow their expertise enough to build the second section of the school building. And so, every new phase is built by the students and with the expertise gained in the classrooms and workshops of the previous phase. Thereby it becomes an ever-growing process of testing ideas and techniques in the real world, on the school grounds, for everyone to see and share in.

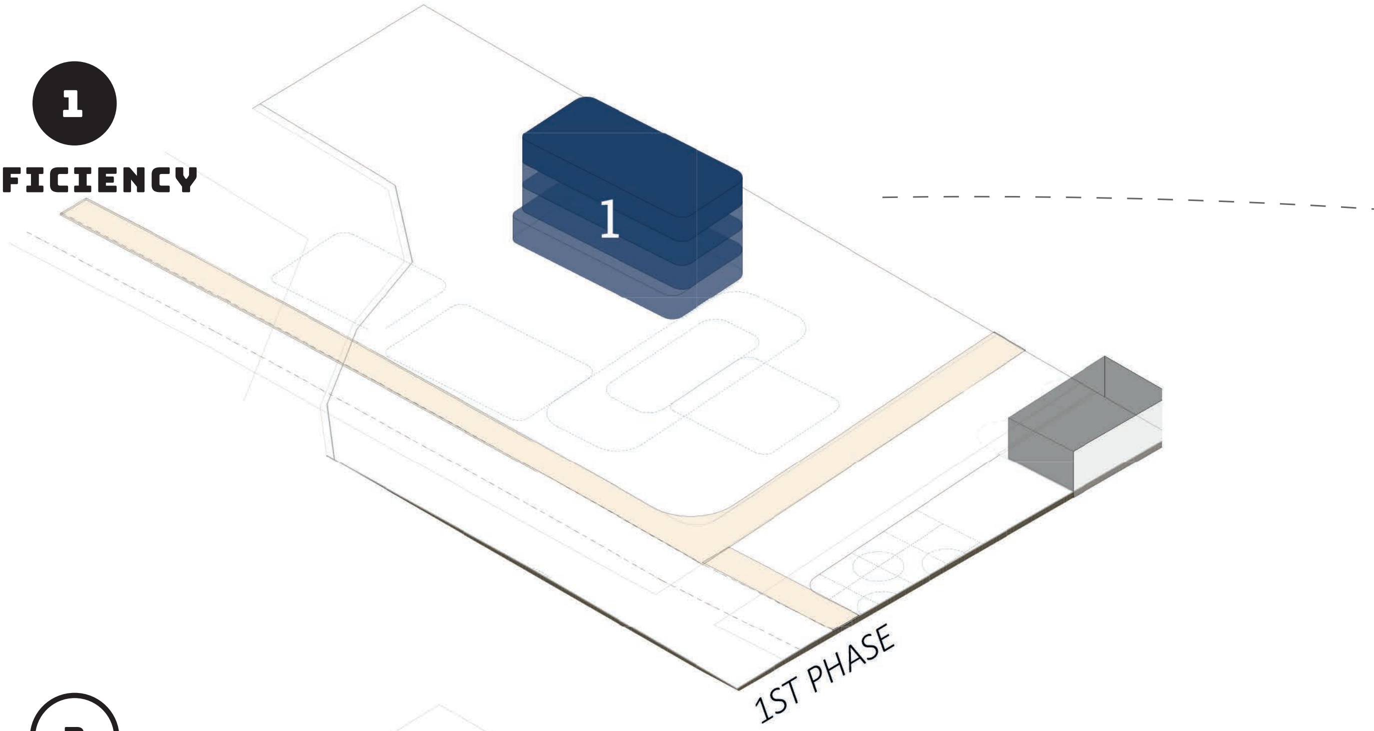
In this way the building becomes a living time line showcasing the different aspects and capabilities of the technology as it develops over the years. Maybe in a few decades it becomes time to disassemble the first section built during the initial years of the school's history, to be replaced with an optimized alternative of the current day. And then maybe a few examples of the first ever printed members are preserved to remain part of the building and the story it tells.

The following pages contain some initial conceptual explorations of the designs and methods that can be used to construct the building in phases. It sets out to investigate three general phases, each emphasising a different aspect of the technology. The first phase focuses on efficiency in terms of the speed and cost of construction. This initial part of the building must be finished as fast and affordable as possible to allow the first students and staff to move in and start with their research and training. This allows them a space to start designing and developing the techniques to build the sections of the second phase. The main focus of the second phase would be the expressive qualities of the technology. Whereas the final phase works towards optimizing designs, materials, and techniques to actualize the potential the technology has in being both more efficient and expressive than its conventional predecessors.

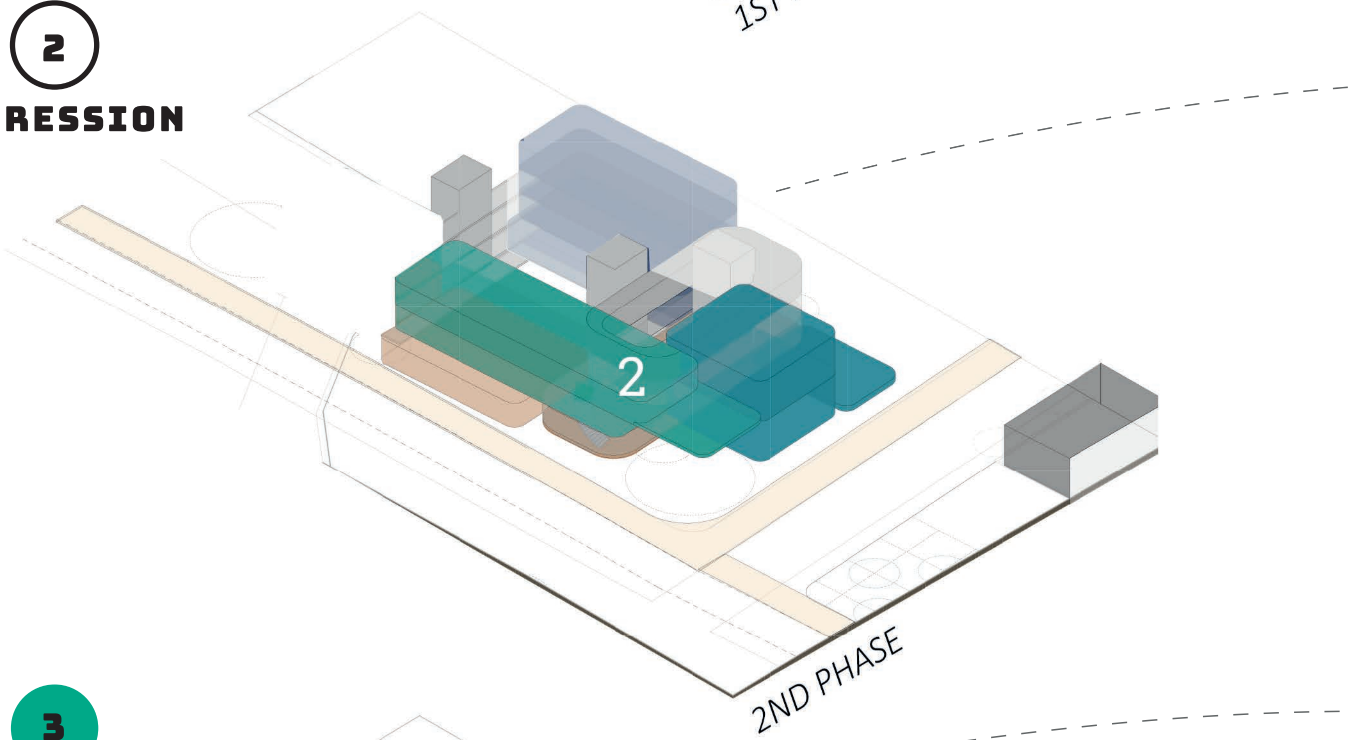
The team to build the first section of the school would also have to be its first students.



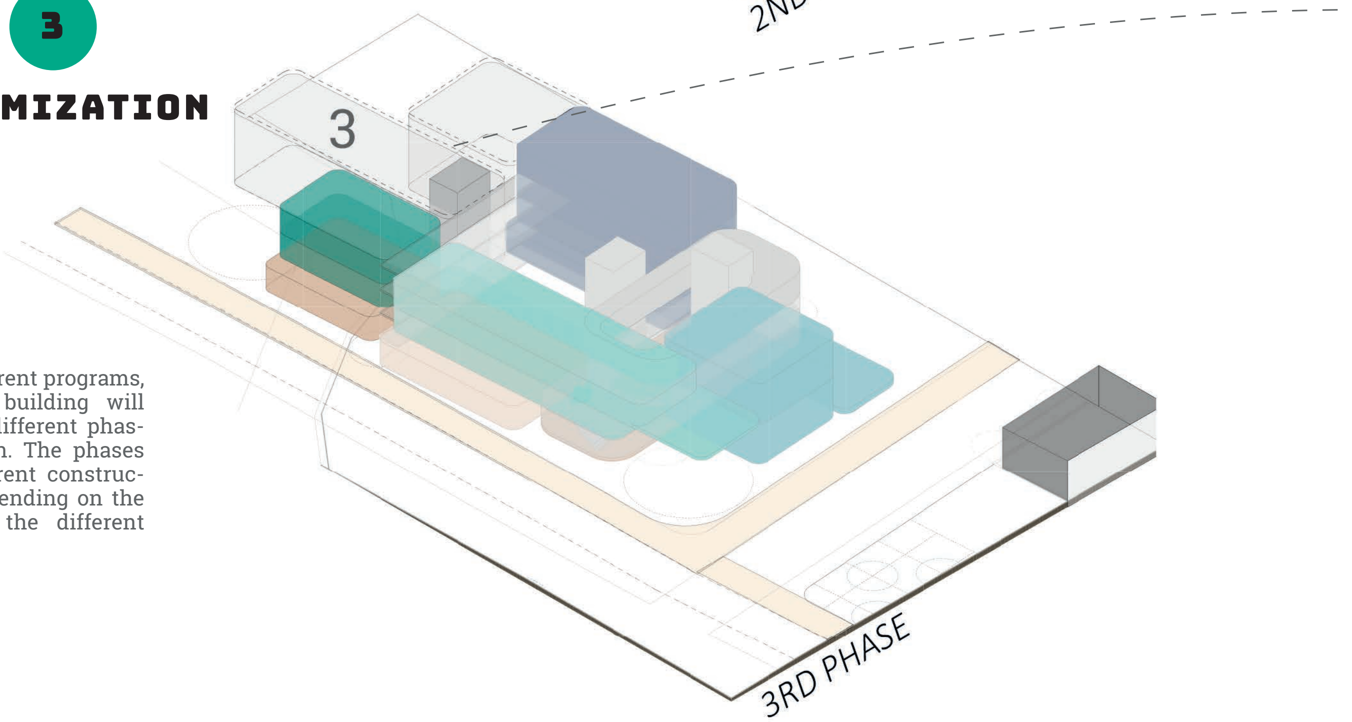
1
EFFICIENCY



2
EXPRESSION

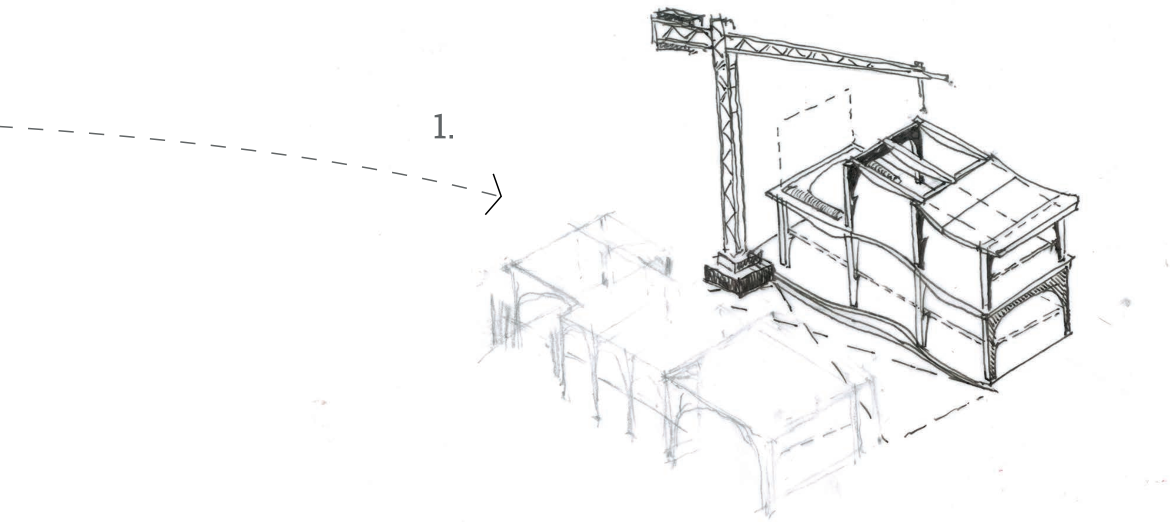


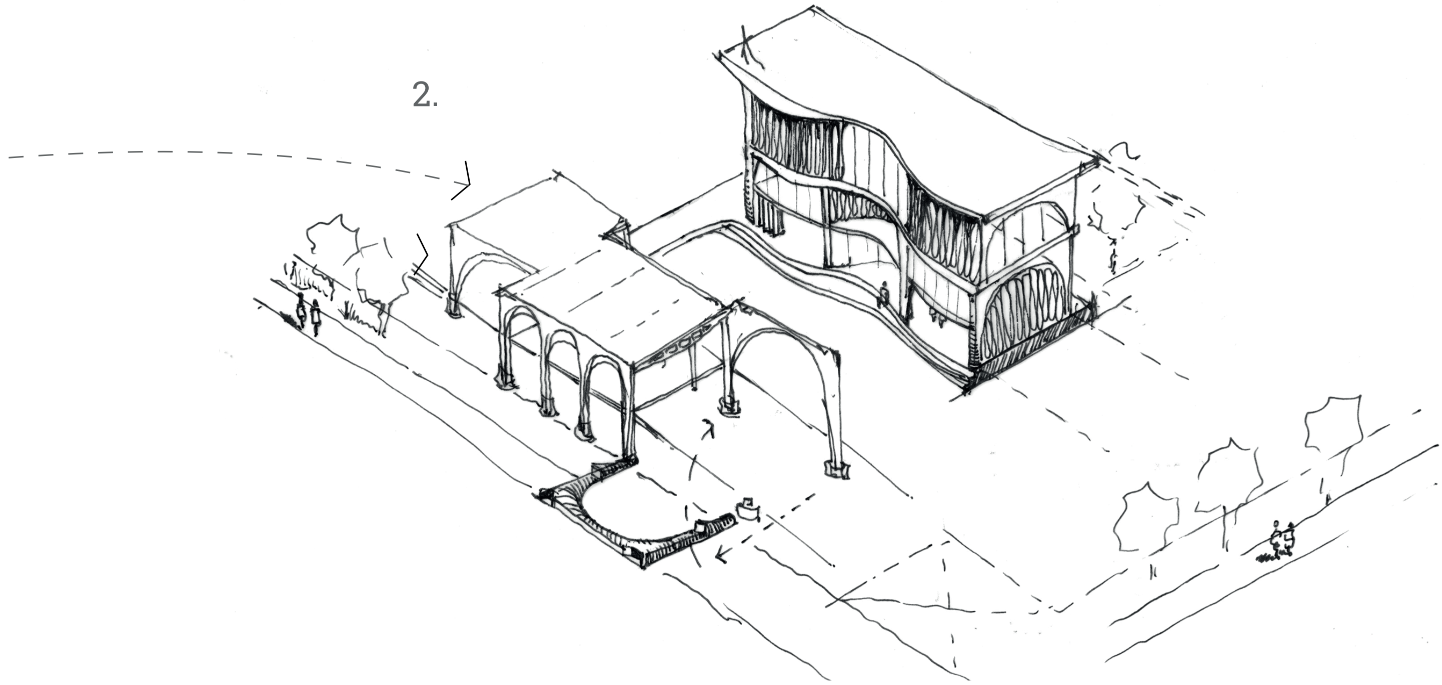
3
OPTIMIZATION

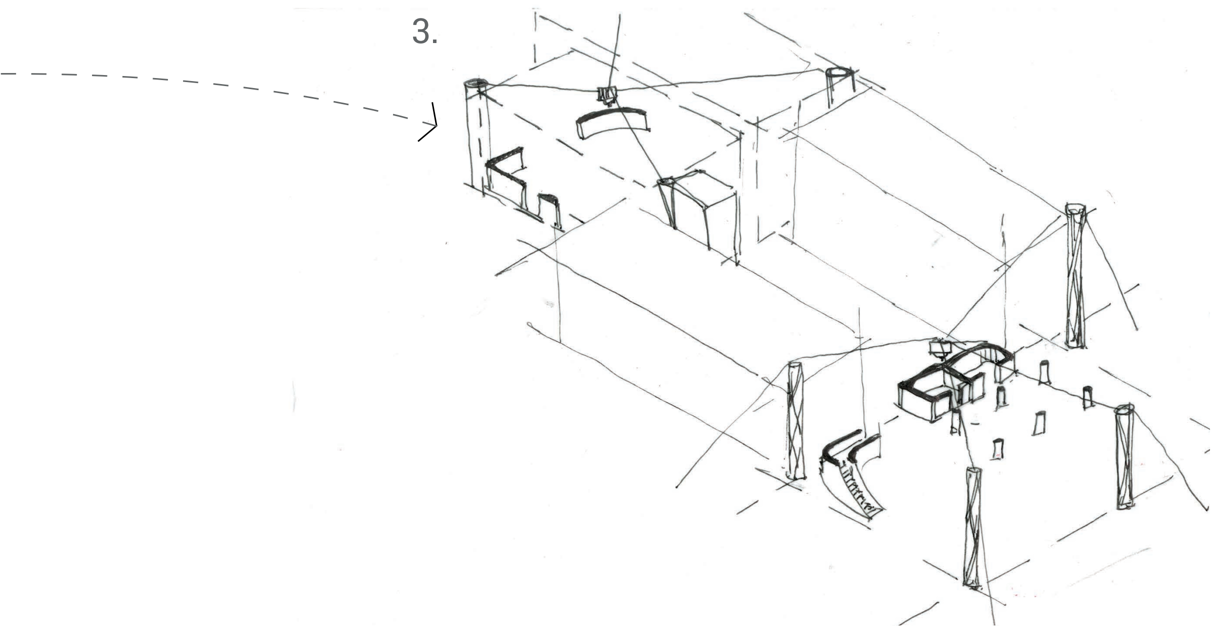


Based on the different programs, sections of the building will be built during different phases of construction. The phases will employ different construction methods depending on the requirements of the different programs.

FIG 130







1: The school facilities will be built during the first phase. Since it needs to go up fast and affordable it will make use of the tilt-up structure method.

2: The research facilities and public retail space will be built during the second phase. Since these double as exhibition spaces to showcase the technology, it will make use of in-situ printed walls, columns, stairs and other load-bearing elements.

3: Any future expansions of school, research or public facilities will be built using an optimized, dual-nozzle, 3D printing system based on the current Gantry systems. This allows for efficient construction without limiting the expressive value of the technology

FIG 131

1

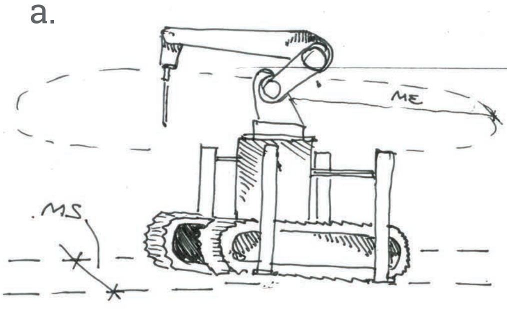
PHASE 1
EFFICIENCY

The first phase focuses on efficiency of construction. This initial part of the building must be finished as fast and affordable as possible to allow the first students and staff to move in and start with their research and training.

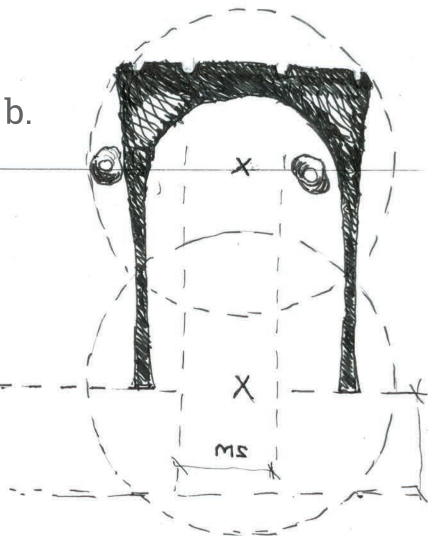
A simple method of printed concrete tilt-up frames is used. Printing these frames with concrete instead of casting them comes with a number of advantages. Firstly, it is possible to print hollow forms without the use of formwork. Secondly, with the addition of the z-axis, extra components could be printer on top , like for instance an extra ledge for a beam to rest on so a mezzanine floor could be added in the future (see fig. c)

If for example the CyBe robotic arm printer with a print radius of 3m is used, the design of the frames would be influenced by this limitation (see fig a +b). Another factor that influence the design would be the layout of the frames on the floor they will be printed on (see fig d).

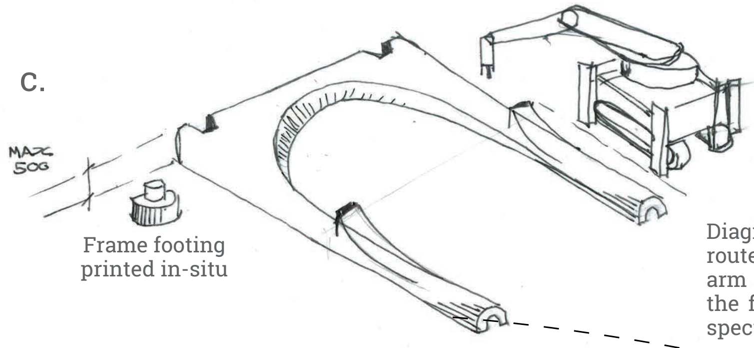
a.



b.



c.



Frame footing printed in-situ

Diagram showing the route a 3m radius robotic arm would take to print the frames and their respective footings.

d.

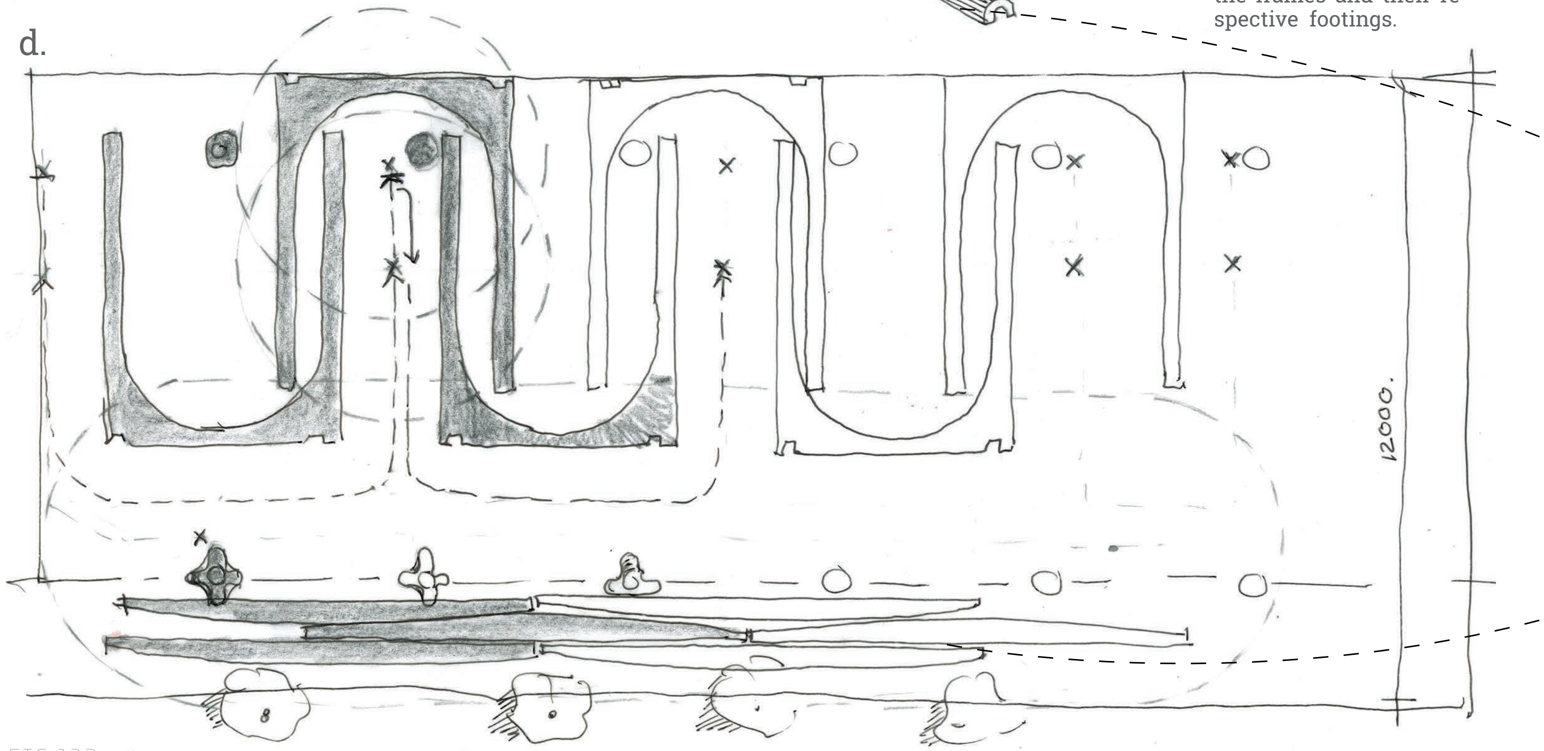
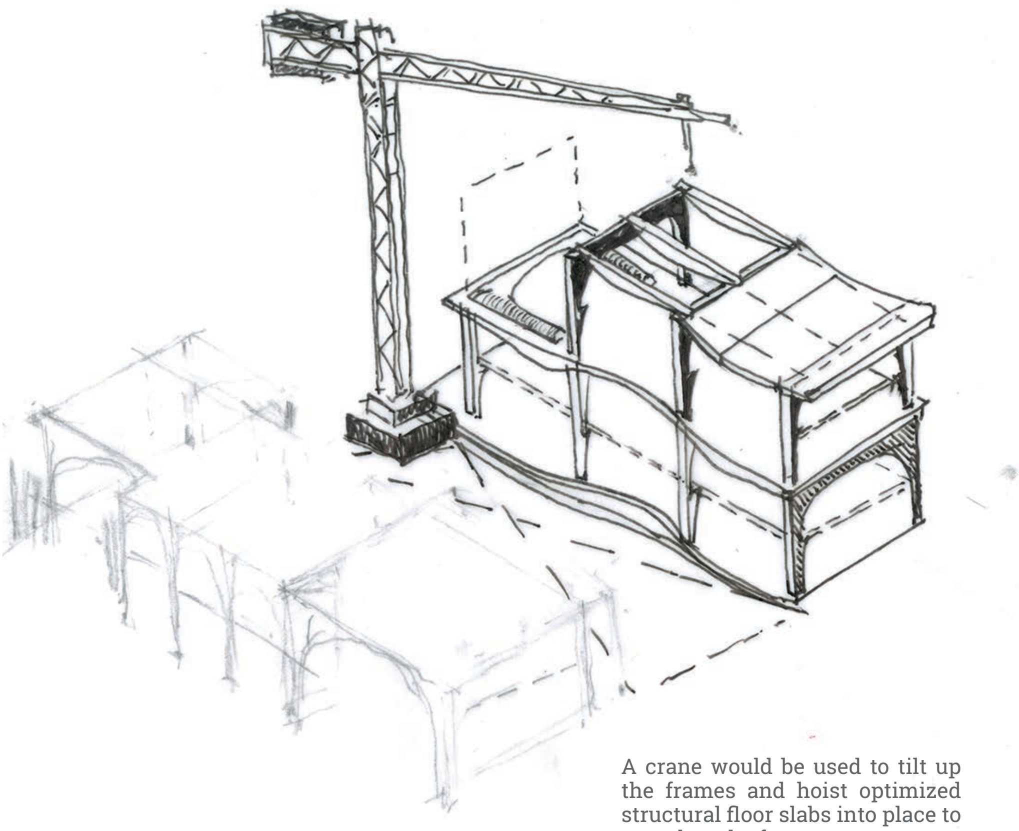


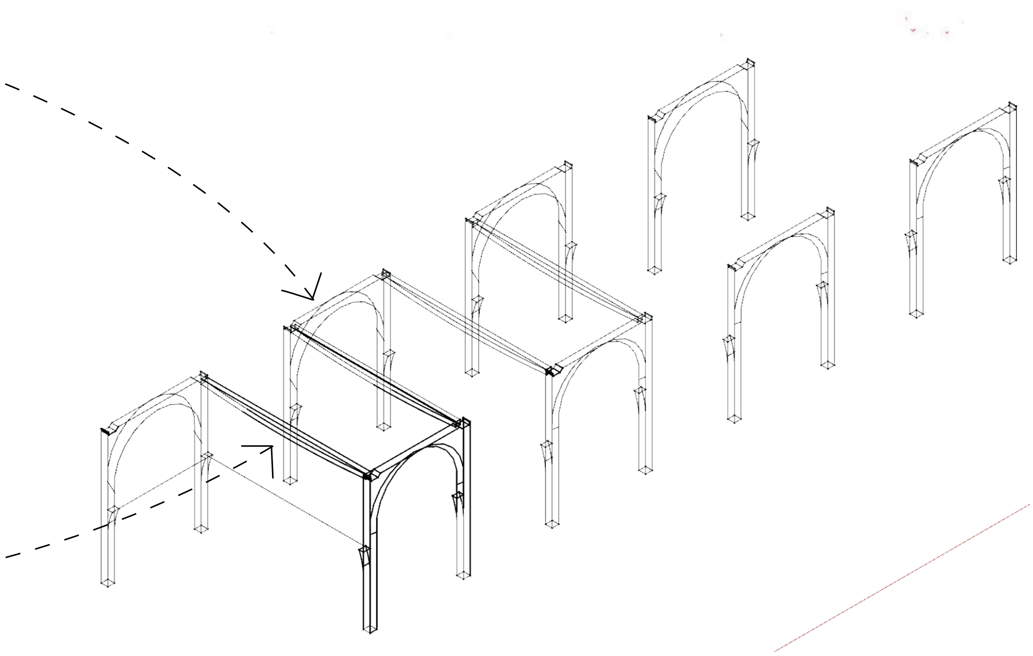
FIG 132



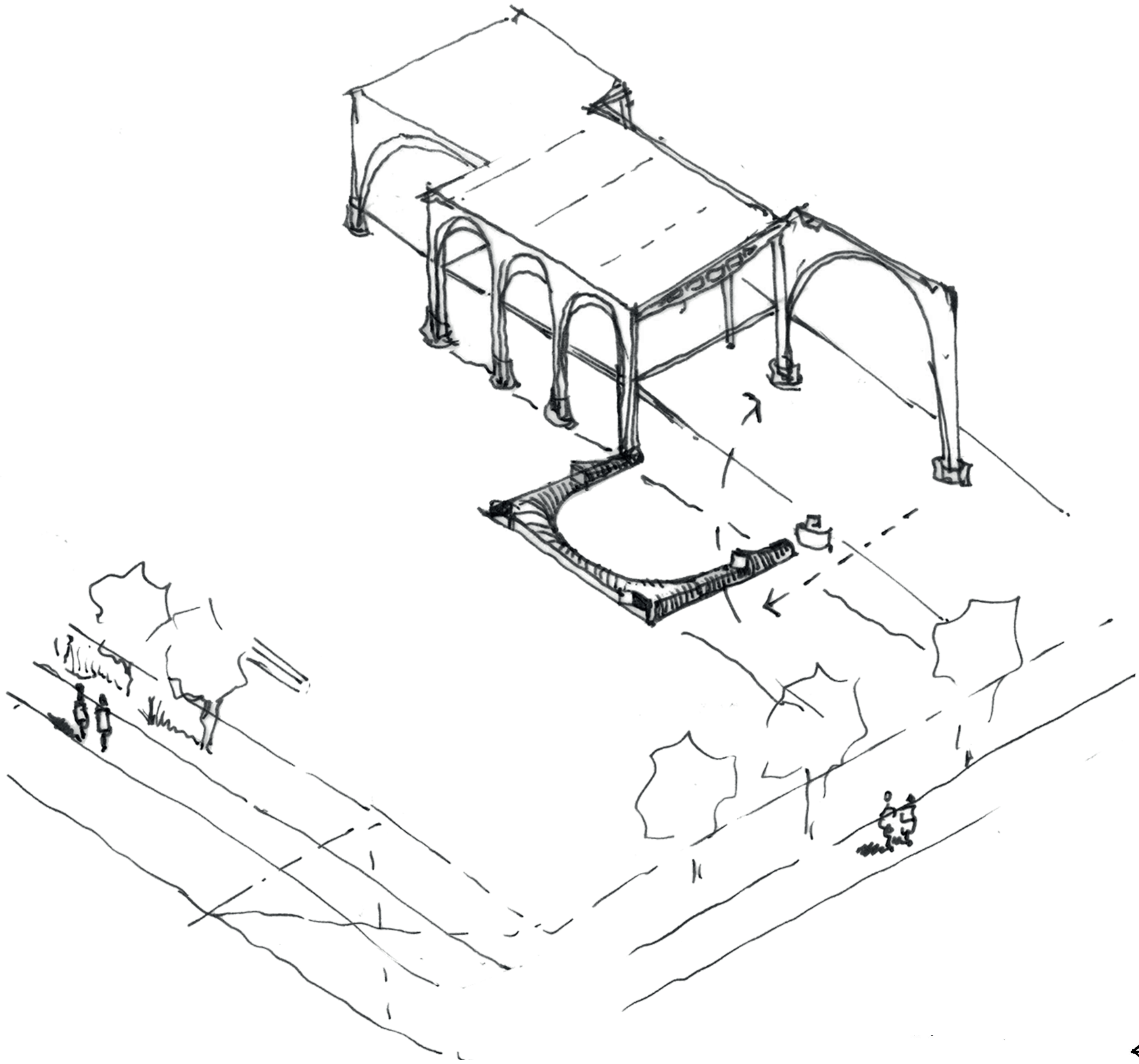
A crane would be used to tilt up the frames and hoist optimized structural floor slabs into place to complete the frame structure as a whole.

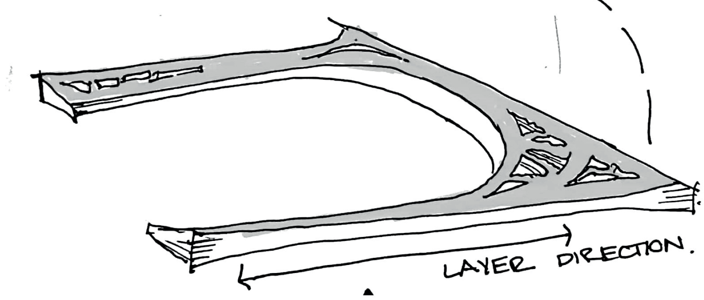
FIG 133

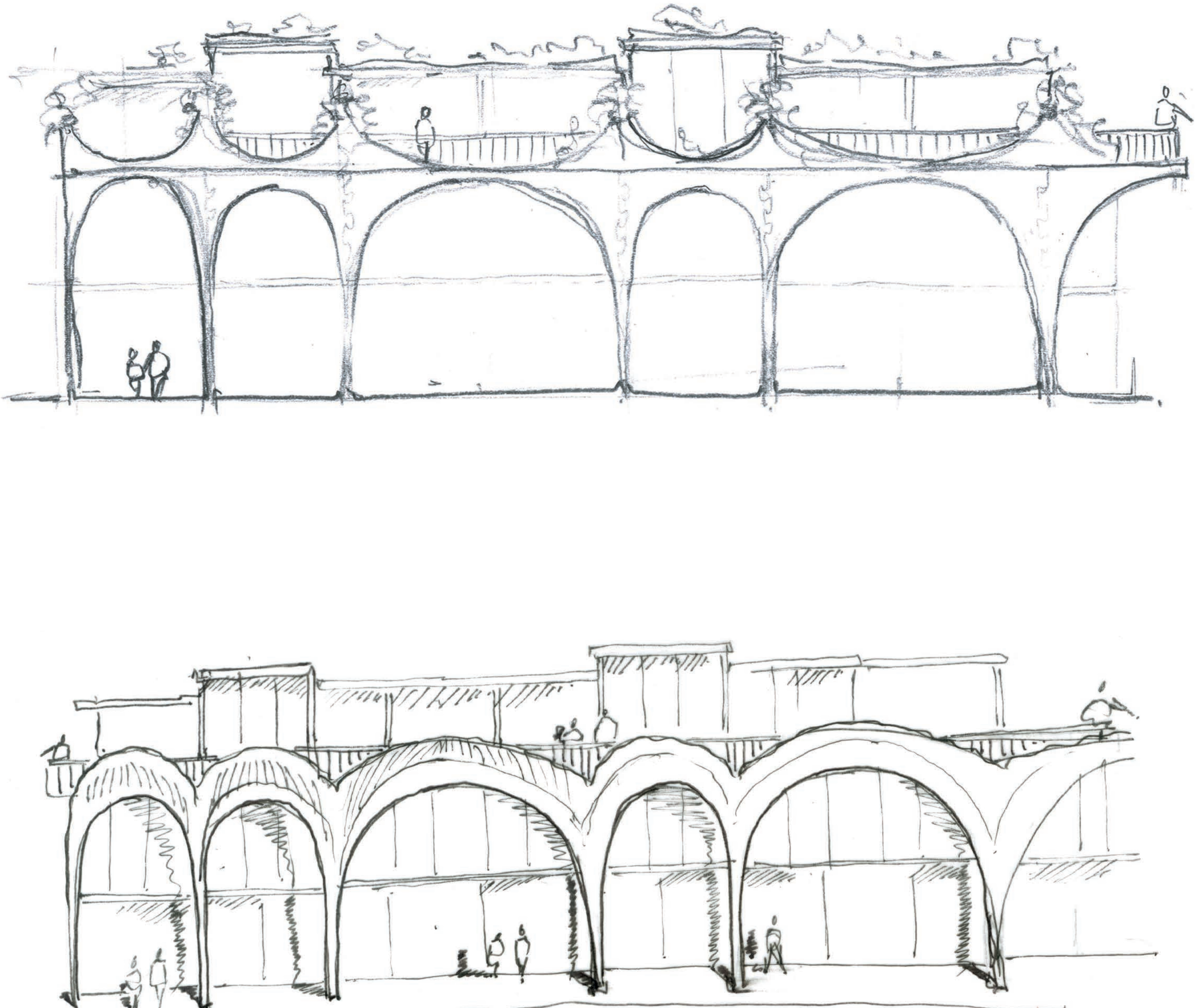
The concept of printing horizontally and tilting up the frames were inspired by the experiment with the clay objects.



More explorations of how a frame tilt-up method could work and the type of architecture it would produce...







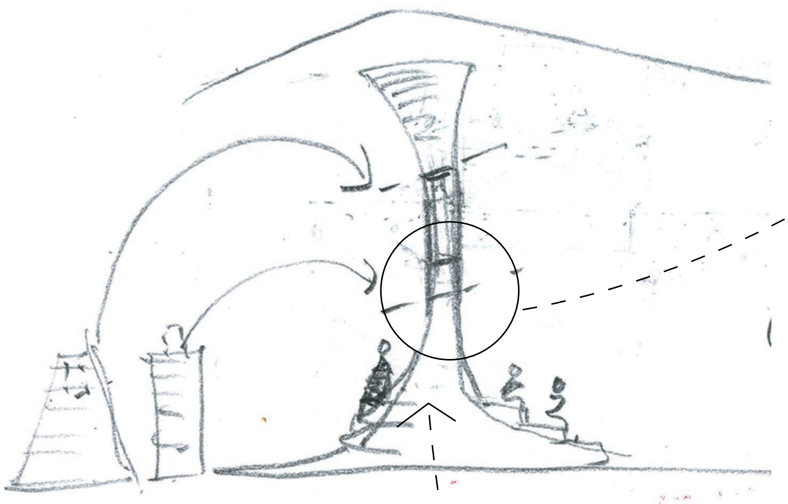
Exploring what the facade could like when using this method of construction

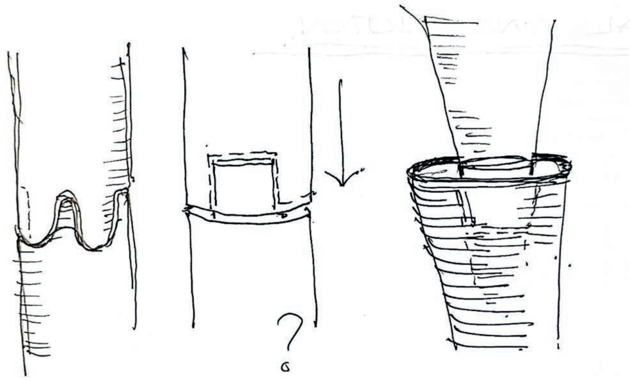
FIG 134

2

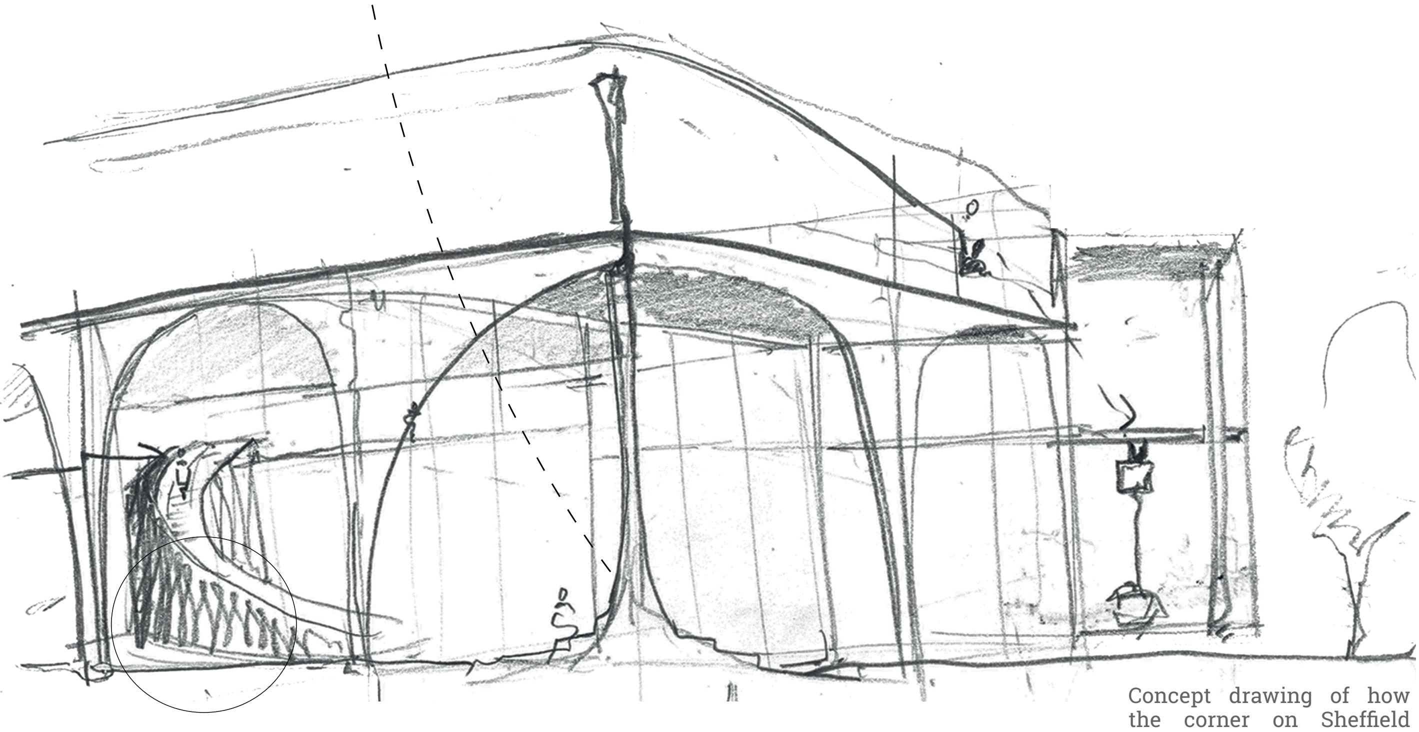
PHASE 2
EXPRESSION

During this phase of the project the public and research sections of the building would be constructed. Therefore there is opportunity to explore the expressive value of the technology to showcase it to the street outside and visiting academics.



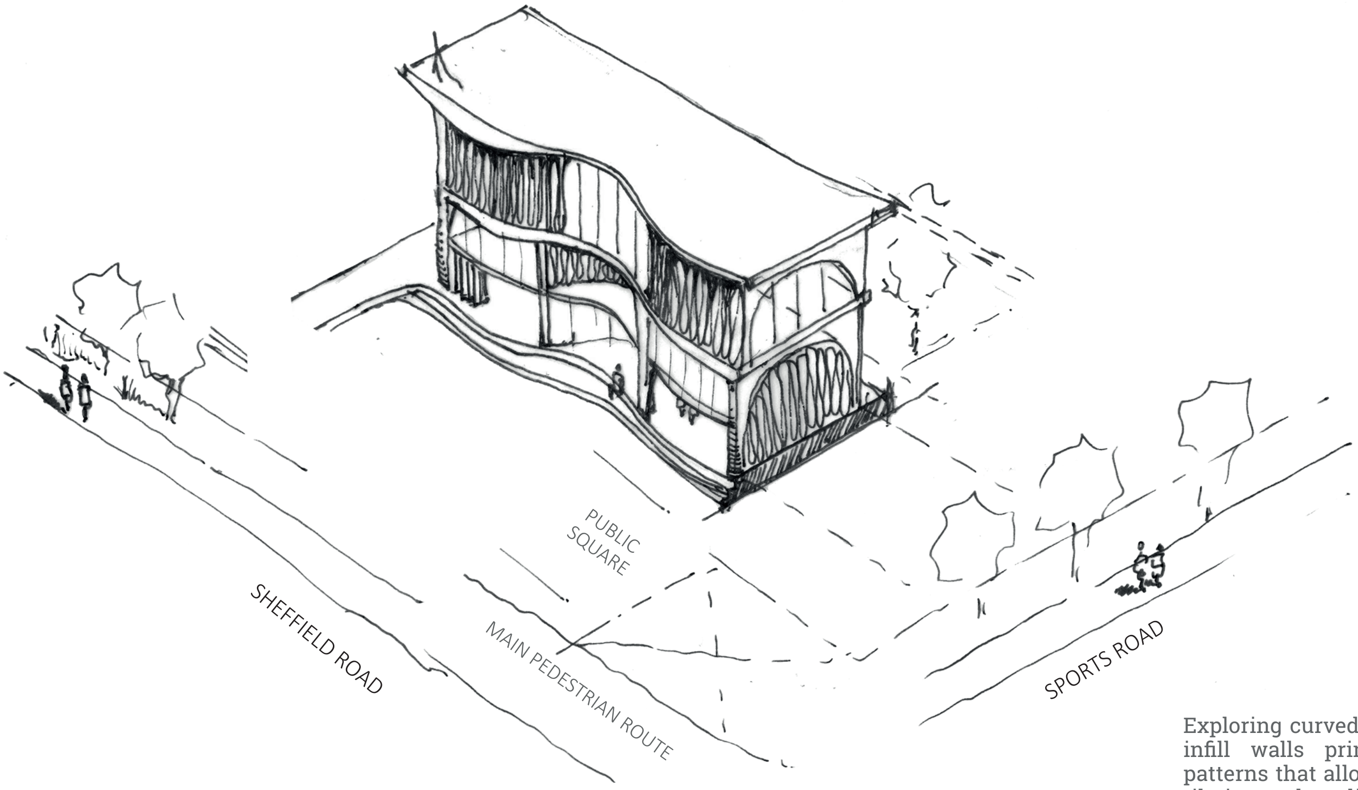


Exploring different ways tall columns could be printed in sections and joined.



Concept drawing of how the corner on Sheffield road with the public square could look like.

FIG 135



Exploring curved slabs and infill walls printed with patterns that allow for ventilation and sunlight where appropriate

Concept drawing of the North facade on Sheffield road with retail spaces on the ground floor.

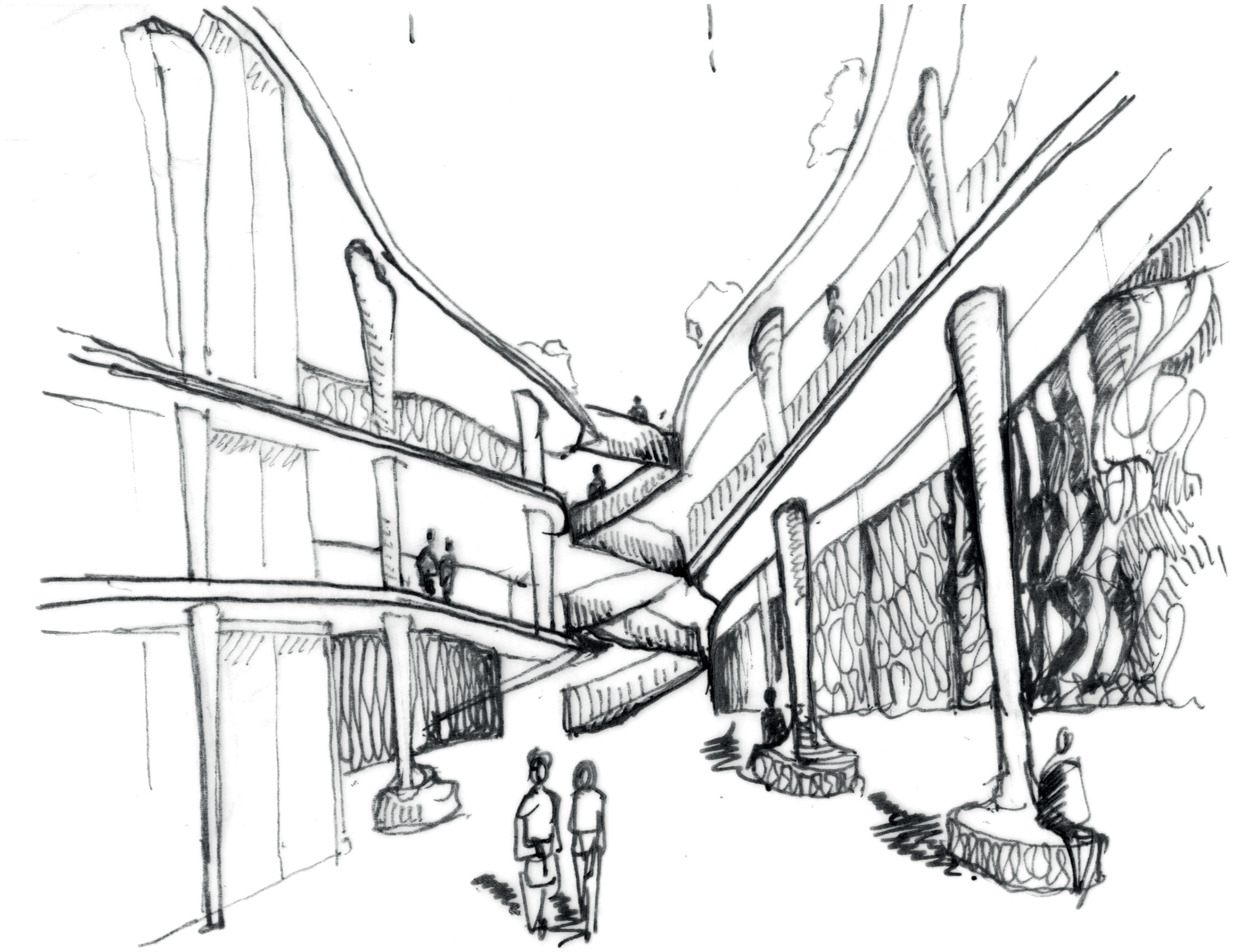


FIG 136.A

Concept drawing of the atrium in the main circulation core. Using methods of in-situ printing to make columns, walls and stairs that form part of the structure.

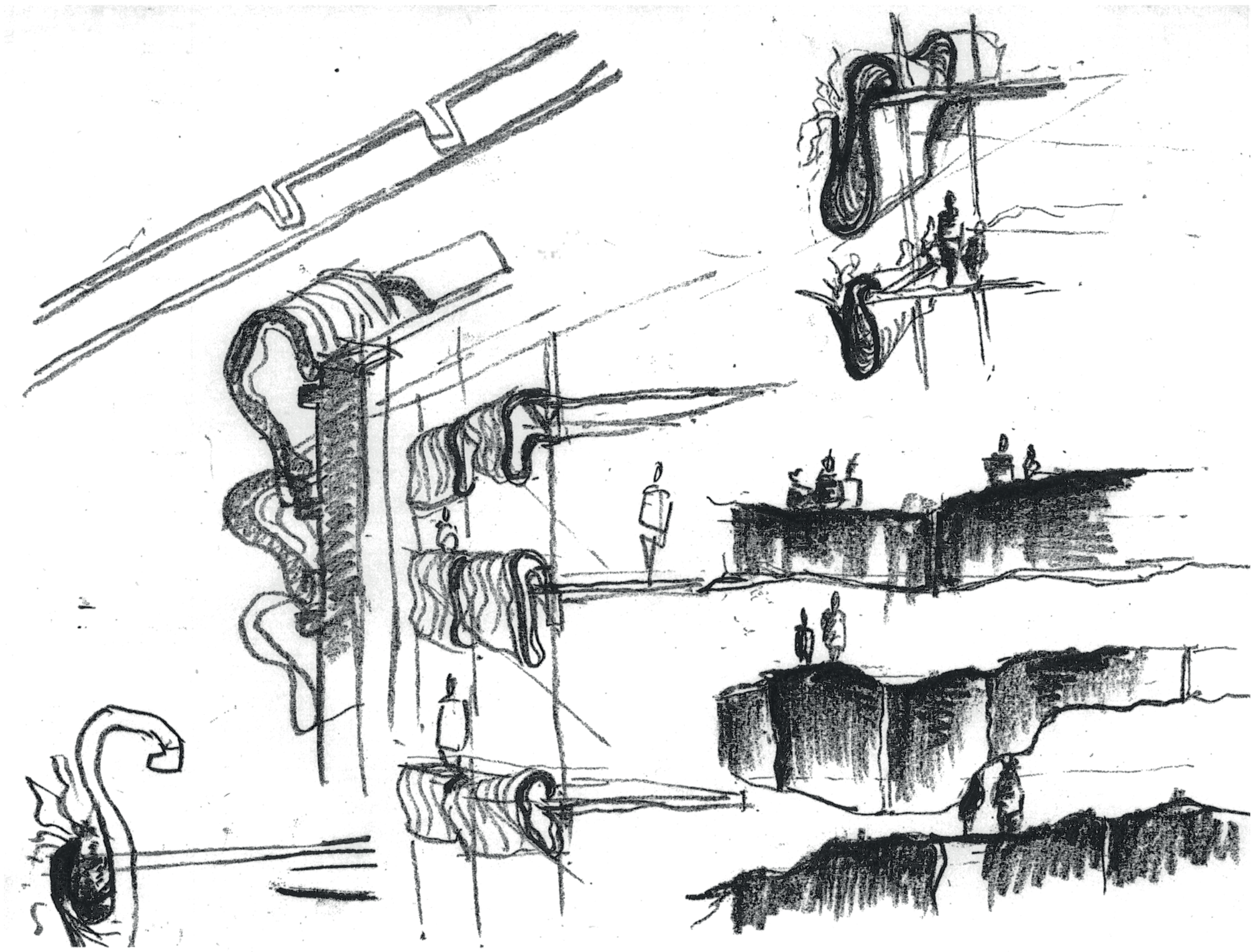


FIG 136. B

Exploring an expressive asssembled facade system with bespoke 3D printed elements that hang from the main structure.

3

PHASE 3
OPTIMIZATION

The third phase, and any that come after it, can now really push innovation and optimize on the theories and techniques of 3D printing. By this time the number of students and staff that know how to use the technology as well as the local field of knowledge on 3D printing construction would have grown.

For the construction of the buildings in this phase I imagine a large scale cable gantry system that works on the same principle as the overhead cameras or SkyCams we see at big sport stadiums (see fig. 137). Four cables suspended from the four corners of the site carry the 3D printer head to print anywhere on the site. This would drastically increase the efficiency of the construction process without compromising on the expressive quality of the printed forms. This is made possible by using a dual-nozzle print set-up (or two separate print heads where the one follows to print after the other). The first nozzle prints non-structural materials as supports for the structural concrete mix printed by the second nozzle (see fig. 138). This could also work the other way around where the structural members are printed first and filled in afterwards by lightweight non-structural materials like hemp or foam. Eventually the system could be optimized even further to print both materials simultaneously.

To reach this kind of optimized system, a lot of innovation and development needs to happen in local field of 3D printing construction. But this is where the value of speculative design comes in. We can begin by imagining how it could work differently and then work towards making it a reality.

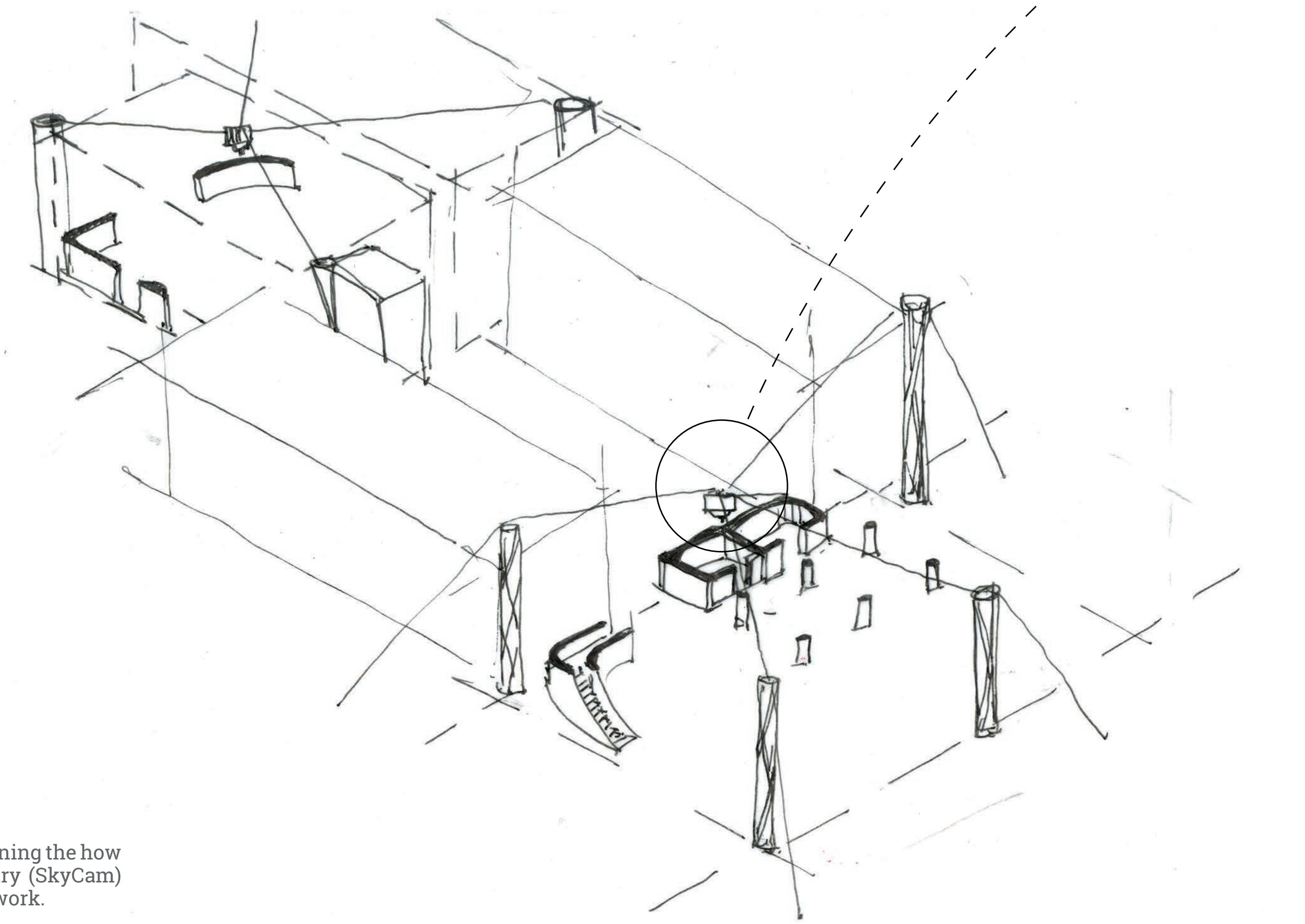
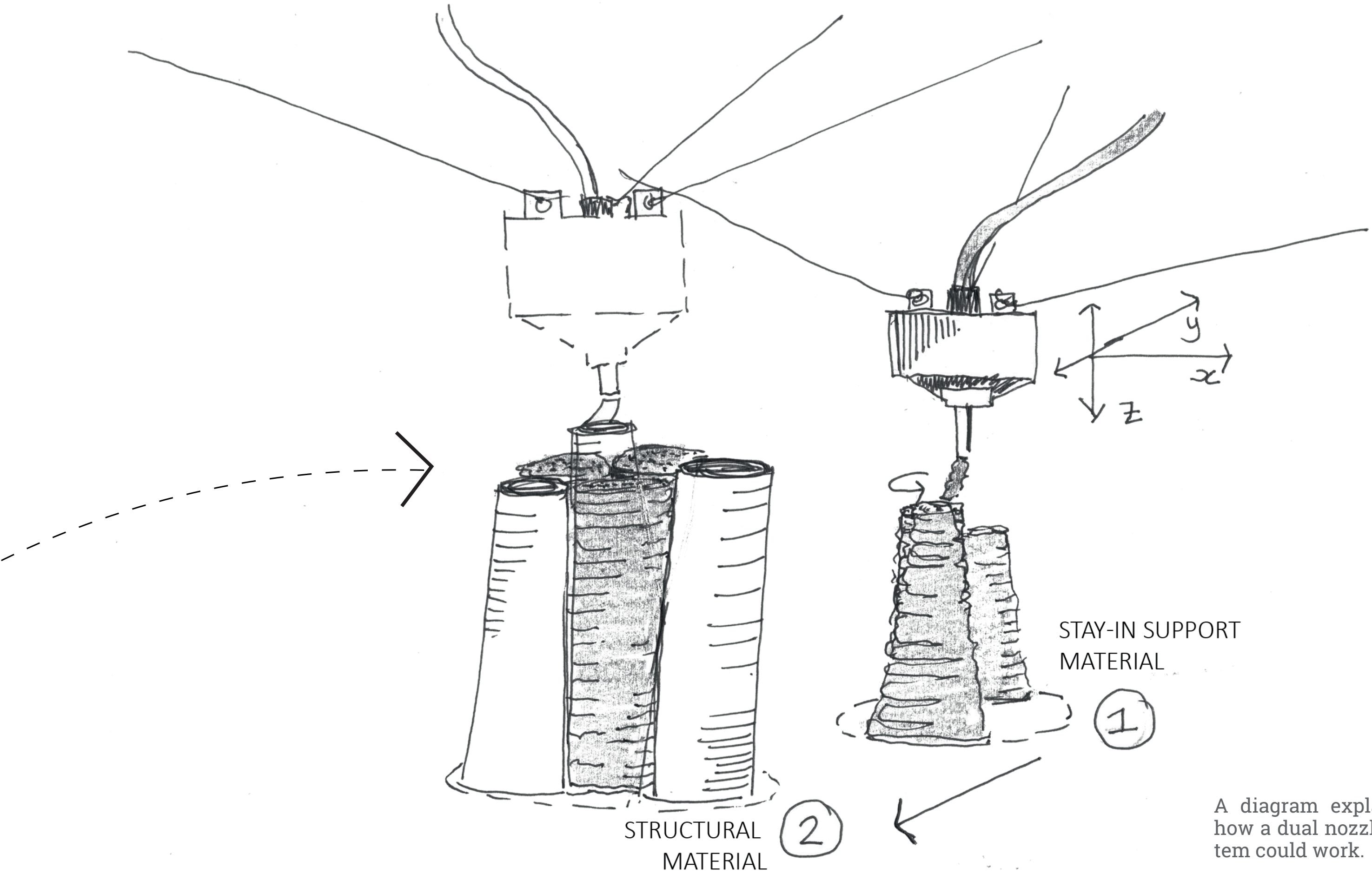
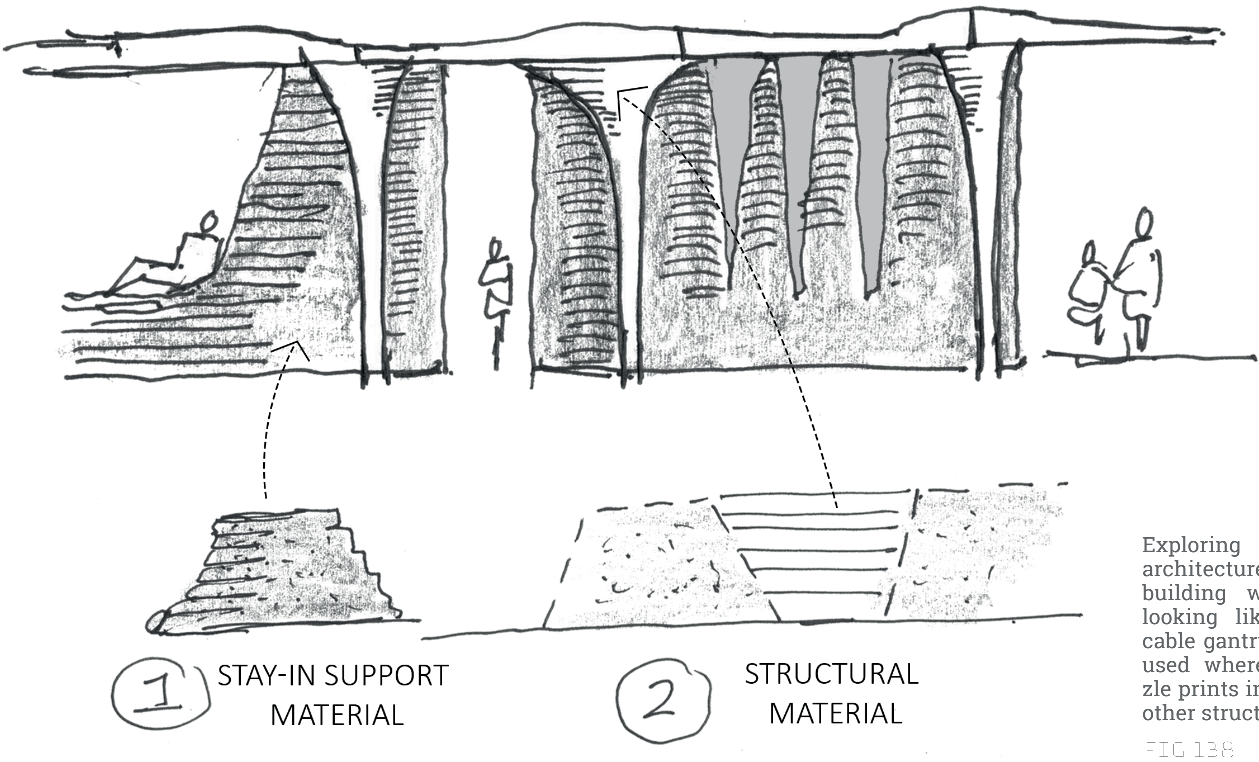


Diagram explaining the how the cable -gantry (SkyCam) system would work.

FIG 137

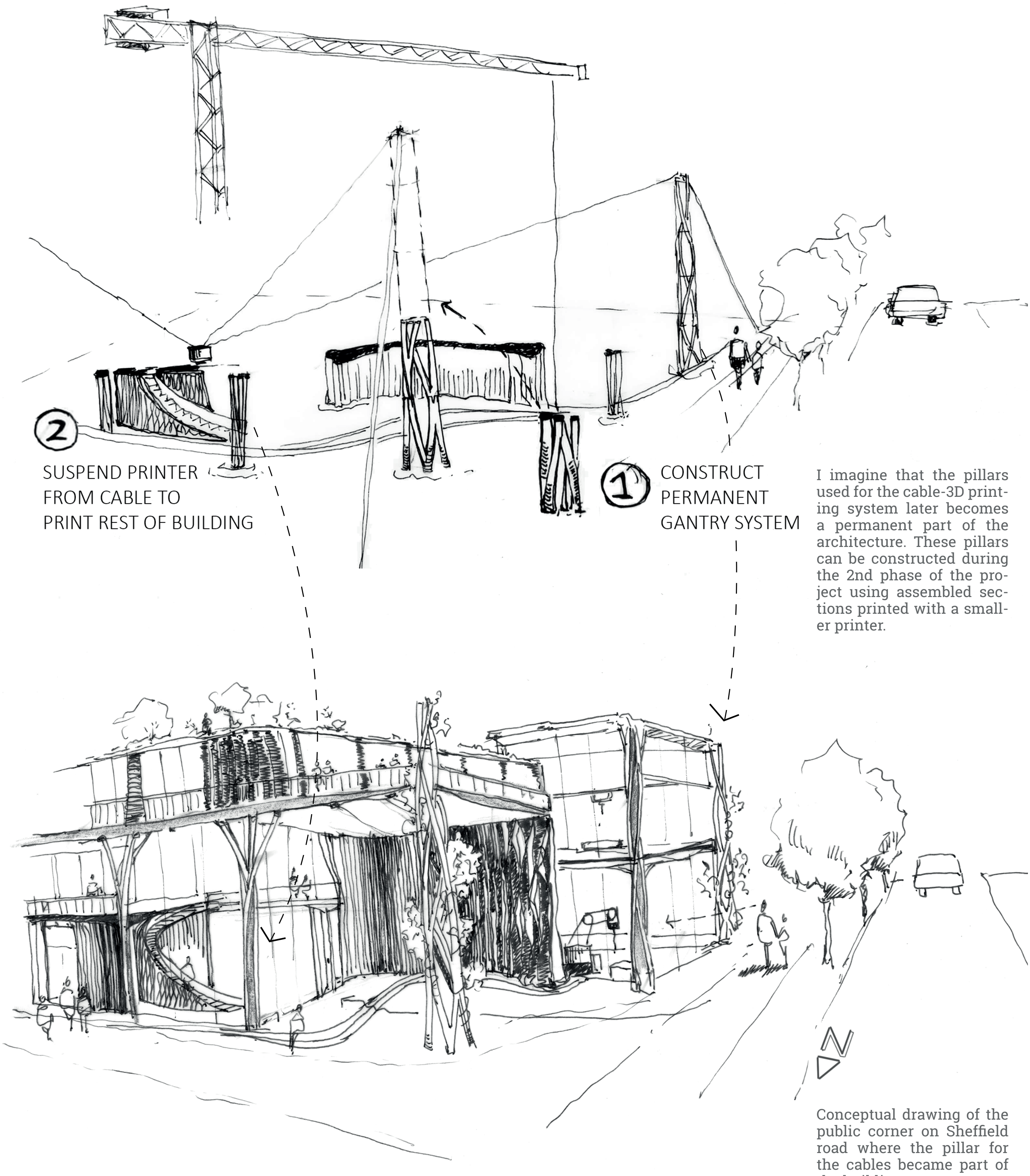


A diagram explaining how a dual nozzle system could work.



Exploring what the architecture of the building would start looking like when a cable gantry system is used where one nozzle prints infill and the other structure

FIG 138



I imagine that the pillars used for the cable-3D printing system later becomes a permanent part of the architecture. These pillars can be constructed during the 2nd phase of the project using assembled sections printed with a smaller printer.

Conceptual drawing of the public corner on Sheffield road where the pillar for the cables became part of the building.

FIG 139

As part of the optimization phase a new system of concrete slabs could be developed. These drawings explore a method that could be used to make structural slabs. A mould would be printed with a recyclable material like waste fly-ash or a foam (see fig. 140.a). These moulds can be extremely complex because they are printed and don't have to be constructed with timber. The concrete is then cast and removed when it has cured. The result is a optimized slab in terms of material use and structural capacity. The slabs can be highly customized to span the required spans between support members (see fig 140.b)

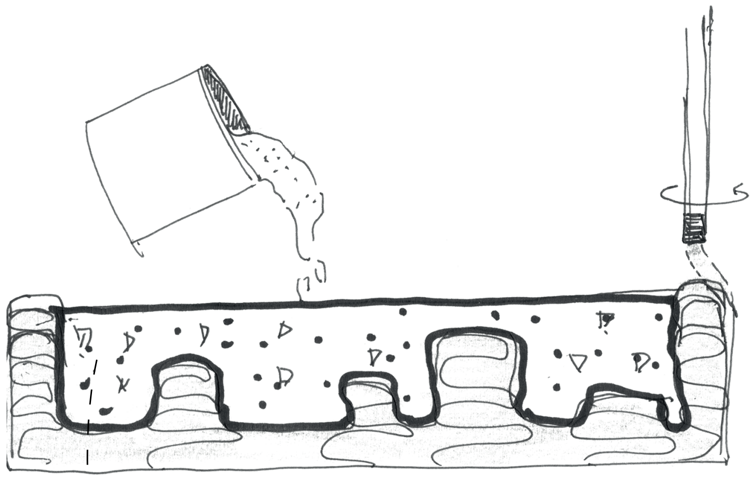
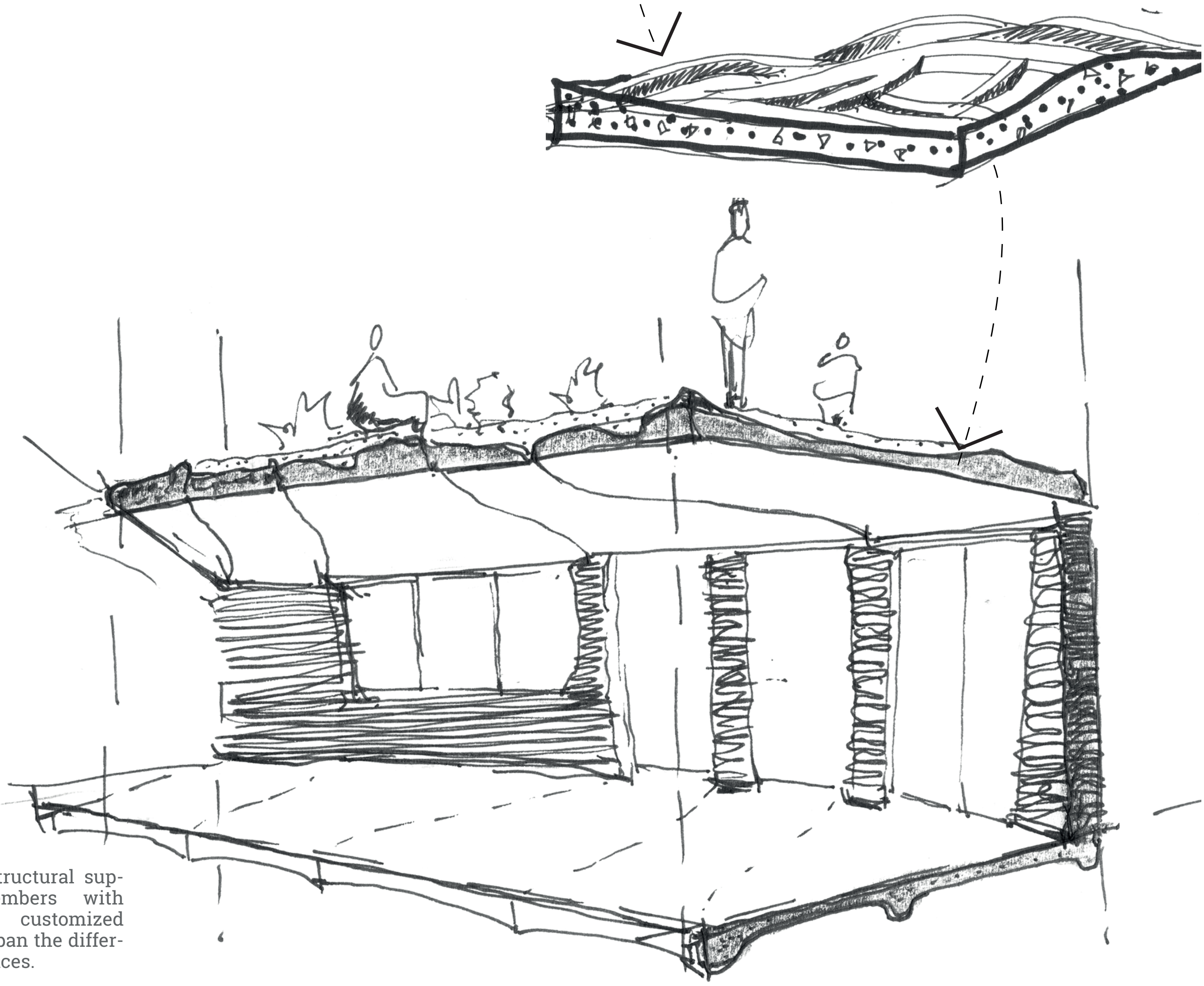


FIG 140 A



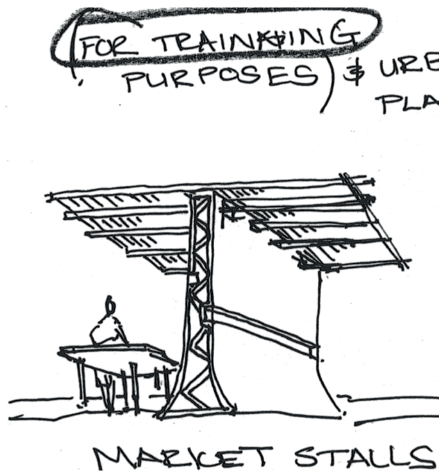
Printed structural support members with highly customized slabs to span the different distances.

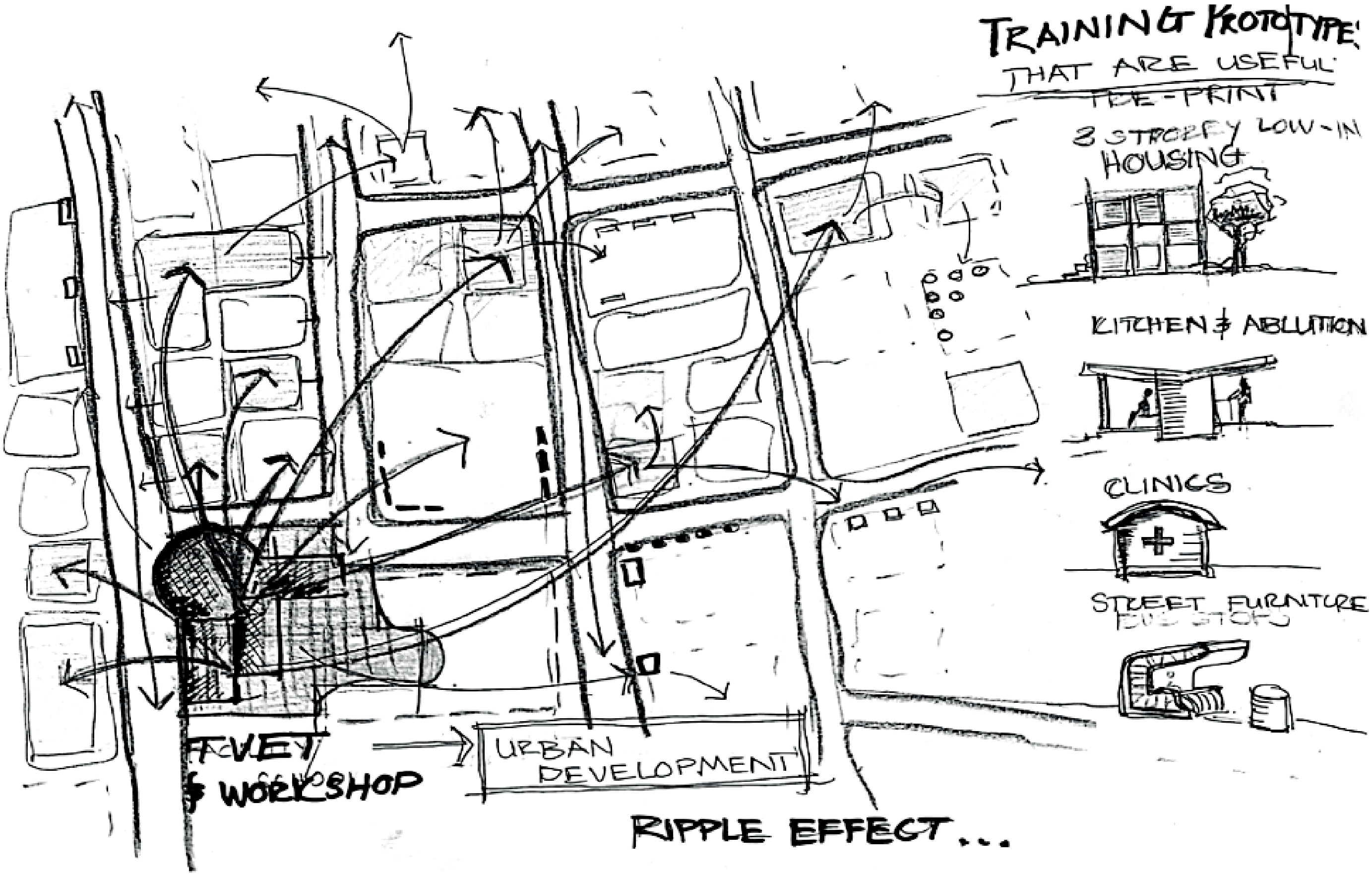
FIG 140 B

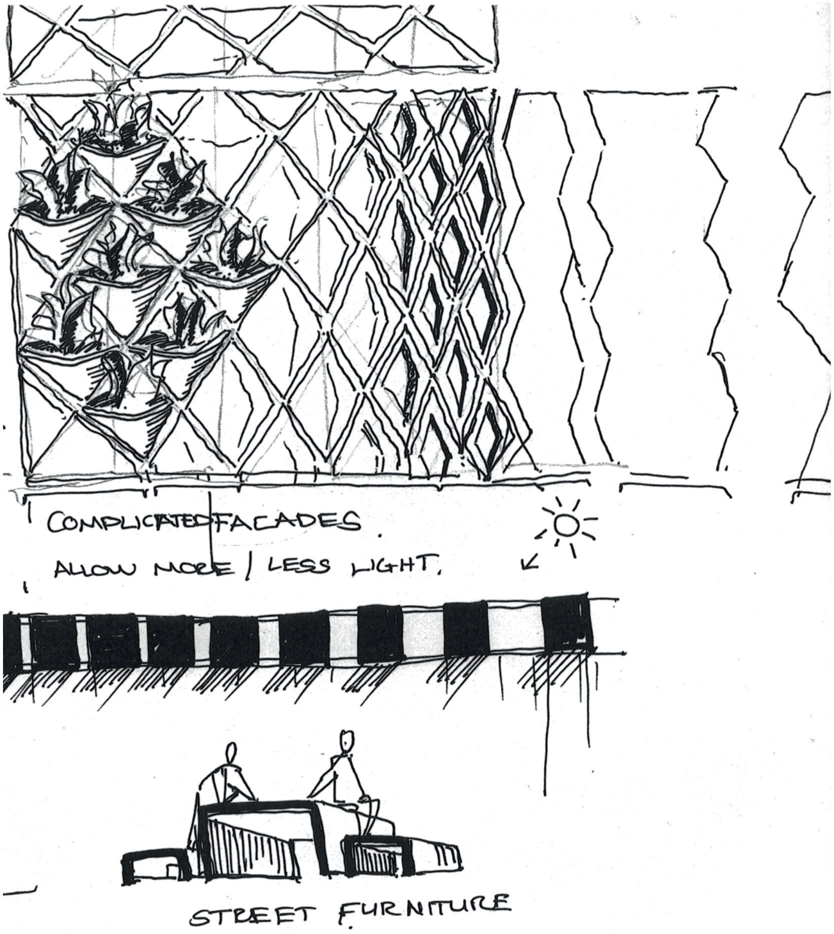
OTHER OPPORTUNITIES FOR 3D PRINTING IN PHILIPPI

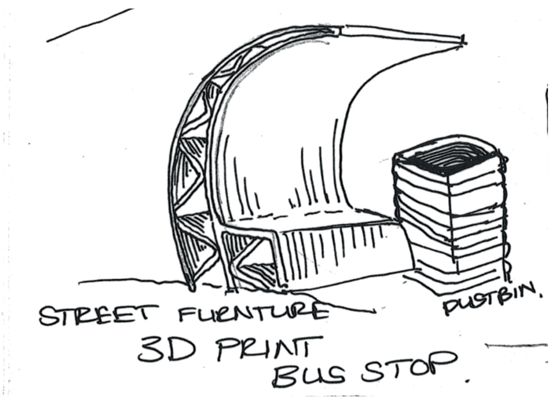
The technology of 3D printing has potential beyond this first building in Philippi. The knowledge, experience and skills gained at the school are directly transferable to other industries like furniture and home ware design. Hopefully what starts at the college will have a ripple effect on the surrounding streets and markets. When the technology eventually matures and small robotic-arm printers become affordable, entrepreneurs can combine their capital and invest in one of their own to start a small manufacturing business to make furniture, hydroponic planter boxes, crockery, and more. The printers are actually very affordable when we consider the extremely complex forms it can make and at an unprecedented speed without needing a whole factory. Open-source designs and material mixes paired with a willing and opportunistic workforce can lead to a resilient economy in Philippi.

The idea is also that the objects printed at the school as part of course work and research can form part of the street fabric outside. Instead of printing random prototypes for training that pile up in the workshops, students can rather print anything from bus stop benches to bollards and waste bins, to market stalls that can all be put to use in the neighbourhood, creating a wave of innovation through Philippi and a greener, more resilient urban fabric.









Examples of 3D printed street furniture, market stall and small community facilities.

FIG 139

THE POINT IS...

by working smart with the technology it can have a positive impact outside the walls of the school building...

What does the project contribute to...

... PHILIPPI ?

Transfers versatile and modern skills:
Locals gain skills and knowledge that will be valuable in next era of construction and multiple other industries. The workforce is enabled to find good, sustainable jobs or start businesses after they finish their course at the college.
Encourages a culture of making and selling:
Affordable and easy manufacturing paired with small capital investments. Local, on-site manufacturing means anyone can have a tiny factory in the form of one machine in their backyard.

... THE LOCAL INDUSTRY ?

Exploration and Speculation:
The dissertation aims to add a small drop in the bucket in advancing the field of architecture and construction by taking an explorative approach to speculate on the possibilities this transformative technology presents for our local industries.

By investigating different applications of the technology, we move closer to finding appropriate solutions that we can start investing in to make them a reality.

CONCLUSION

This project takes a first stab at introducing a transformative technology and whole new industry to a developing community. The design proposals in this project are by no means the only or even best ways to employ 3D printing construction in this context, but it does start to ask the right questions towards finding appropriate solutions.

At its core, the project attempts to imagine a different future with other possibilities and challenges in order to criticize it and open the conversation around how, where, and by whom 3D printing technology should be introduced here, in South Africa.

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LIST OF FIGURES

APPENDIX

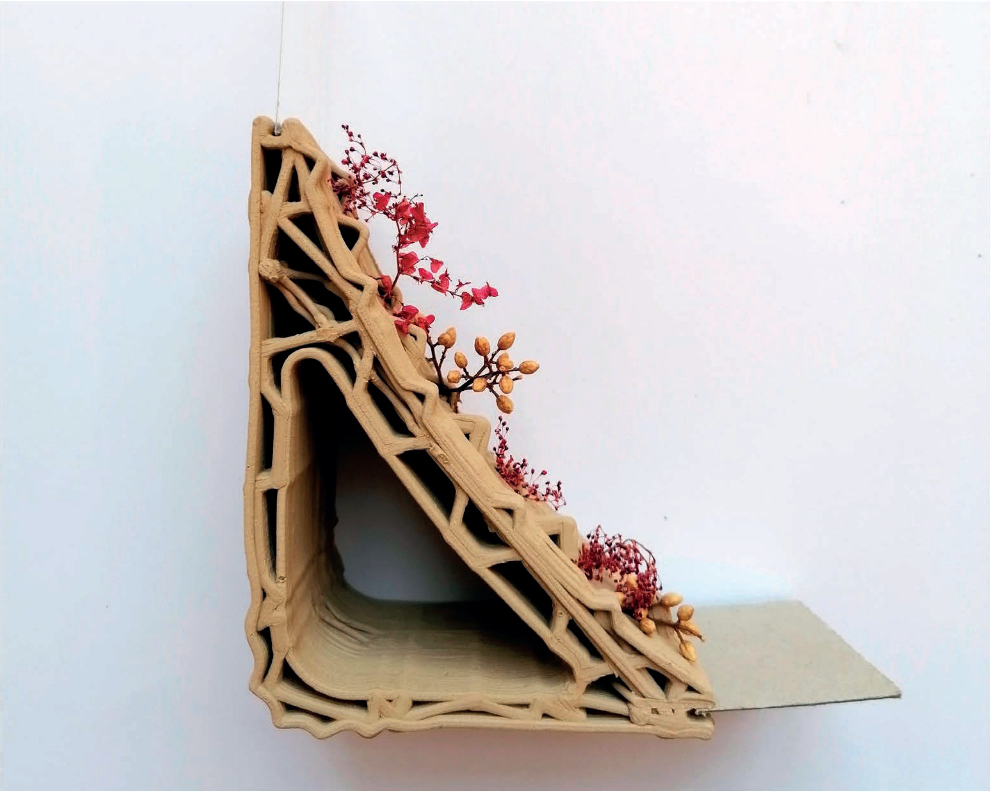
FINAL DESIGN PROPOSAL

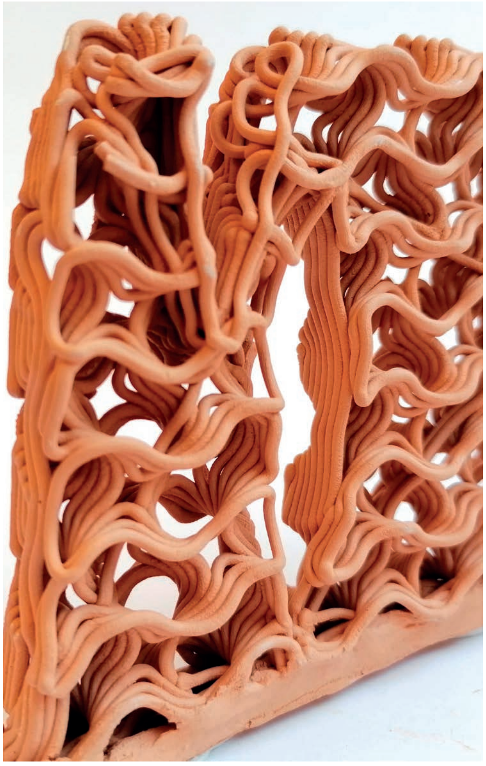
The following scans and photos are of the work presented at the final exam presentation on 21 November 2022. The ideas introduced in the dissertation document were further tested and explored. It is, therefore, in some aspects different from the initial design proposal.

Most notably, the final proposal focuses only on the construction methods that might be used during the second phase of construction. This method of in-situ printing is investigated in depth, while the focus is shifted away from the frame Tilt-up method used during the first phase of construction as mentioned in the dissertation document.

Concept models exploring form and materials

CORNER WALL SECTION - 1 : 25
This portion of the wall hosts services, act as a green wall, and allows for windows deviders to easily slot in





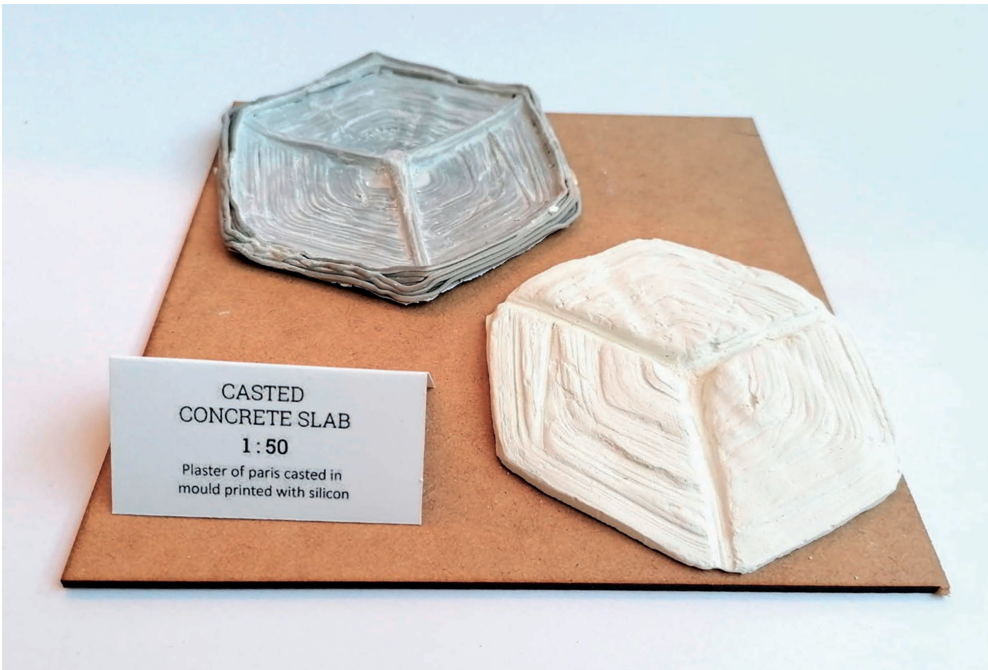
PERFORATED SCREENWALL - 1 : 25
Patern printed with clay to allow for desired light to enter

LOAD BEARING CLAYWALL - 1 : 25
The form lends strength to an otherwise non-loadbearing material

TILT-UP CONCRETE COLUMN SERIES - 1 : 25
Experiment with theperformance of different
print orientatons

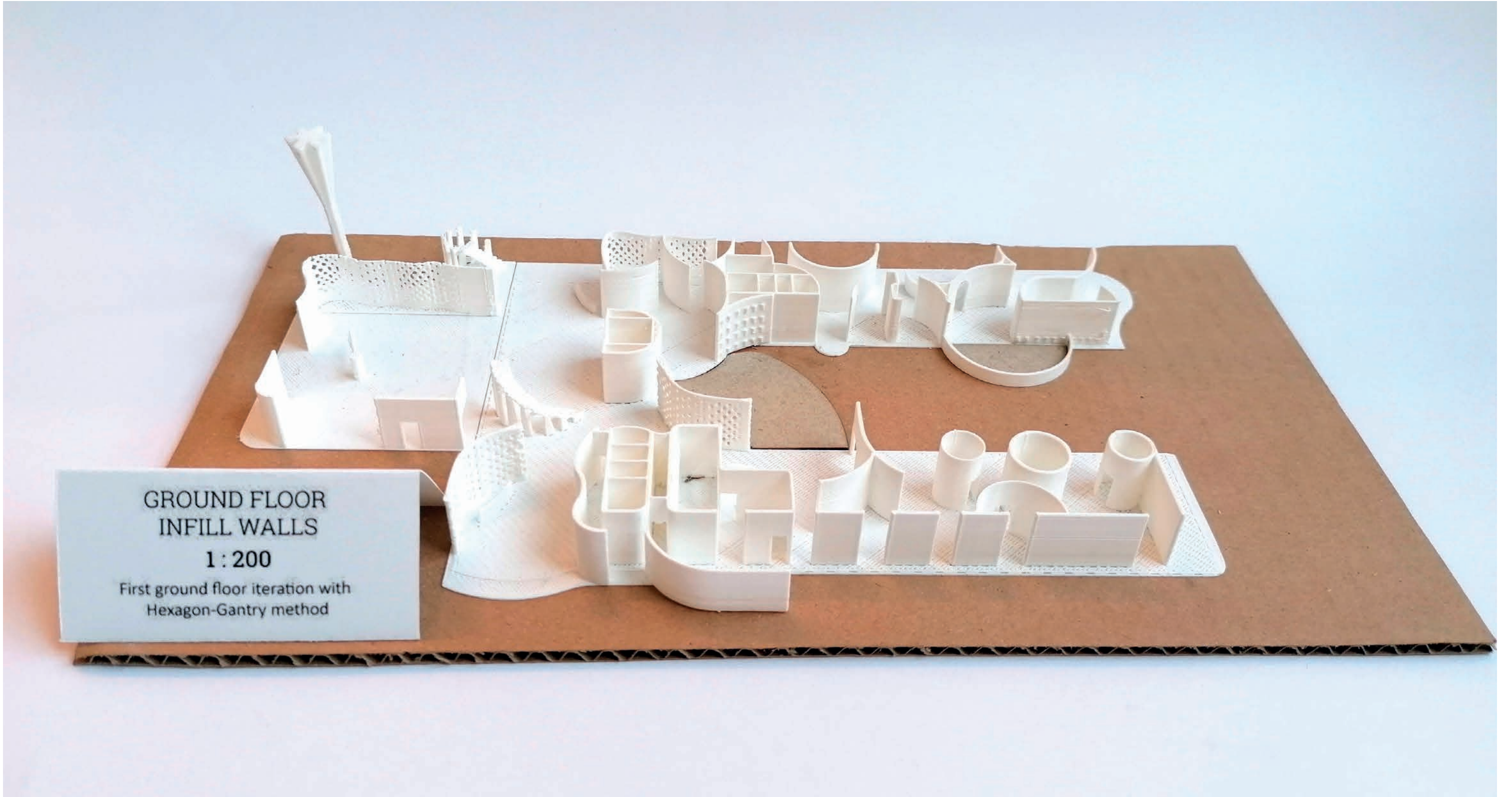
MARKET STALL PROTOTYPE - 1 : 25
Printed with coffee (and additves) on its side to
be tilted up right

PRINTED CONCRETE SLAB - 1 : 50
Printed upside down, then stronger mix is cast
in printed grooves over re-bar to form beams

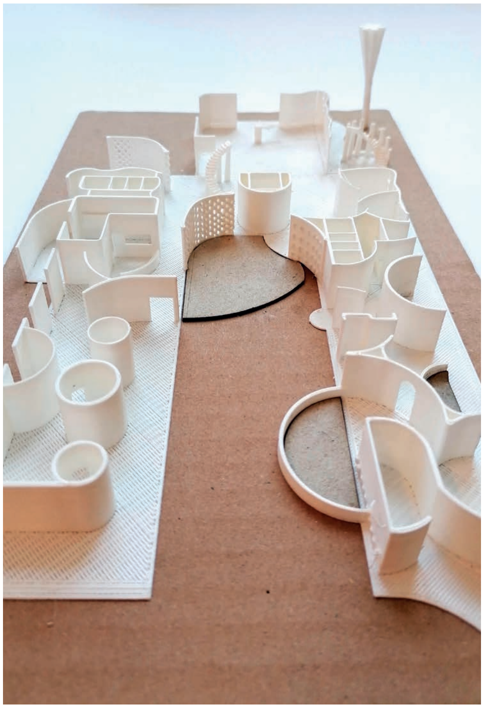


CASTED CONCRETE SLAB - 1 : 50
Plaster of paris cast in mould prined with silicon

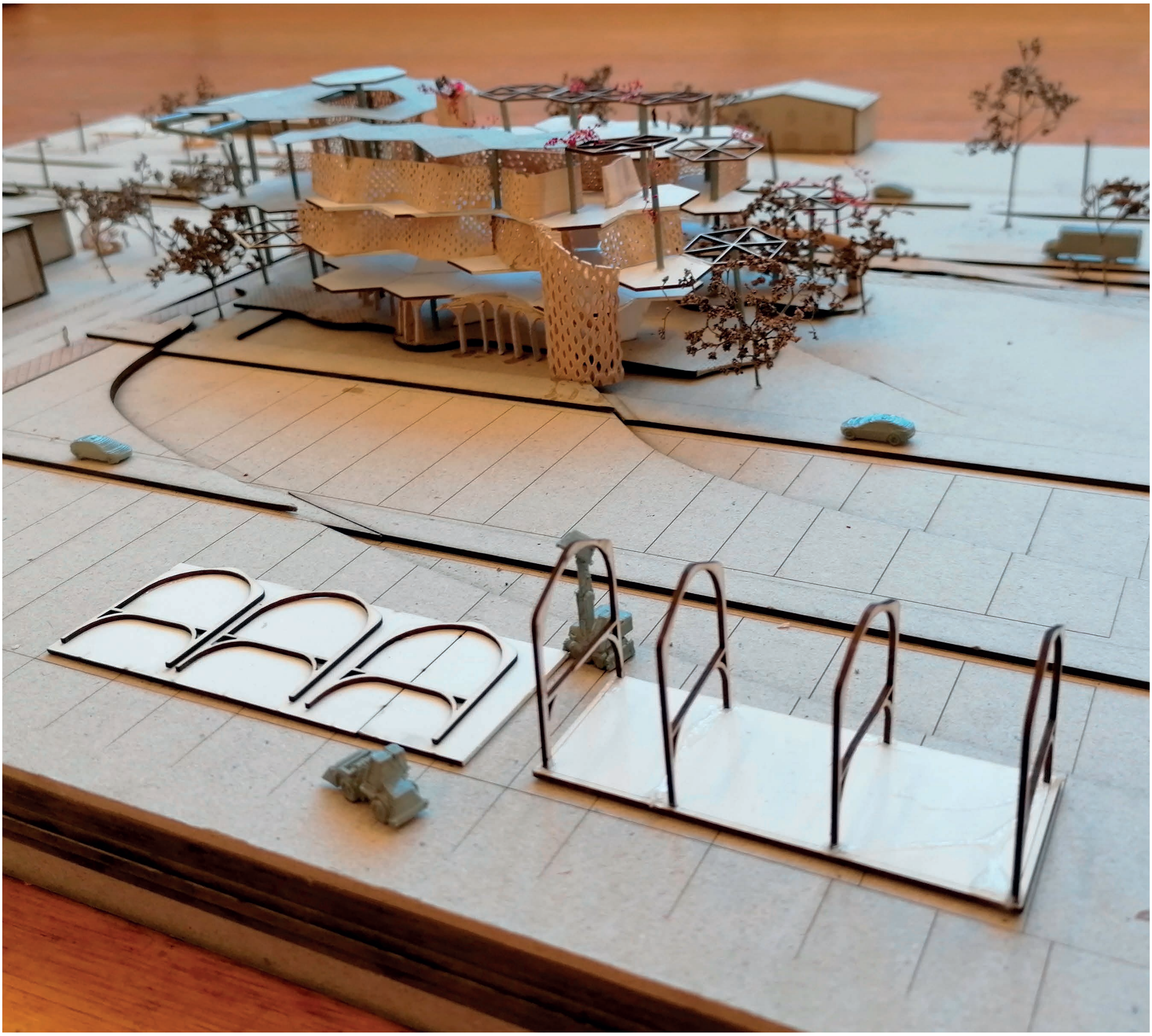
STRUCTURAL COLUMNS - 1 : 50
Explores the strength of the different forms



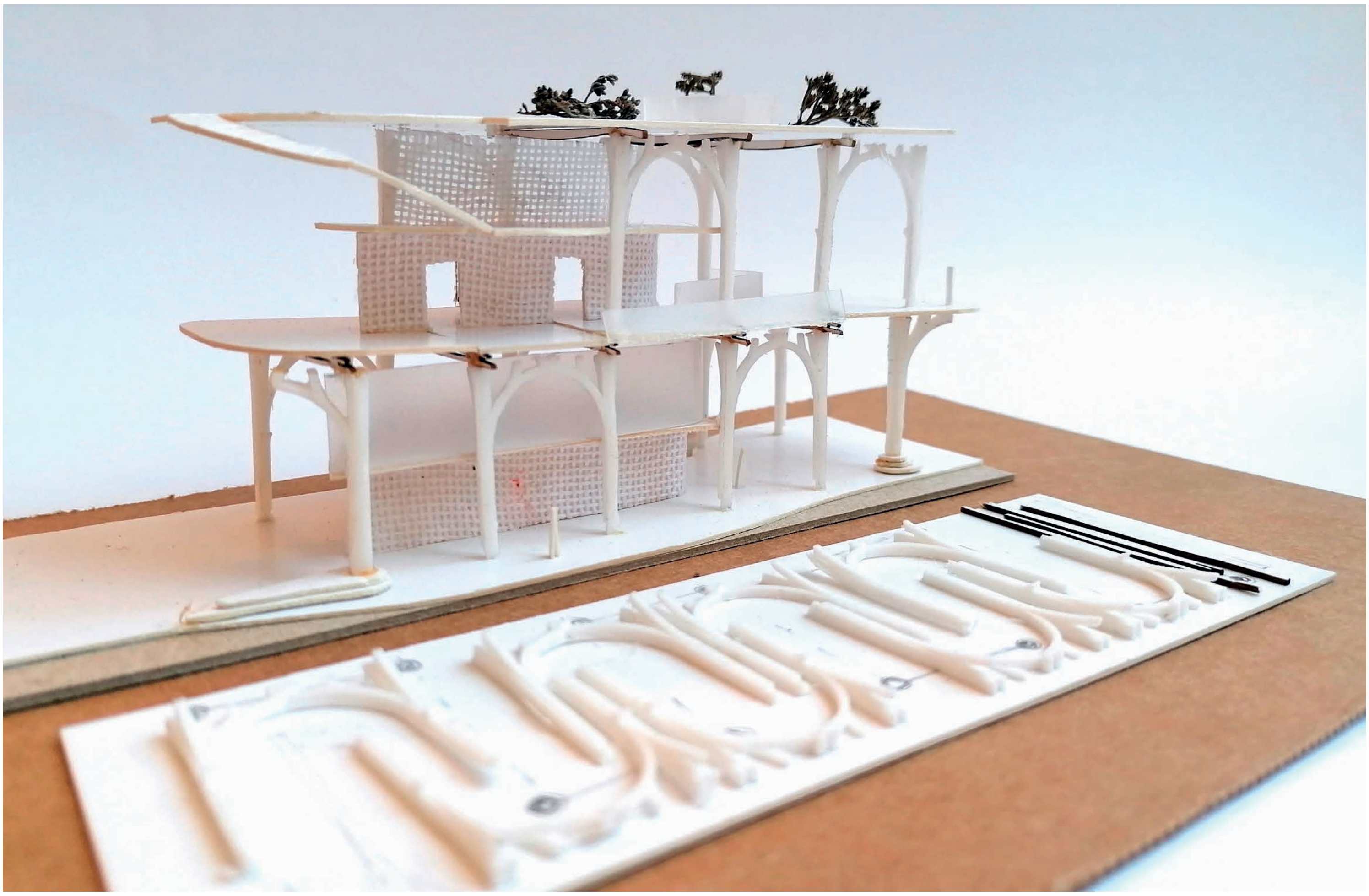
GROUND FLOOR INFILL WALLS - 1 : 200
First ground floor iteration with Hexagon-Gantry method



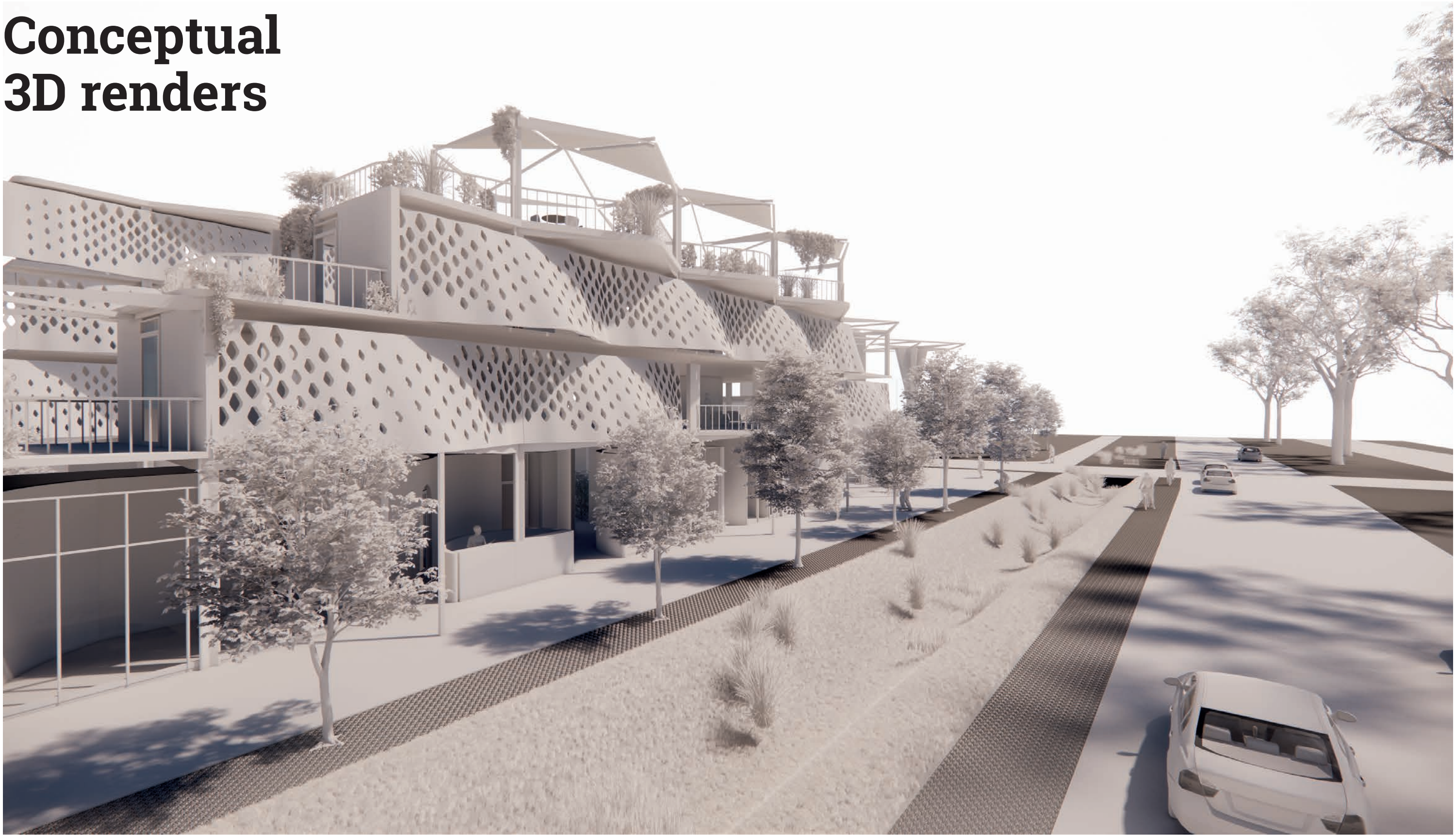
Exploring Tilt-up frame method

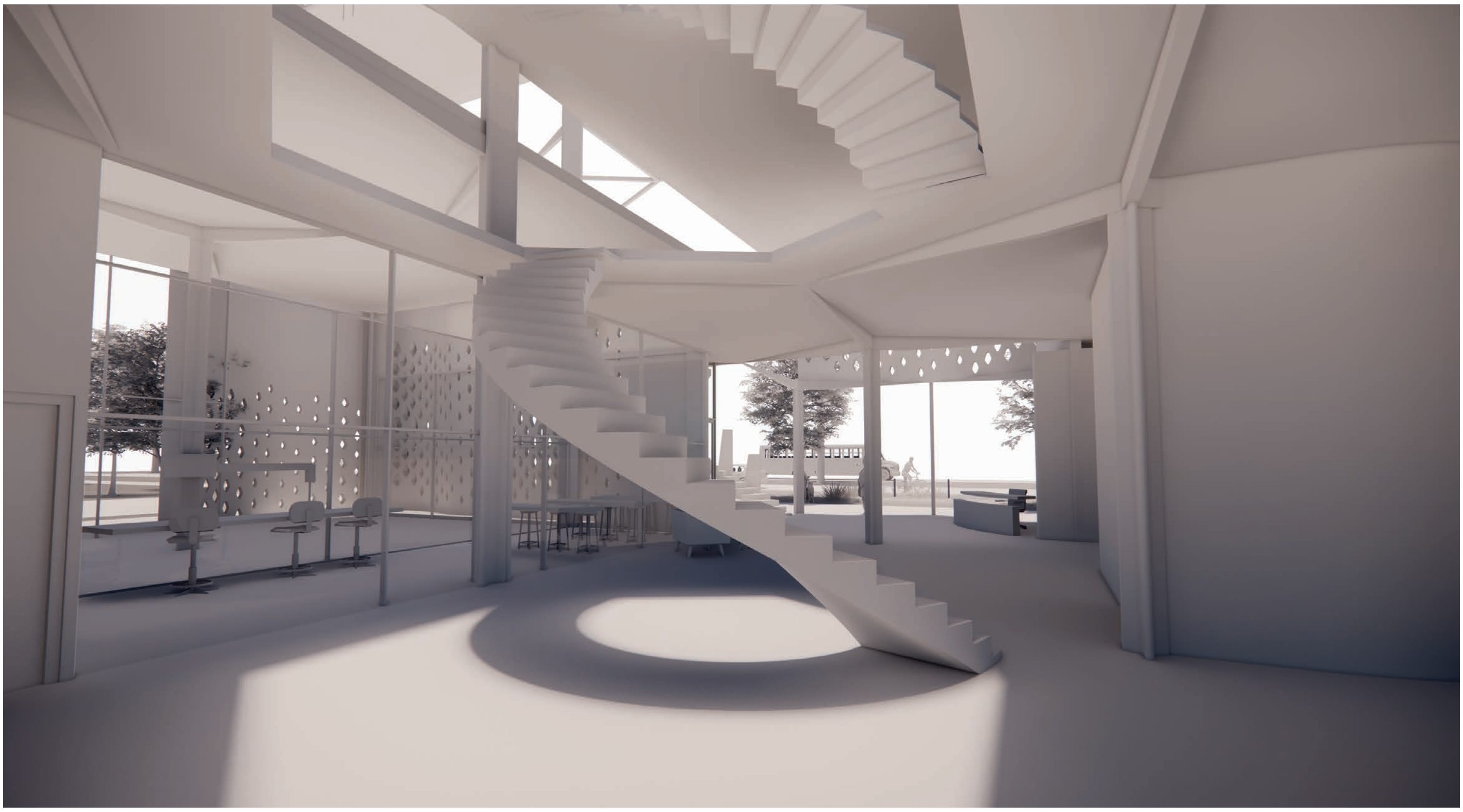


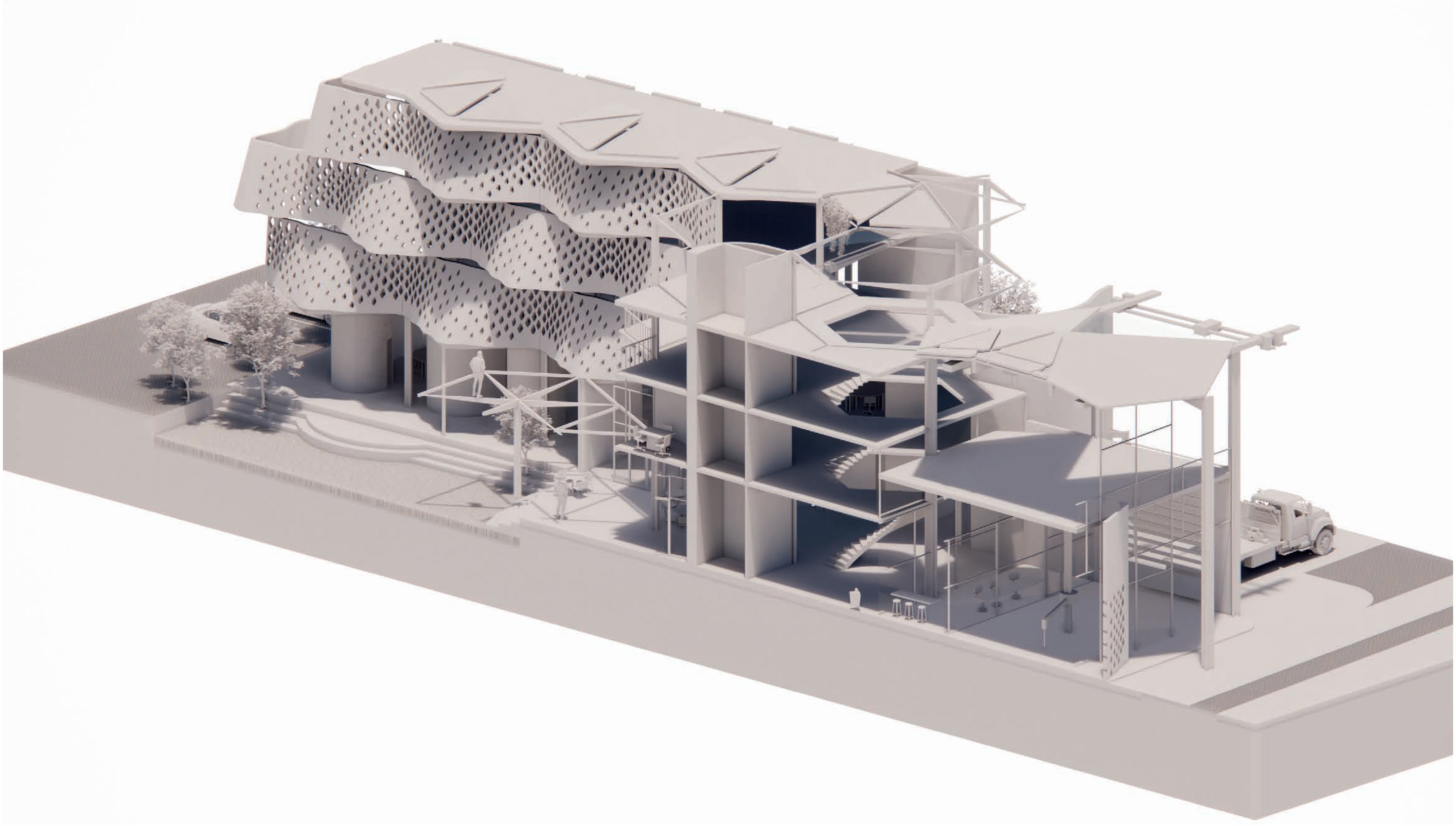
TILT-UP FRAME METHOD - 1 : 200
Explores cost & speed advantages of Tilt-up 3D printed frames for multi-storey housing

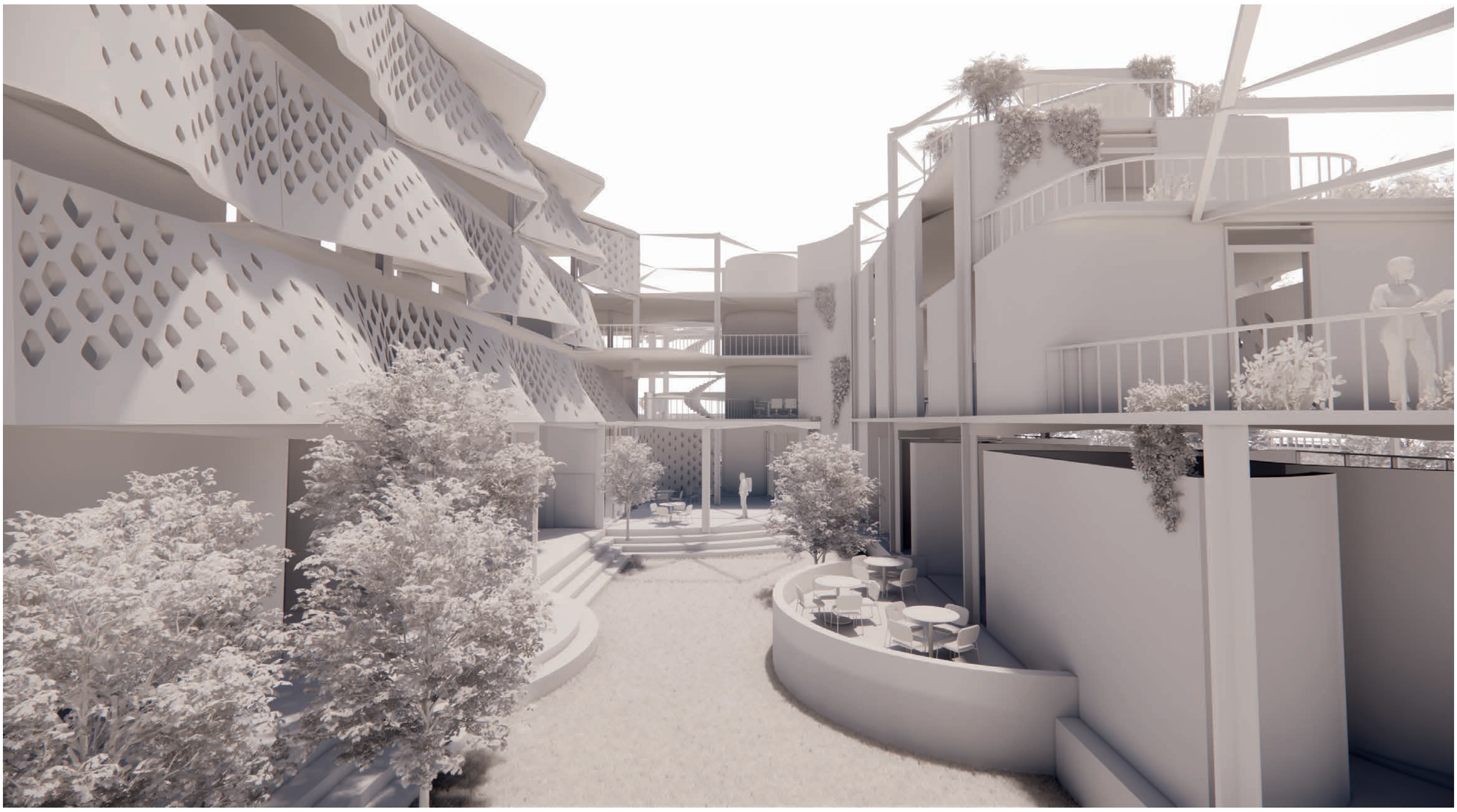


Conceptual 3D renders

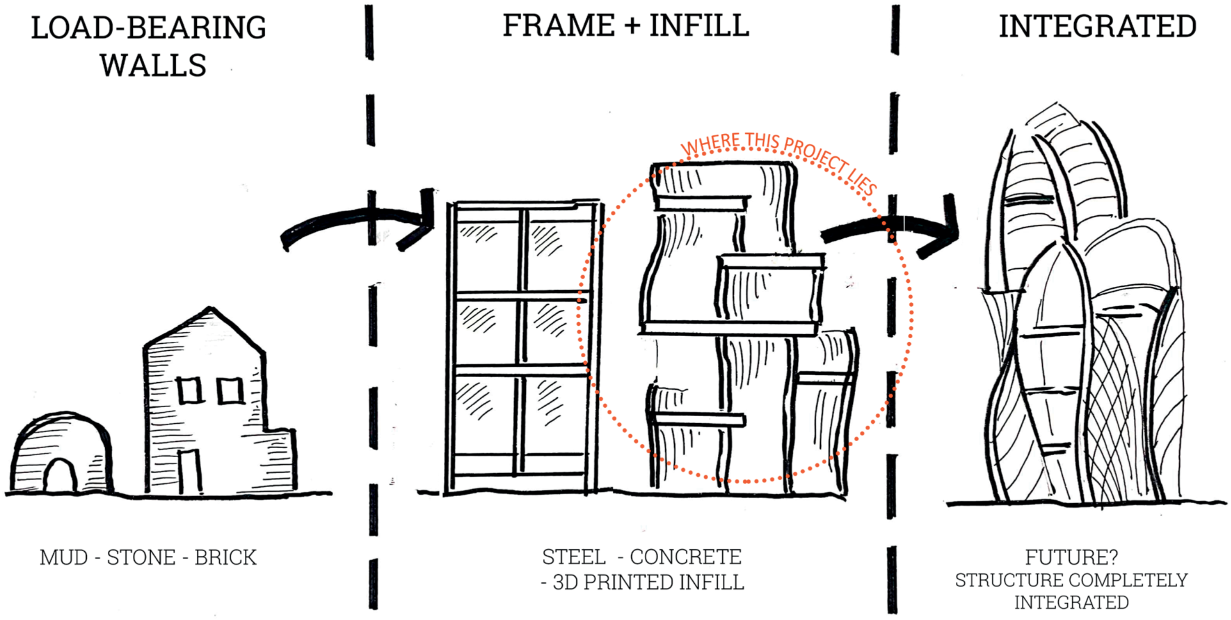








Theory introduction

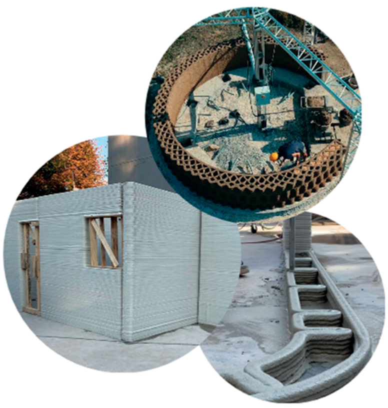


3D PRINTING
IN CONSTRUCTION

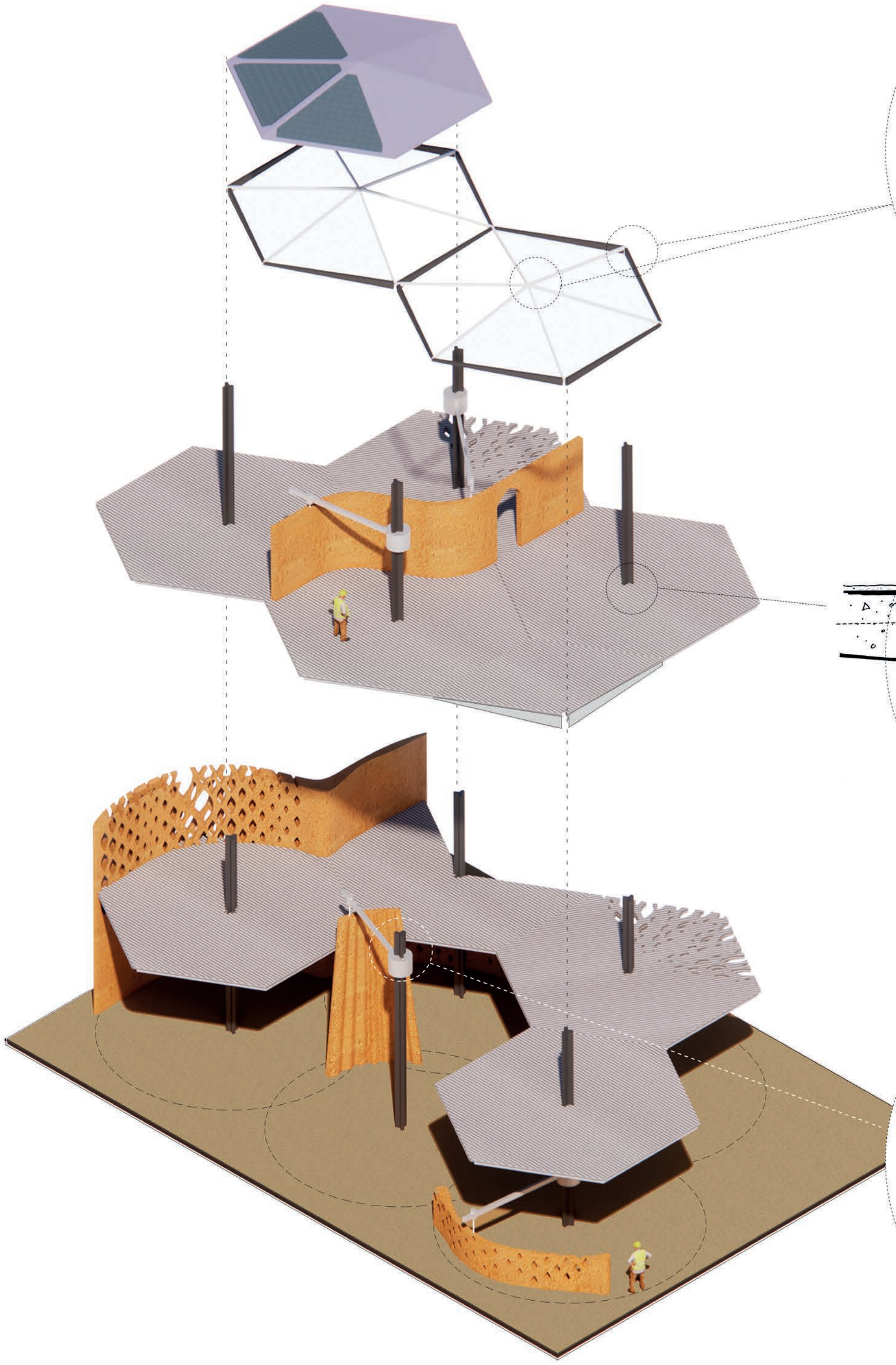
1] PRE-PRINT
Joints
Building components
Bricks, columns

2] IN - SITU
Print walls
of entire
building

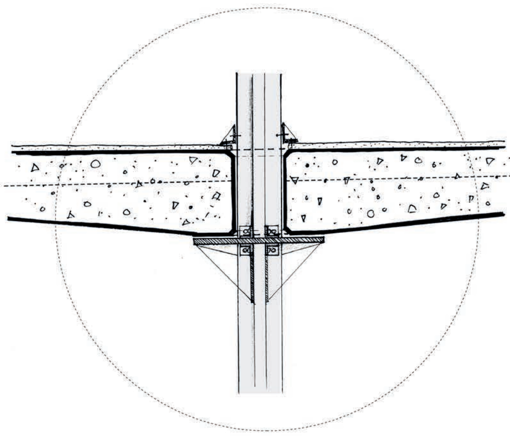
3] APPARATUS
Formwork
Molds



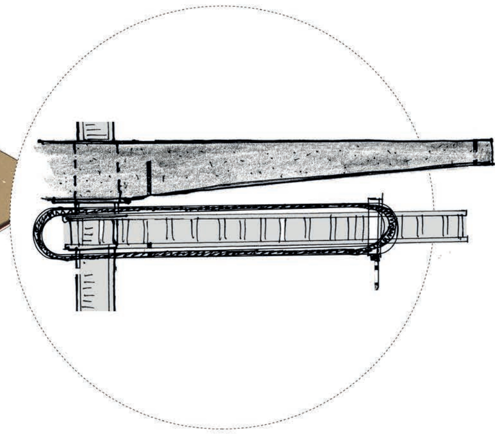
Construction method



BESPOKE 3D-PRINTED PVC NODES
FOR EASY ASSEMBLY AND DISASSEMBLY



STEEL COLUMNS CONNECT THROUGH
HOLES IN COMPOSITE 3D-PRINTED
CONCRETE SLABS.



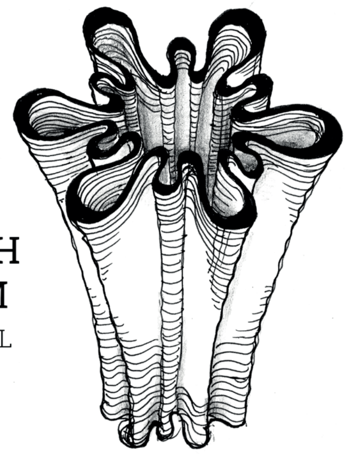
PRINTING ARMS ARE ATTACHED TO THE
STEEL COLUMNS WHERE AND WHEN
CONSTRCUTION IS REQUIRED

(Print)ciples

1

STRENGTH IN FORM

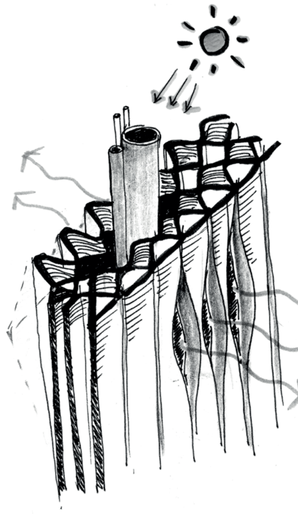
NOT MATERIAL



2

MULTIPLE FUNCTIONS

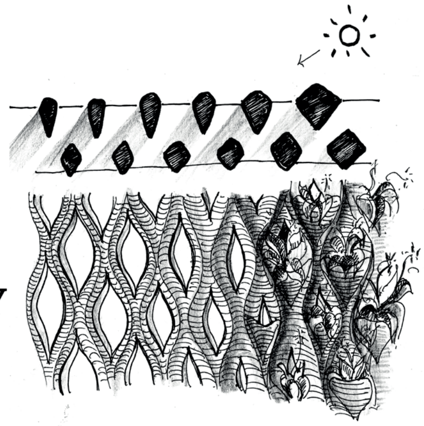
SHADING + VENTILATION



4

VARIETY + COMPLEXITY

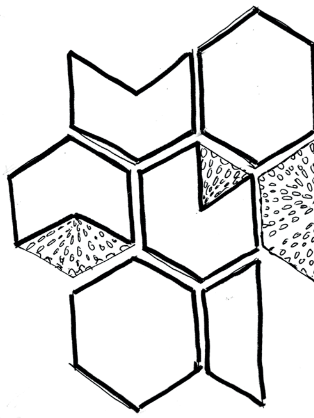
AT NO COST



5

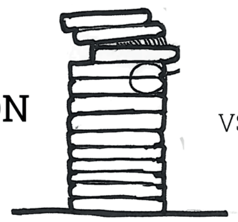
CUSTOMI-ZATION

AT NO COST



7

PRINT ORIENTATION



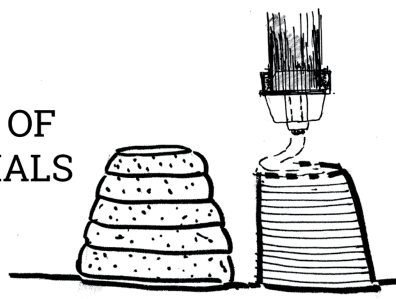
VS.

HORIZONTAL

VERTICAL

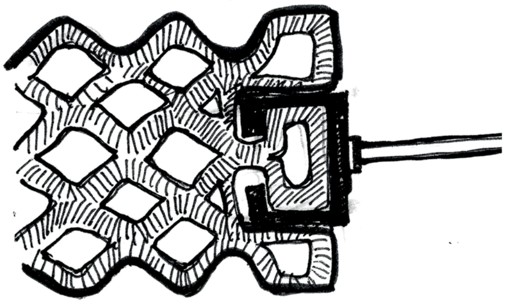
8

RANGE OF MATERIALS



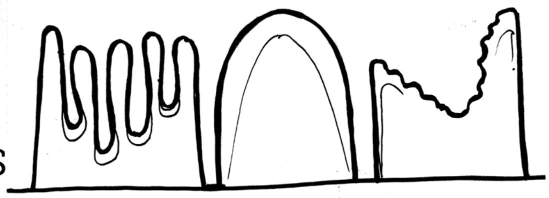
3

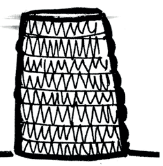
INTEGRATED JOINTS



6

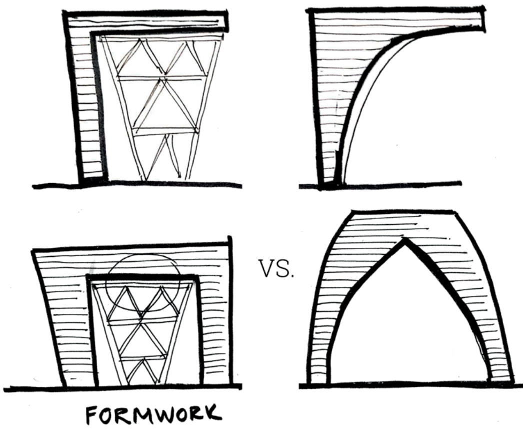
EXPRESIVE WALL PROFILES

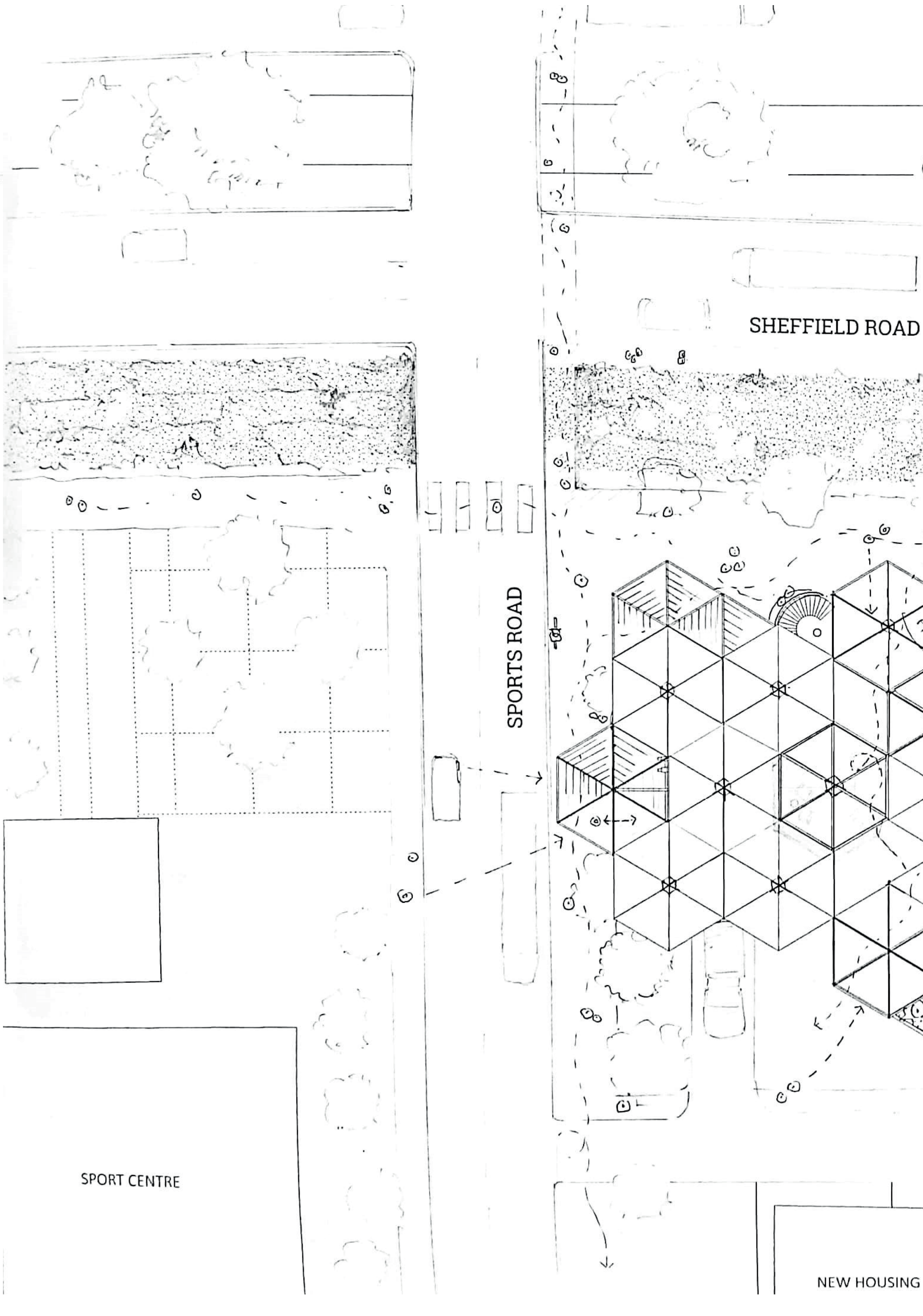


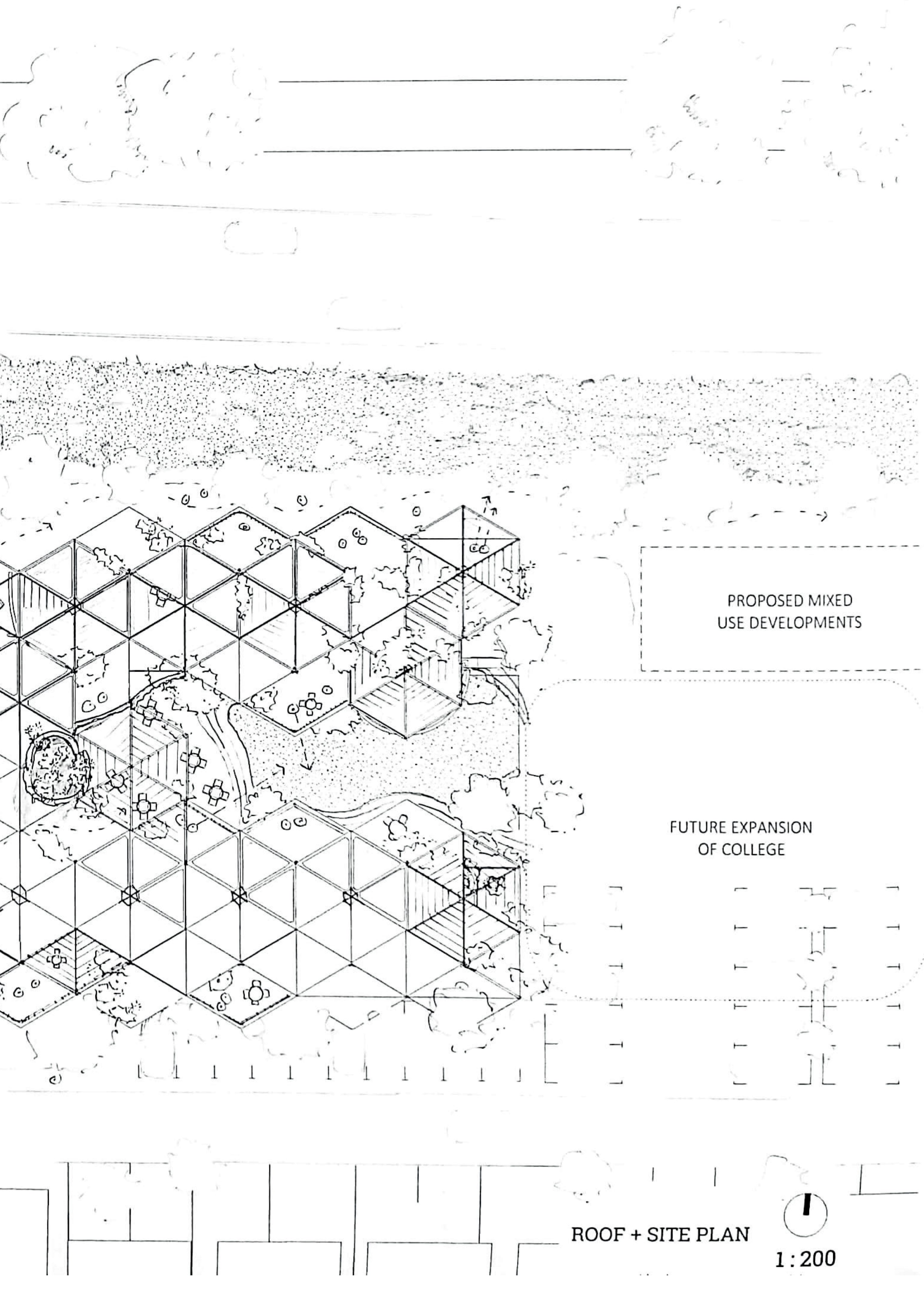


9

OPENINGS + CANTILEVERS

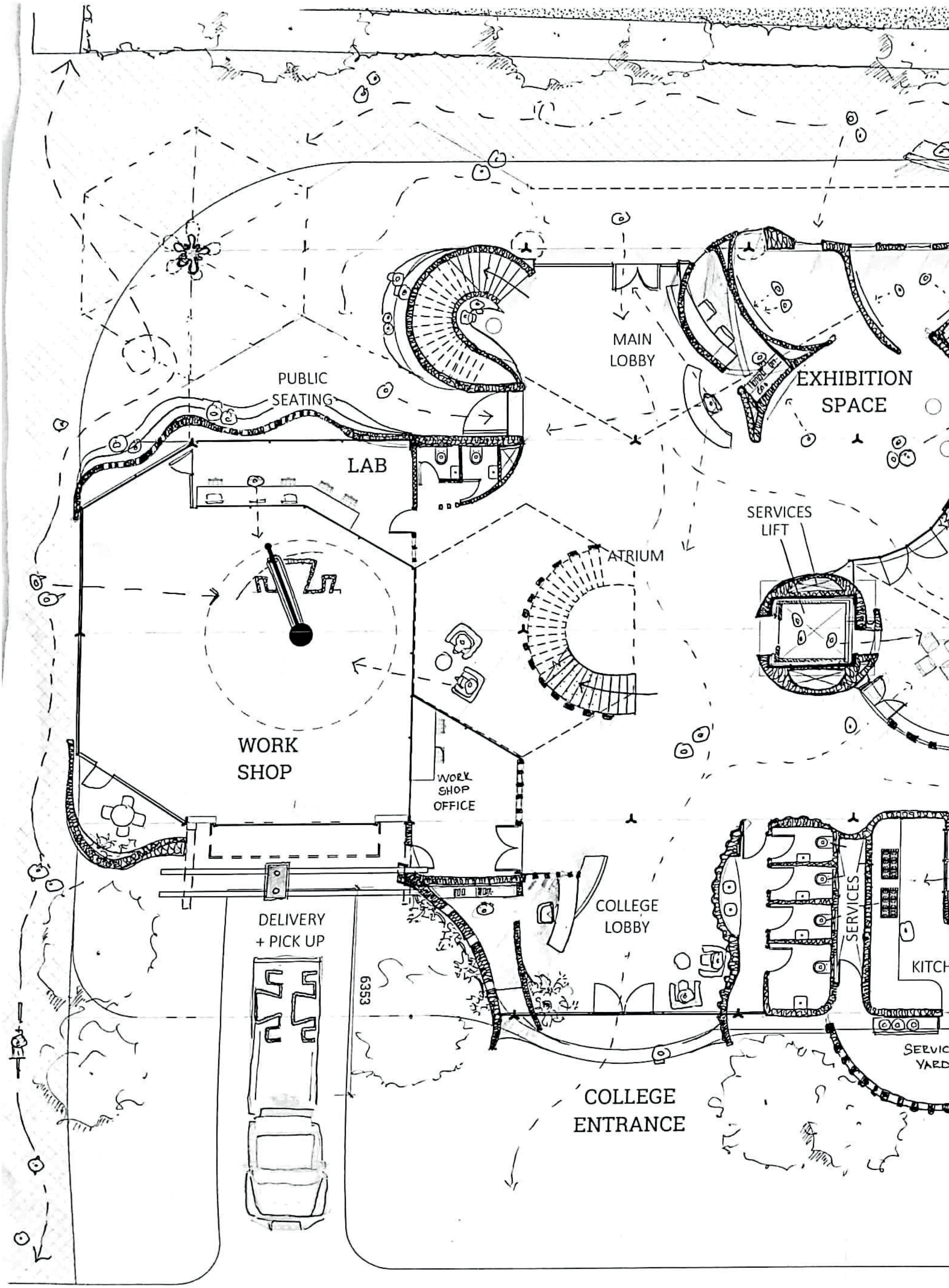


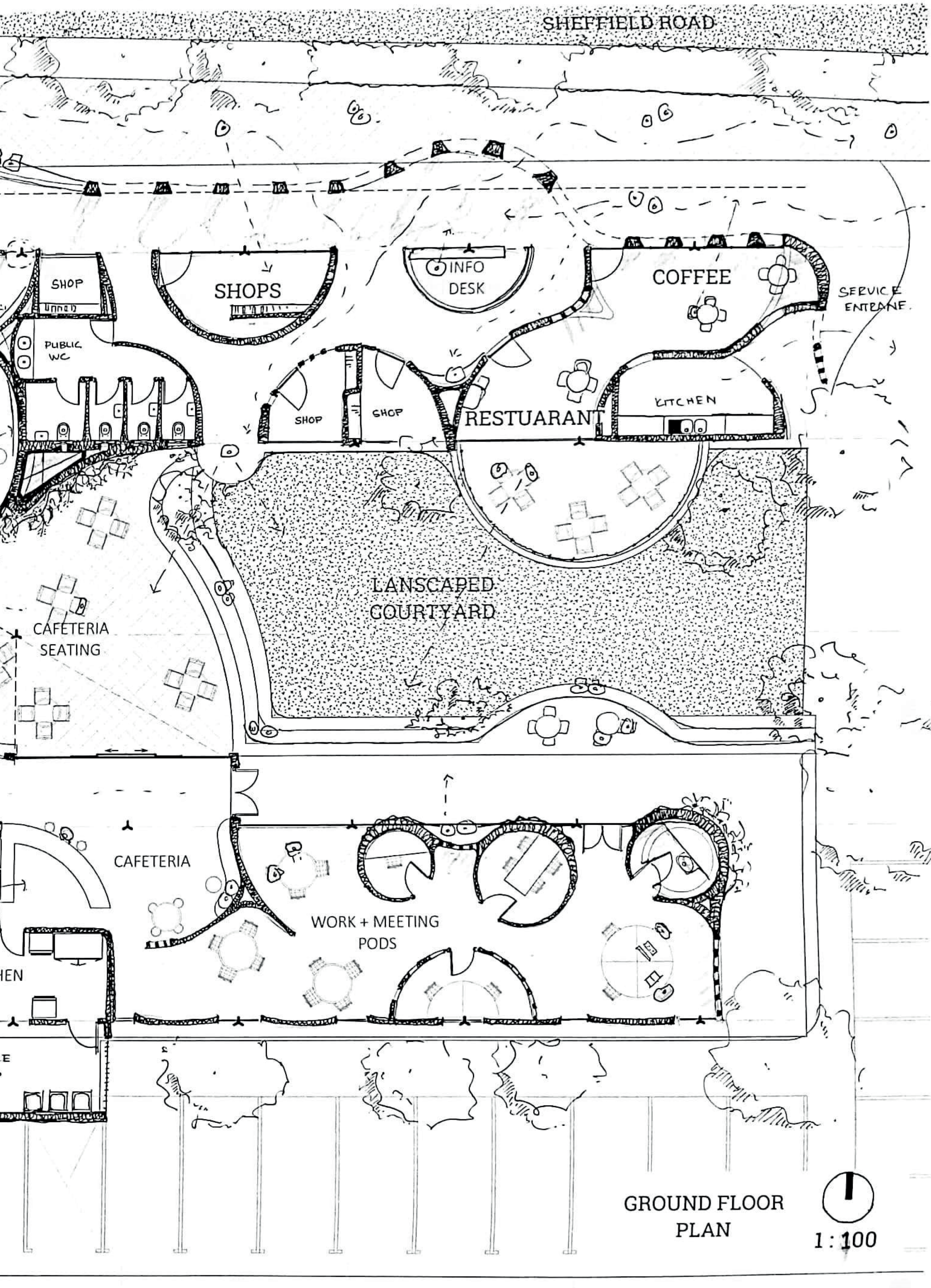

SHEFFIELD ROAD
SPORTS ROAD
SPORT CENTRE
NEW HOUSING

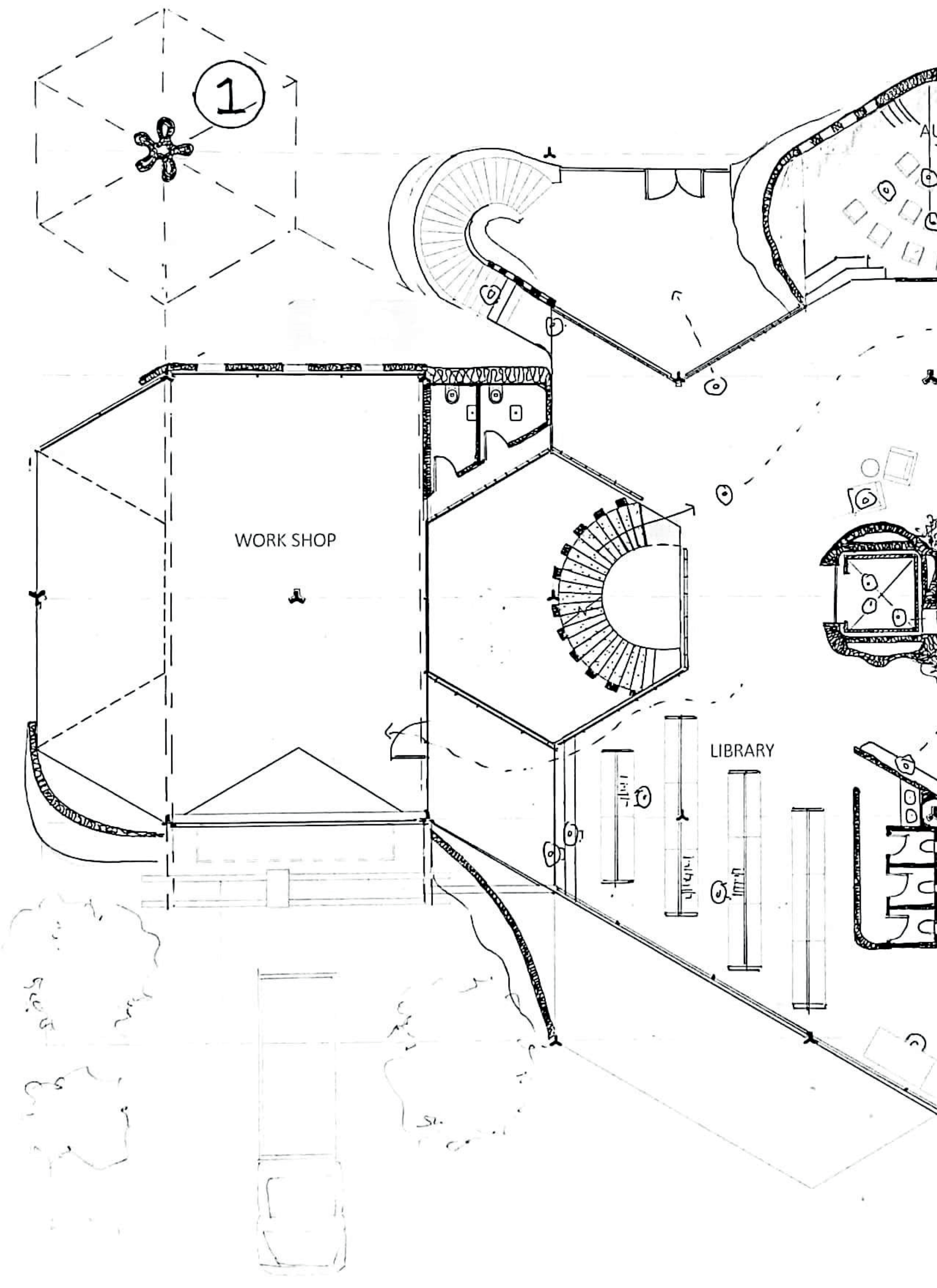


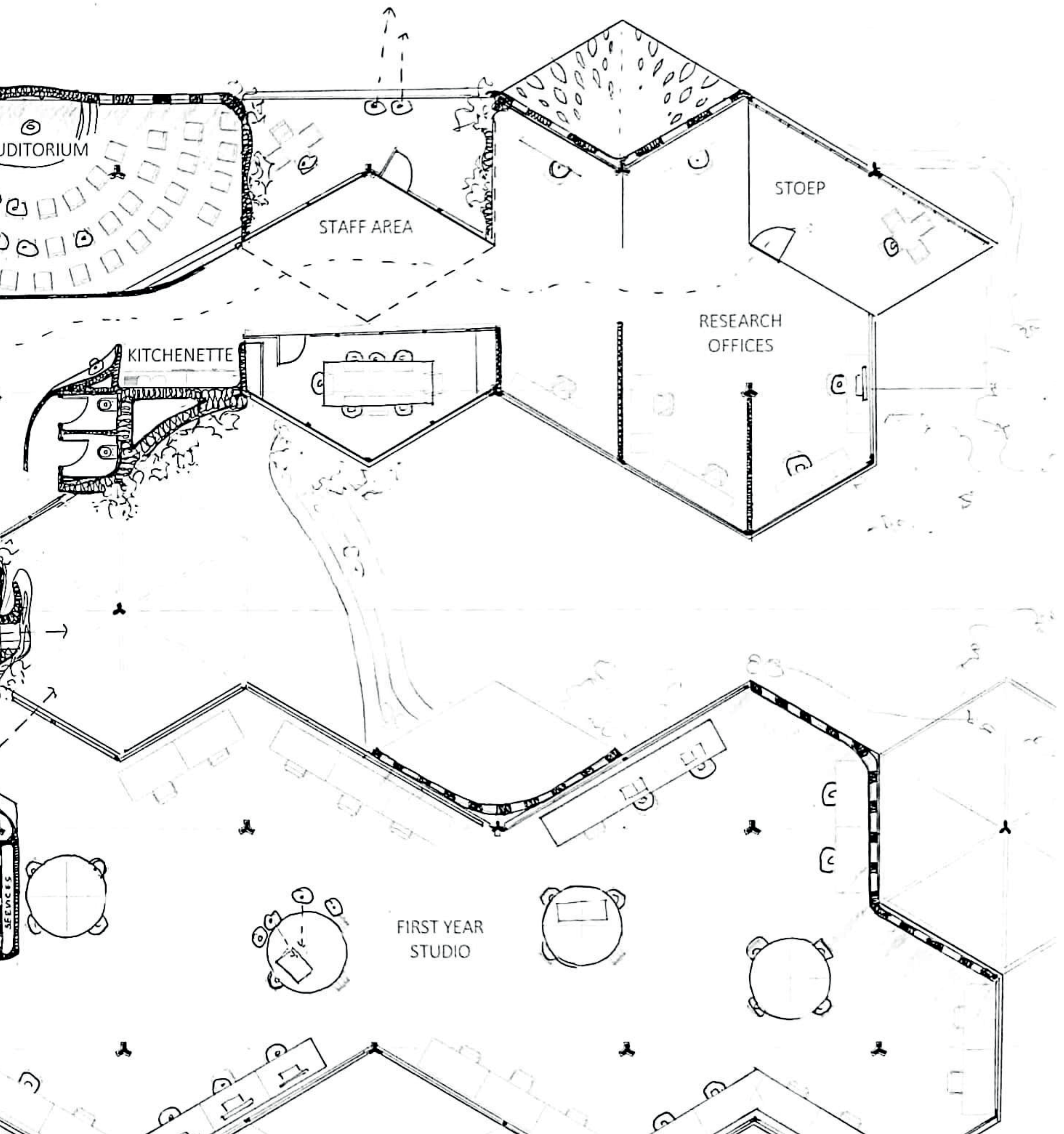
ROOF + SITE PLAN

1:200


PUBLIC SEATING
MAIN LOBBY
EXHIBITION SPACE
LAB
SERVICES LIFT
ATRIUM
WORK SHOP
WORK SHOP OFFICE
DELIVERY + PICK UP
6353
COLLEGE LOBBY
SERVICES
COLLEGE ENTRANCE

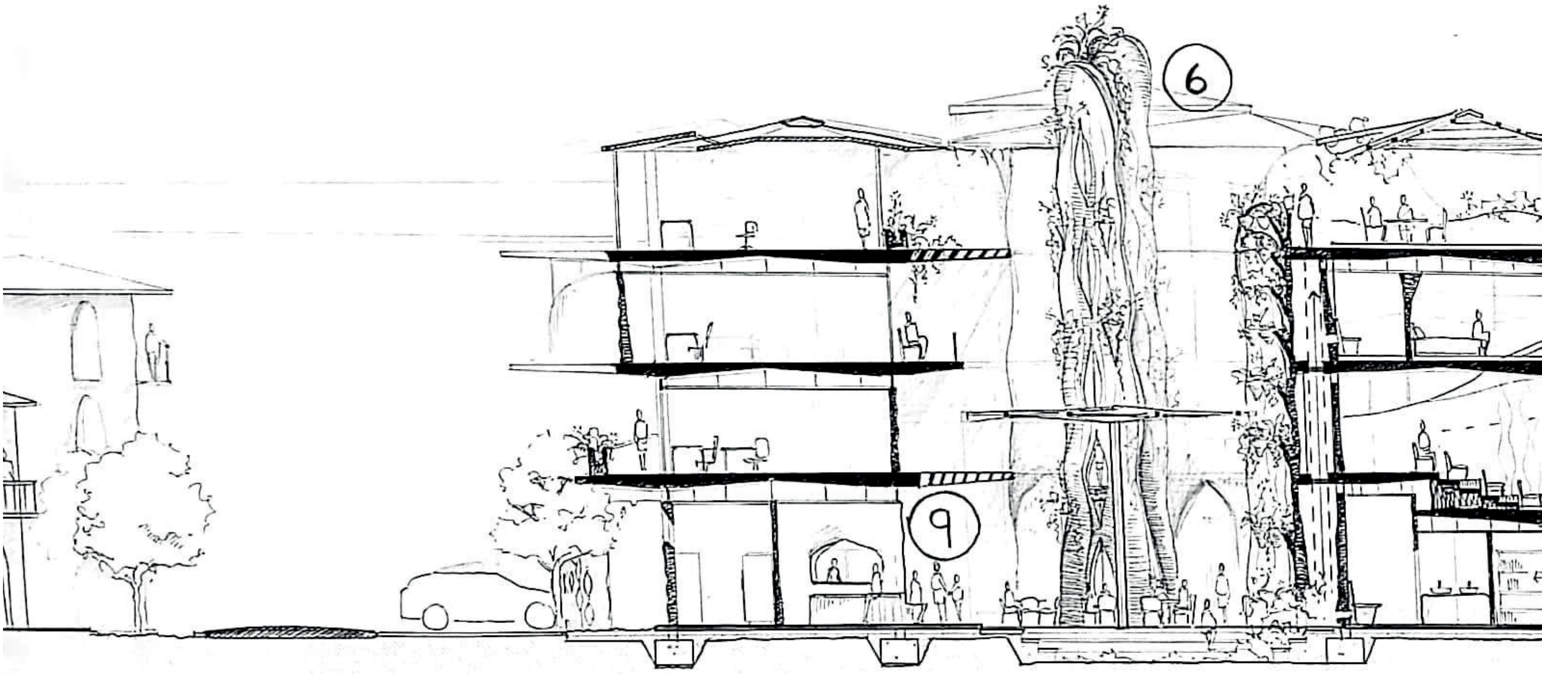

SHEFFIELD ROAD
SHOP
SHOPS
INFO DESK
COFFEE
SERVICE ENTRANE.
PUBLIC WC
SHOP
SHOP
RESTUARANT
KITCHEN
LANSCAPED COURTYARD
CAFETERIA SEATING
CAFETERIA
WORK + MEETING PODS
GROUND FLOOR PLAN
1 : 100


1
WORK SHOP
LIBRARY

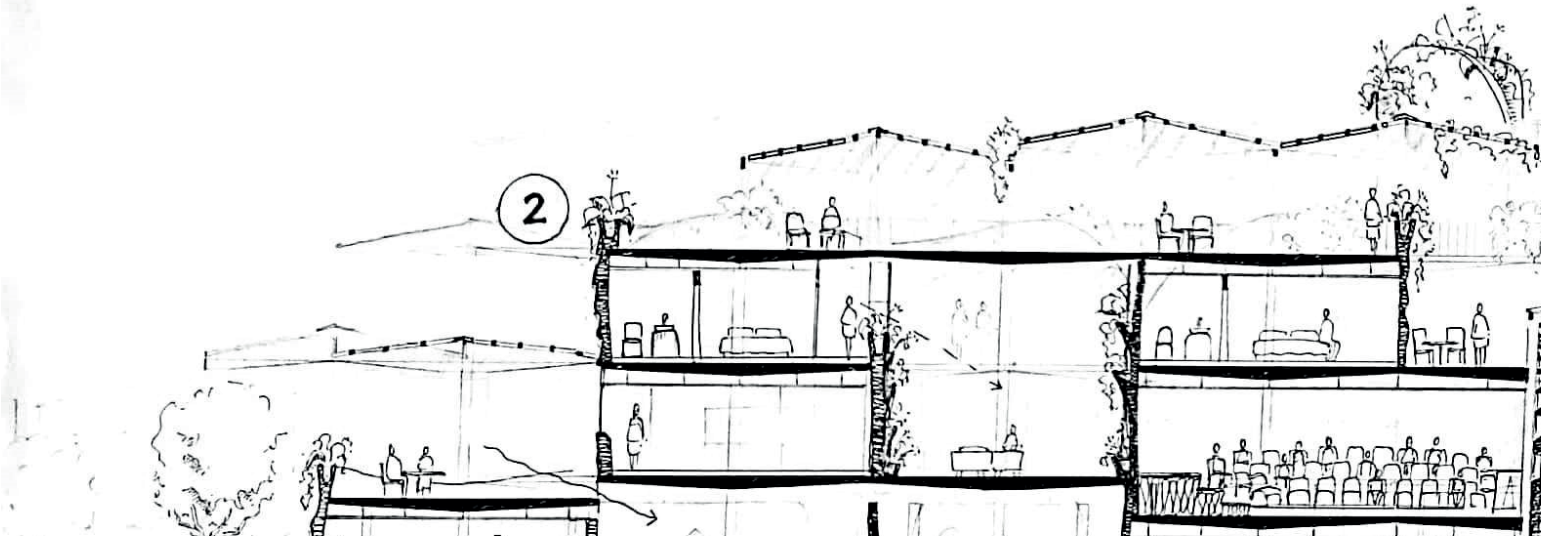


LEVEL 1
FLOOR PLAN

1:100

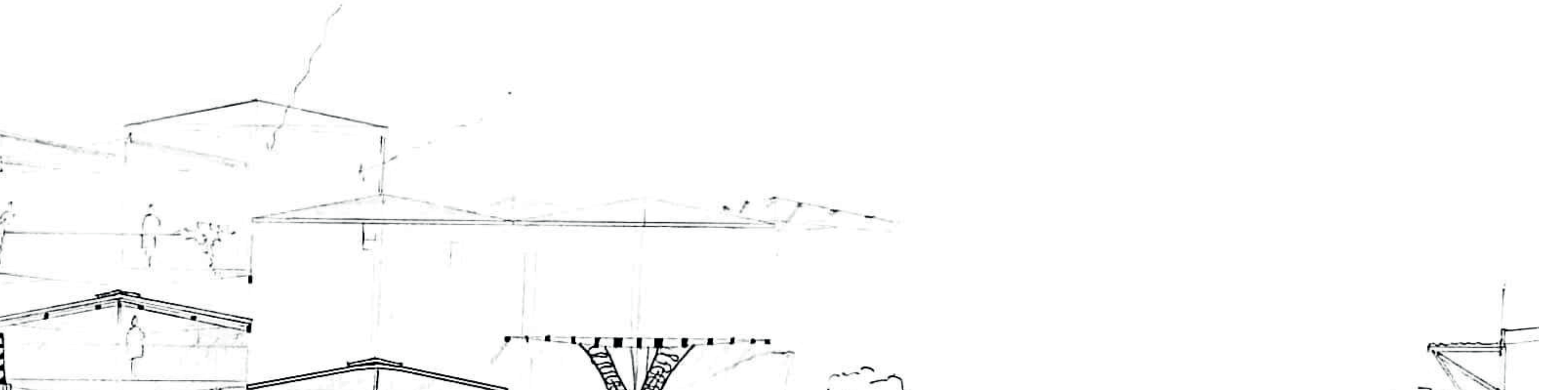


6
9

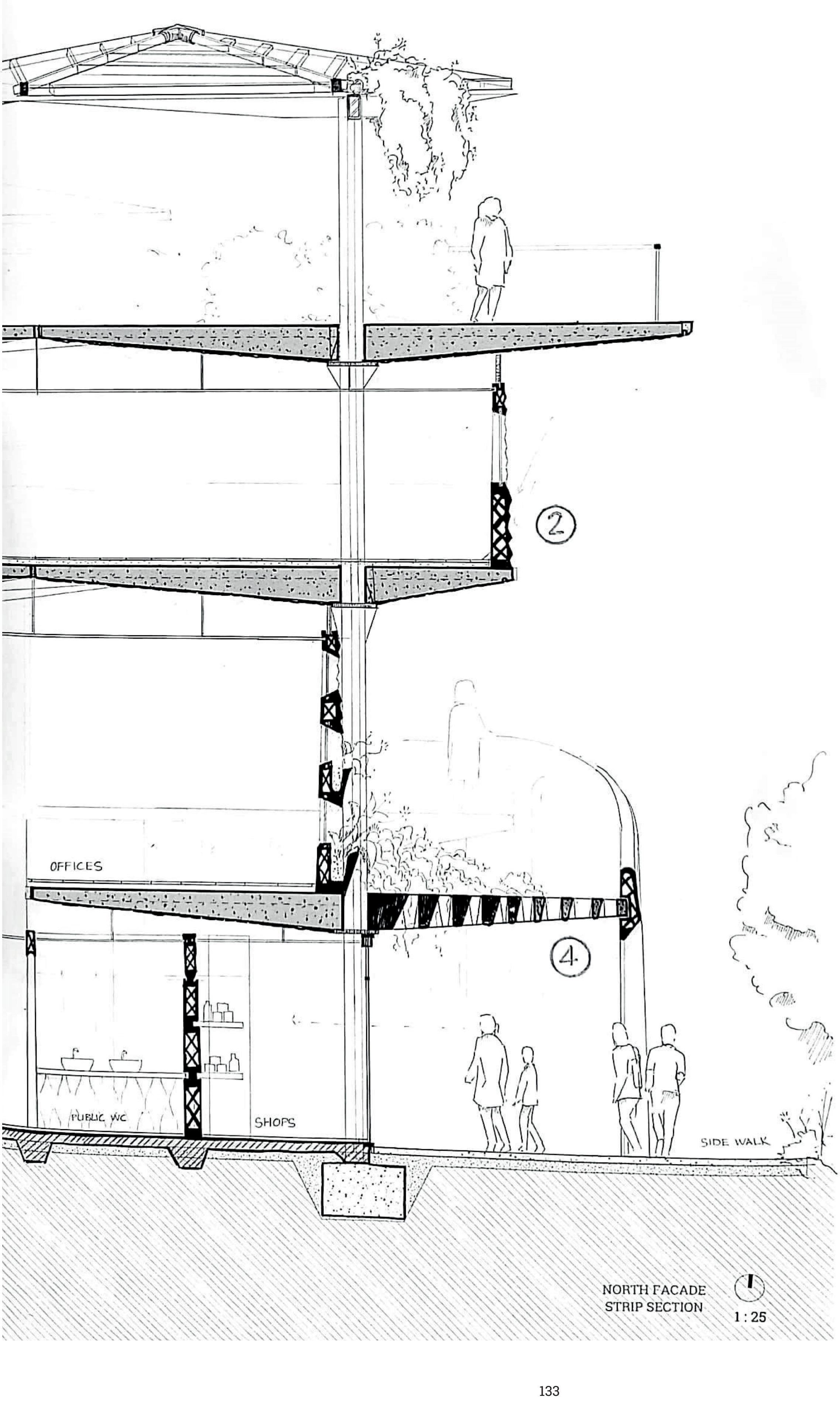


2
7000
7000
7000
7000
7000

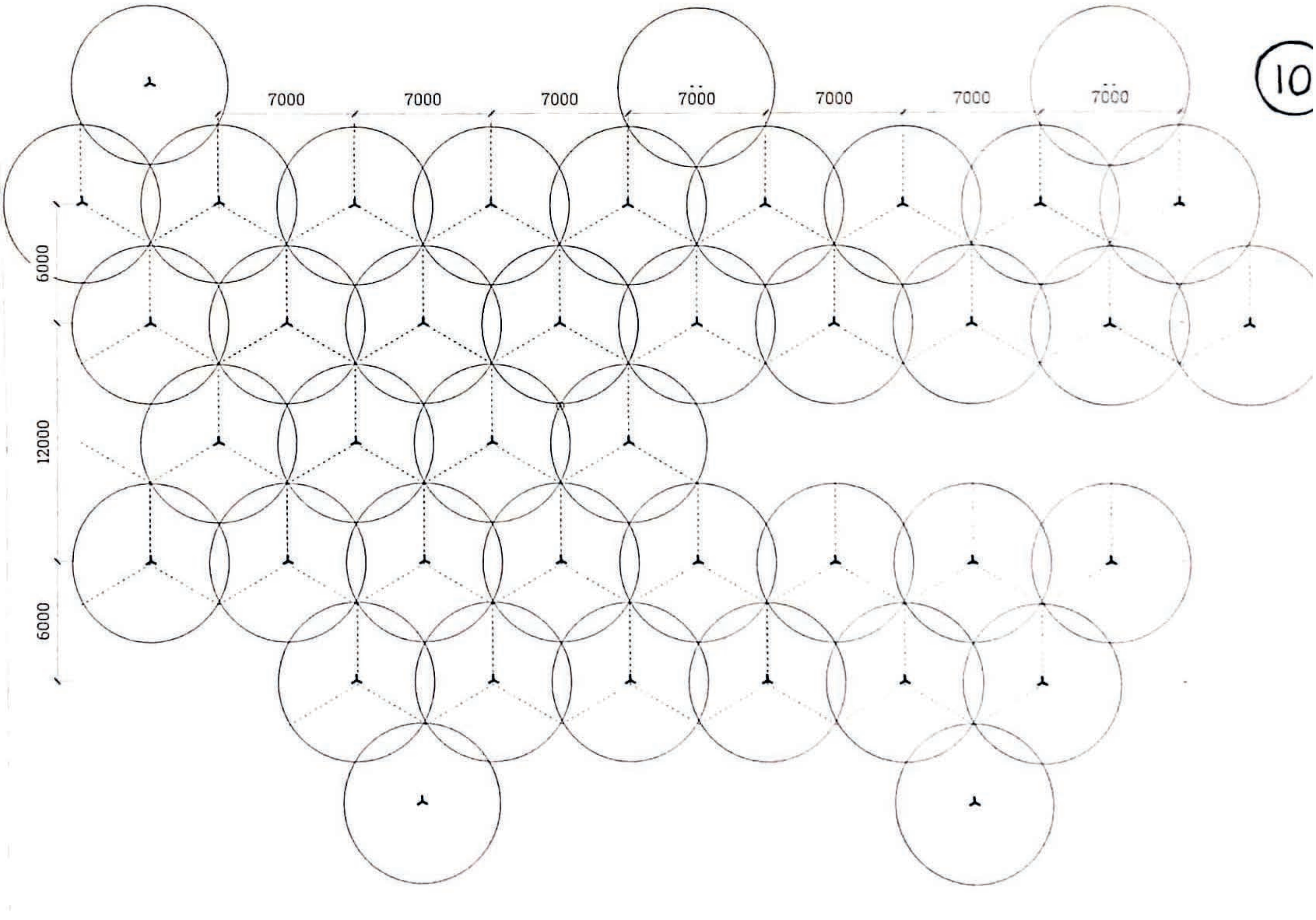
CROSS SECTION
(NORTH-SOUTH)
1:100



LONG SECTION
(EAST-WEST)
1:100



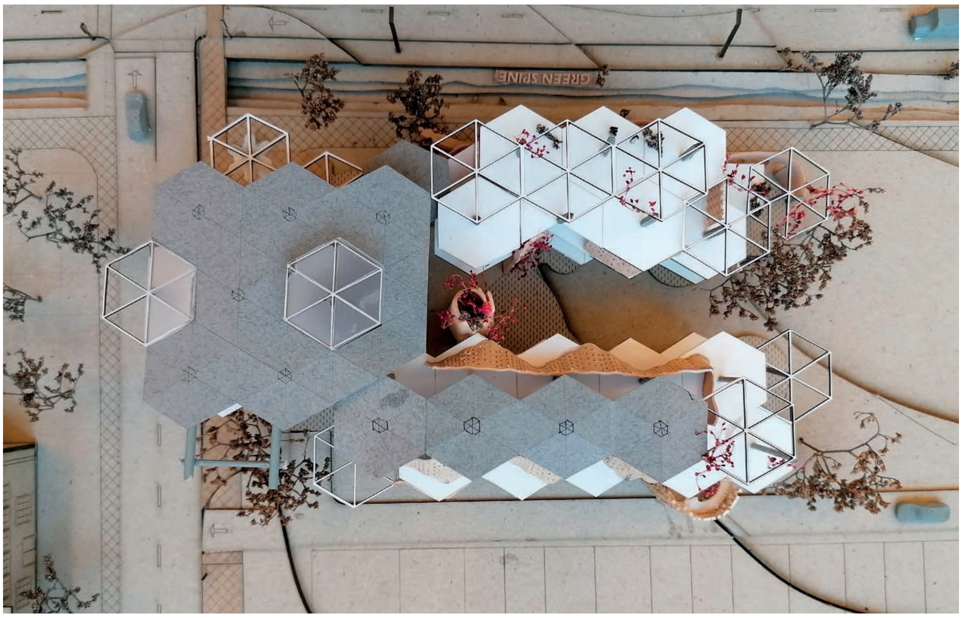
2
OFFICES
4
PUBLIC WC
SHOPS
SIDE WALK
NORTH FACADE
STRIP SECTION
1 : 25

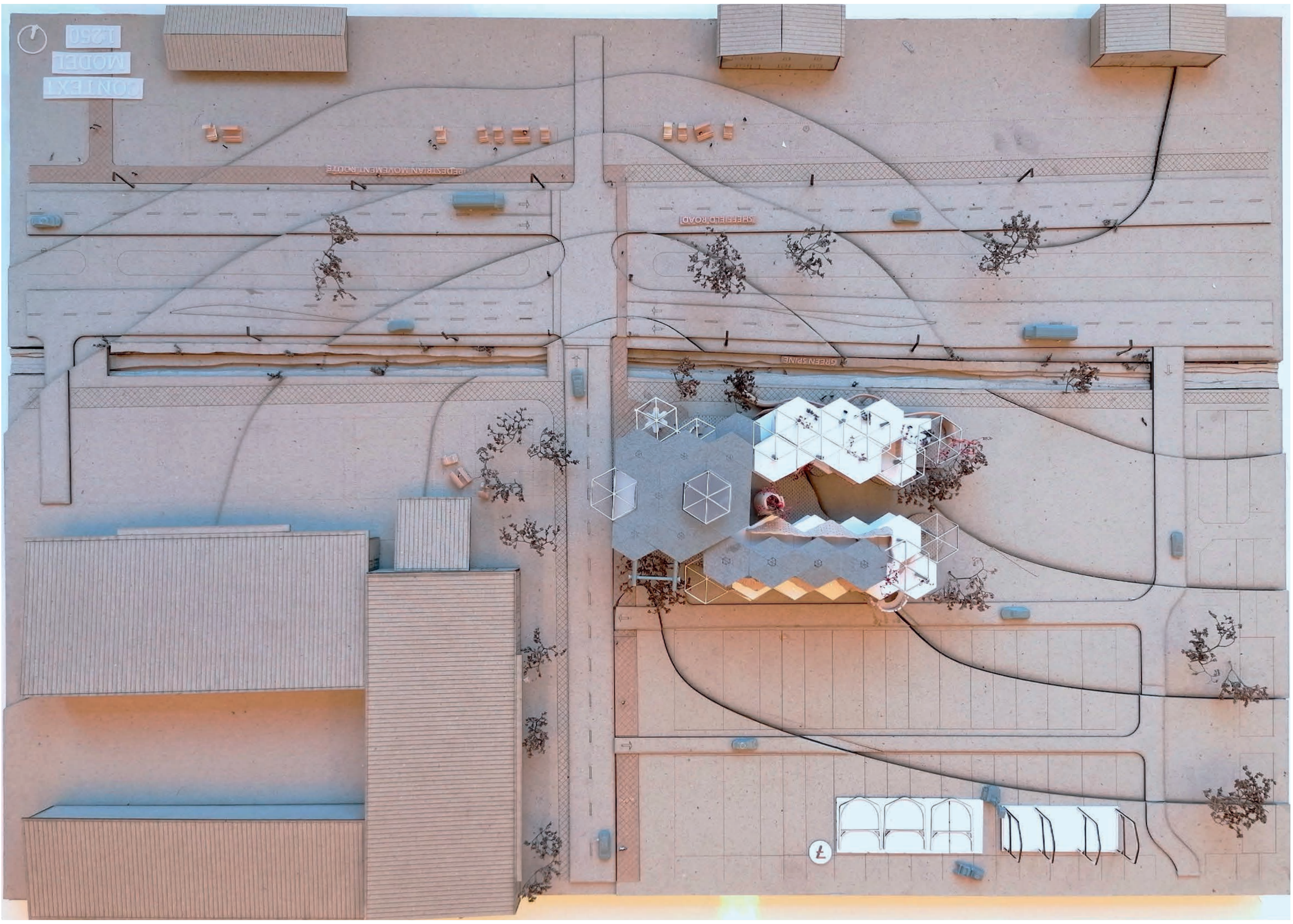


STRUCTURAL GRID
+ PRINTABLE AREA

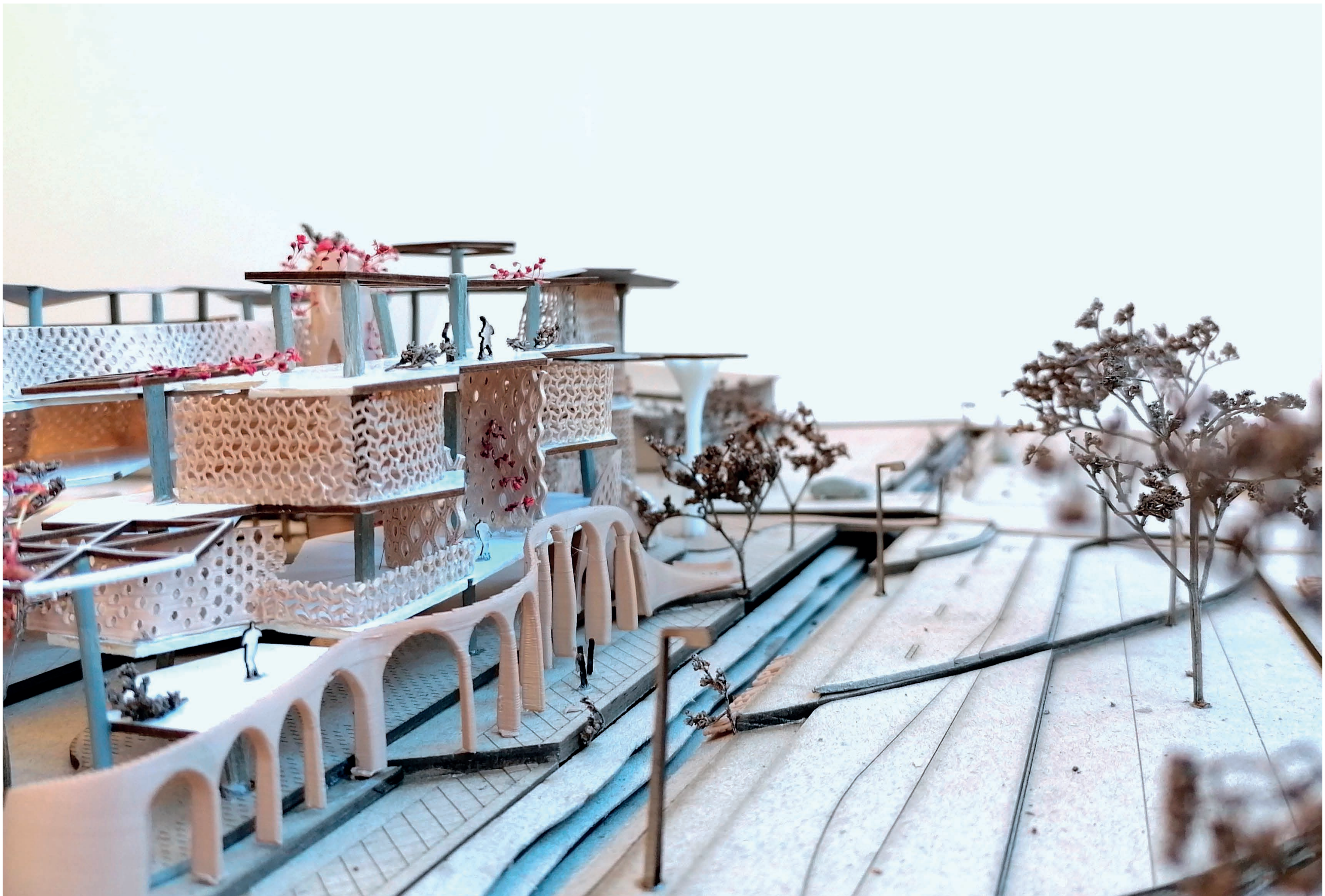
1:200

Final Model
1 : 250

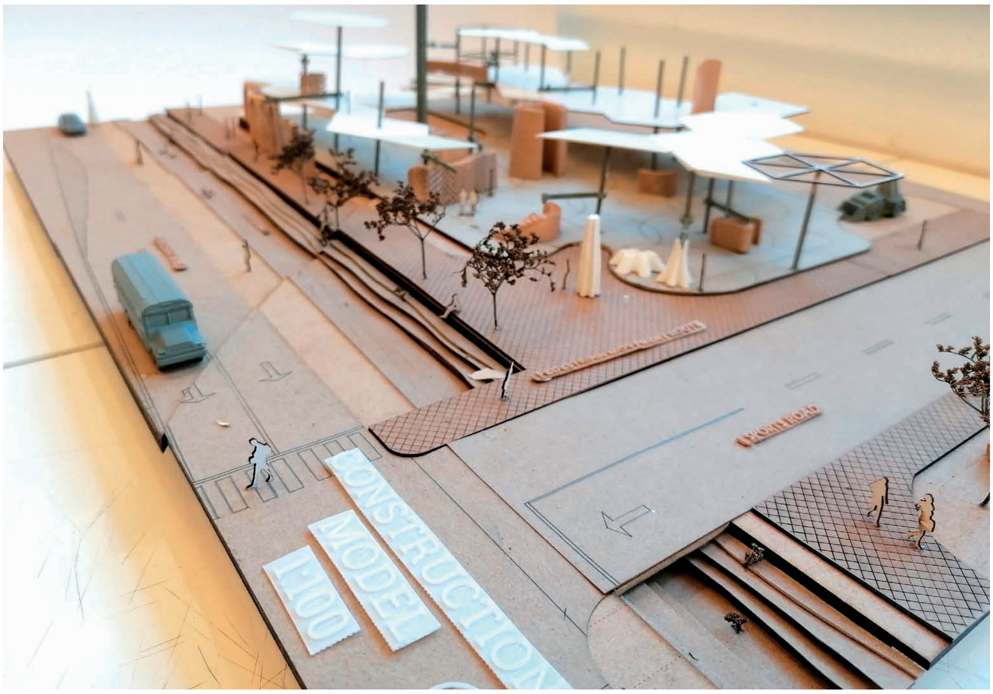


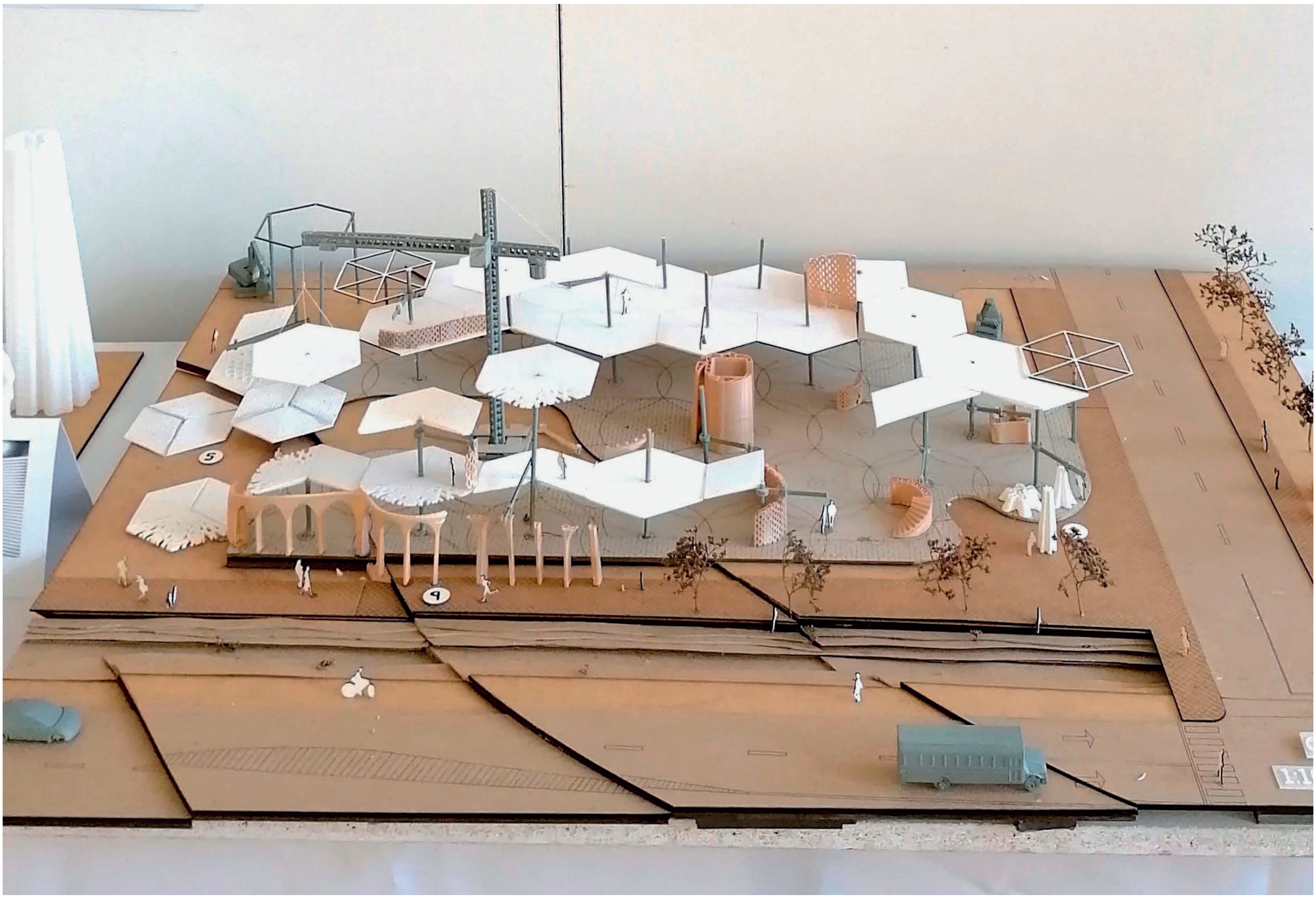


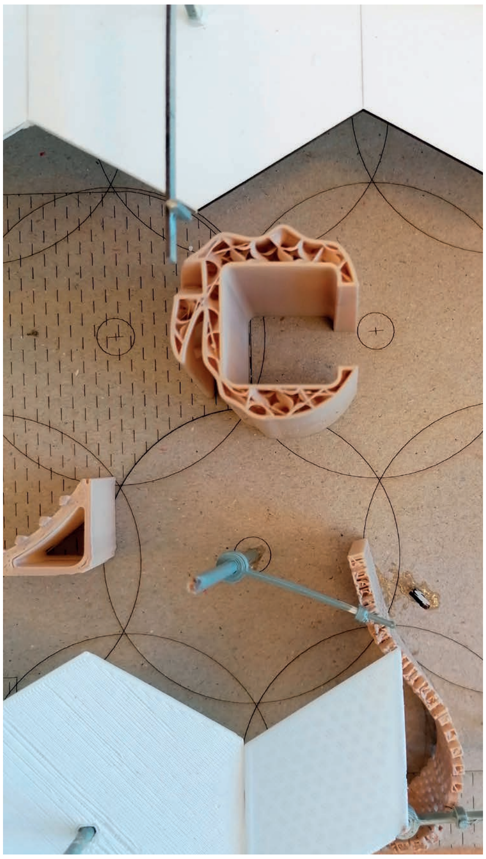

CONTEXT
MODEL

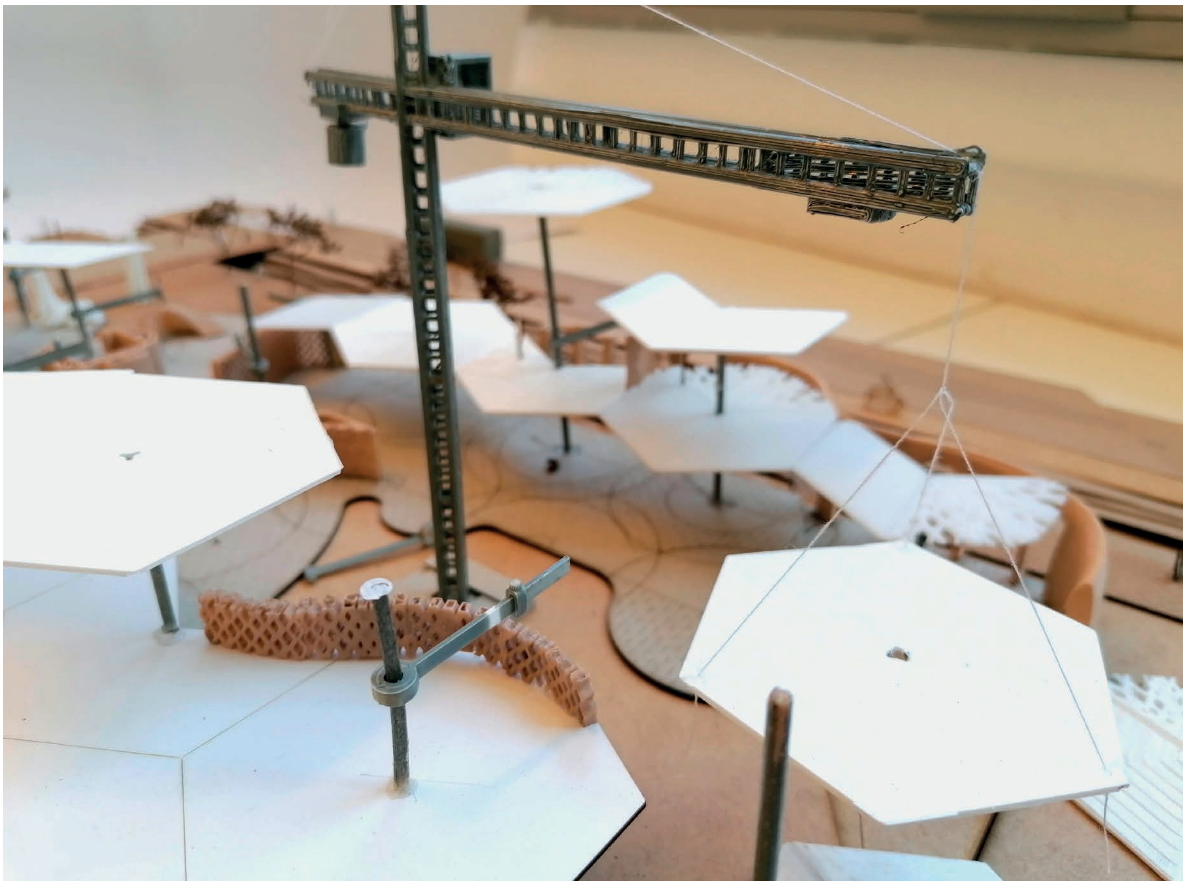


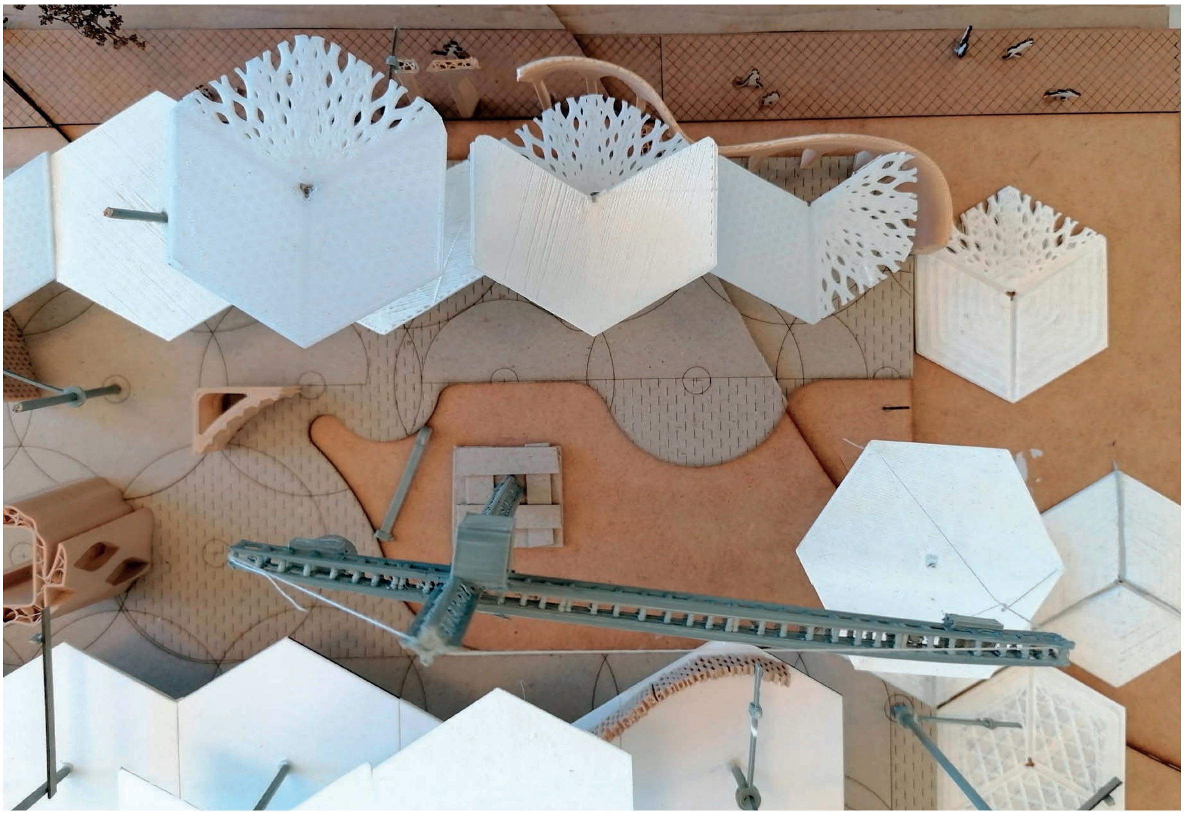
Final construction model 1 : 100

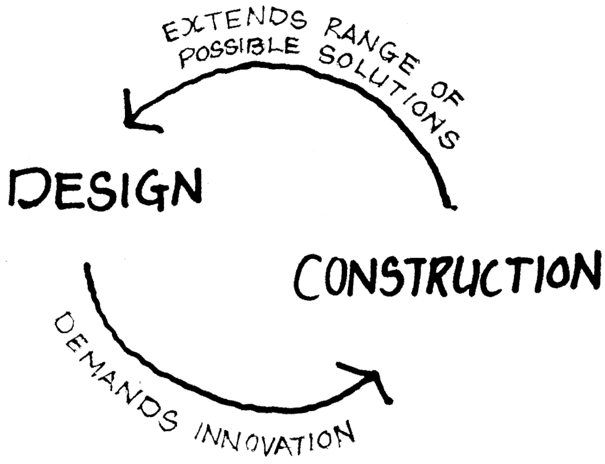












First and foremost, the dissertation aims to emphasize the connection between methods and materials of construction and architectural design. How construction leads to design and design can lead to construction. The restrictions of construction methods influence architects' designs and they must therefore continually update their construction knowledge and design process as new technologies are introduced to extend the range of design solutions available to them. Thus, **the project sets out to understand what this design-construction feedback loop looks like for 3D printing construction**, one of the most recent additions to the industry. It investigates the potential and limitations of the technology in the local context and how the new capabilities of the technology influence the language of the architecture it produces. What forms and aesthetics are inherent within, and generated by this drastically different construction method?

Secondly, the work aims to highlight **how architects can boost innovation in the construction industry through design.** Speculative designs of local projects that showcase the potential of 4th Industrial revolution (IR) technologies can accelerate the local development and adoption of modern methods. The new manufacturing technologies promise great potential in the South African context as they are more sustainable and effective.

The research is done within the context of a struggling economy in the developing city node of Philippi, Cape Town. The value and implications of introducing a revolutionary technology like 3D Printing in a place like Philippi are investigated through the design of a Technical and Vocational Education and Training (TVET) college. The college's main role is to educate and promote the use of 3D printing and other 4th IR manufacturing technologies. **The school building, workshops and public facilities are not only built using 3D printing construction but also train local workers in the craft to give them useful and modern skills** that will soon be in high demand as the technology of the future matures to become a mainstream fabrication method internationally and in South Africa.

The 3D printing skills gained at the college are directly transferable into other industries like furniture and home ware design and provide the opportunity for emerging manufacturers to build a business around it. **The value the technology holds for Philippi lies in its versatility and efficiency. It enables unskilled making on all scales, with a range of materials at a cost and time-effective rate.**