UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

CITY CIRCULAR

Circularity-based architectural model as agent of regenerative design and cultural-economic resilience

Brentan Gouws
MArch [Prof] 2021
University of Pretoria

DECLARATION

In accordance with Regulation 4[c] of the General Regulations [G.57] for dissertations and theses, I declare that this dissertation, which I hereby submit for the degree Master of Architecture [Professional] at the University of Pretoria, is my own work and has not previously been submitted by me for a degree at this or any other tertiary institution.

I further state that no part of my dissertation has already been, or is currently being, submitted for any such degree, diploma or other qualification.

I further declare that this dissertation is substantially my own work. Where reference is made to the works of others, the extent to which the work has been used is indicated and fully acknowledged in the text and list of references.

Brentan Gouws

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

Department of Architecture,
Faculty of Engineering, the Built Environment and Information Technology,
University of Pretoria, 2021

Course Coordinator: Dr. Arthur Barker
Supervisor: Dr. Calayde Davey
Co-Supervisor: Dr. Carin Combrinck

ACKNOWLEDGEMENTS

To Calayde. Thank you for your limitless wisdom, guidance, and support through this journey.

To all my friends, family, and loved ones. Your support, love, and encouragement means the world.

A special thank you to Daniel, Kerryn, Alexia, Yosh, Alex and Dale. When times were tough, your friendship and support could always be counted on.

Finally, to Leandri. You constant and endless love and support is what carried me through.

This is for all of you.

PROJECT SUMMARY

Author: Brentan Gouws
Study Leader: Dr. Calayde Davey
Co-Supervisor: Dr. Carin Combrinck
Course Coordinator: Dr. Arthur Barker
Research Field: Unit for Urban Citizenship

Clients:

- Southern African Biogas Industry Association (SABIA)
- Bio2Watt
- City of Tshwane
- The Department of Agriculture, Forestry and Fisheries (DAFF)
- Tilapia Aquaculture Association of South Africa (TAASA)

Site Description:

Pienaars River Buffer Zone and Tributary Boundary between Mamelodi East&West
Zoning - Public Open Space
Coordinates:
25°42'30.70 S, 28°22'19.00 E

Programme:

Primary: Closed-Loop Resource Production Facility (Biogas and Aquaponics)
Secondary: Education and Skill Development Facility (extension of Tsako Thabo High School)
Tertiary: Didactic Social Infrastructure (Productive Agricultural Landscape, Flood Protection, Ecological Corridor and Promenade)

Key Words:
Circularity, closed resource-loops, resilience, urban metabolism, anaerobic digestion, aquaponics, waste streams

Architectural Theoretical Premise:
Circularity, with its multi-scalar, regenerative, resilient, and urban metabolic foundation, is the spatial driver that manifests in an architectural response that acts as agent of regeneration and cultural-economic resilience.

Architectural Approach:
Using the theory of circular economics as a spatial driver to manifest in a regenerative architectural spatial model that facilitates the closing of resource loops to aid in the improved resilience and quality of life of a community.

SOUTH AFRICA

GAUTENG

CITY OF TSHWANE

ABSTRACT

The current spatial models and construction practices of architecture and city-making have a violent appetite. Linear resource consumption patterns, coupled with a rapidly increasing urban population, has pushed the planet to its ecological boundary. Although spatial designers have made massive leaps in the performance and energy efficiency of the interventions they design and construct, being "less bad" on the environment is simply not good enough. We need a radical change in the way we design and construct our cities to change the current trajectory of the urban environment. We need a new spatial model, a model that is built on regenerative principles to counteract the historical linear model of consumption and waste.

This dissertation investigates circular economics as a possible answer to the linear model of resource consumption. With the elimination of waste and the closing of resource loops at the core of circular thinking, circularity within design manifests as a "whole-system-thinking" response, a response that has been compared to that of a human metabolism. In the spatial design discourse, Urban Metabolism has been very helpful to understand and unpack the interplay between various resource flows and systems within the urban environment. Using circularity and urban metabolic thinking, we can identify systems and resource flows that can be closed through a design response. Closed-looped resources systems aid in the regeneration of our natural environment and lead to resilience with the urban community.

Mamelodi, a community plagued with vulnerability due to past injustices and current spatial isolation from economic opportunity, requires intervention to break the cycle of poverty and aid in developing cultural economic resilience. This dissertation, through the lens of circularity and urban metabolic thinking, identifies untapped resources within the community of Mamelodi that can lead to cultural-economic resilience. The programme, a closed-loop resource production facility, along with complimentary programmes of education and skills development facility, facilitates upward mobility within the community to aid in breaking the cycle of poverty. To counteract the linear model of consumption within South African construction practices, this dissertation adopts a prefabricated mass timber construction methodology. In combination with the carbon sequestering properties of mass timber, this dissertation utilizes low embodied carbon construction methods, such as locally manufactured adobe brick, to develop a regenerative spatial model.

CONTENTS

PART 1

Understanding

PART 2

Identifying

PART 3

Manifesting

PART 4

Constructing

PART 5

Reflecting

LIST OF FIGURES

PART 1

Understanding

PART 2

Identifying

PART 3

Manifesting

PART 4

Constructing

PART 5

Reflecting

PART 1

UNDERSTANDING

The purpose of Part 1 is to introduce the dissertation's issues, the research problem and the research questions, as well as to demonstrate an understanding of the theoretical premise and principles of the relevant theories:

Circular Economics in the Built Environment
Regenerative Design Strategies
Urban Cultural-Economic Resilience

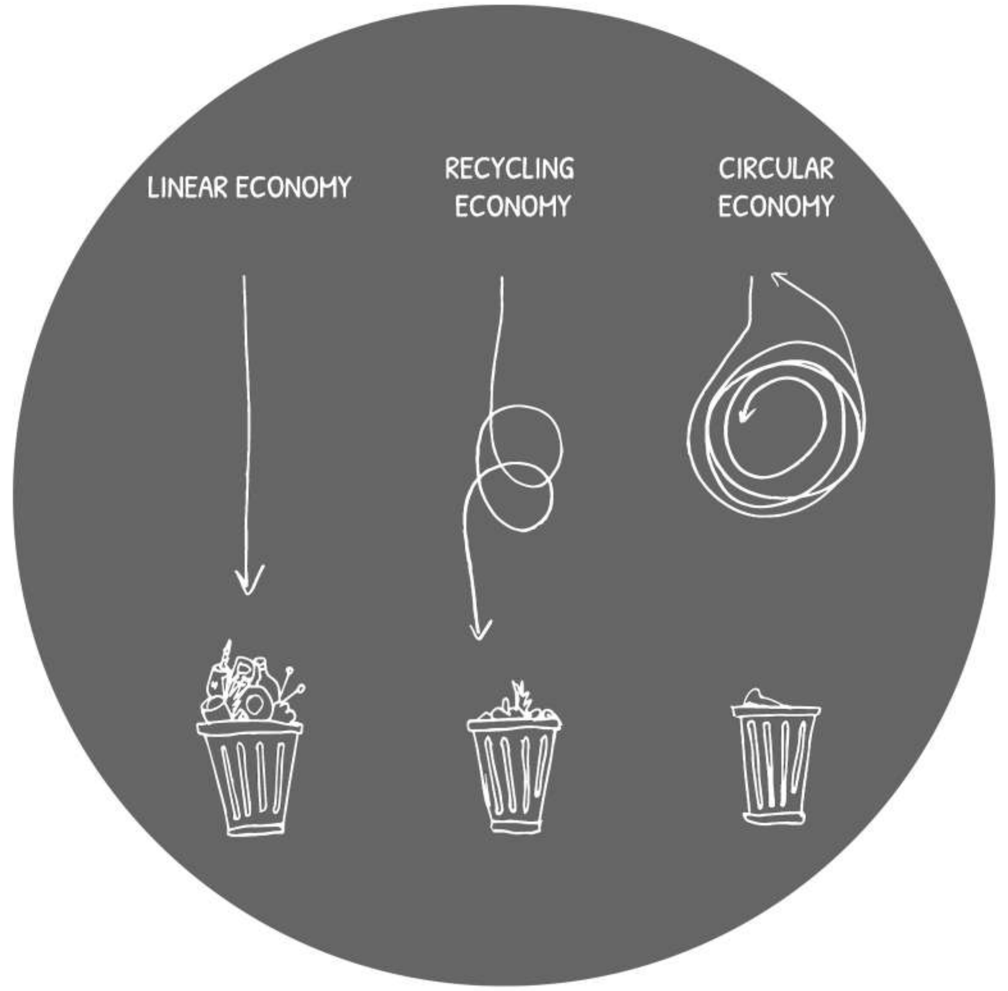


Figure 1.1: The Circular Economy (Zero Waste Scotland 2021)

TERMINOLOGY

CIRCULAR ECONOMY
An economic model that aims to decouple economic growth from the consumption of exhaustible resources (Ellen MacArthur Foundation 2013).

RESILIENCE
The capability of individuals, social groups, or social-ecological systems including towns and cities not only to live with changes, disturbances, adversities or disasters but also to adapt, innovate and transform into new more desirable configurations (Harrison et al. 2014).

QUALITY OF LIFE
A multi-dimensional concept that objectively and subjectively assesses the conditions of life. The domains include housing, safety and security, health, infrastructure, transportation, ICT, work opportunities, education, services such as water, energy, environment, green spaces, and air quality (City of Tshwane 2013: 15)

WHOLE-SYSTEMS-THINKING
The recognition that the entirety of existence is interconnected — environmental, cultural, and socio-economic systems, as well as the forces behind their actions.

URBAN METABOLISM
The sum total of the technical , socio-economic, and ecological processes and systems that occur in cities, resulting in growth, production of energy, and elimination of waste.

DESIGNING FOR DISASSEMBLY
To design objects from components and materials whose connections can be reversible after usage, without causing damage to the original components or materials (3XN 2019: 34).

WASTE MATERIAL
A discarded material or product not fulfilling its potential value and function. An untapped resource (Lendagar Group 2018: 43).

UPCYCLE
To recover or reuse a waste material by making it a new resource, but using innovation to create a product that increases in value or outperforms its original benchmark (Lendagar Group 2018: 43).

CASCADING
The idea of prolonging a material's life and value for as long or as many times as possible. To exploit the inherent potential and value of any material, before we let it go to waste (Lendagar Group 2018: 43).

INTRODUCTION

On December 12th, 2015, the world took a major leap forward towards combating climate change as world leaders signed the Paris Agreement. The primary goals of the agreement are to 1) limit global temperature rise to 1.5°C by 2030 (compared to 2010 levels), and 2) to achieve carbon neutrality by 2050. However, in February 2021, more than five years after the agreement was signed, UN Secretary-General Antonio Guterres issued a "Red Alert" for our planet. The "Red Alert" stated that governments are "nowhere close" to the degree of ambition needed to meet the goals of the Paris Agreement or the UN's Sustainable Development Goals (United Nations FCCC 2021, United Nations 2021). The planet's current state of "Red Alert" is primarily due to a linear economic model, commonly referred to as the "Take-Make-Waste-Dispose" model. This linear model is characterised by the extraction of natural resources which, after the manufacturing of products or materials, are disposed of as waste with very little to no recycling of the resources.

Within the built environment, the linear model has also been adopted. This is particularly evident in the construction process. The conventional construction methodology contributes to massive amounts of environmental degradation and biodiversity loss due to the raw material extraction process to develop building materials (Aboginije, Aigbavboa and Thwala 2020). With a large proportion of building materials ending up at landfills as C&D waste after their life-cycle, a clear, linear model emerges. With the built environment following this linear practice, we are generating tremendous systemic pressure and stress on the habitats we inhabit. To counteract this, various systems and strategies such as LEED and BREEAM have been developed to encourage sustainable architectural development and practices. Yet, globally, this is not enough.

As recent as 2019, publications and reports indicate that the built environment is still globally responsible for 40% of virgin material extraction, 40% of solid waste streams and 30% of greenhouse gas emissions (ESI, Africa 2019). In addition, data from Dixon, Eames, Hunt, and Lannon (2014) suggest that the projected increase in urban population, from 55% in 2018 to 68% in 2050, will likely exacerbate the climate change and resource depletion patterns. Although the architectural and urban planning discourse has seen great advances in the field of sustainability, the term "sustainable" has become so vague that it includes any attempt made by the designer to create an architectural response that is "less bad" on the environment (Lendager Group 2018). A design and construction paradigm shift is needed that goes beyond the "less bad" approach but instead fundamentally change the trajectory of built environment design practices for the long-term outcomes that matter.

Our current practice in city-making and economic systems have been exposed as flawed in supporting people for the long-run. We need to find alternatives to counteract the various pressures faced by the urban realm, while building resiliency in our communities. Our cities and the processes and rituals that occur in cities need to switch to a model that goes beyond sustainable — a model that is restorative and regenerative. We need a model that builds reciprocal and mutually symbiotic relationships with the ecosystems from which it draw resources (Novakovic 2020). Instead of designing along the lines of a linear-thinking model, cities need to adopt a circular model where the inputs and outputs of the metabolic processes of our cities are recycled. This means we need new kinds of reconfigurations in space and design, where the outputs of one system become the inputs of another system (Amulya et al. 2020, Mahmoud 2017). This dissertation investigated this new circular economic model and how it could be implemented within the built environment to produce spatial solutions that are agents of regeneration and urban cultural-economic resilience.

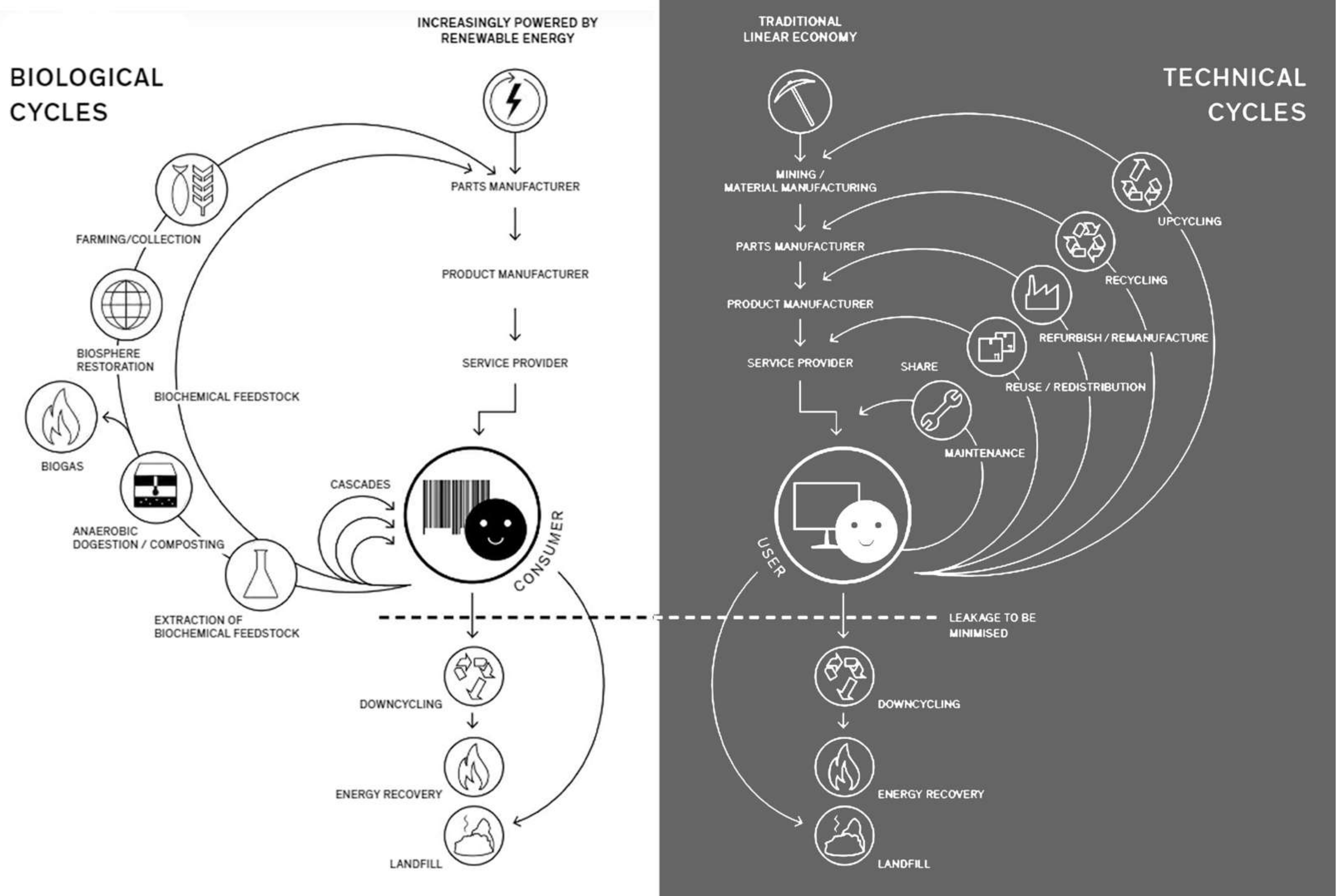


Figure 1.2: Biological and Technical Cycles (Lendager Group 2018)

GLOBAL ISSUE

The Circularity Gap: Ending the "Take-Make-Waste-Dispose era

Current urban development analysis and strategies still largely represents a largely linear flow of resources with a large amount of waste produced. However, it is possible to produce architecture on circular principles. For example, the architectural theory and research done by Bill Reed and Pamela Mang in the article: Shifting our Mental Model – "Sustainability" to Regeneration and Regenerative Development and Design, describes a possible paradigm shift for architecture to move from a linear to a circular model (Mang and Reed 2013). Mang and Reed argue that although sustainable architectural design may already incorporate a systems-thinking approach, these systems are typically understood as "open systems" — systems that need continuous input — as opposed to "closed systems" — systems that do not need external input. Open systems require a continuous input of energy and resources in order to be sustained (Mang and Reed 2013). This is a critical point where conventional sustainable design falls short. The very notion of requiring a continuous input of resources directly contrasts the definition of sustainability. Open entropic systems, however efficient and intelligent the technology that govern them, represents linear systems and will inevitably lead to further degradation of the environment. In addition to counteracting the flaw in conventional sustainable design practices, we also need to account for the dramatic increase in human population in urban environments (Dixon, Eames, Hunt and Lannon 2014). The shift from a linear model to a circular model shows promise in the right direction.

The alternative theory and approach of a Circular Economy (CE) based spatial-model as a resilient and regenerative design solution for the current "take-make-waste-dispose" linear economic model is showing promise to change our urban trajectories towards greater restorative and regenerative outcomes (Jaca, Ormazabal and Prieto-Sandoval, 2018). This alternative theory and approach of circularity-based design includes the theories of resilient and regenerative design, which are based on "Whole-Systems-Thinking" (Reed 2007). Whole-Systems-Thinking recognizes that the entirety of existence is interconnected — natural systems, human socio-economic systems, and the forces behind their actions. A CE is defined by the Ellen MacArthur Foundation (2013) as an economic model that aims to decouple economic growth from the consumption of exhaustible resources. CE represents a paradigm shift towards a triple-bottom-line (people, planet, profit) approach, with the goal of establishing sustainable and resilient economic growth whilst providing social and environmental benefits (Ellen MacArthur Foundation 2013).

Figure 1.3: The Circular Gap (Circle Economy 2018) - edited by Author (2021)

URBAN ISSUE

The Struggle for Urban Resilience:
Overcoming the scars of the past, creating a model for the future

Both globally and locally, cities and urban populations face a wide range of challenges. The current linear economic model has produced various man-made systemic pressures such as climate change, environmental degradation and biodiversity loss. Together with the man-made pressures, natural pressures and the risk of natural hazards and pandemics, as well as rapid and sustained urbanisation and population growth, lead to cities that are in a state of vulnerability and that are struggling to adapt and thrive within current conditions (ARUP 2016).

Mamelodi, the study area, is an example of a region within this state of vulnerability. Together with the various man-made and natural pressures of the present, Mamelodi is struggling to overcome the spatial legacy of the Apartheid planning scheme of the past. Mamelodi is isolated geographically and systemically from socio-economic nodes and opportunities, resulting in a fragmented and disconnected urban fabric, and a state of near-complete dependence on external systems and resources (Levy 2020). This isolation and state of dependence has created a burden on the livelihoods of the community, placing them in a state of decreased quality of life and in a high degree of risk and vulnerability to system shocks. This state of vulnerability manifests as a disruption in the ability of Mamelodi to achieve urban resilience.

To counteract the systemic pressures and to mitigate the ever increasing risks, theories in natural and social resilience seem to be offering some hope of alternative and thriving futures. Resilience theory is a particularly important strategy for deployment in vulnerable urban systems (ARUP 2016). Resilience, as defined by Harrison et al., refers to the "capability of individuals, social groups, or social-ecological systems including towns and cities not only to live with changes, disturbances, adversities or disasters but also to adapt, innovate and transform into new more desirable configurations" (Harrison et al. 2014). Therefore, the approach of a circular economic spatial-model, driven by resilience theory, is a relevant avenue of investigation as an agent towards improving cultural-economic resilience in both the current and future conditions of Mamelodi.

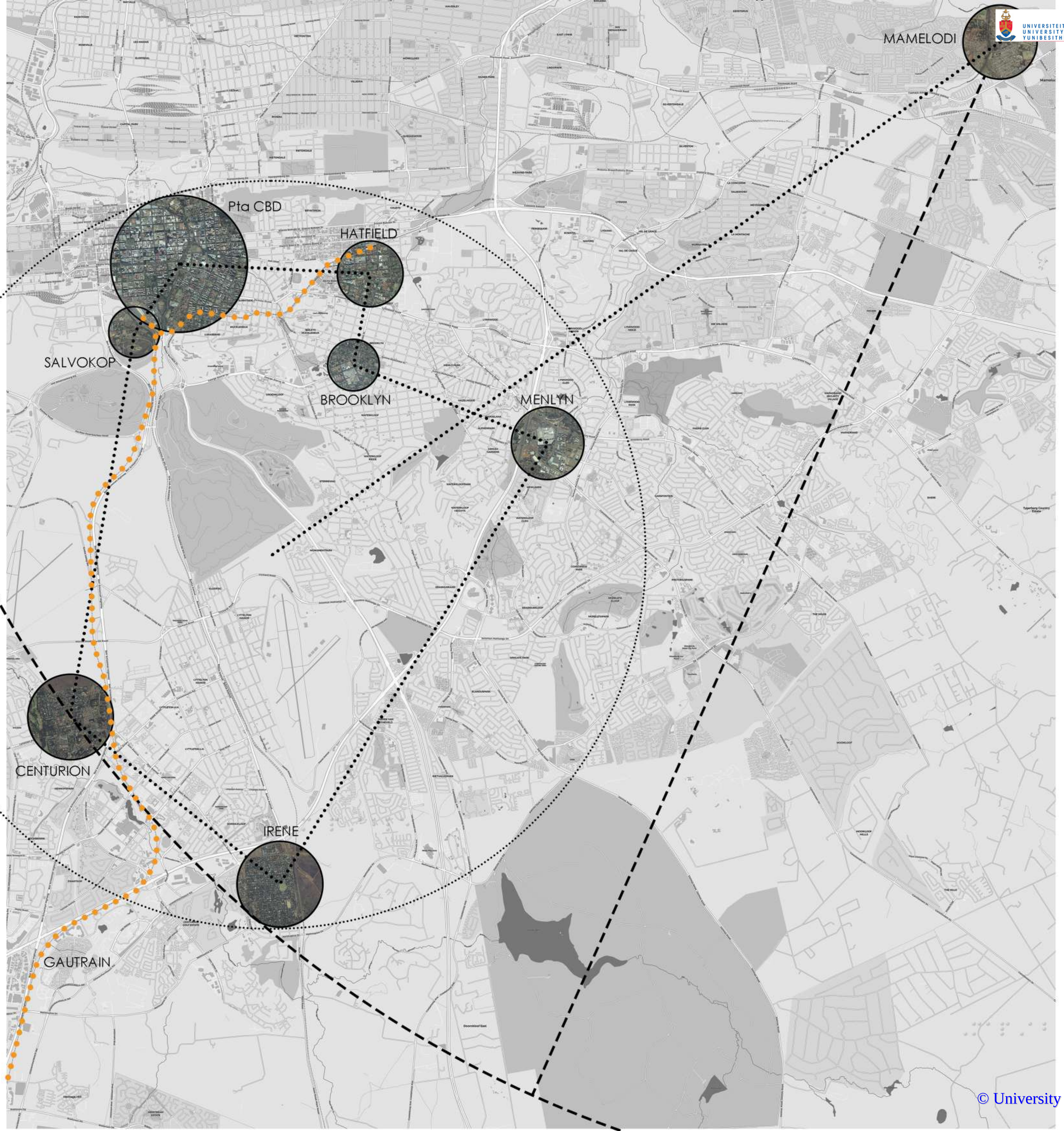


Figure 1.4: Mamelodi removed (Author 2021)

ARCHITECTURAL ISSUE

Barriers in the way of Neutrality:
The need for a new regenerative architecture and construction methodology in the South African built environment

The way we currently design, construct, and operate building has led cities to consume nearly 75% of the world's energy (King 2017). Cities are also responsible for a similar percentage of the global carbon emissions. As previously mentioned, urban population is predicted to increase from 55% in 2018 to 68% in 2050 (Dixon, Eames, Hunt and Lannon 2014). This increase in urban population will only exacerbate the energy consumption and global carbon emission patterns of cities. We need to fundamentally change the trajectory of the built environment through a new architecture and construction methodology – and we need it immediately.

This is where the conversation about carbon within architecture and construction and the target of carbon neutrality by 2050 becomes important. There have been great leaps made in the performance of buildings being designed and constructed today. Although many newly designed and constructed buildings are being classified as carbon neutral, with some even being classified as carbon-positive, the classification only refers to the operation carbon of the building and does not include the embodied carbon of the construction materials with their associated manufacturing process (King 2017). Operational carbon accounts for 80% of the total energy consumption of a building over its life-span, therefore it is understandable that the sustainability movement has placed focused its efforts on eliminating the operation carbon of the built environment (McDade 2017). However, if we want to reach the target of carbon-neutrality by 2050 as set out within the Paris Agreement, the 20% embodied carbon cannot be ignored. Furthemore, as stated by Erin McDadade (2017) in "The New Carbon Architecture", new research demonstrates that the significance of embodied carbon emissions has been greatly underestimated.

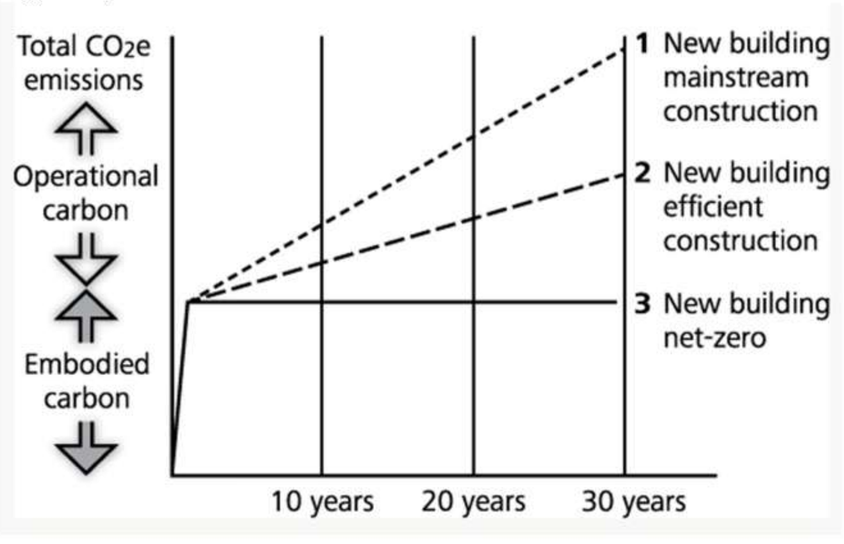


Figure 1.5: Embodied Carbon in Buildings (King 2017)

The argument is made that for a building to be classified as truly carbon-neural, total neutrality – both embodied and operational carbon – need to be demonstrated (De Wolf, Rodriguez-Droguett and Simonen 2017). The total embodied carbon of a building is typically evaluated by conducting a Life Cycle Assessment (LCA). A LCA is conducted by integrating the data about the entire life-cycle of a building and the data about the carbon emissions of each process throughout the process-chain (ibid).

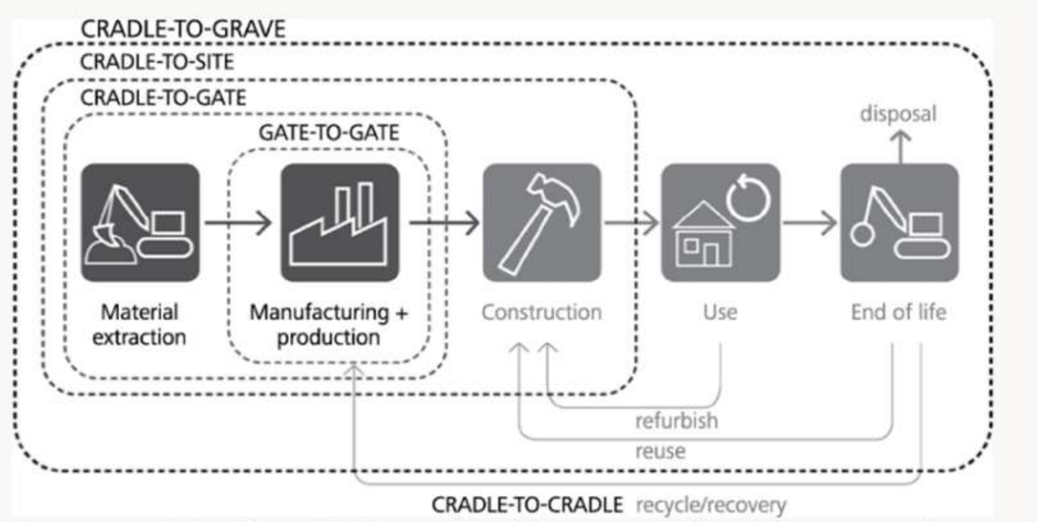


Figure 1.6: Building Life-Cycles (De Wolf, Rodriguez-Droguett and Simonen 2017)

So where in the process-chain is all the embodied carbon? It has been calculated that up to 80% of the embodied carbon in buildings lies within the materials we construct them with (Strain 2017). Catherine De Wolf, in "Low Carbon Pathways for Structural Design: Embodied Life Cycle Impacts of Building Structures" (2017), compares the embodied carbon (kgCO2e/m²) for different structural materials, showing that concrete and steel containing a great amount of embodied carbon as compared to timber.

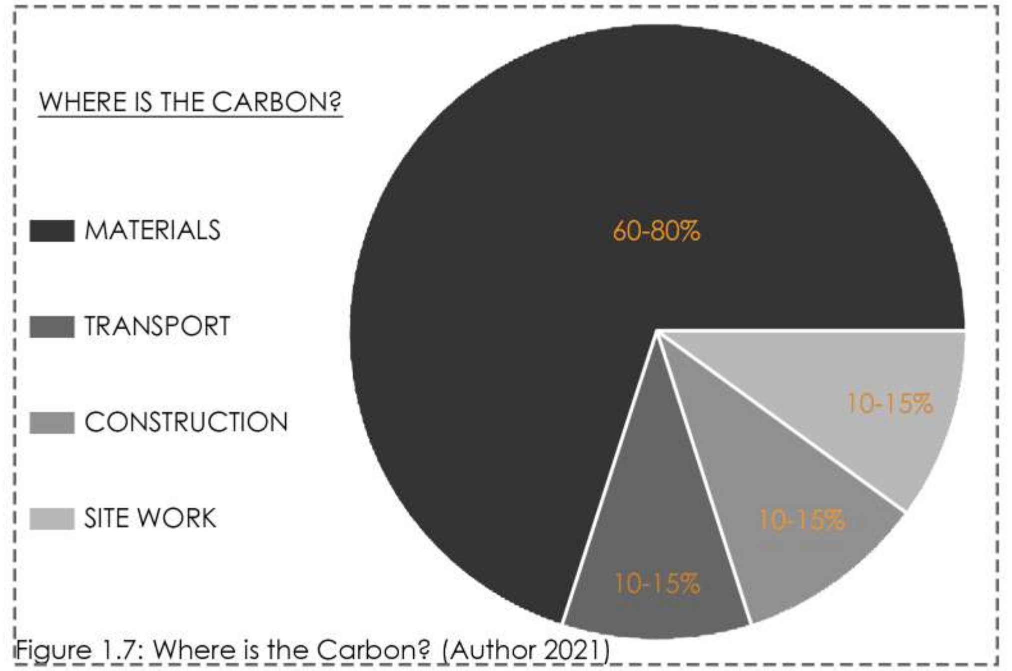


Figure 1.7: Where is the Carbon? (Author 2021)

"If our remarkable success in high performance design continues, embodied carbon may well prove to be our downfall – or the key to solving climate change. It's up to us to decide."

Strain (2017) demonstrates that the most effective strategy to reduce embodied carbon emissions is to not build any more new buildings, but to rather retrofit, renovate, and reuse existing buildings and waste materials. This strategy allows for no additional embodied carbon to be emitted. However, with the projected rapid increase of urban population, this strategy will simply not be possible. Therefore, if we have to build new buildings, how can we design and construct those buildings to achieve total carbon neutrality? The answer may lie within the carbon sequestering potential of timber (Lawrence and Yang 2017). A study done by ARUP, comparing the carbon emissions between timber design and concrete design over the life cycle of structural materials in a twelve-story tower, confirmed the sequestration potential of using timber as the structural material as opposed to steel or concrete to reduce carbon emissions (King 2017). A further in-depth study on timber and its benefits as a structural material is conducted in the theoretical framework and technical resolution section within this dissertation.

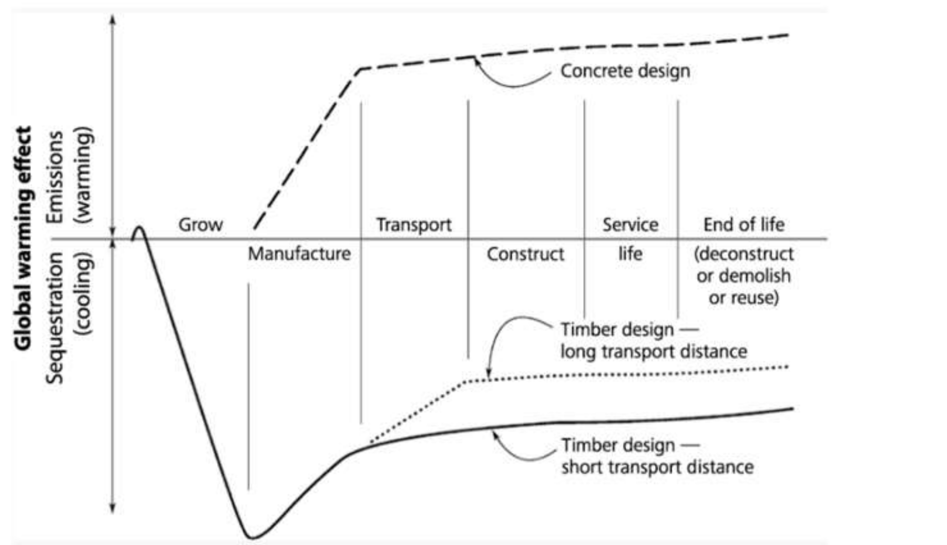


Figure 1.8: Mass Timber vs Concrete (Lawrence and Yang 2017)

So how is the South African built environment measuring up it terms of achieving total carbon neutrality by 2050? Firstly, the structural material palette within South African architecture and construction practices predominantly consists of concrete, steel, and masonry. This is concern number 1, as we now know the high levels of embodied carbon within these materials. Secondly, a report on construction and demolition (C&D) waste management practices within South African revealed the second concern; waste. The report revealed that an estimate of 15% of materials arriving at a construction site will end up as waste at landfills, whilst at a demolition site it is estimated that between 80-100% of materials will end up as waste at landfills. Furthemore, the report revealed that approximately 90% of C&D waste found at landfill are easily recyclable, however, in 2011 only 10% of all C&D waste was recycled (Aboginije, Aigbavboa and Thwala 2020).

If the South African built environment is going to play its part is combating climate change and working towards total carbon neutrality by 2050, we need to radically change the conventional architecture and construction methodology. Seeing as the core principle of circular economic theory is "Designing out Waste" – a methodology of minimizing/eliminating waste out of a system – this dissertation proposes a new architecture and construction methodology based on the principles of circularity. This dissertation proposes that combining the principles of circularity with the carbon sequestering and regenerative principles of timber construction will aid in the South African built environment achieving the target of total carbon neutrality by 2050.

PROBLEM STATEMENT

RESEARCH PROBLEM

Within vulnerable urban contexts, plagued with socio-economic dependency, existential risk, vulnerability, decreased quality of life, and an inflexible urban fabric unable to adapt to changing conditions, conventional architectural and construction practices and interventions fail to be regenerative within their context and fail to manifest resilience in the community it serves.

RESEARCH QUESTIONS

Sub Questions are:

a) How can circular economic theory drive an architectural spatial model to develop a regenerative architectural response which aids in the resilience of urban community, contains a high degree of flexibility of programme and adaptability of space in order to future proof architectural interventions within changing conditions?

b) How can the scales or layers be identified to understand where circularity can be integrated within conventional architectural and construction practices?

c) How can architecture serve as a mediator between conventional design and construction practices and circular economic design principles? How does the theory and principles of circularity manifest architecturally and tectonically?

d) How can a circular economic theory drive architecture to facilitate the integration of conventional construction methods with local skills and building materials?

RESEARCH METHODOLOGY

Theoretical Framework

The dissertation is initiated through an establishment of a theoretical framework that defines and develops an understanding of circularity and its spatial conceptions and structures. The definition of circularity, as it pertains to city-making, is unpacked to gain a deeper understanding of the integrated theories such as urban metabolic theory, cyclical design strategies and resilience theory, and their application within architecture and the built environment. This was achieved through various sources of literature and case study analysis.

Study Area Analysis

The study area research and analysis was conducted through four methods: a) Field Work b) System Analysis, c) Waste-stream Analysis d) Secondary data analysis.

The aim of the study area analysis was to uncover the most appropriate programme and site selection.

a) Social-Cultural Systems Field Work - Various field work methods were conducted to uncover the essence of the study area and to identify the needs of the community. These methods include transect walks through the study area, analysing the community and its dynamics through unobtrusive observations, typology studies, and discussions with local community members, informally and through KOBO-Toolbox questionnaires, to better understand and uncover the invisible layers and interconnections between the community and the study.

b) Spatial-Economic Systems Analysis - This method included various desk-top mapping techniques and qualitative research to uncover the various spatial challenges and opportunities, as well as analyze and identify the various systems at play within the study area. This research was analyzed to investigate and identify how design interventions could potentially cause positive spatial change and either support or negate the various systems within the study area.

c) Waste-stream analysis - This method included the utilization of process-stream mapping and value-stream mapping to identify waste-streams within various physical and non-physical systems within the study area.

d) Secondary Data Analysis - Mamelodi, and the neighbourhoods adjacent to the Pienaars River buffer zone in particular, has been one of the study areas for the Unit for Urban Citizenship (UUC), led by Dr. Carin Combrinck, for the past few years. Secondary data from the 2019 and 2020 UUC may be analyzed in addition to any primary data collected.

The Mamelodi Portrait

Based on Kate Raworth's "Doughnut Economic Model", the Mamelodi Portrait represents the study area's socio-economic and ecological shortfalls towards achieving urban resilience. This instrument serves as a programmatic informant to inform relevant design decisions.

Ethics Protocol

This dissertation falls under the "blanket" ethics approval of the Unit for Urban Citizenship (UUC) research field. Due to the vulnerable nature of the community within the study area context, all ethics protocol considerations complies with the guidelines as set out by The Department of Architecture and EBIT Faculty.

Urban Circularity: A methodology towards regenerative design and cultural-economic resilience

Circular Economics within the architectural discourse – an integrated definition.

The concept of circular economics, in its early definition as an economic model that aims to decouple economic growth from the consumption of exhaustible resources, has predominantly been business focused. Only recently has circular economics further been explored to identify how circularity could create economic, social, and resilience in city making (De Meulder and Marin 2018). An updated definition by Pietro-Sandoval et al., as quoted by De Meulder and Marin (2018), expands on the definition of circular economic as it pertains to architectural design and planning discourse, stating that circular economics is "an economic system that represents a change of paradigm in the way that human society is interrelated with nature and aims to prevent the depletion of resources, close energy and materials loops, and facilitate sustainable and resilient development through its implementation at the micro (enterprises and consumers), meso (economic agents integrated in symbiosis) and macro (city, regions and governments) levels. Attaining this circular model requires cyclical and regenerative environmental innovations in the way society legislates, produces and consumes".

Unpacking the Definition

Unpacking the integrated definition of circular economics and its application towards creating a "circular city" - as a socially, environmentally, and economically resilient city - various themes emerge:

1) Closing Resource Loops – Designing out Waste

Arnsperger and Bourg (2016) argues that the primary focus of an authentic circular economy should be on the reduction of resource consumption on a systemic level. Reducing resource consumption through the principles of circularity works by designing waste out of a system. Waste can be understood as both physical and non-physical. In architectural and construction practices, physical waste can represents resource flows (that are in a linear cycle), and building materials that have reached the end of its life-cycle. Non-physical waste represents any activity/process that does not contribute direct value within a process-stream (Lean Built Environment - Afrika 2019).

Non-Physical Waste:

Identifying non-physical waste within a system is not always easy and requires some effort. To streamline the process of "waste-finding", The Lean Built Environment Afrika (LBE-Afrika), within their LEAN Starter Kit, describes ten forms of non-physical waste as it pertains to the built environment and construction practices:

Physical Waste

When we look at waste in physical terms, we can see the construction and demolition (C&D) system flows very clearly. An in-depth report on the C&D waste management practices within South Africa was conducted by Aboginije, Aigbavboa and Thwala (2020) and highlighted three crucial obstacles in the way of achieving circularity in conventional architectural and construction methodologies. First, the report revealed approximately 90% of C&D waste found at landfill are easily recyclable, however, in 2011 only 10% of all C&D waste was recycled. Second, the report revealed that an estimate of 15% of materials arriving at a construction site will end up as waste at landfills, whilst at a demolition site it is estimated that between 80-100% of materials will end up as waste at landfills (Aboginije, Aigbavboa and Thwala 2020). Lastly, the report revealed that within South Africa there is the perception that the implementation of an alternative waste management strategy is more expensive than discarding C&D at landfills (ibid).

In order to explain why the conventional architectural and construction practices result in a large amount of waste, the linearity of the life-cycle of conventional design practices needs to be understood. The life-cycle of buildings can be simplified into four phases (Tu Delft - edX 2021):

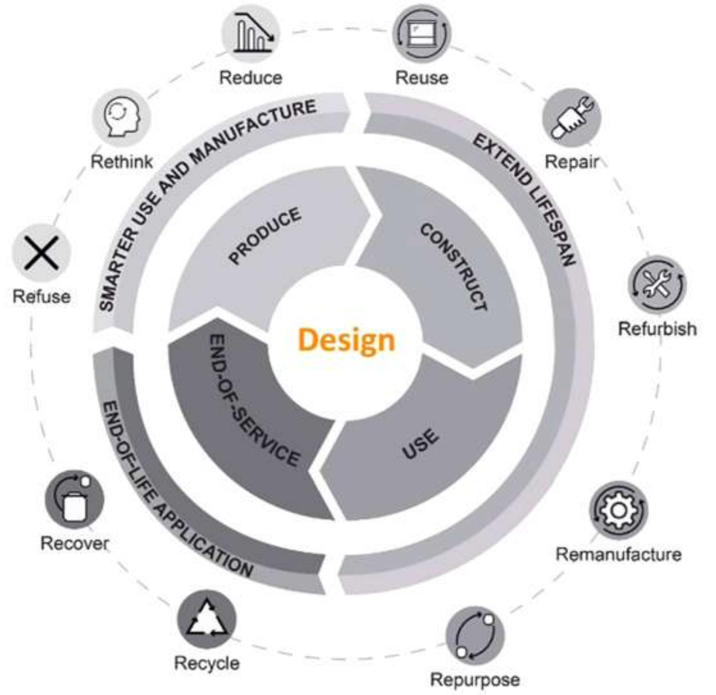


Figure 1.9: (left) Ten Non-Physical Waste Streams (The Noun Project 2021)
Figure 1.10: (above) Building Life-cycle phases (TU Delft - edX 2021)

i) Producte — this includes the extraction of virgin natural resources and the production processes to manufacture construction materials. This phase often requires a massive amount of energy input, leading to construction materials with a high level of embodied carbon (energy), resulting in an unsustainable methodology.

ii) Construct — this phase represents the construction and assemblage of building materials and components. Conventional construction practices utilizes permanently fixed methods of assembly, such as in-situ cast concrete and steel welding, resulting in a low level of flexibility and adaptability.

iii) Use — this phase represents the functional and programmatic use of the building.

iv) End-of-Service — this phase, within conventional design practices, represents the demolition of the building, resulting in a large amount of waste.

2) The Multi-Scalar nature of Circularity

Pomponi and Moncaster (2017) critiques current discourse on circular economic theory as it pertains to the implementation within the built environment, stating that the research does not fully take into account the complex multi-dimensionality nature of cities. Although the definition of the circular economy by Pietro-Sandoval et al. already recognizes the multi-scalar nature of circularity, Pomponi and Moncaster further expands there upon by demonstrating the scales as which circularity can be implemented within the built environment. The scales identified by Pomponi and Moncaster (ibid) is; (1) the macro scale – similar to Pietro-Sandoval, referring to the city, (2) the meso scale – referring to the building scale, and (3) the micro scale – referring to individual building elements. However, critique on the proposed scales of possible implementation of circularity in the built environment has led to a possible alternative scale for implementation. Cayuela, Miller, and Waldron (2013) states that at the meso scale (building scale) individual buildings are limited in its capacity to influence larger multi-dimensional systems and resource flows within cities. Boyle, Michell, and Viruly (2018) argues that at the macro scale (city scale) there is the potential that the fine grain nuances and complex interconnections between existing place-based communities being overlooked. Building on the above critique, the argument is made for implementing circularity between the meso and macro scale ie. at the neighbourhood scale. Implementation at the neighbourhood scale offers the advantage of being able to integrate the fine grain quality of existing communities whilst simultaneously being capable of fitting within a larger, complex, and multi-dimensional urban framework with its associated economic, social, and environmental systems and resource flows (Berg and Nycander 1997, Laprise, Pérez, Rey and Riera 2018).

3) Placed-Based, Systemic Resilience

Various sources of literature have aimed at framing or assessing urban resilience. The two main schools of thought have either focused on urban assets or urban systems (Arup 2016). Due to the interconnected nature of the tangible (ecological) and intangible (human, culture, social networks and knowledge) assets and their respective behaviours, the systems-based approach is more closely aligned with the concept of urban resilience (Perez 2016).

Building on the systems-based nature of urban resilience and the whole-systems-thinking quality of regenerative design (Reed 2007), the interplay and flows between these systems — which includes economic, social, cultural, and environmental systems — that feed cities are likened to the idea of a metabolism in the human body (Ulgiati and Zucaro 2019). In spatial design discourse, Urban Metabolism theory can be very helpful to unpack these interplays. An updated definition by Richard Kennedy and quoted by Gonzalez (Gonzalez et al. 2013), describes Urban Metabolism as the "sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste".

Phillip Vandenbroeck expands on the concept of an urban metabolism and developed a framework to define and organize the spatial practices of urban metabolism thinking. The framework highlights the trans-disciplinary nature of urban metabolism and how different worldviews spatial manifest the concept of urban metabolism. Within Vandenbroeck's framework he highlights two fundamentally different worldviews; (1) the objectivist worldview, and (2) the constructivist worldview (Vandenbroeck 2017).

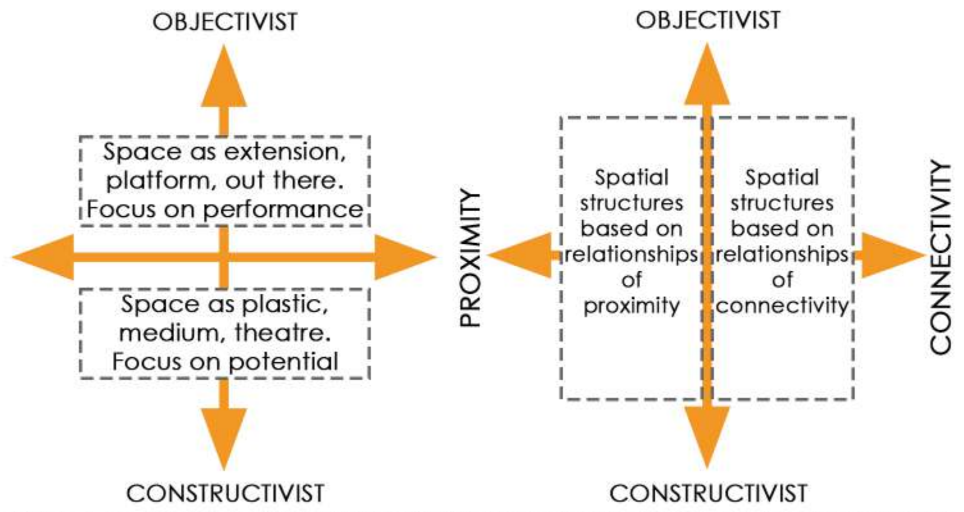
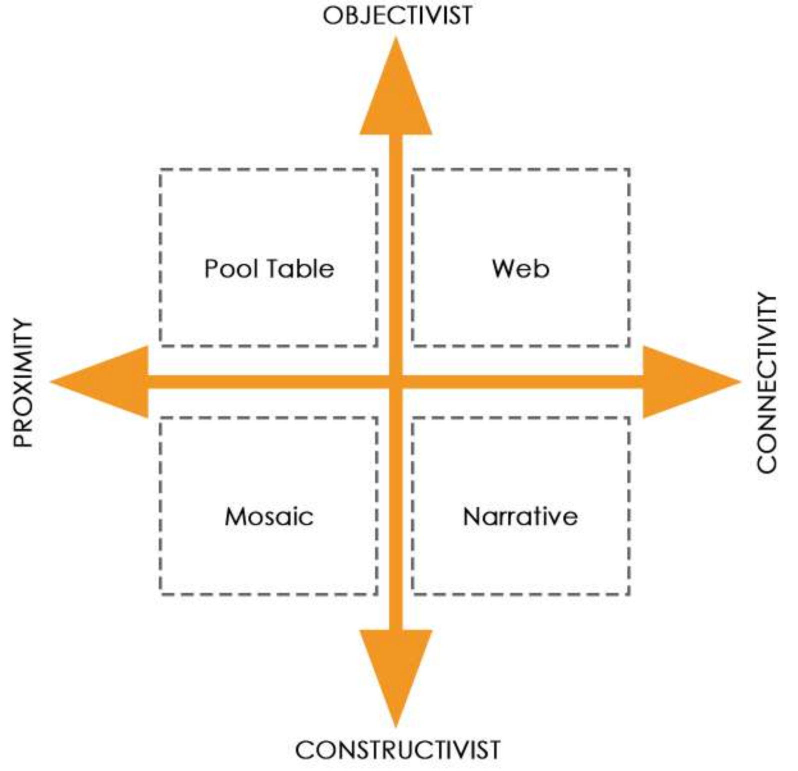


Figure 1.11: (above) Circularity World Views and Spatial Structures (De Meulder and Marin 2018) edited by Author (2021)
Figure 1.12: (below) Urban Metabolism Spatial Conceptions (De Meulder and Marin 2018) edited by Author (2021)

The objectivist worldview resembles a top-down spatial strategy with performance and efficiency as the key drivers, and seeing the inhabitants of the space as human resources and objects of control. The constructivist worldview, in contrast, can be seen as a bottom-up spatial strategy focusing on the potential of the interconnected resources within the space. Building on the spatial manifestation of urbanism metabolism, Vandenbroeck differentiates between two spatial structures; (1) spatial structures based on relationships of proximity, and (2) spatial structures based on connectivity (De Meulder and Marin 2018). Spatial structures developed on proximity manifest as closed resource loops, within a localized network of reinforcing stocks and flows. Spatial structures developed on connectivity manifest in the formation of relationship and the physical connection between places and stakeholders through symbiotic resource flows (ibid). Placing the two worldviews and the two spatial structures on a Cartesian plane, Vandenbroeck develops four different urban metabolic spatial conceptions; (1) Pool Table, (2) Web, (3) Mosaic, and (4) Narrative (ibid).



(1) Pool Table Metabolism: Environmental and economic gains through strict control and efficiency of resource flows.
(2) Web Metabolism: Optimization of resource use towards environmental and economic gains, safety, and convenience. Smart City concept.
(3) Mosaic Metabolism: Based on a developmental and restorative model. Focused on the spatial interconnections and interactions between humans, culture, and ecology. Emancipatory in nature.
(4) Narrative Metabolism: Complex typology resulting from the seemingly incoherent and a-symmetrical interconnection of resources and networks.

4) Regenerative (Biomimetic) Design - Constructing Circularity

Along with the above mentioned fields of theory, Biomimetic Design, or Biomimicry, represent an architectural and design approach driving innovation that has been inspired by nature. Janine Benyus, a pioneer in the field of biomimicry, defines biomimicry as "a discipline that studies nature's best idea and then imitates these designs and process to solve human problem" (Ellen MacArthur Foundation 2021).

A Case for Mass Timber Construction

As previously discussed within the Architectural Problem of this dissertation, embodied carbon within the built environment may prove to be our downfall in the fight against climate change. Regardless of the circularity and efficiency of our systems and resource flows, if we do not transition to a regenerative model of design and construction to accommodate the projected increase of urban population, the current trajectory of the built environment in terms of meeting the target of total carbon neutrality by 2050 will remain unchanged. Mass timber construction may be the key to unlock the path towards this transition.

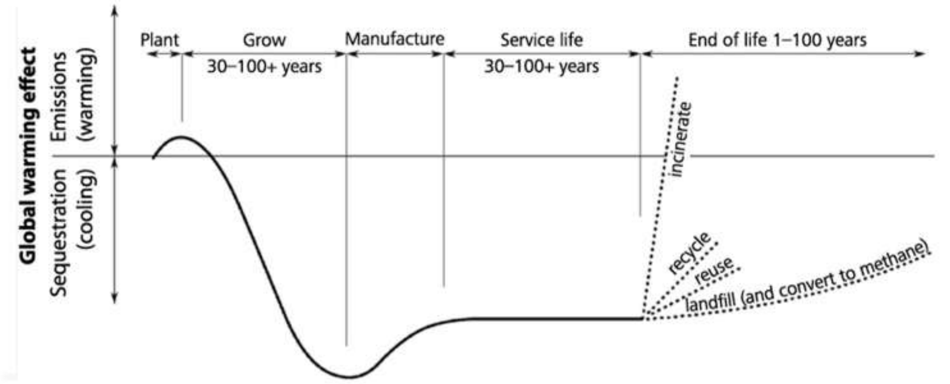


Figure 1.13: Timber Carbon Sequestration (Lawrence and Yang 2017)

Within South Africa, due to the high embodied carbon and waste production quantities of our current design and construction practices, mass timber construction represents a regenerative alternative with untapped biomimetic potential. Mentioned previously, mass timber has a confirmed carbon sequestering and global cooling effect on the environment as opposed to the carbon emitting and global warming nature of concrete and steel manufacturing (Lawrence and Yang 2017). Furthermore, mass timber construction, due its engineered nature, represents a construction methodology that is able to drastically reduce waste through the process of prefabrication. Prefabrication of structural components represents the opportunity to shorten the process-stream of the construction phase (Earthworld Architects 2021). By working directly with the manufacturers, structural components can be accurately developed, in factory conditions ensuring the quality of the product, as a kit-of-parts and then transported to site. Due to the kit-of-parts nature of prefabrication, faster installation on site, and therefore reduced cost, is possible whilst incorporating unskilled labourers in the construction process (ibid). The process of prefabrication, and the advantages thereof as opposed to conventional construction practices, will be explored further in the design development and technical resolution section of this dissertation.

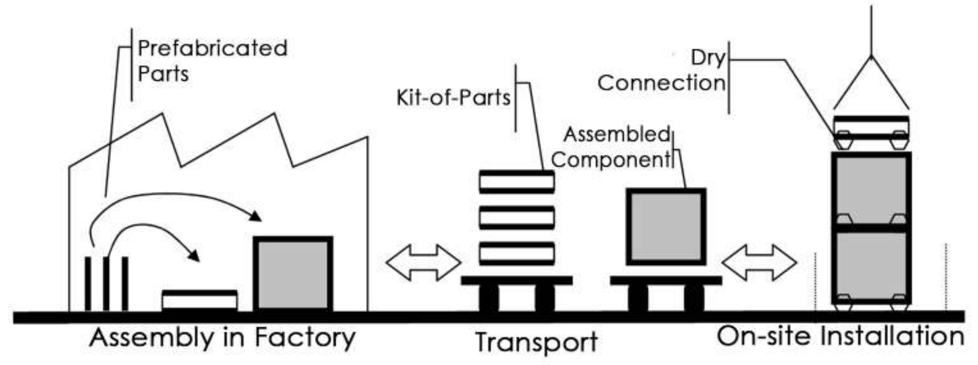
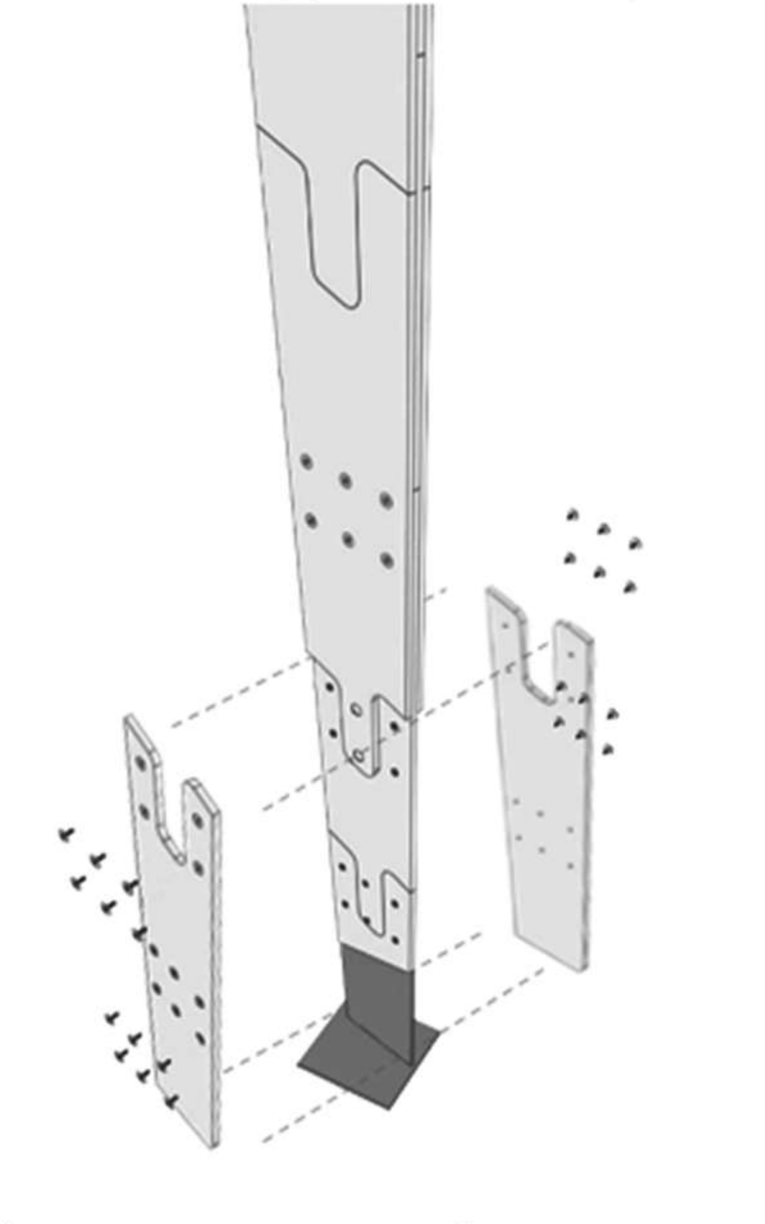


Figure 1.14: Prefabricated Kit-of-Parts (The Noun Project 2021)
Figure 1.15: Kit-of-Parts Column Design (Earthworld Architects 2018)



Theoretical Framework Conclusion

The theoretical framework highlighted the complexity, interconnection of theory, trans-disciplinary, multi-scalar, and systemic nature of circularity. Within South Africa, and more specifically within the study area of this dissertation – Mamelodi – various obstacles exists in the path towards achieving circularity. The theoretical framework, and in particular the urban metabolic spatial conceptions developed by Vandenbroeck, highlights possible strategies capable of overcoming those obstacles.

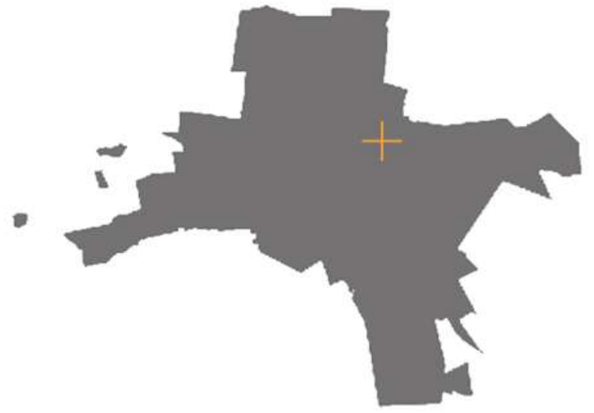
URBAN ANALYSIS

LOCATION

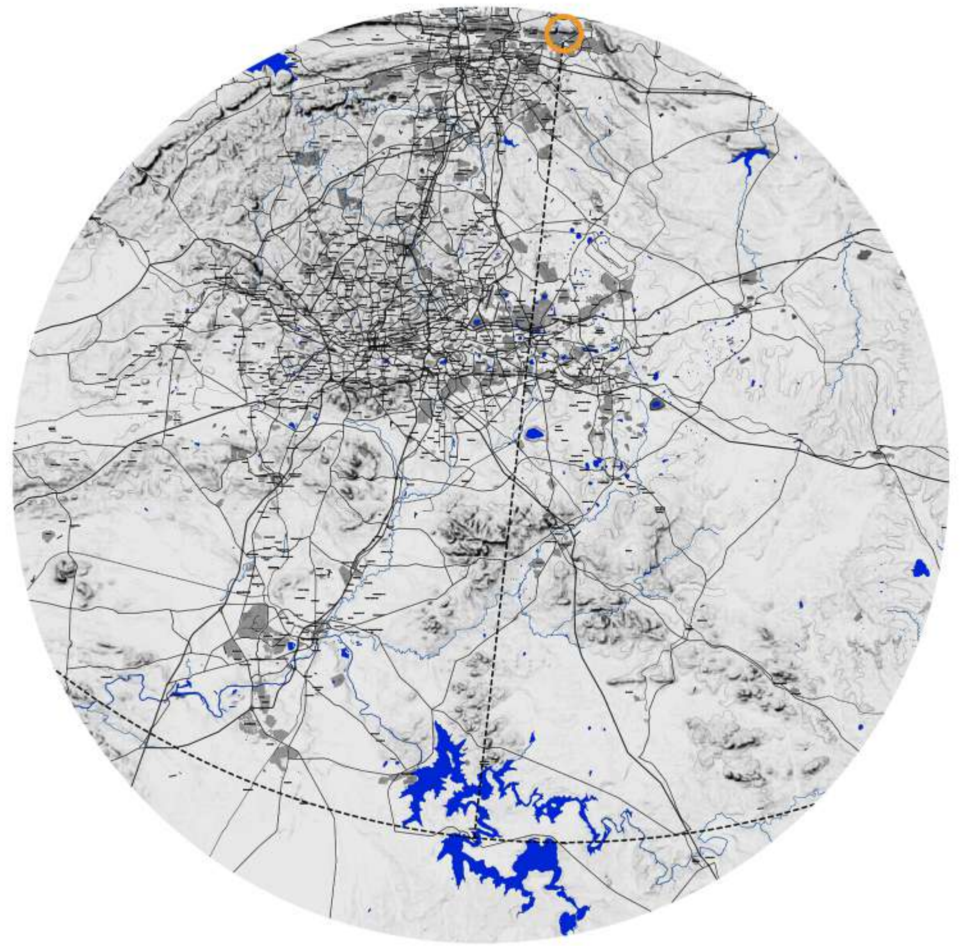
SOUTH AFRICA

GAUTENG

PRETORIA



MACRO SCALE STUDY



MESO SCALE STUDY

MICRO SCALE STUDY

Figure 1.16: (top) Study Area Location (Author 2021)
Figure 1.17: (bottom) Urban Analysis Scales (Author 2021)

MACRO SCALE STUDY

The following urban analysis develops an understanding of the study area as it performs within its urban scale ie. the city scale

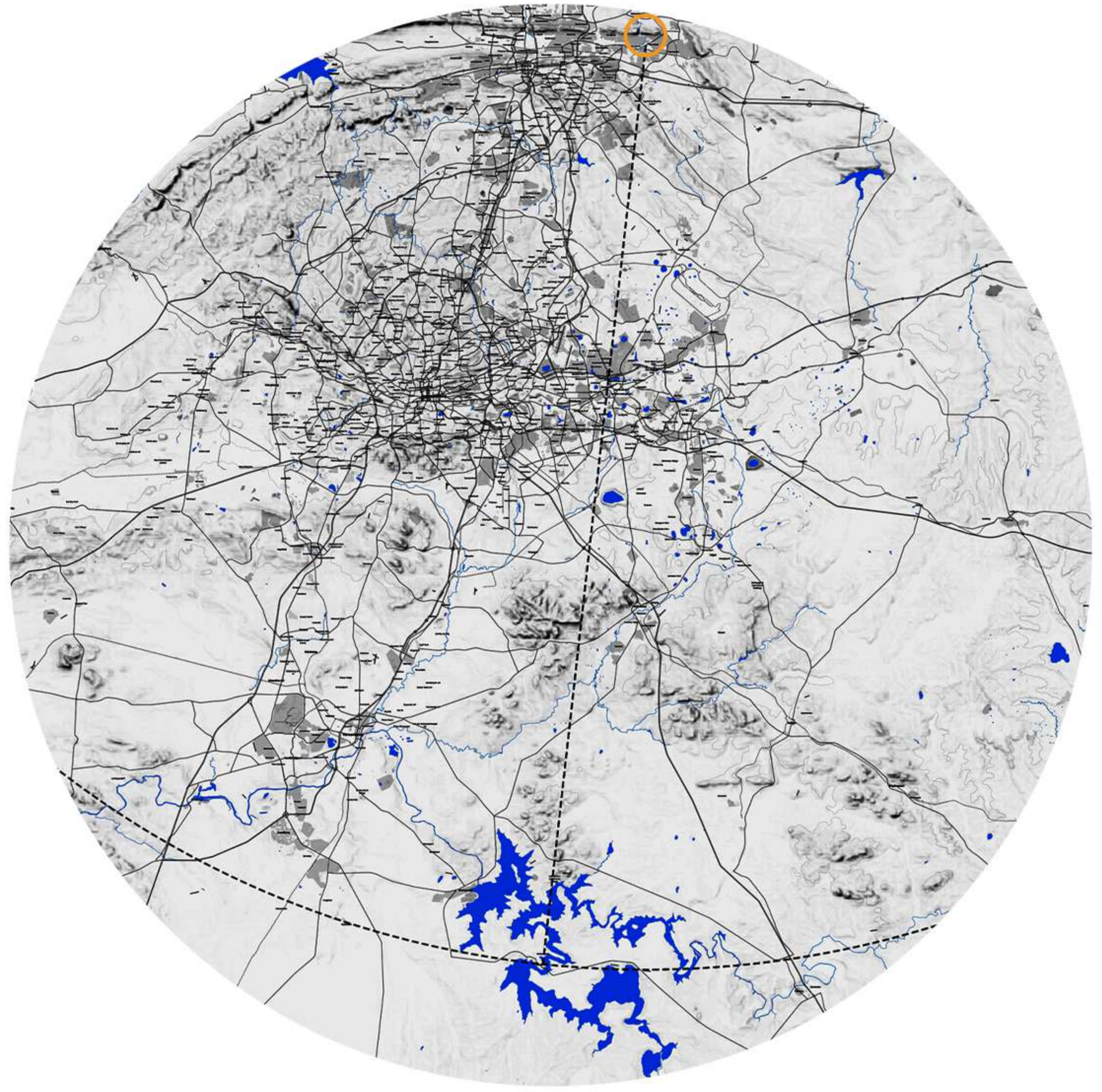


Figure 1.18: Macro Scale Study (Author 2021)

TSHWANE VISION 2055

The Tshwane Vision 2055 is a spatial development framework for the City of Tshwane. The vision translates into four "city-making" goals that represent the urban developmental strategy of the vision.

(1) A resilient and resource efficient city
(2) A growing economy that is inclusive, diversified, and competitive
(3) Quality infrastructure development that supports liveable communities
(4) An equitable city that supports happiness, social cohesion, safety, and healthy citizens

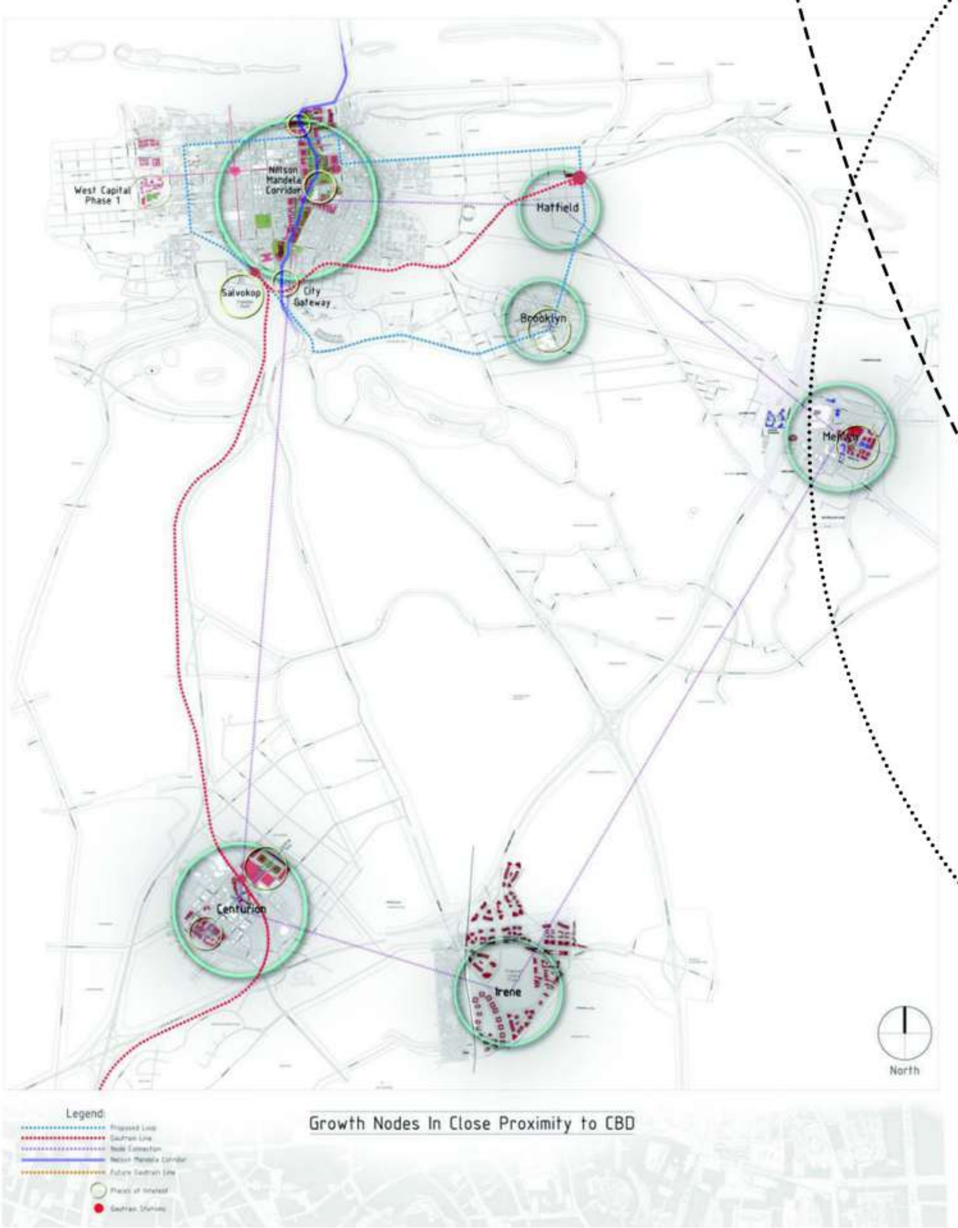


Figure 1.19: Tshwane Vision 2055 Development Nodes (CoT 2013: 99)
Figure 1.20: Mamelodi Food and Economic System Boundaries (Author 2021)

FOOD, WATER & ECONOMIC SYSTEM BOUNDARY

From a food and water security perspective, the site falls drastically short of the goals and visions of the Tshwane Vision 2055 and the UN SDGs. There is currently no internal system, developmental or design strategy that aims to combat food and water scarcity within the study area. Further system shocks, such as Covid -19 and climate-event such as droughts or flooding, will place the already vulnerable system under greater stress. This results in an opportunity for architecture intervention to create an internal closed-loop resource system to facilitate food and water security in the study area.

From an economic growth and opportunity for income perspective, the site falls outside the proposed "economic-node loop" as illustrated by the Tshwane 2055 vision. This places a great deal of stress on the economic system and resilience of the site. Community members within the study area have to travel great distances to find employment and opportunities for income. The stress on the economic system has been further exacerbated by the Covid-19 system shock. The vulnerability of the economic system of the study area greatly hinders the urban resilience of the community. This provides an opportunity for architectural invention to establish socio-economic infrastructure towards a transformation of the study area from a transient space to a thriving socio-economic node within its greater context.

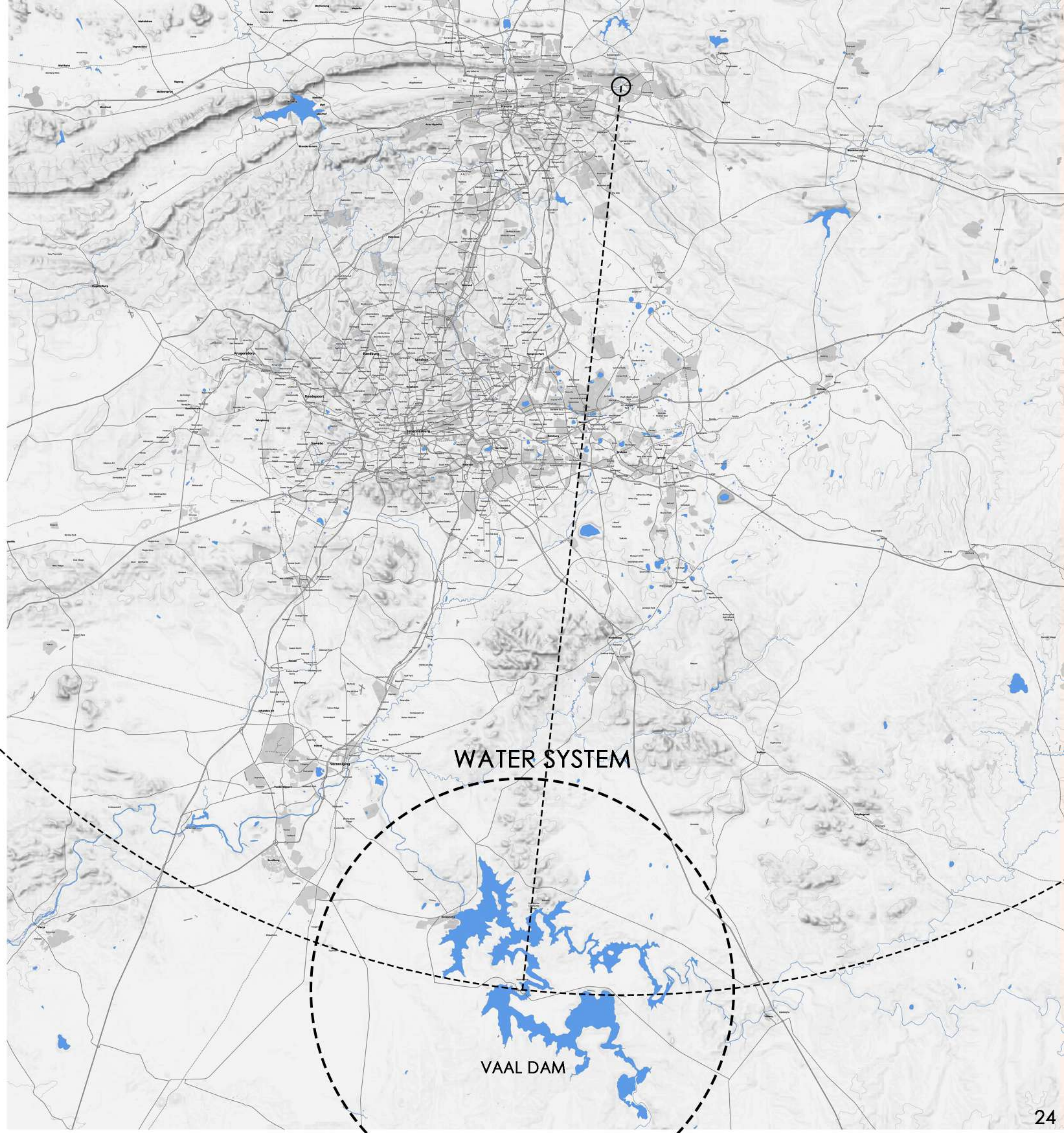


Figure 1.21: Mamelodi Water Supply System Boundary (Author 2021)

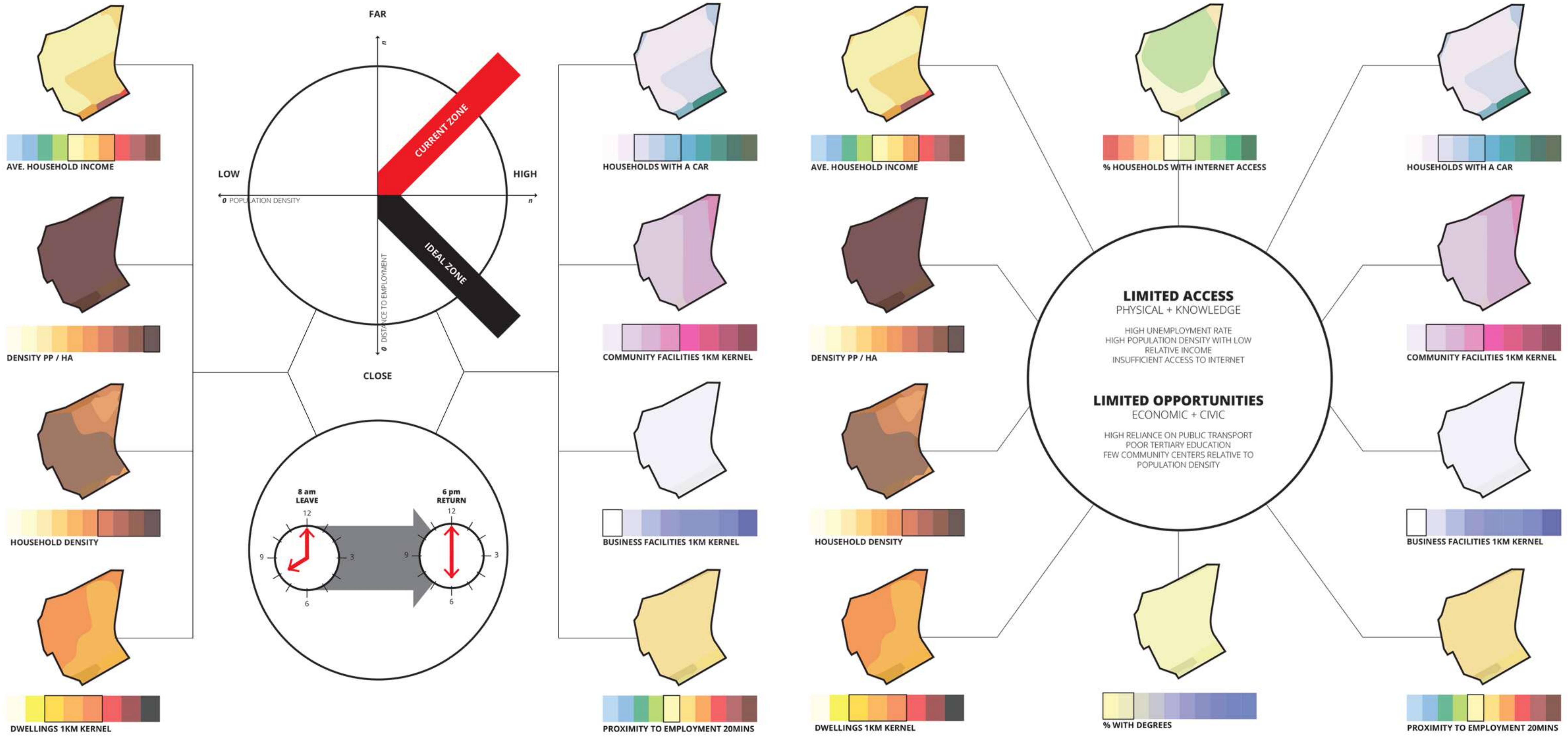
MESO SCALE STUDY

The following urban analysis develops an understanding of the study area at a meso scale ie. the neighbourhood scale. This analyis demonstrates the performance of the neighbourhood in various quantitative and qualitative metrics.

Figure 1.22: (left) Meso Scale Study (Author 2021)
Figure 1.23: (right) UUC 2020 Meso Scale Analysis (Levy 2020)

UNIT FOR URBAN CITIZENSHIP 2020

During 2020 as part of her research masters dissertation, Maxine Levy conducted a detailed analysis of Khalambazo, a neighbourhood within the study area, was conducted as part of the Unit for Urban Citizenship programme. This analysis revealed valuable insight and understanding of the pressures faced by the study area. The meso-scale analysis identified four 4 key spatial conditions that are present within the study area: 1); Dormitory Settlement; , 2) Pendulum Migration; 3), Inherent Spatial Limitations, and; 4) Spatial Injustices (Levy, 2020)



1) Dormitory Settlement
Euclidean spatial planning of the Apartheid government resulted in a mono-function urban fabric disconnected from surrounding neighbourhoods and economic activity, resulting in a settlement in a state of socio-economic dependency.

2) Pendulum Migration
Due to the isolation from areas of greater economic activity, and the inadequate access to affordable public transportation, members of the community have to travel far distances to find employment. This isolation also results in a high level of unemployment due to the inability to travel far for employment due to home-life responsibilities

3) Inherent Spatial Limitations
The limitations placed on the community due to the Euclidean spatial planning and urban isolation negatively impacts the urban resilience and also contributes to a decreased quality of life.

4) Striving to overcome Spatial Injustices
Despite the inherent spatial limitations placed on the community of Khalambazo, the residents have displayed innovative ways of increasing urban resilience and improving quality of life through a network of informal economies through various methods of dwelling adaptation.

DOUGHNUT ECONOMICS

In order to identify the obstacle in the path towards achieving urban resilience, this dissertation utilizes the instrument developed by Kate Raworth (2021) — the "doughnut economic model." The doughnut economic model analyses quantitative and qualitative metrics of a study area to identify any socio-economic and ecological shortfalls towards achieving urban resilience.

This instrument creates a "portrait" of the study area, from which relevant programmatic informants may be extrapolated to counteract any shortfalls identified. The various quantitative and qualitative metrics are cross-referenced with the higher order goals of the United Nations 2030 Sustainable Development Goals (Mossin 2020) as well as the goals from the Tshwane Vision 2055 framework (City of Tshwane 2013).

United Nations SDG's as Programmatic Drivers

Within the UN's SDG's and the Tshwane Vision 2055 framework, additional emphasis is placed on the importance of developing urban resilience. Goal 11 from the UN SDG's (along with the various sub-goals and targets) states: "Make Cities and Human Settlements inclusive, safe, resilient and sustainable", whilst the Tshwane Vision 2055 highlight the importance of inclusive, safe, resilient, green and public spaces with an emphasis on the preservation of cultural and natural heritage and the support of social, economic and environmental linkages (City of Tshwane 2013, Fabbricatti and Biancamano 2019, Mossin 2020).

Figure 1.24: (above) UN SDG's as programmatic informants (United Nations 2021)
Figure 1.25: (center) Doughnut Economic Model - Amsterdam (Raworth 2021)
Figure 1.26: (right) Mamelodi Doughnut Portrait (Author 2021)

DOUGHNUT MODELS

AMSTERDAM

WATER:
1) Population % without access to water - 9%
2) Population % without access to improved sanitation - 32%

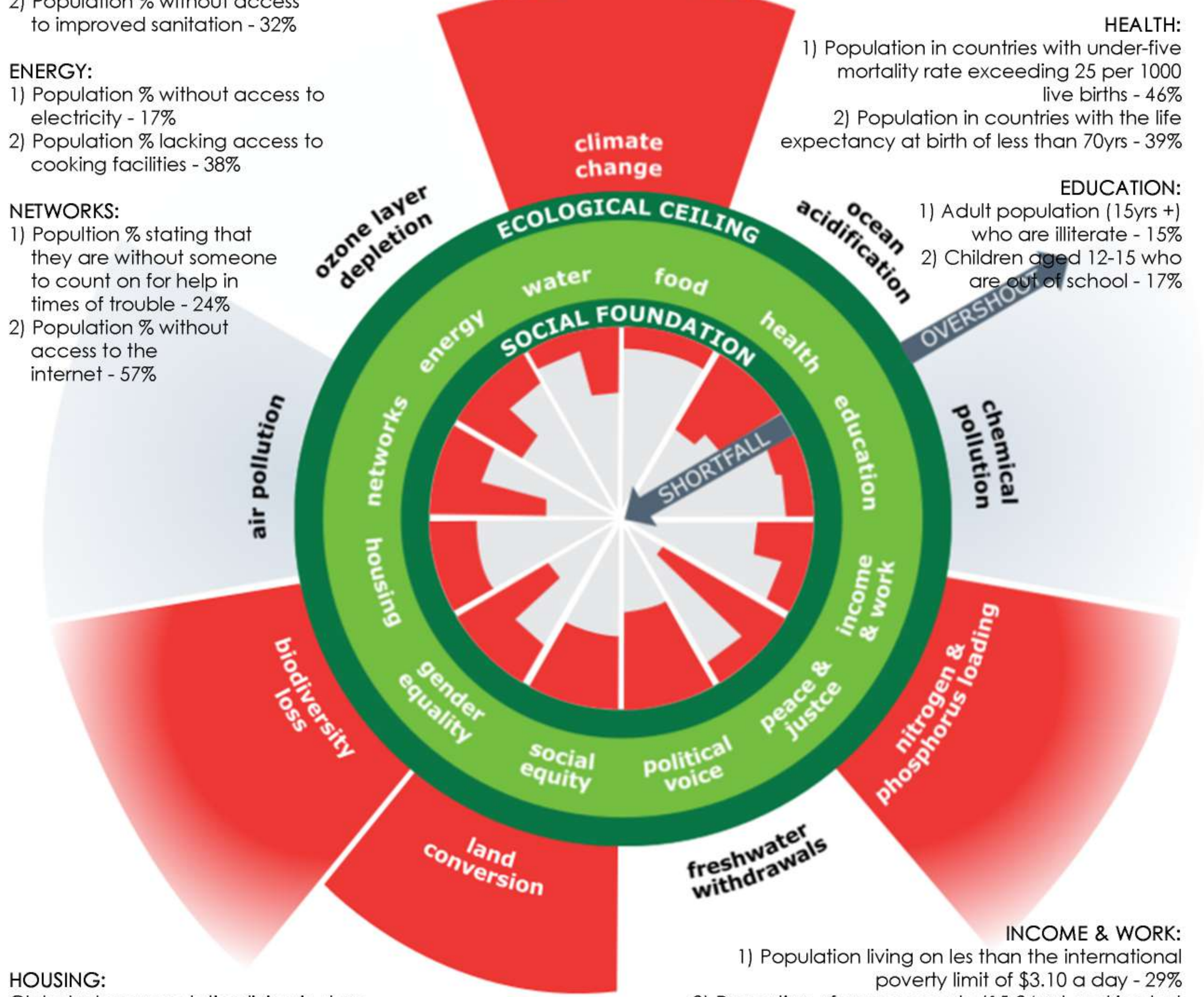
ENERGY:
1) Population % without access to electricity - 17%
2) Population % lacking access to cooking facilities - 38%

NETWORKS:
1) Popultion % stating that they are without someone to count on for help in times of trouble - 24%
2) Population % without access to the internet - 57%

FOOD:
Population % undernourished - 11%

HEALTH:
1) Population in countries with under-five mortality rate exceeding 25 per 1000 live births - 46%
2) Population in countries with the life expectancy at birth of less than 70yrs - 39%

EDUCATION:
1) Adult population (15yrs +) who are illiterate - 15%
2) Children aged 12-15 who are out of school - 17%



INCOME & WORK:
1) Population living on les than the international poverty limit of $3.10 a day - 29%
2) Proportion of young people (15-24yrs) seeking but not able to find work - 13%

HOUSING:
Global urban population living in slum housing in developing countries - 24%

GENDER EQUALITY:
1) Representation gap between women and men in national parliaments - 56%
2) Worldwide earnings gap between women and men - 23%

SOCIAL EQUALITY:
Population living in countries with a Palma Ratio of 2 or more (the ratio of the net income share at the top 10% of people to that of the bottom 40%) - 39%

PEACE & JUSTICE:
1) Population in countries scoing 50 or less out of 100 in the Corruption Perceptions Index - 85%
2) Population in countries with a homicide rate of 10 or more per 10000 - 13%

POLITICAL VOICE:
Population in countries scoring 0.5 or less out of 1.0 in the Voice and Accountability Index - 52%

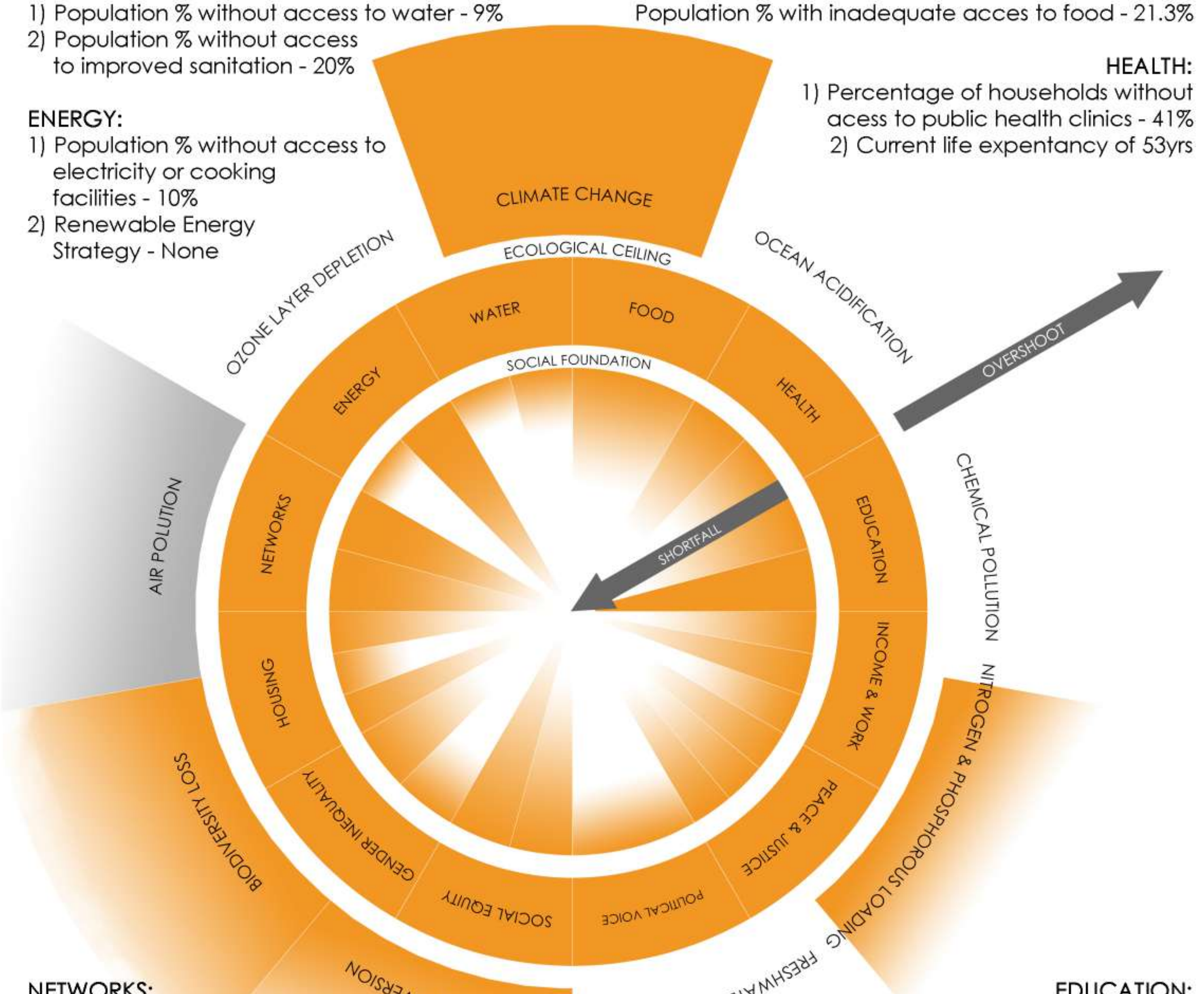
MAMELODI

WATER:
1) Population % without access to water - 9%
2) Population % without access to improved sanitation - 20%

ENERGY:
1) Population % without access to electricity or cooking facilities - 10%
2) Renewable Energy Strategy - None

FOOD:
Population % with inadequate acces to food - 21.3%

HEALTH:
1) Percentage of households without access to public health clinics - 41%
2) Current life expentancy of 53yrs



NETWORKS:
1) Population % without internet access - 90%
2) Community facilities within 1km kernel - Below 3

HOUSING:
1) Percentage impoverished households - 20-30%
2) Number of child-headed households - 3762
3) Percentage infromal households (shacks) - 16.4%

GENDER EQUALITY:
1) Representation gap between women and men in national parliaments - 49%
2) Worldwide earnings gap between women and men - 23%

SOCIAL EQUALITY:
1) Palma Ratio - 7.9
2) Gini Coefficient - 0.63

EDUCATION:
1) Population % with Matric - <60%
2) Population % with Degree - <5%

INCOME & WORK:
1) Percentage of popualtion living below the upper poverty line of R1077 per month - 31.3%
2)Population % unemployed - 34.4%
3) Poverty Gap Index -17.3%

PEACE & JUSTICE:
1) Corruption Index Score - 44 out of 100
2) Population % "Feelings of Safety" feeling fairly safe in their area of residence (day) - 34.8%
3) Population % "Feelings of Safety" feeling fairly safe in their area of residence (night) - 27.3%

POLITICAL VOICE:
Voice and Accontability Index score - 0.67

MAMELODI CITY PORTRAIT

MICRO SCALE SITE SELECTION

The site is selected to allow the circularity-based spatial model to act on a neighbourhood scale by integrating and stitching together the fragmented landscape cause by the spatial legacy of the Apartheid planning scheme. This allows the design intervention to respond to the various socio-cultural and spatial-economic systems and the various stresses existing within the study area. Furthermore, the Tshwane Vision 2055 framework highlights the importance of public green and the preservation of natural heritage, therefore, the site selection allows for the development of a larger urban vision that includes the ecological rehabilitation of the Pienaars River buffer zone and river-edge condition. The final site selected for architectural intervention and development will be identified in Part 2 of this dissertation.

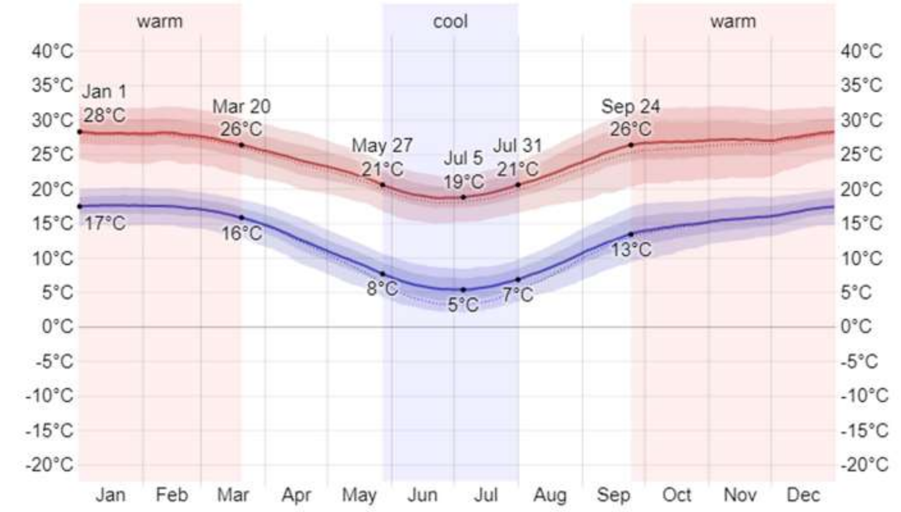
MICRO SCALE STUDY

The following urban analysis develops an understanding of the study area at a micro scale ie. the site specific scale. This analyis reveals the place-based qualities and characteristics of the site within its context.

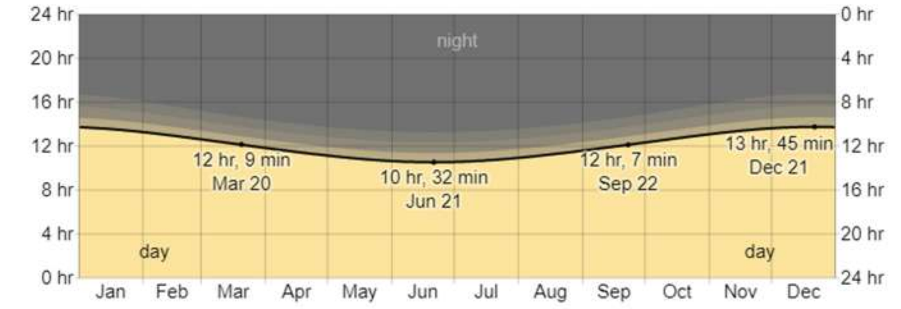
Figure 1.27: Micro Scale Study Area (Author 2021)

FIGURE GROUND, TOPOGRAPHY, CLIMATE STUDY

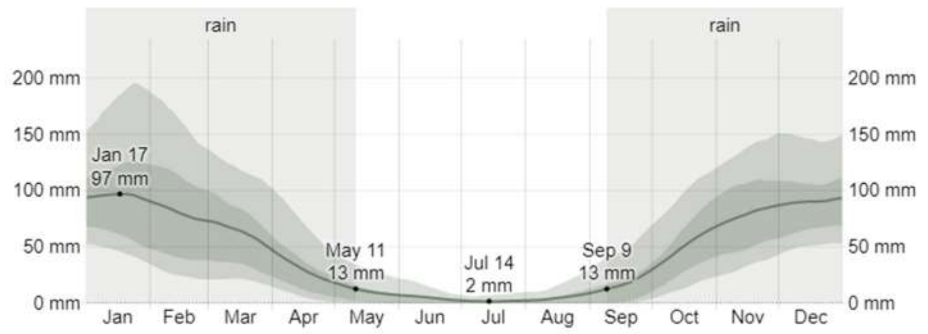
Average High and Low Temperatures



Hours of Daylight and Twilight



Average Montly Rainfall



Wind Direction

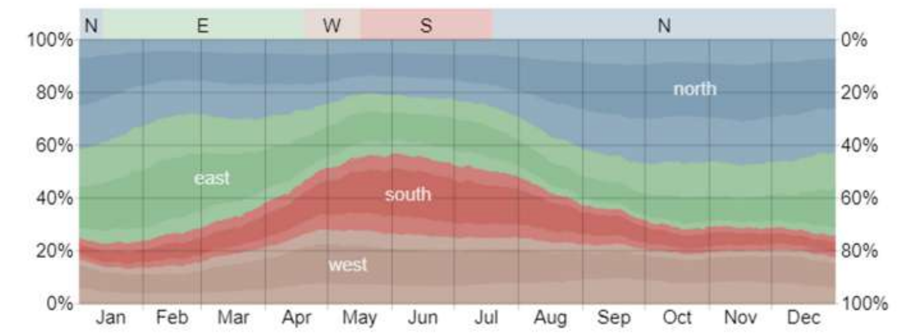
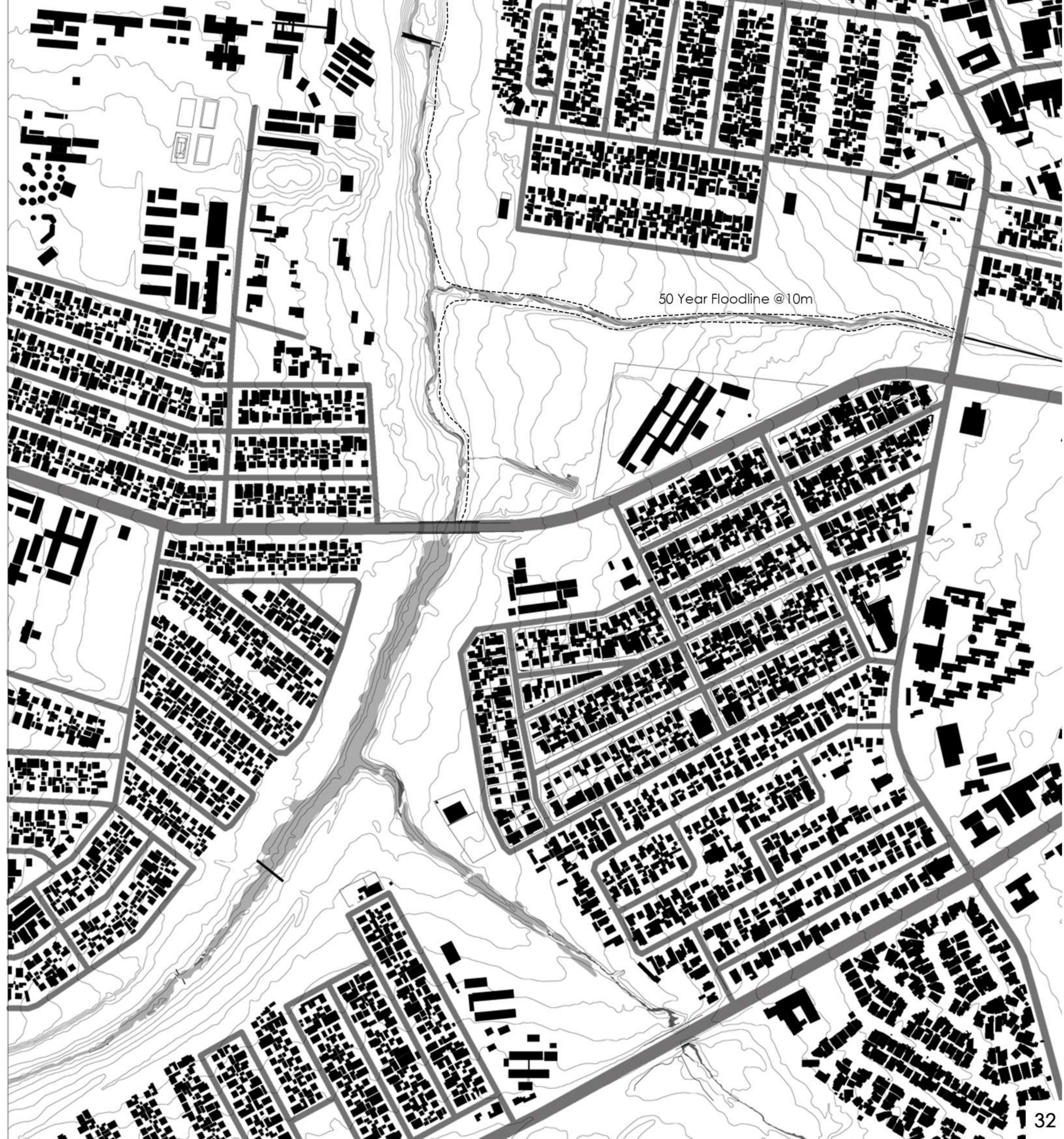


Figure 1.28: Figure Ground & Topography (Author 2021)
Figure 1.29: Climate Data (Weatherspark 2021)



CHARACTERISTICS OF SITE

LEGEND

Danger Zones

Ecological Degradation and Waste Sites

Informal Economies
Pedestrian Activty
Buffer Zone Pedestrian Circulation
Cattle Circulation

Zoning

Figure 1.30: (above) Zoning (Tshwane Gis 2021)
Figure 1.31: (left) Nuances & Perception of Site (Author 2021)

INTERNAL RESOURCES - UNTAPPED POTENTIAL

The study area, although facing various form of socio-economic stressors, has developed a strong internal network of informal economies.

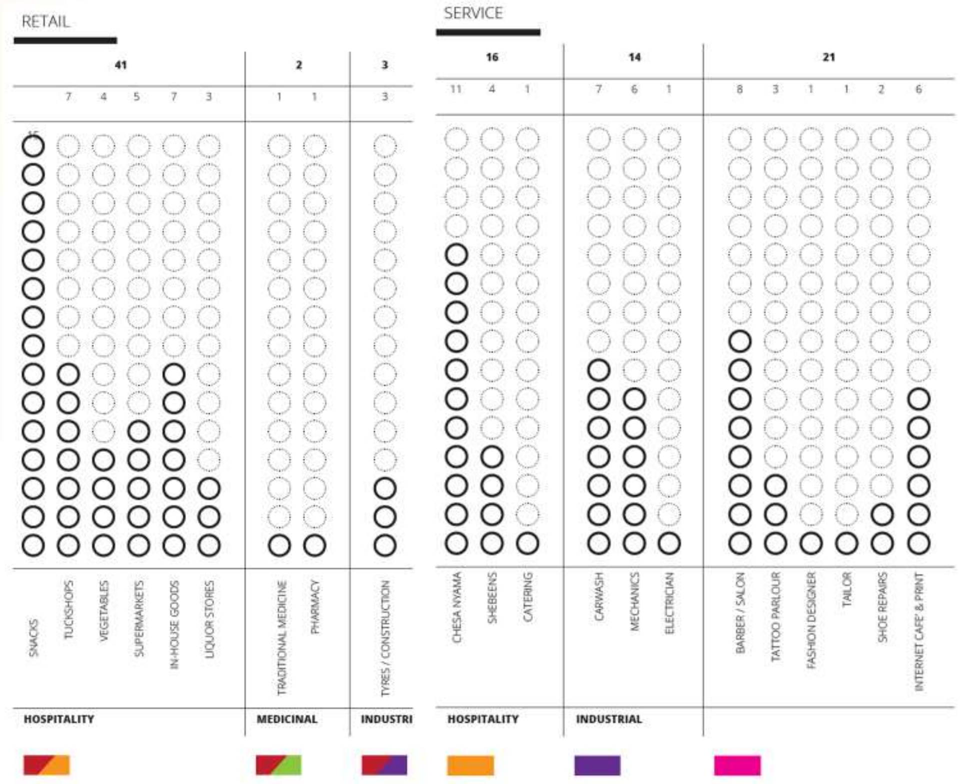


Figure 1.33: Informal Economies (Levy 2020: 208-209)

The food sector, both in the retail and service realm, has been identified as the most abundant form of informal economy business within the study area. Building upon this resource and the prinbciples of circularity and closed-resource loops, the food waste generated from this sector may prove to be a valuable input resource. The culture and statistic of food waste within the study are is conducted in more detail in Part 2 of this dissertation.

Other sources of untappe latent potential within the study area is the manufacturing of adobe clay bricks. This earthern construction material and method contains a very low level of embodied carbon and allows unskilled workers to participate within the construction process.

Finally, along with the organic waste from the informal food economy, the untapped potential of cattle herding, and more specifically the catle manure as resource input, is prevalent in the study area. Both of these organic waste resource inputs is explored further in this dissertation as inputs within an anaerobic digestion system.

Figure 1.32: (right) Internal Resources - Untapped Potential (Author 2021)

PART 2

IDENTIFYING

The purpose of Part 2 is to demonstrate the identified programmatic and design informants as developed from Part 1. Part 2 demonstrates the waste streams identified within the study area that are reinterpreted as resource inputs within a closed-loop system through the principles of circularity. Lastly, Part 2 identifies a programme and design concept that informs and drives an architectural intervention to act as agent of urban resilience.

Figure 2.1: Part 2 - Identifying (Bio2Watt 2021)

INTRODUCTION

Part 2 of this essay is a continuation of Part 1, extending the research, theoretical framework, and study area analysis into design. Informed by Part 1, Part 2 develops and translates the knowledge and understanding gained of the study area and selected micro-scale site into a set of programmatic and spatial infromants. A series of precedent studies are conducted to gain insight into the existing spatial manifestation of the identified programmatic and spatial drivers. The identified precedents are carefully selected for their exemplary performance or achievement with regards to their conceptual, spatial, and/or programmatic drivers. Furthermore, the selected precedents are critically evaluated against the Spatial Circularity Framework, as developed by De Meulder and Marin (2018). Although the selected precedents may not all have been designed with circularity as a spatial or programmatic driver, all of the precedents represent qualities of circularity and how those qualities can be manifested spatially.

The Spatial Circularity Framework:
Building on the constructivist and objectivist urban metabolic worldviews, as well as the proximity and connectivity spatial structures of urban metabolism, as established by Vandenbroeck, De Meulder and Marin expands on the research through the development of a spatial circularity framework. This framework reconceptualizes the objectivist and constructivist worldviews into circularity-driven spatial strategies. De Meulder and Marin (2018: 16-17) describes the framework as a departure point to start manifesting circularity spatially. It is important to note that the framework is not designed to be a one-site-fits-all strategy or checklist, but rather a holistic overview of the spatial drivers of circularity.

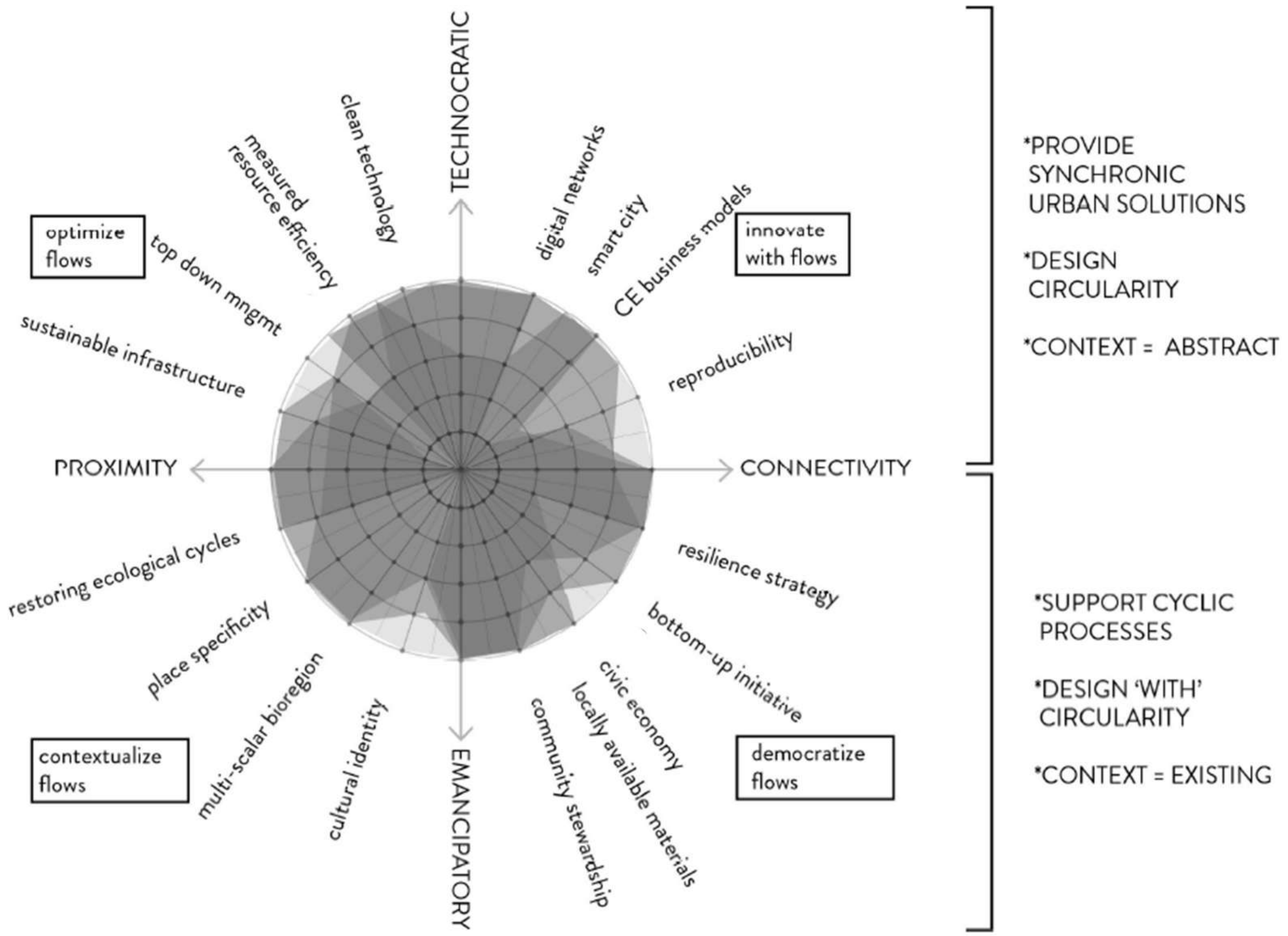
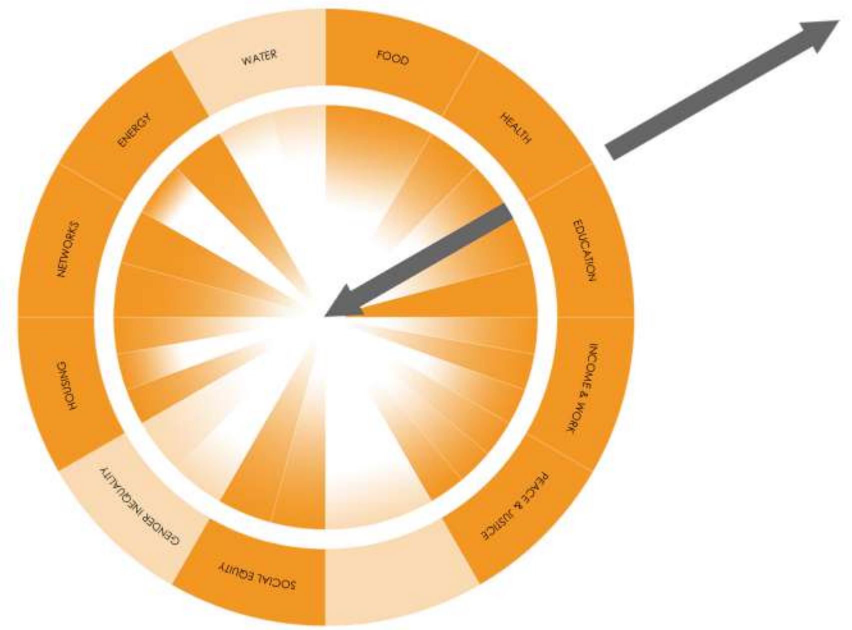


Figure 2.2: Spatial Circularity Framework, edited by Author, originally from De Meulder and Marin (2018:16-17)

UNPACKING THE PROGRAMMATIC DRIVERS

Theoretical Framework & Study Area Analysis

Building on the established theoretical framework and the study area analysis, in particular the social foundation of the Mamelodi City Portrait, various programmatic informants are identified. The programmatic intention of the dissertation is to develop a holistic circularity-based architecture response that aids in the improved resilience of the neighbourhood and community. To achieve the programmatic intention, the worst performing metrics of the Mamelodi City Portrait were utilized as programmatic informants to generate the highest degree of effectiveness with the programmatic intentions. The worst-performing social foundation metrics are highlighted below.



The Resilience Index, developed by ARUP (2016) provides additional metrics and informants towards developing urban cultural-economic resilience. The Resilience Index and Mamelodi City Portrait metrics, along with study area analysis informed the final programmatic drivers.

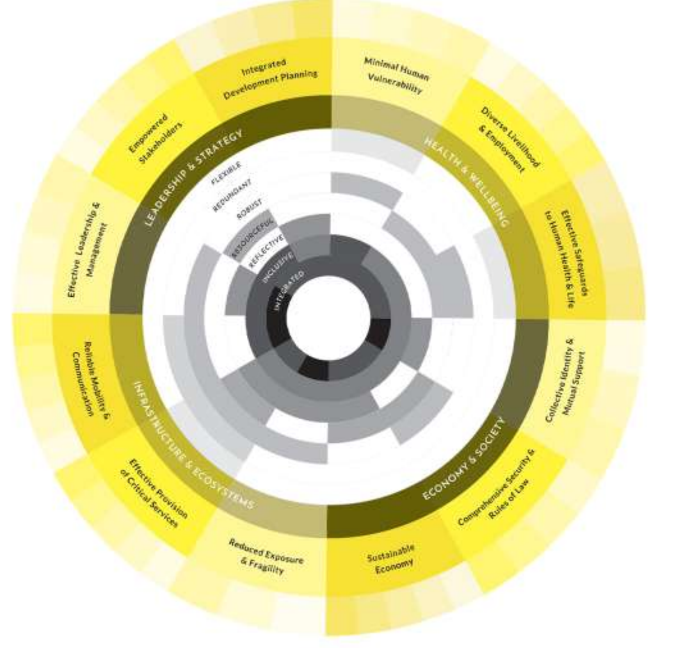


Figure 2.3: The Mamelodi City Portrait (Author 2021)
Figure 2.4: The Resilience Index Framework (ARUP 2016)

Programmatic Drivers

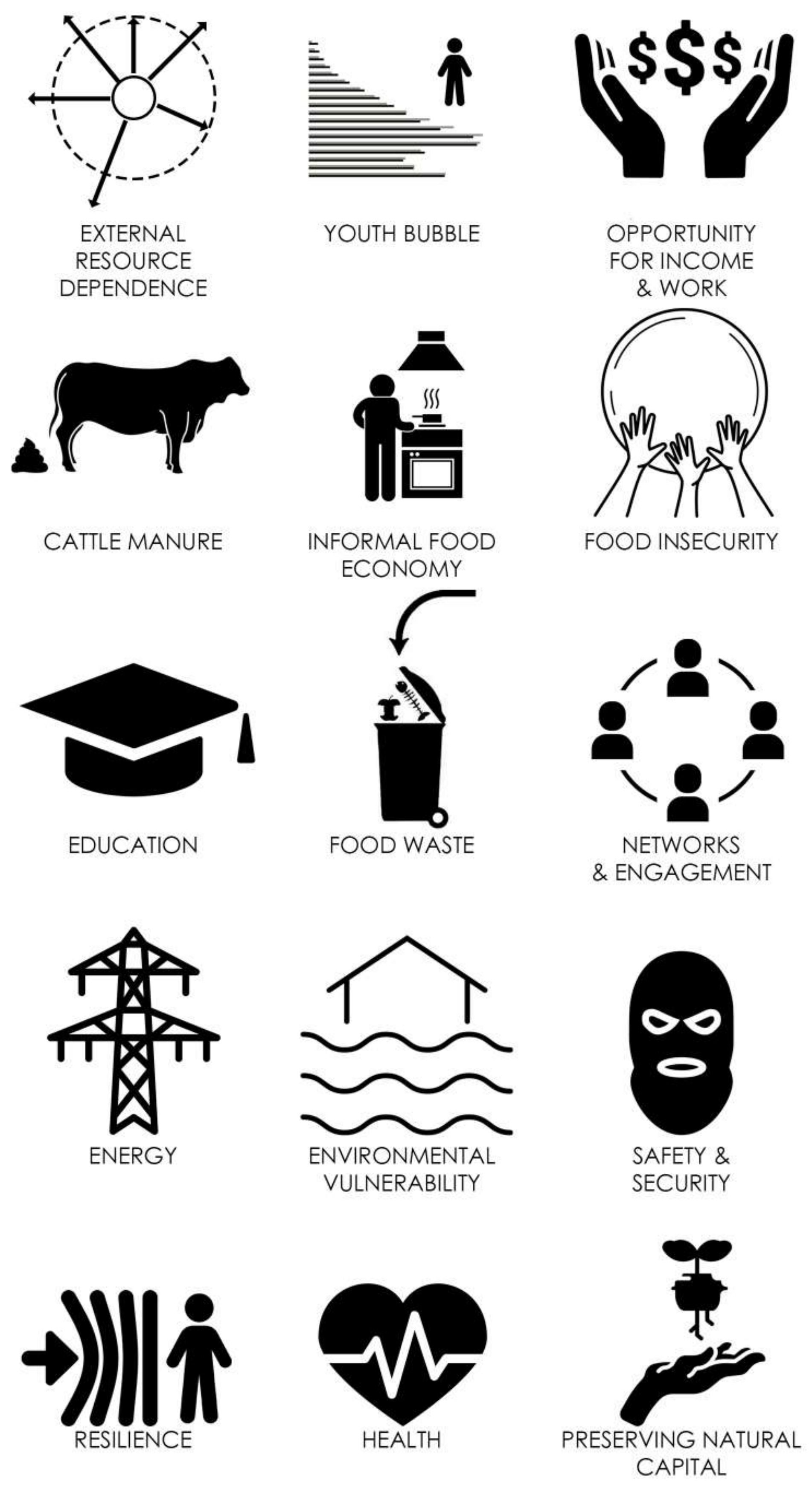


Figure 2.5: Programmatic Drivers, edited by Author, vectors from The Noun Project (2021)

Untapped Potential of Organic Waste

Food Waste in South Africa

The linear consumption model of food and produce in South Africa produce a massive amount of food waste. The WWF (2017) conducted a study of the food waste culture within South Africa and developed the following "food waste portrait". Along with the large amount of organic waste as a programmatic driver, the value-chain study of produce also serves as a programmatic driver to reduce the non-physical waste within the food production system and to develop food security within the study area.

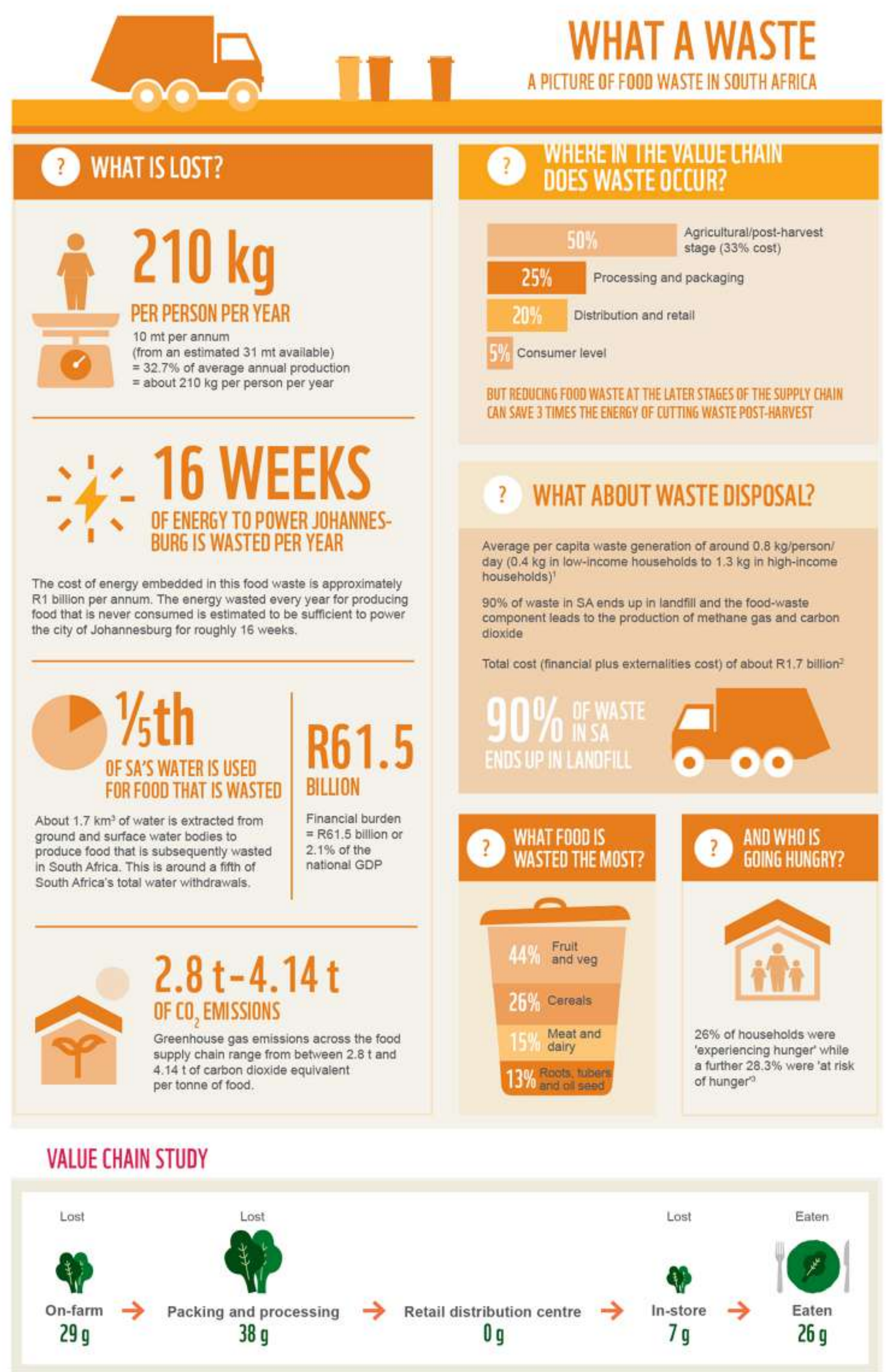
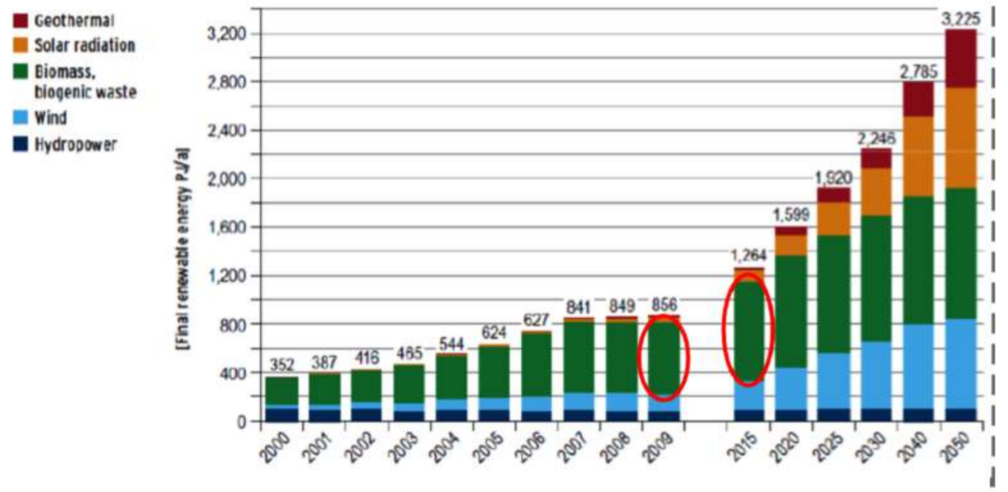


Figure 2.6: What a Waste - A Picture of Food Waste in South Africa (WWF 2017)

Viability of Anaerobic Digestion

Based on a report by Cape Advanced Engineering (2015), the developers and designers of the Uilenkraal Biogas Project, evidence suggests that Biogas Production within the global and South African context remains a largely untapped resource of renewable energy production. Biogas driven renewable energy production is projected to greatly out-perform all other forms of renewable energy production for at least the next 3 decades (ibid).



Although, it is important to understand the current challenges in the way of biogas energy production. Another detailed report of the potential of biogas energy production in South Africa, conducted by GreenCape (2017), concluded that the major factors in the failure of biogas projects included the lack of resource input, and the cost-factor of the energy demand of the biogas facility.

Within this dissertation, the project and programme mitigates the above-mentioned risk-of-failure. Firstly, to address the concern of resource input, the project utilizes a combined resource input of sewage waste, the large amount of organic waste from the informal food economy, as well as the cattle manure. This provides a consistent stream of resource input into the digester. Secondly, the project employed an additional renewable energy production source, solar, to mitigate the energy demand of the biogas plant. The detailed breakdown of the solar potential is discussed in the appendix of this dissertation.

Figure 2.7: Projection of Renewable Energy (CAE 2015)
Figure 2.8: Bio2Watt Biogas Plant (Bio2Watt 2021)

PROGRAMME SELECTION

The macro, meso, and micro-scale study analysis from Part 1 revealed the socio-cultural and spatial-economic pressures, vulnerabilities, and opportunities within the study area. The analysis is consolidated and translated as programmatic drivers. Organic waste, as an internal resource and resource system input, is identified as a dominant programmatic driver towards a holistic place-based, multi-scalar, circularity driver design response.

The selected programme manifests as a holistic and multi-dimensional architectural response that serves as an agent to facilitate cultural-economic resilience and an improved quality of life. This programme is to develop close-resource loops by eliminating waste out of the resources system and establishing a cyclical-design approach. The primary programme eliminates community's dependence on external resources by establishing a localised network of urban agriculture, decreasing food insecurity, whilst offering the opportunity for job-creation.

The intervention achieves the above mentioned intentions through a multi-scalar, ecological urban vision that includes a rehabilitation and revitalisation strategy of the Pienaars River. The dissertation establishes an ecological corridor and promenade as resilient social infrastructure. The promenade, an activated spine of flexible and multi-socio-economic inclusive spaces foster increased urban resilience and improves quality of life, whilst reducing the community's vulnerability to flood-risk through a flood-prevention retaining wall.

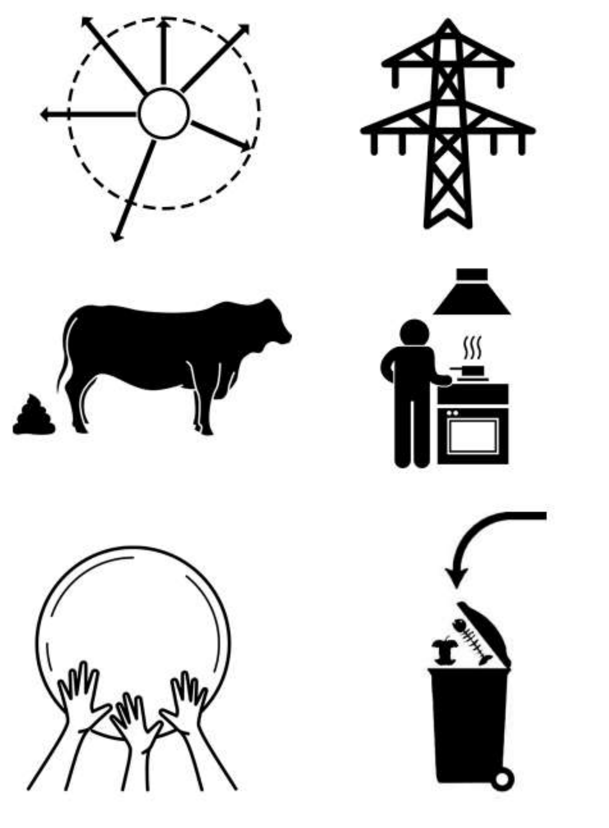
The programme reimagines and transforms the Pienaars River, and its surrounding buffer zone, from a control-method of segregating and isolating communities to a beacon of thriving social interaction and inclusivity, production, safety and resilience.

PRIMARY PROGRAMME

Closed-Loop Resource Integration Facility

- Biogas/Anaerobic Digestion Plant
- Aquaponics Growing Facility

Responding to Programmatic Drivers



SECONDARY PROGRAMME

Education Facility & Skills Development

- Classrooms & Workshop Spaces
- Library
- Computer Centre
- Sports Facility

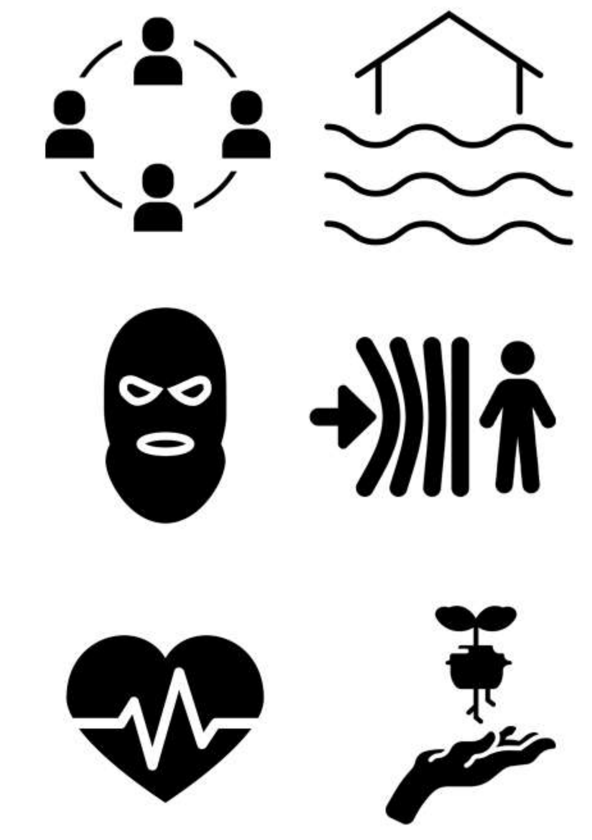
Responding to Programmatic Drivers

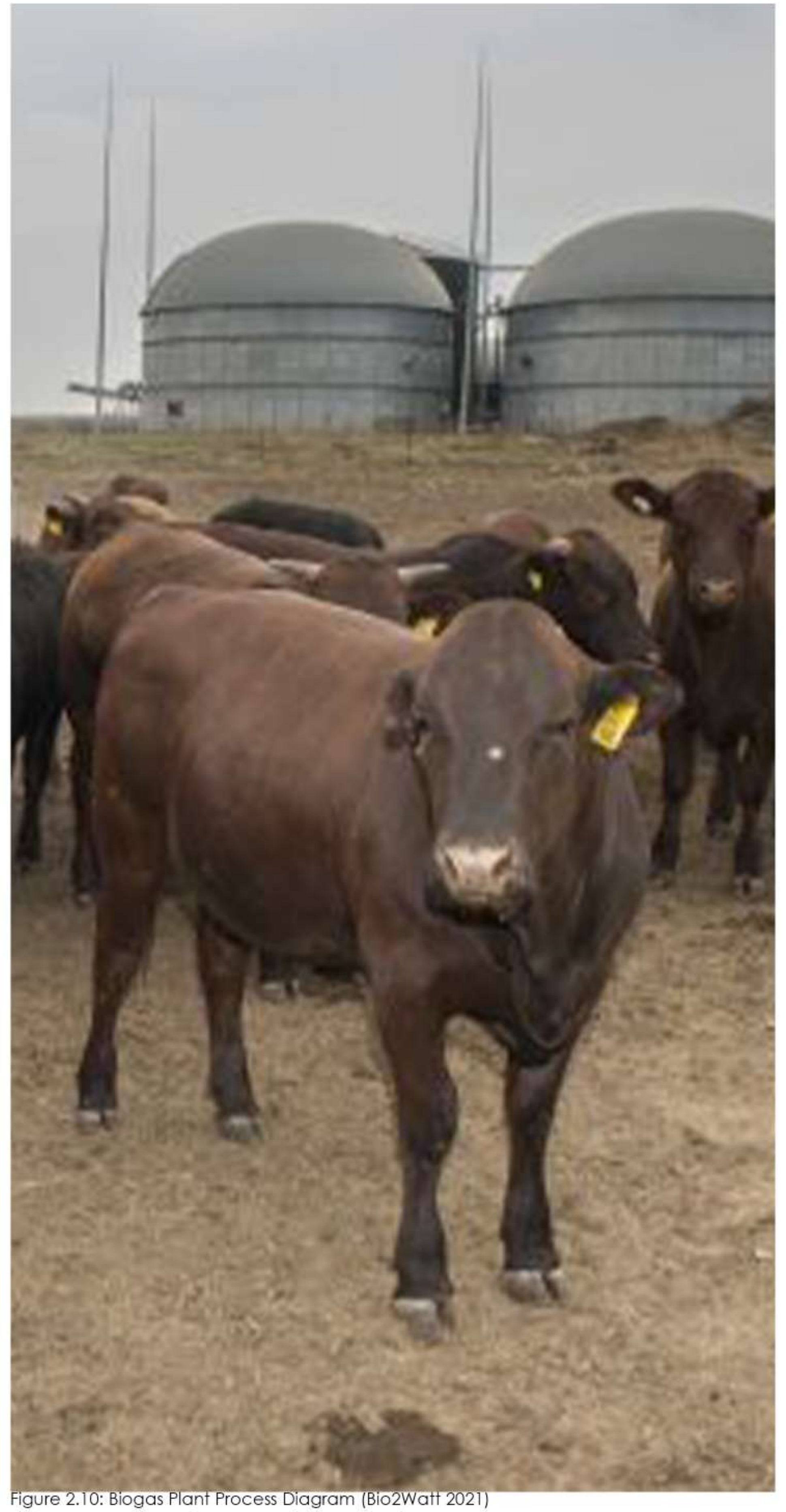
TERTIARY PROGRAMME

Social Didactic Landscape

- Cafe
- Public Ablutions
- Social & Productive Landscape
- Ecological Promenade

Responding to Programmatic Drivers

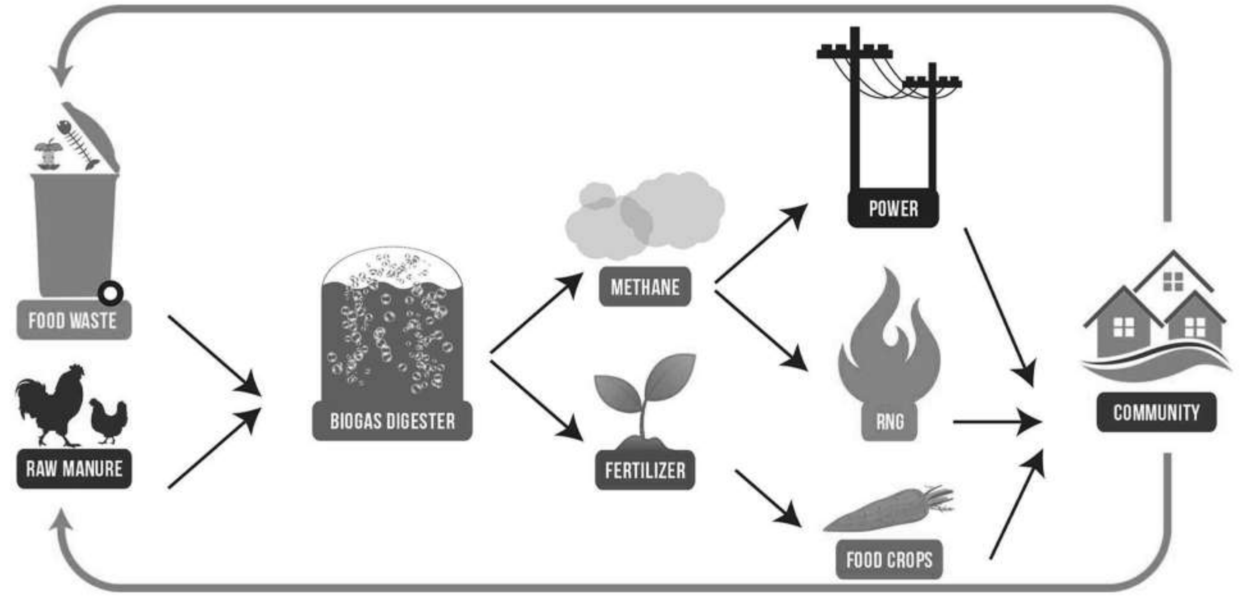




Biogas - Anaerobic Digestion Plant

The urban analysis revealed two large organic waste streams:
1) Food waste from the large informal food economy network
2) Cattle manure from the cattle herding practices within the community.

The biogas plant works with the process of anaerobic digestion, converting the organic waste to biomethane. Biomethane, once processed, can then be returned to the informal food economy as gas for cooking, or the biomethane can be used to generate a renewable electricity source through a gas turbine generator.



Aquaponics

Aquaponics is a form of soil-free agriculture, utilizing the nutrient-rich water supply of fish farming. Water from the fish rearing tanks is high in nutrients due to the excreted fish waste. This nutrient-rich water solution provides great stimulus for the crops to grow. Although a small percentage of water is lost due to evaporation, aquaponics systems function on a closed-loop water cycle, making the system highly efficient.

In addition to the agricultural produce, fish farming provides a healthy source of nutrition. Within South Africa, Tilapia is the most commonly used fish species within aquaponics systems.

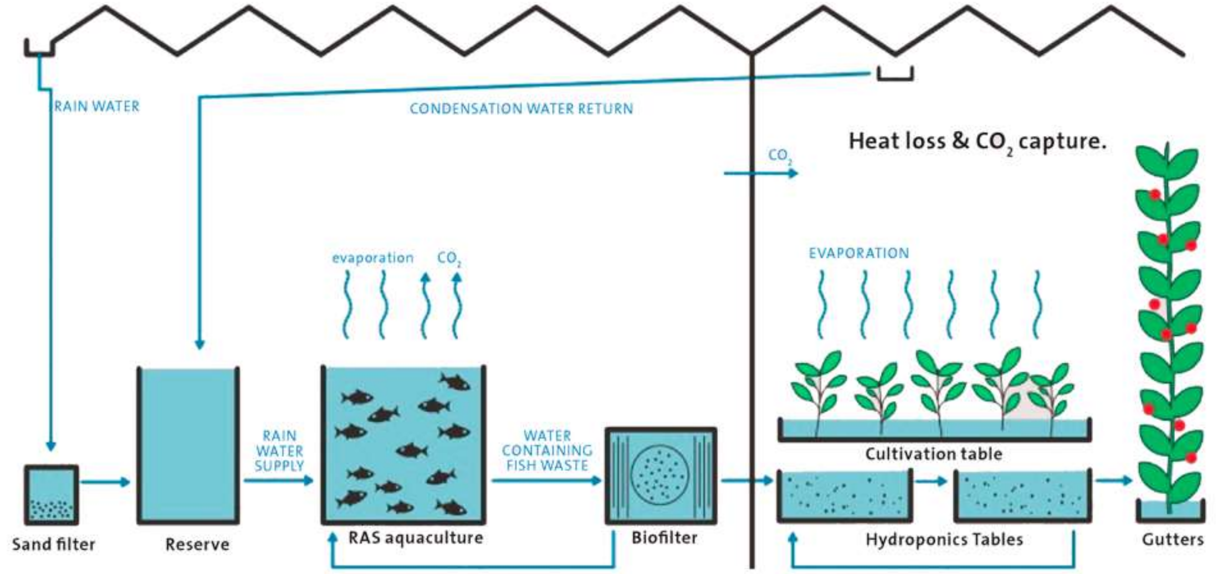


Figure 2.10: Biogas Plant Process Diagram (Bio2Watt 2021)
Figure 2.11: Aquaponics Process Diagram (Beckers 2019)
Figure 2.12: Aquaponics Growing Facility (BIGH 2021)

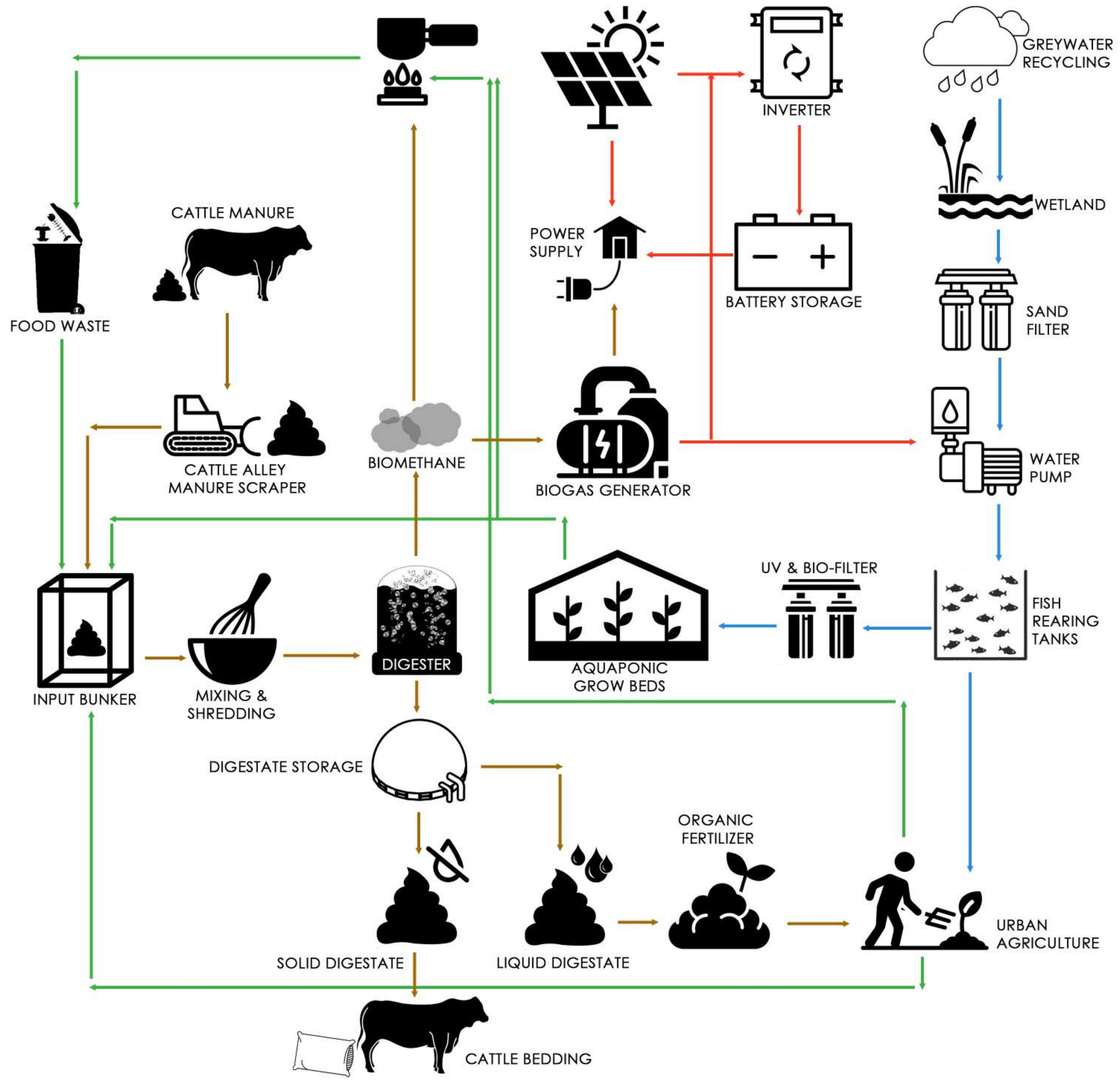


Figure 2.13: Cyclical Design of Biogas and Aquaponics Systems - An Integrated Systems Approach (Author 2021)

PRECEDENT STUDIES

CONTEXTUAL

PRODUCTION

RESILIENCE
CYCLICAL DESIGN

RESILIENCE
SPATIAL FLEXIBILITY

RESILIENCE
SOCIAL INFRASTRUCTURE

URBAN CIRCULARITY

PRECEDENT - CONTEXTUAL

Earthworld Architects - Future Africa Innovation Campus
Location: UP LC de Villiers Campus, Pretoria, South Africa
Status: Completed 2017

The Future Afrika Innovation Campus exemplifies the integration of a didactic social landscape within the urban architectural realm. The landscape and circulation routes weave between and stitch together the various architectural structures on the site (Earthworld Architects 2021). Programmatically, the intervention is developed as a trans-disciplinary campus for post-doctoral students and researchers, whereas the landscape is an extension of the internal programme, continuing the didactic experience beyond the architecture. Furthermore, the pedestrian circulation routes throughout the landscape are designed to create a social landscape with numerous opportunities for spontaneous interaction between the users.

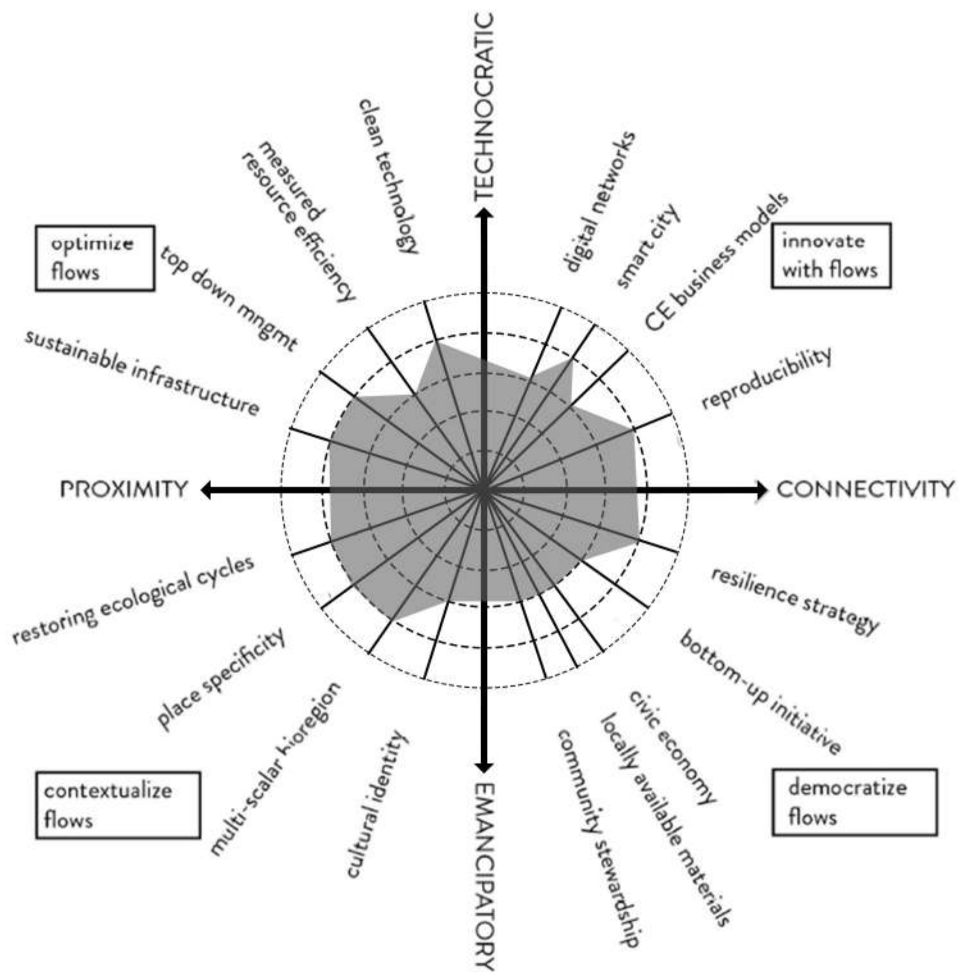


Figure 2.14: FIAC Landscape Plan (Earthworld Architects 2021)
Figure 2.15: FIAC Didactic Landscape (Earthworld Architects 2021)
Figure 2.16: FAIC Spatial Circularity Framework (Author 2021)

Bio2Watt

Uilenkraal Biogas Project

Bio2Watt Bronkhorstspruit & Uilenkraal Biogas Project

Bio2Watt and the Uilenkraal Biogas Project both demonstrate large-scale commercial biogas production plants. There are two key differences between these two successful projects: (1) is their manure collection methods, and (2) their anaerobic digester design (SABIA 2016). In terms of manure collection, Bio2Watt has a large cattle pan where manure is collected manually with the use of labourers and scraper trucks, depositing the manure at a specified location. The Uilenkraal Biogas Project accommodates the cattle in a "free-stall" barn typology where the manure is collected in "cow-alleys" with a mechanical scraping device that scrapes the manure over a slatted floor into a manure collection pit. In terms of anaerobic digester design, Bio2Watt has a constructed anaerobic digestion tank, where Uilenkraal utilizes a lagoon digester system.

This precedent analysis highlights the different methods for anaerobic digestion. Both systems have their respective advantages and disadvantages, however, the choice of digestion method will be context specific.

Cattle Pan vs Free-Stall:
Due to the location of the selected site and the close proximity of the river, utilizing a cattle pan will not be feasible as this will lead to land degradation and possible ground-water toxification due to the nitrates from the manure seeping into the groundwater.

Digester Tank vs Lagoon Digester:
Due to the urban context of the selected site, and the need to preserve and rehabilitate the natural capital of the site, using a lagoon digester, although lower in cost, will not be a viable option.

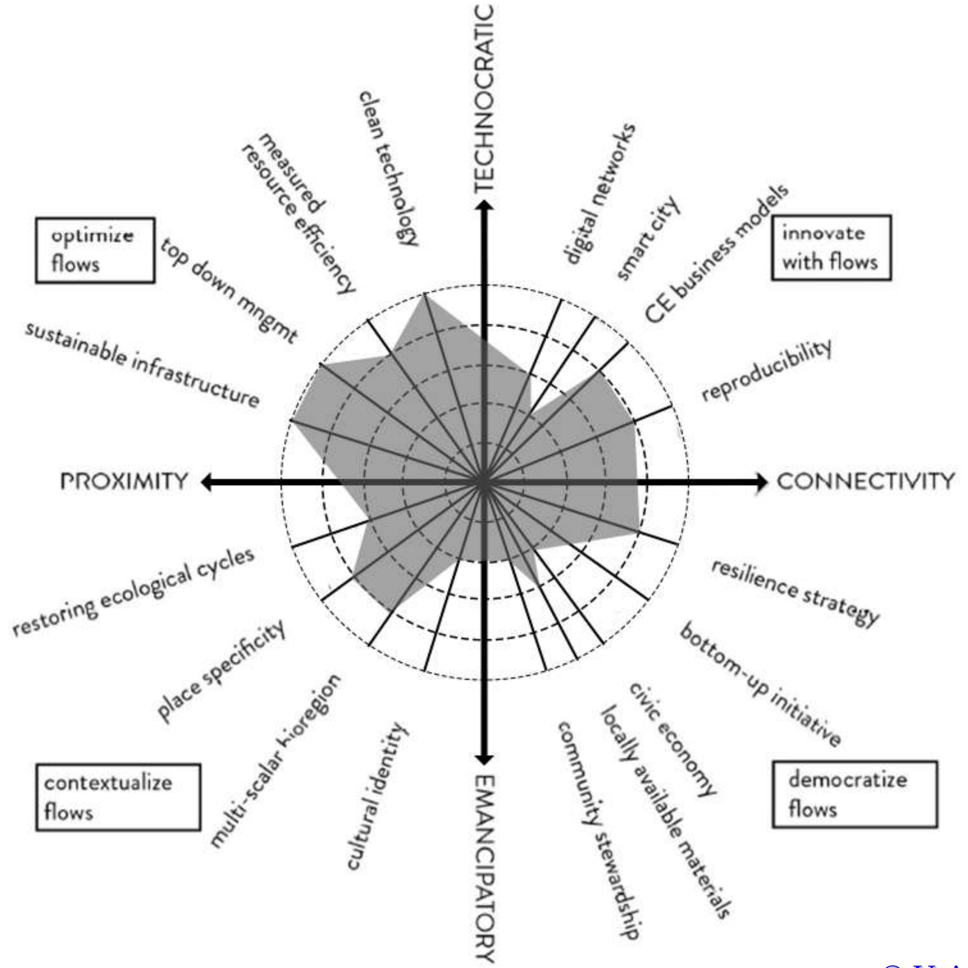


Figure 2.17: Bio2Watt Bronkhorstspruit (Bio2Watt 2021)
Figure 2.18: Uilenkraal Biogas Project (CAE 2015)
Figure 2.19: Production Spatial Circularity Framework Analysis (Author 2021)

BIGH - Ferme Abattoir
Location: Brussels, Belgium
Status: Completed 2015

Ferme Abattoir, or The Abattoir Farm, is a circular economic driven architectural intervention on the rooftop of a food market within Brussels. The project is driven by the principles of circularity and utilizes the various synergies between the farm's systems, the architecture, and the larger community and neighbourhood (Beckers 2019). The intervention is based around an aquaponics production system. The nutrient rich water from the fish rearing tanks are utilized within the greenhouse for growing produce, recreating the natural ecosystemic process. The precedent is developed to shorten the process-chain of food consumption, as the majority of food waste in the process occurs within the processing and transportation of produce, by creating a localised urban agricultural economic model (ibid). Along with controlled-conditions of the greenhouses, the includes large community garden spaces which encourage social interaction and community engagement.

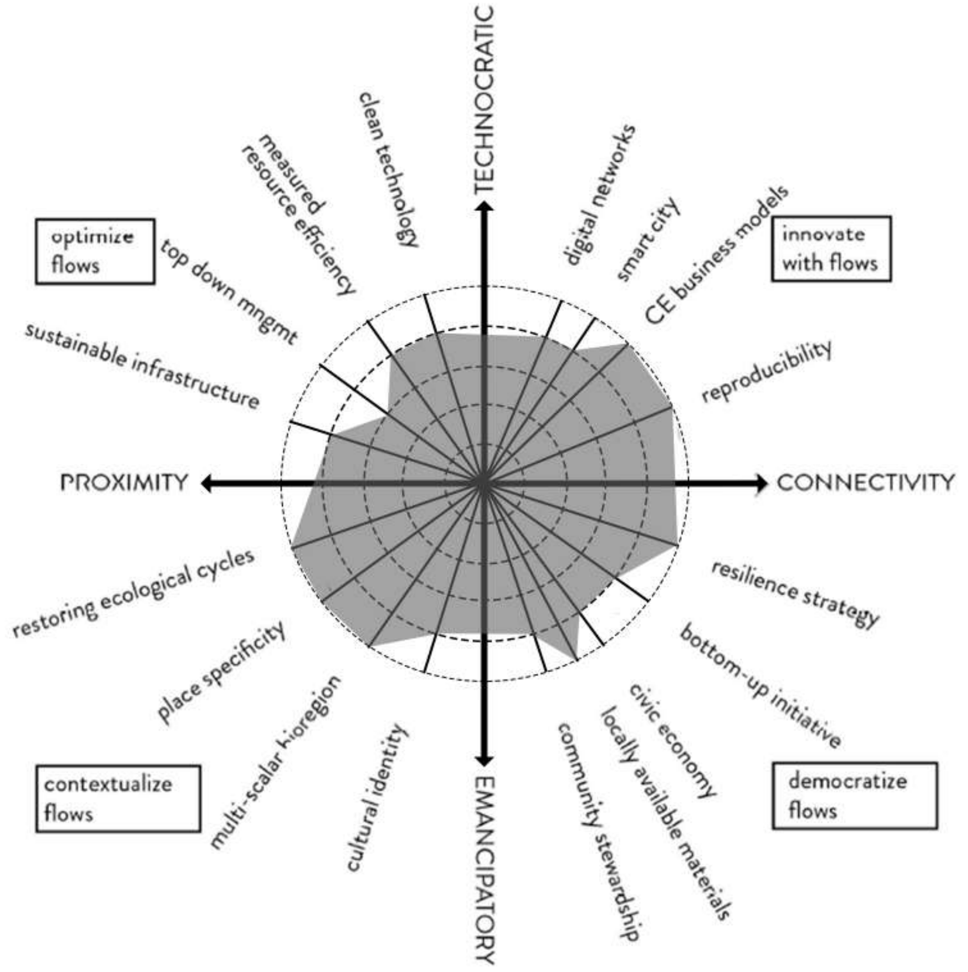
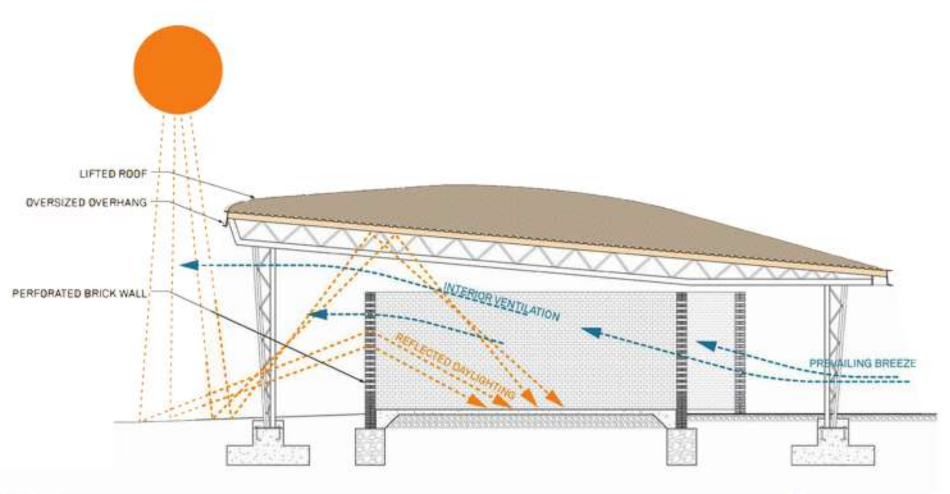
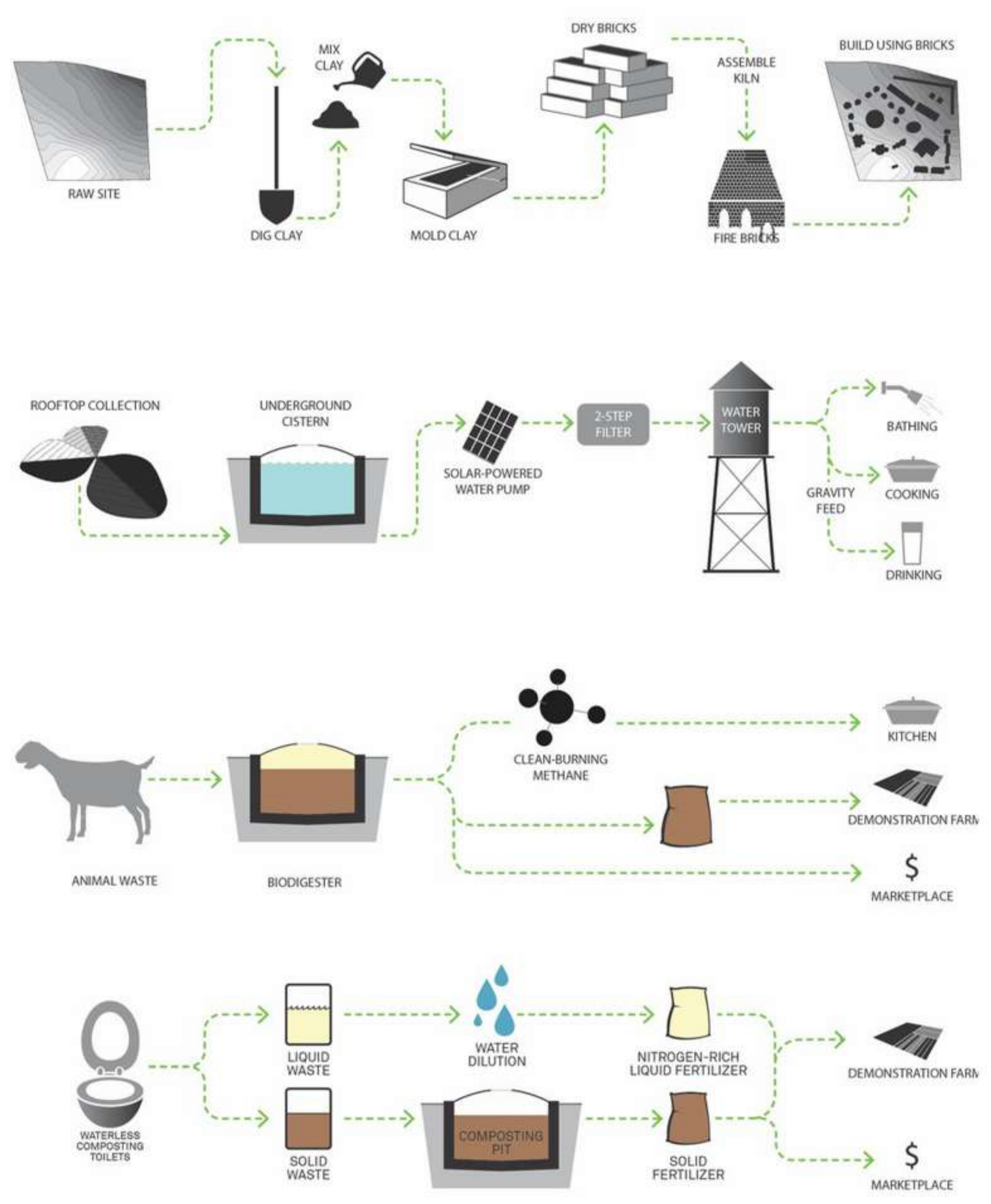


Figure 2.20: BIGH Ferme Abattoir Images and Aquaponics Process (BIGH 2021)
Figure 2.21: BIGH Ferme Abattoir Spatial Circularity Framework Analysis (Author 2021)





Sharon Davis Design - Women's Opportunity Centre
Location: Kayonza, Rwanda
Status : Completed 2013

The intervention creates a strong sense of identity through the incorporation of a vernacular Rwandan village typology and construction methods (Sharon Davis Design, 2021). The intervention demonstrates a layered approach to skills development and the creation of economic opportunities. The community were taught how to create sun-dried clay bricks, utilizing the soil found on site. The intervention contains a community agricultural programme to develop food security as well as a source of income from selling produce. Various livestock is kept on site. The community were taught how to raise the various animals which can then be an additional source of nutrition and income. Furthermore, partnerships were established to utilize the manure of the animals as an input within the biogas-energy facility.

The intervention demonstrates the place-based and multi-scalar manifestation of circularity,as well as a holistic systems-approach, and climatic-adaptive design strategies (ibid). By utilizing earthen-materials and construction methods, the embodied carbon of the intervention is minimized. The perforated brick walls also allow for passive ventilation, whilst creating a sense of privacy. The roof-shape allows for rainwater harvesting, which is then stored in underground storage tanks as well as a water tower. Composting toilets, as an alternative approach to the pollutive pit latrines typically found in Rwanda, are utilized to reduce water consumption as well as to capture nitrogen-rich solid and liquid waste. The waste, after being processed, can then be utilized as organic fertilizer with the agricultural programme or can be sold as a further economic opportunity.

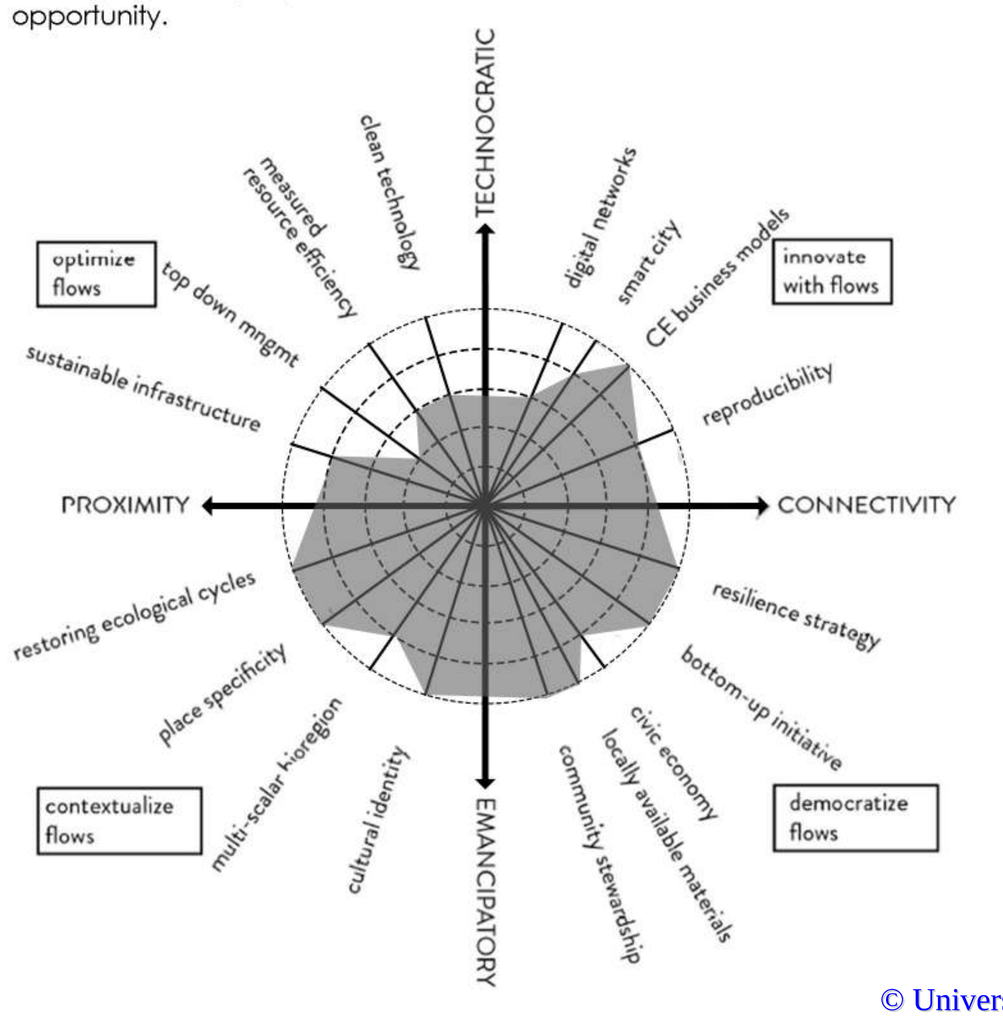
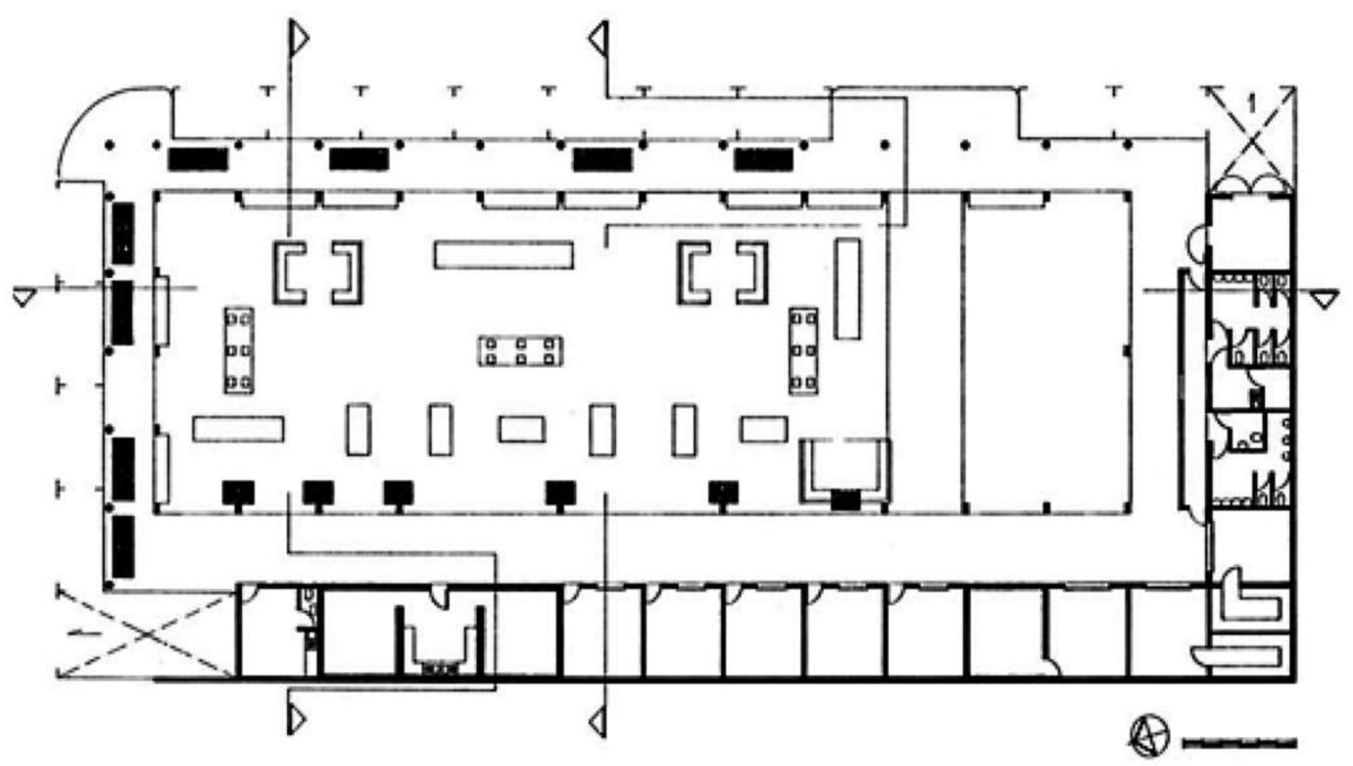


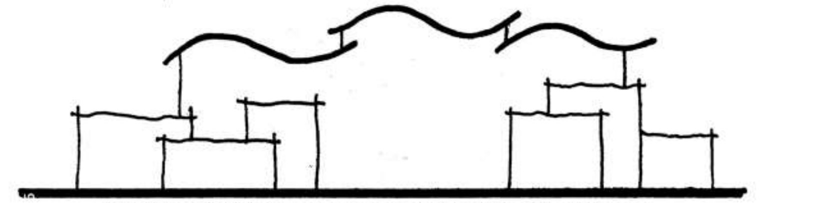
Figure 2.22: Women's Opportunity Centre Systems Diagram (Sharon Davis Design 2021)
Figure 2.23: Women's Opportunity Centre Perspectives (Sharon Davis Design 2021)
Figure 2.24: Women's Opportunity Centre Spatial Circularity Framework Analysis (Author 2021)



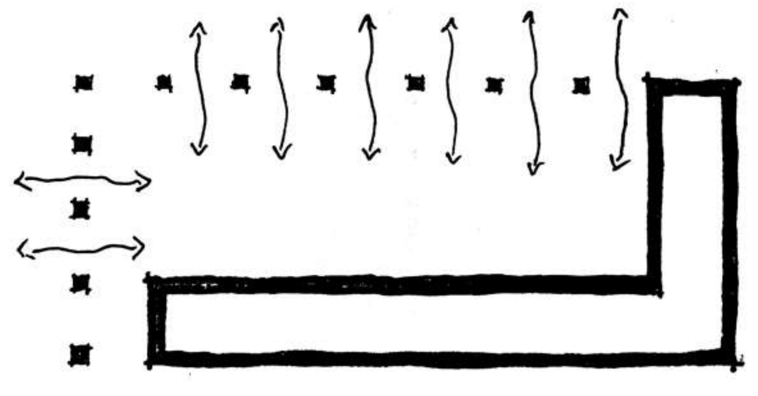
Carin Smuts Architects - Gugulethu Central Meat Market
Location: Gugulethu, Western Cape, South Africa
Status: Completed 1996

The Gugulethu Central Meat Market is an exemplary precedent of a bottom-up design approach. Extensive workshops were conducted with the local community to understand the needs of the community, which was then translated into an architectural intervention. The intervention demonstrates an interplay between permanence and flexibility, as well as permeability and impermeability. On plan, the design is L-shaped. The architect, Carin Smuts (Carin Smuts Architects, 2021), describes the permanent programmatic accommodation - spaza shops, public ablutions, offices, etc - as being contained within a "thickened wall". The northern and eastern facades contain a high degree of permeability towards the streetscape. Roller shutter doors are utilized to close the market at night. Due to a large-span, steel roof structure, the internal space is freed up to allow for flexibility of programme. Furthermore, the roof shape, which resembles a giant wave, contributes to an iconic silhouette on the horizon, acting as a landmark structure in its context.

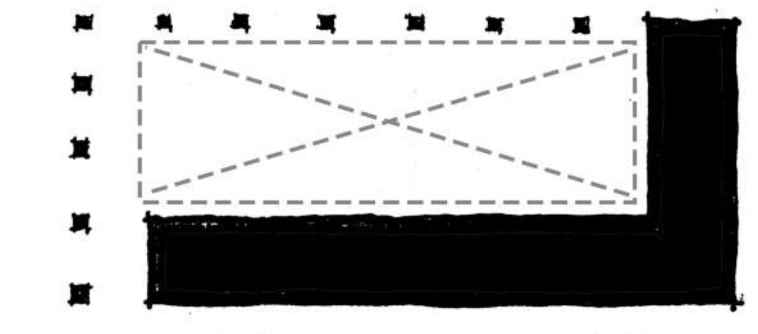
The precedent represents resilience in terms of its flexibility of programme due to the large open-plan development of the intervention. By utilizing a structural methodology capable of large spans , the floor plan has a high degree of flexibility and allows the community to appropriate the space to meet their changing needs (3XN 2019).



Iconic roof-structure serves as landmark on the horizon.



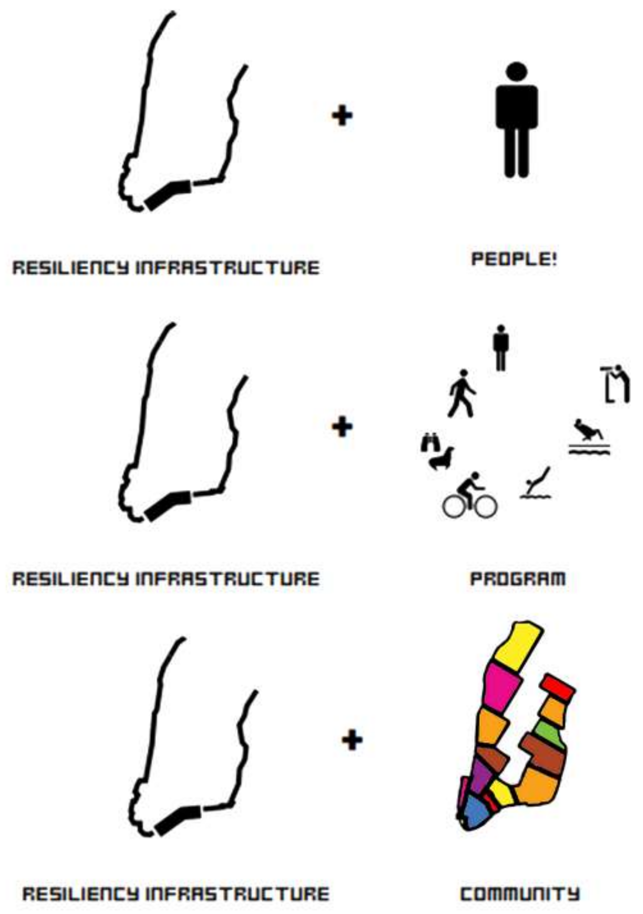
L-Shaped plan creates strong sense of permeable vs impermeable.



"Thickened Wall" of fixed programmatic functions vs flexibility of programme within internal space.

Figure 2.25: Gugulethu Central Meat Market Plan (Carin Smuts Architects 2021)
Figure 2.26: Gugulethu Central Meat Market Perspectives (Carin Smuts Architects 2021)
Figure 2.27: Landmark, Permeability, Flexibility Diagrams (Author 2021)

PRECEDENT - RESILIENT SOCIAL INFRASTRUCTURE



Bjarke Ingels Group - The Big U
Location: Lower Manhattan, New York
Status: In Progress

After the devastating effects of hurricane Sandy in 2012, various structural and environmental vulnerabilities were exposed within communities in the affected areas. The project is a winning competition entry for the Rebuild by Design competition, an initiative aimed at minimizing the above-mentioned vulnerabilities. The project is conceptualized as a piece of resilient, social infrastructure, extending beyond the scope of creating a flood-protection system by developing a dynamic and flexible social landscape with various opportunities for interaction, play and rest (BIG 2021).

Similar to that of hurricane Sandy, Covid-19 also exposed various social, economic and environmental vulnerabilities within the study area and the adjacent communities. With the threat of additional climate-events, this precedent exemplifies a design methodology that functions in a hybrid-state, aiding in environmental and infrastructure resilience, whilst also developing social and cultural resilience.

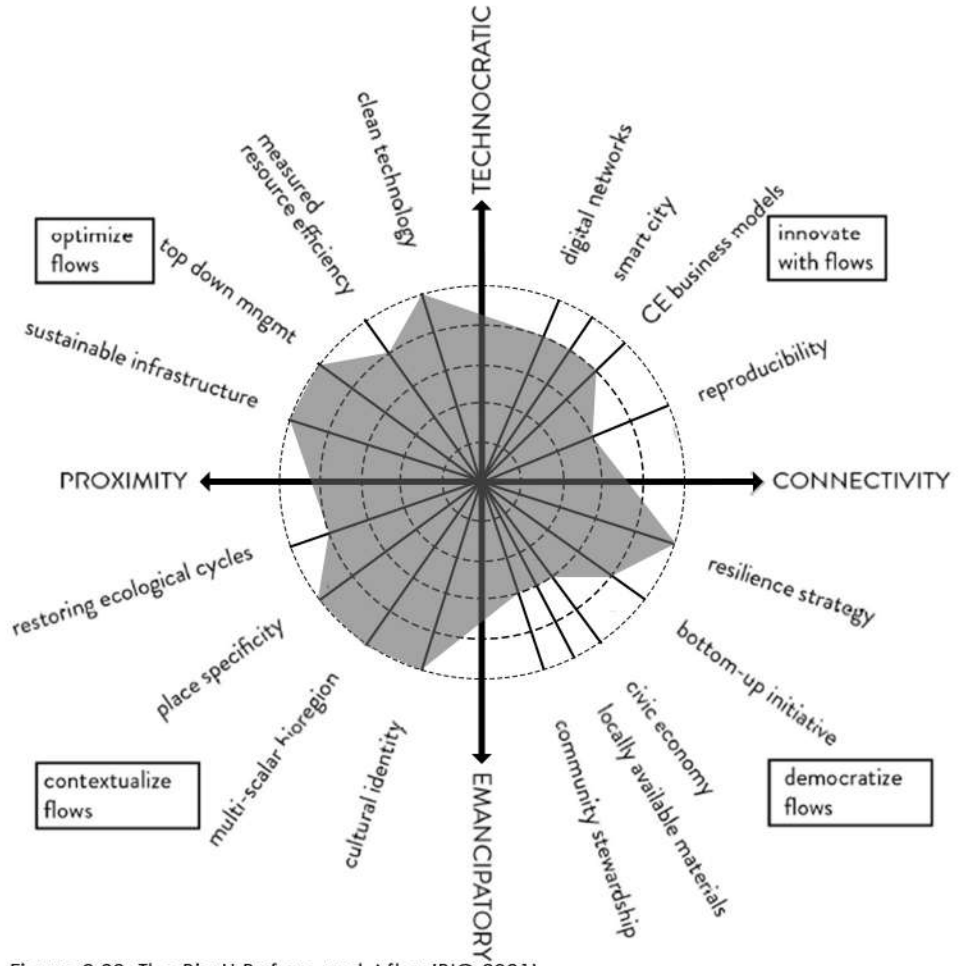
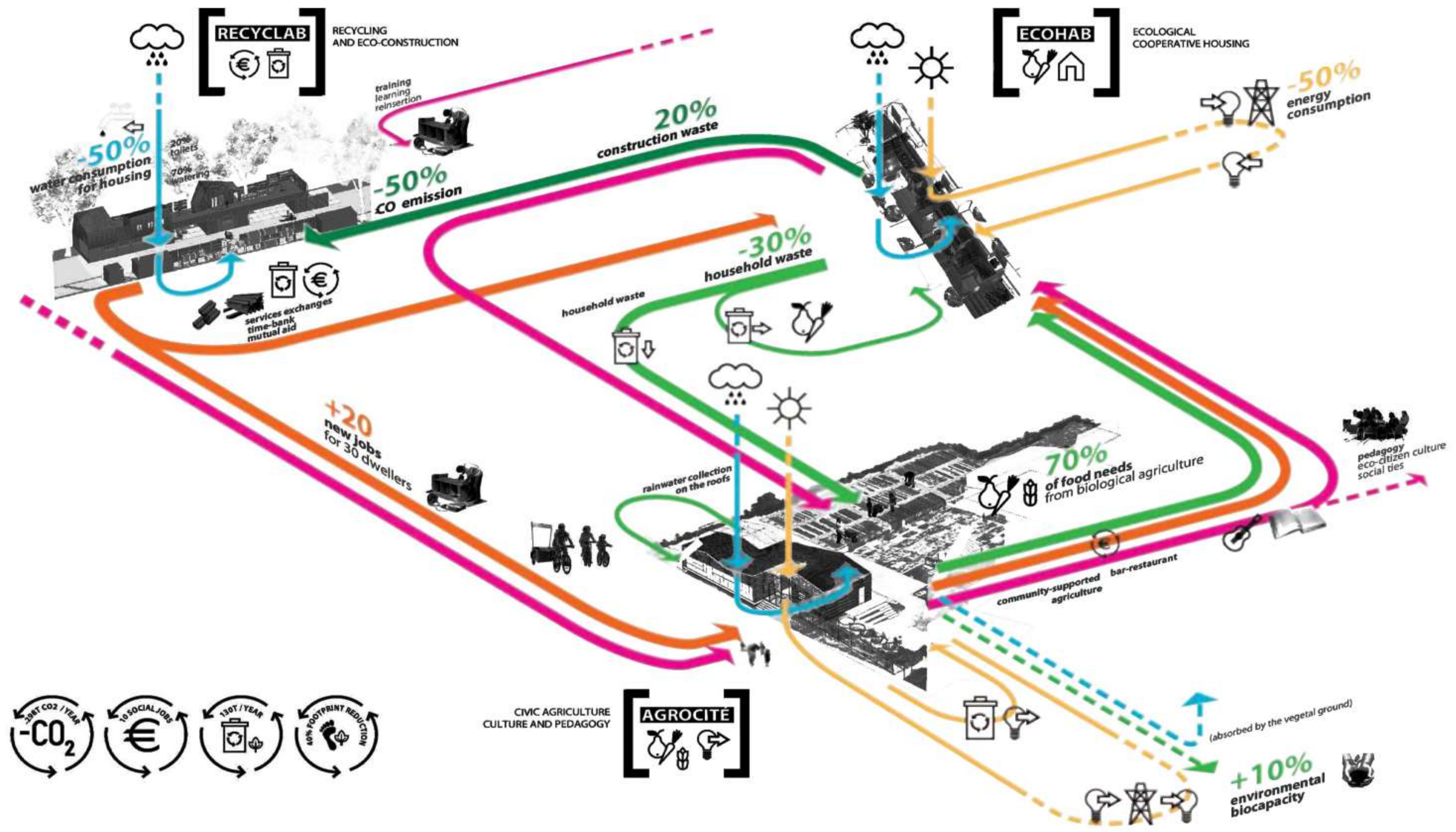
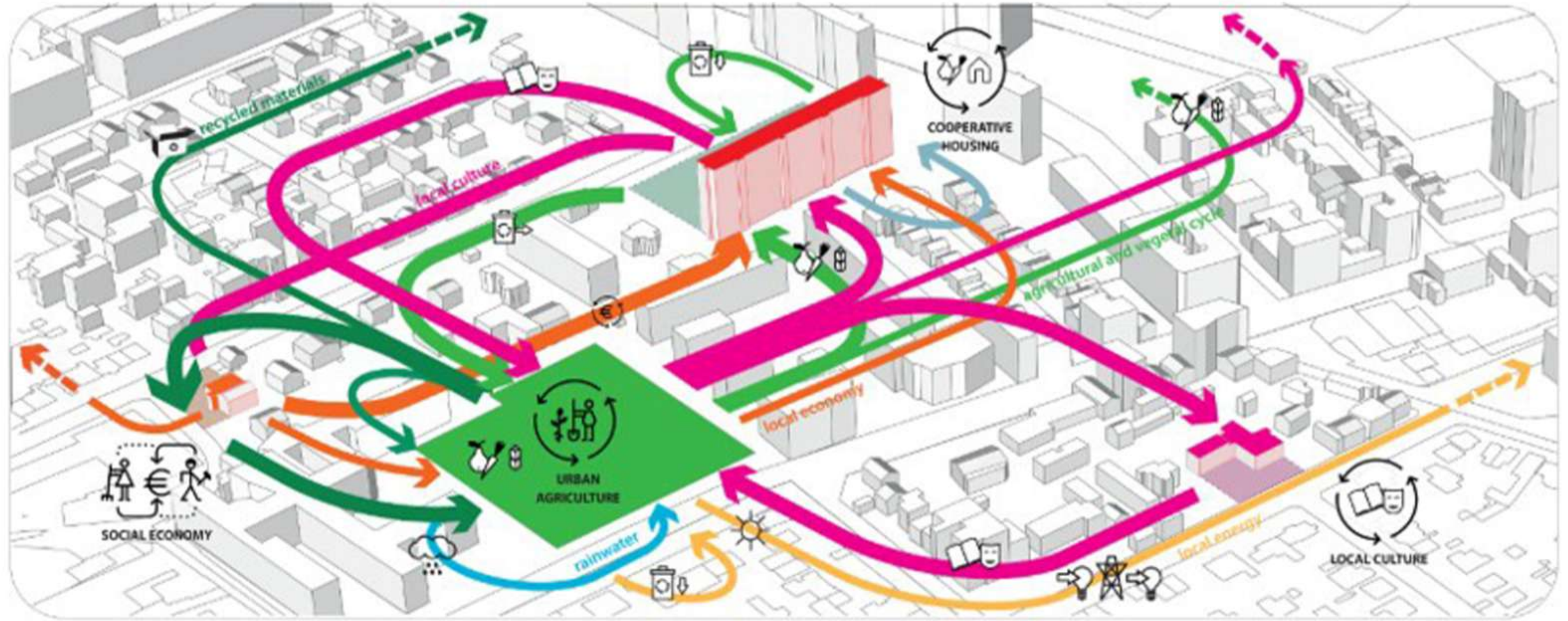


Figure 2.28: The Big U Before and After (BIG 2021)
Figure 2.29: The Big U Diagram - People, Programme, Community (BIG 2021)
Figure 2.30: The Big U Spatial Circularity Framework Analysis (Author 2021)

PRECEDENT - URBAN CIRCULARITY





Atelier d'Architecture Autogeree (AAA) - R-Urban
Location: Colombes, France
Status: Completed 2008

R-Urban is a bottom-up framework that was developed to generate regenerative urban resilience through closed-looped resource cycles. The framework builds upon the theoretical premise of Howard's Garden City (1889) and the theory of ecological urbanism. The project is closely aligned to Vandenbroeck's constructivist spatial worldview and connectivity-based urban metabolic spatial structure. Unlike top-down planning spatial structures, this intervention is driven through an emancipatory strategy of co-production and inclusive participation. This strategy of emancipation is aimed at building social and cultural-economic resilience over time.

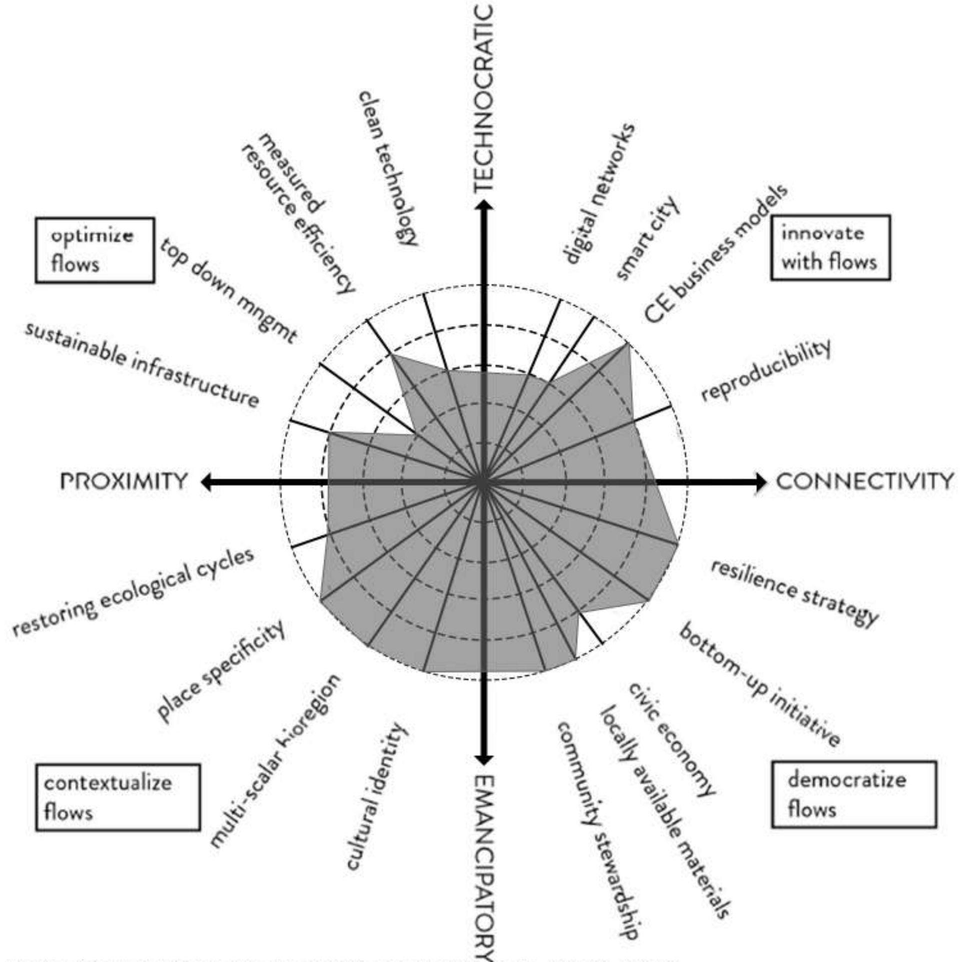


Figure 2.31: R-Urban Cyclical Systems Diagram (R-Urban 2021)
Figure 2.32: R-Urban Multi-Scalar Integration (R-Urban 2021)
Figure 2.33: R-Urban Spatial Circularity Framework Analysis (Author 2021)

The Circularity Spatial Manifesto

The Circularity Spatial Manifesto is developed to be place-based, multi-scalar, and a response to open and linear resource loops and systems that cause vulnerabilities of the study area. Due to the existing linear and open resource loops and systems, a diminishing reinforcement feedback loop - vicious cycle - is created (Meadows, 2008)). The vicious cycle of vulnerability and lack of resilience decrease the study area's ability to recover from system shocks such as Covid-19 and climate events (ARUP, 2016).

Building on the theoretical framework, study area analysis, Spatial Circularity Framework, and the precedent studies, a consolidated design manifesto is created as a spatial manifesto for circularity. The Circularity Spatial Manifesto serves as a strategy to inform design decisions that will aid in reducing the vulnerabilities and stresses of the study area, whilst developing resilience and increasing the liveability of the community.

Contextual Spatial Informants

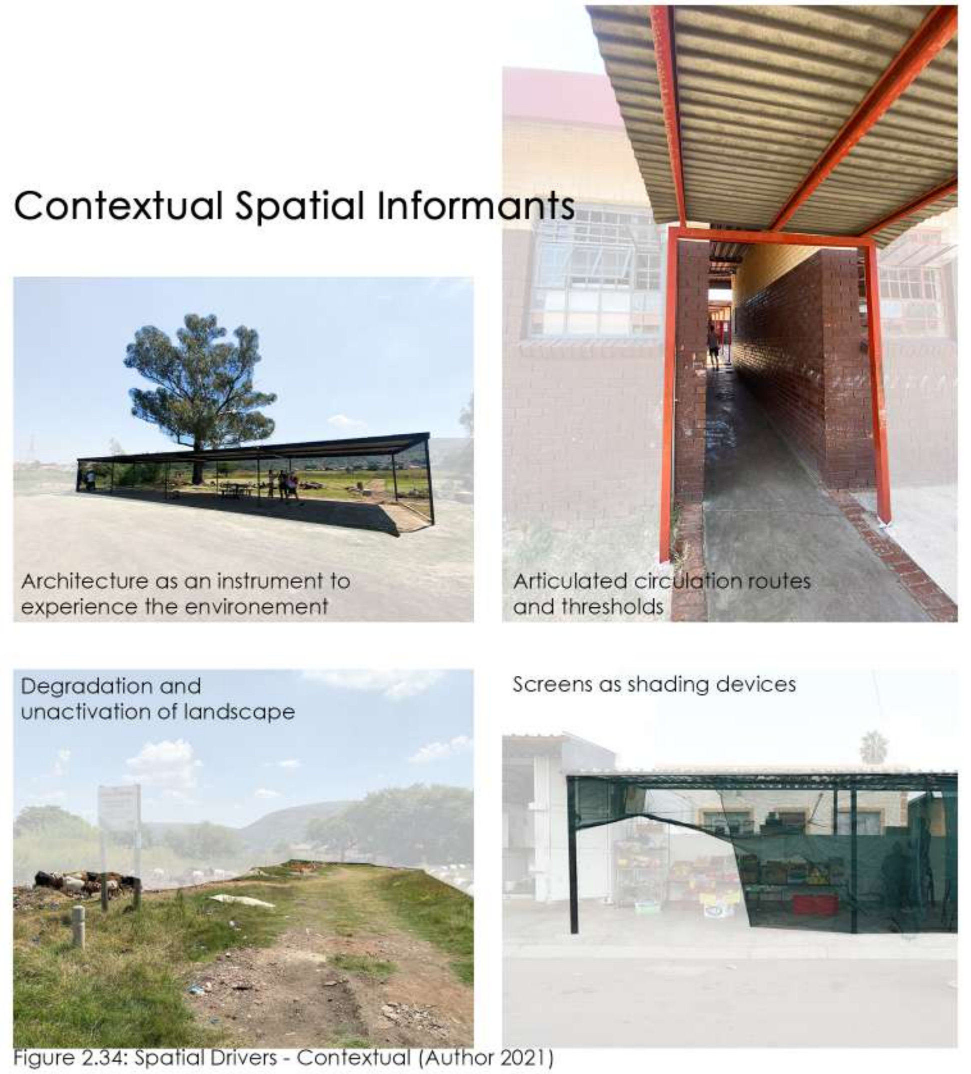


Figure 2.34: Spatial Drivers - Contextual (Author 2021)
Figure 2.35: Spatial Drivers - Circularity Spatial Manifesto (Author 2021)
Figure 2.36: Summary of Spatial Drivers (Author 2021)

ACCESS & CONNECTEDNESS

The intervention must provide access to a healthy and productive environment. This includes basic services such as sanitation, education and the internet, health facilities, as well as access to a range of economic opportunities and a healthy physical environment.

CITY IS NATURE

The intervention must integrate ecological design strategies with the design to develop an integrated and regenerative response between the built and natural environment. The principles of biophilic and regenerative design have shown to provide a positive impact on societal health.

LOCAL IS GLOBAL

The Intervention must utilize local resources and skills, drawing upon indigenous knowledge and practices.

VALUE-ADDED DESIGN

The intervention must add value and create a positive impact on the local community and within the greater context. The intervention must create a growing reinforcement feedback loop to create a virtuous cycle of resources and opportunities within its specific context.

SERVICE LIFE

The intervention must be designed with the life-cycles and maintenance of the various components in mind. This relates to a design with visible and accessible services and connections so that elements with short life-cycles can easily be changed without disruption of the usual operations of the intervention. The concept of Shearing Layers, developed by Stewart Brand, is used to understand the various elements of an intervention and their respective life-cycles.

INCLUSIVITY, DIVERSITY & EQUALITY

The intervention must engage with and include all members and cultures of the community as well as vulnerable groups. The intervention must foster a sense of shared ownership and agency, safety, community identity, and create equal opportunities for engagement, interactions, and work to develop resilience.

WHOLE-SYSTEMS THINKING

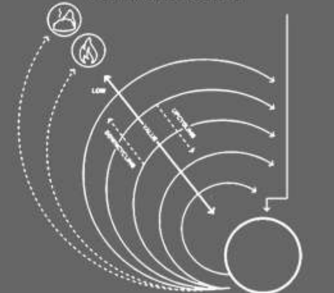
The intervention must be designed to respond and fit into a "larger context" system as opposed to a reductionist approach. This applies to both programmatic intention of the intervention as well as the integrated systems within the intervention such as climatic adaptation and resource usage.

FLEXIBILITY

The intervention must incorporate systems that are capable of adapting and evolving in order to respond to systems shocks and the changing condition and needs of its specific context. Flexibility within design refers to the ability of the intervention to change, adapt or evolve spatially as well as programmatically.

CASCADING MATERIALITY

The intervention must be constructed of materials with properties capable of fitting within a cascading system of value. Cascading refers to the idea of prolonging a material's life and value for as long or as many life-cycles as possible. To exploit the inherent potential and value of any material, before we let it go to waste. The intervention must also consider its material choices with regards to the embodied energy of the material as well as its ability to sequester carbon out of the environment to produce healthier environments.



DESIGNING OUT WASTE

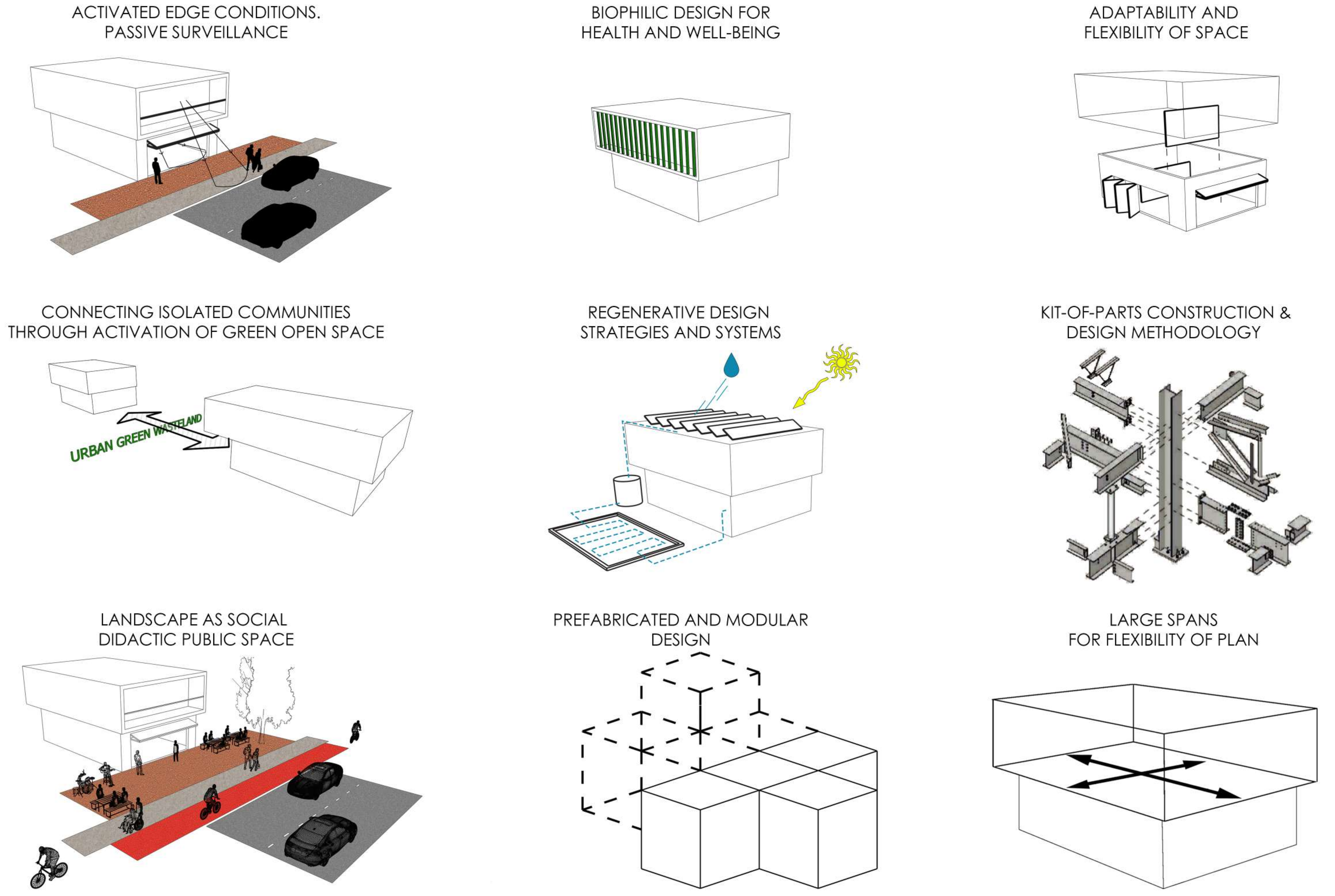
Using the principles of LEAN construction and design, the intervention must be designed through a process & value chain methodology to eliminate any waste out of the design. The intervention must also include a Target-Value-Design strategy.

PREFABRICATED KIT-OF-PARTS

The intervention must be designed with the life-cycles and maintenance of the various components in mind. This relates to a design with visible and accessible services and connections so that elements with short life-cycles can easily be changed without disruption of the usual operations of the intervention. The concept of Shearing Layers, developed by Stewart Brand, is used to understand the various elements of an intervention and their respective life-cycles.

DESIGNING FOR DISASSEMBLY

The intervention must be designed with structural connections that are reversible. Reversible connections allow for repeated assembly and disassembly without causing damage to the original components or materials after a cascading life-cycle.



URBAN VISION

In order to prevent future urban sprawl due to the projected increase of urban population, a masterplan is developed to ensure the rehabilitation and conservation of the natural capital on site.

The urban vision, developed as an ecological corridor, serves as resilient, social and ecological infrastructure to allow for biodiversity conservation and social engagement within the natural landscape.

Projected urban sprawl due to rapidly increasing urban population

Circulation patterns on site informing ecological corridor and urban vision

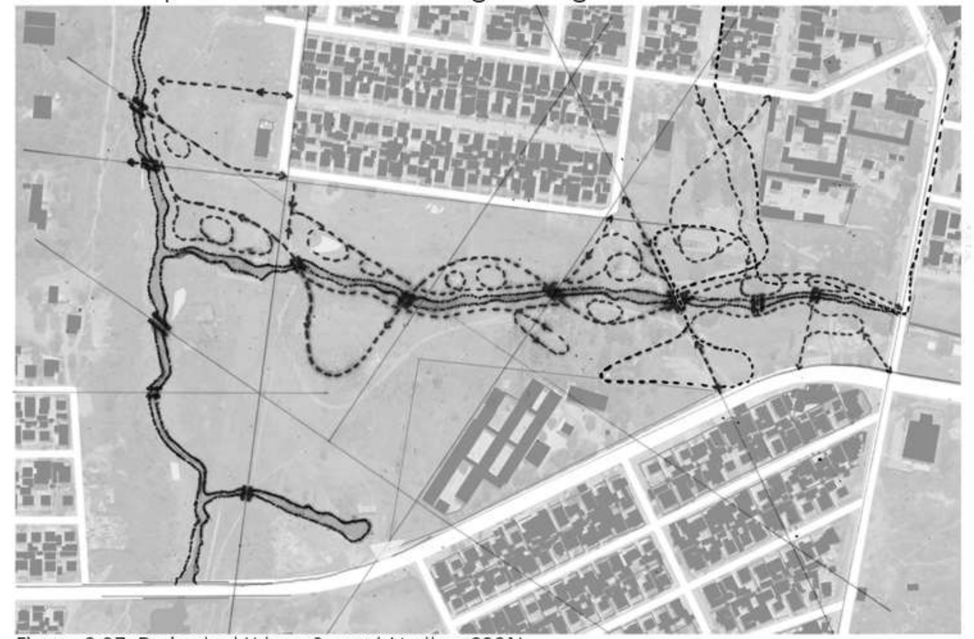
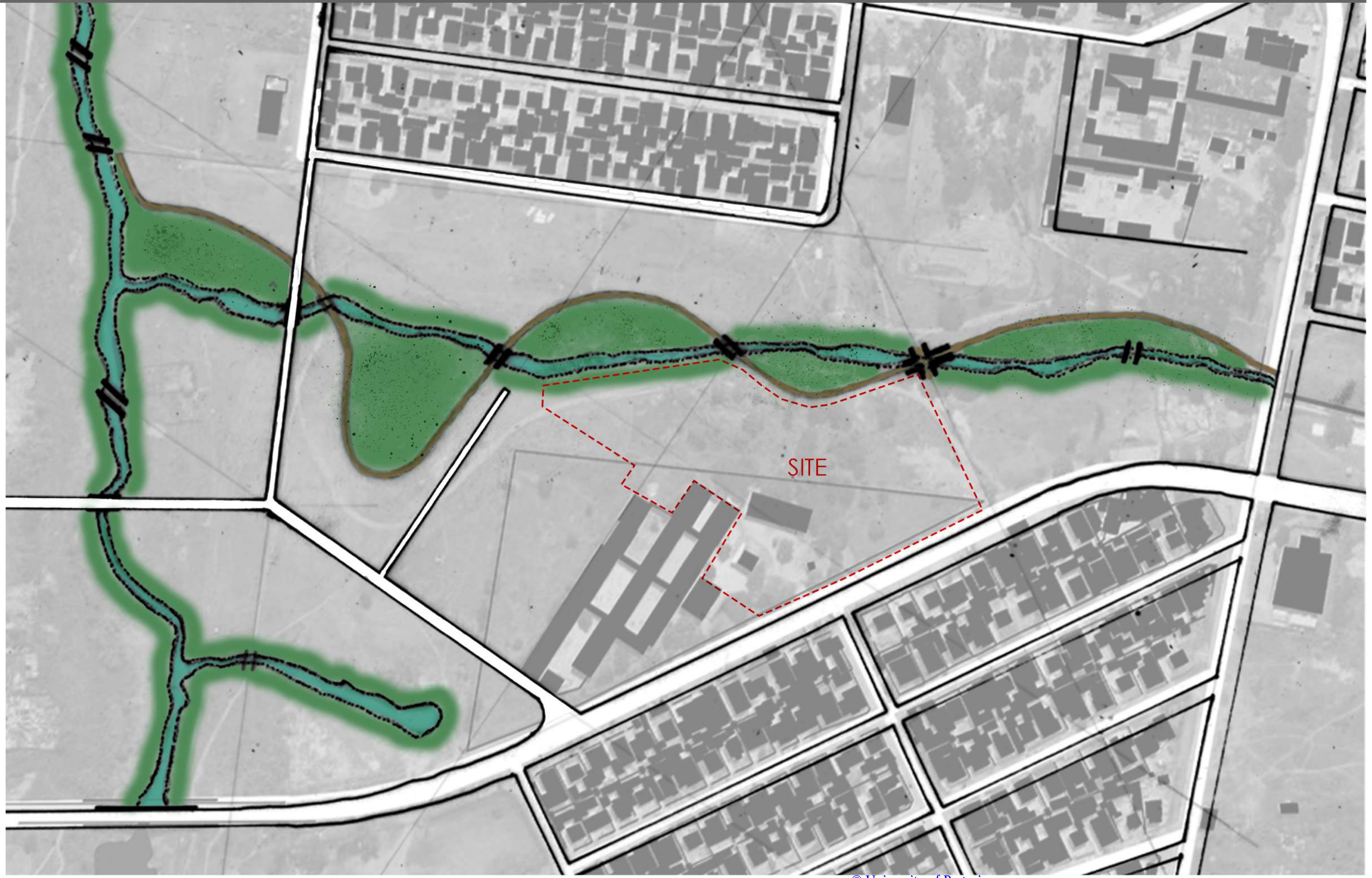
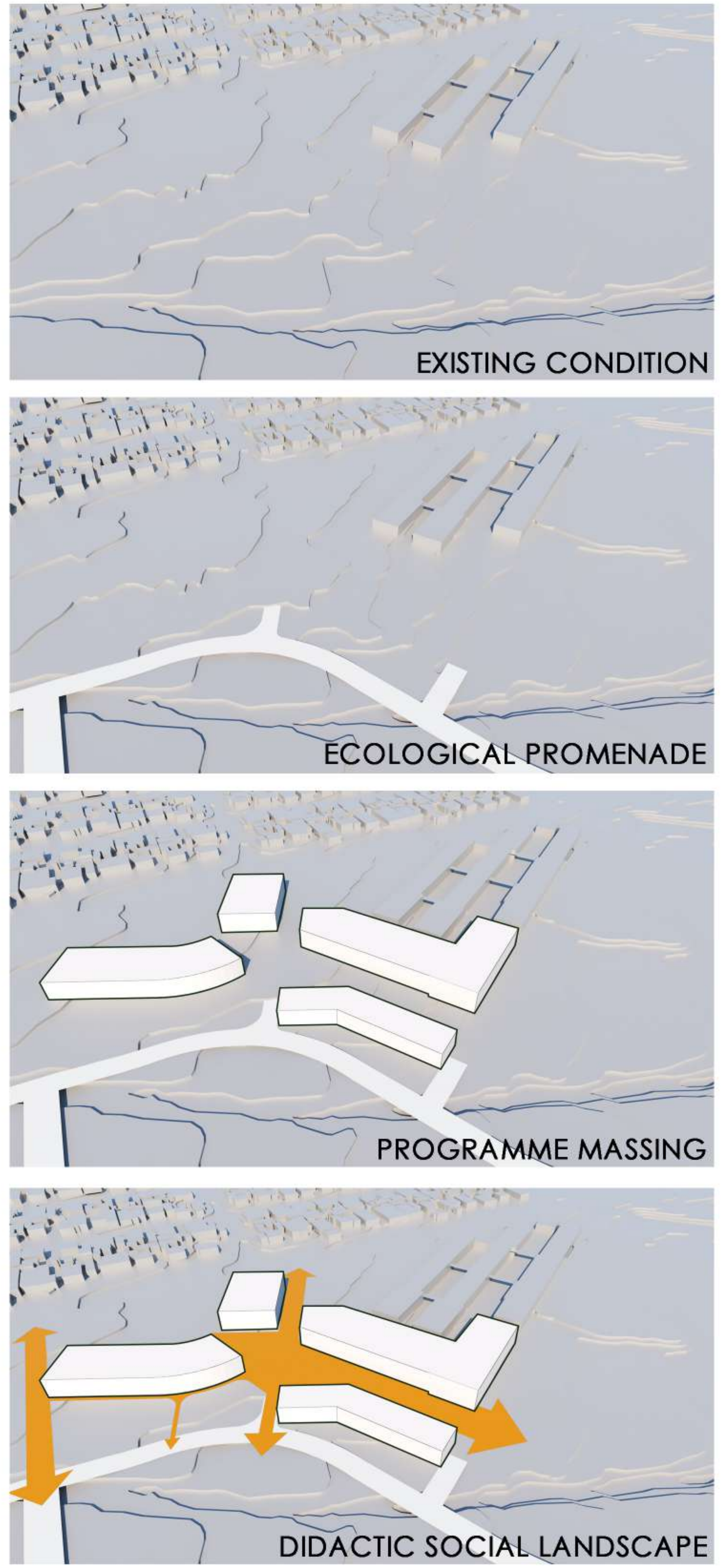


Figure 2.37: Projected Urban Sprawl (Author 2021)
Figure 2.38: Circulation patterns on site informing urban vision (Author 2021)
Figure 2.39: Urban Vision (Author 2021)





SITE SELECTION

SITE SELECTED FOR ARCHITECTURAL DEVELOPMENT

The final site for design development is informed by the theoretical framework, the study area analysis, as well as the selected programme.

The site is selected based on the criteria of the developed programme:
1) Cattle must be present on the site.
2) The site must be able to connect to a primary or secondary school.
3) The site must border the river edge to become part of the rehabilitation and flood-protection strategy.

Based on the above-mentioned criteria, the selected site was revealed as the most appropriate choice.

CONCEPTUAL DEVELOPMENT

THE DIDACTIC SOCIAL LANDSCAPE

The concept builds upon the proposed ecological corridor and seeks to establish an intervention that creates a resilient social, educational, and economic infrastructure.

The development of the programme's form and placement to one another creates an internal shared courtyard that allows for users to engage with the programme as well as the ecological landscape.

CONCLUSION

TOWARDS CHAPTER 3 - MANIFESTING

Building on Chapter 1, Chapter 2 - Identifying - was established to uncover and reveal where circularity can be injected within the study area to act as agent of cultural economic resilience within a place-based, multi-scalar design methodology. Chapter 2 identified the programme and the site, and also generated the Circularity Spatial Manifesto and design drivers that acts as the springboard for Chapter 3 - Manifesting.

.

Figure 2.40: Conceptual Development (Author 2021)

PART 3

MANIFESTING

The spatial manifestation of circularity

The purpose of Part 3 is to demonstrate how the understanding of the circularity spatial manifesto, as developed in Part 2, along with the identified design drivers, can manifest spatially the programmatic intention to develop holistic circularity within the study area of Mamelodi.

Figure 3.1: (left) Social Landscape Perspective (Author 2021)
Figure 3.2 (right): Perspective Render of Final Design (Author 2021)

THE DESIGN PROCESS

Building on Part 2 of this dissertation, Part 3 translates and develops the identified circularity spatial manifesto, as well as the various design drives, into a spatial model that manifests and concretizes the identified programme within its context.

The design process consists of a series of iterations, with each iteration building upon its previous version. This allows for a well grounded and critically evaluated design response

ITERATION 1 - BUMF EXPLORATION

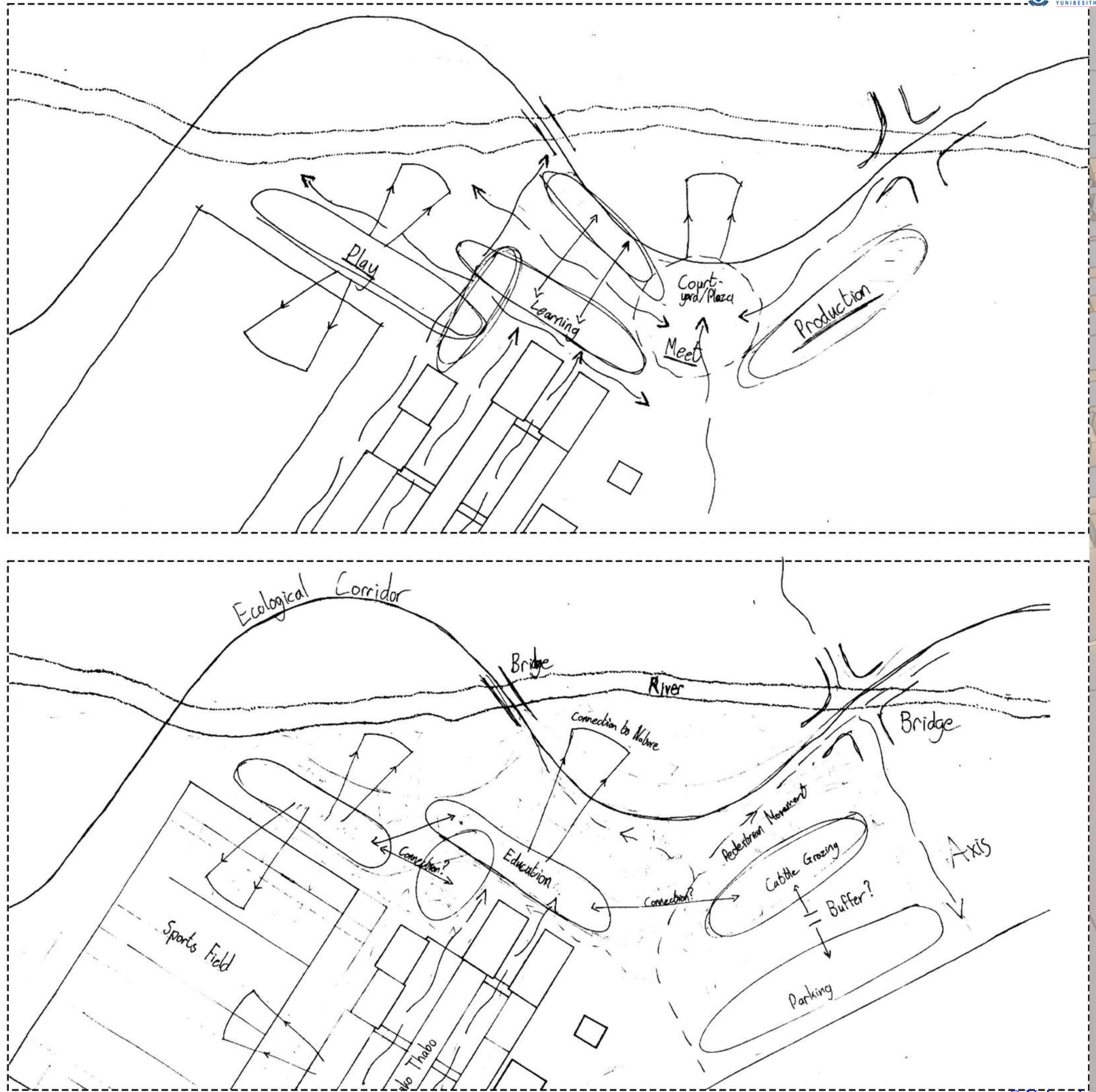
Iteration 1 - Bumf Exploration

From the onset of the design process, the ecological corridor developed within the urban vision of this dissertation plays a leading role in the spatial hierarchy and organisation of space. The identified programme is conceptualized as a series of structures, each with their own respective function, stitched together and connected through the landscape.

The orientation and location of the structures is developed to allow for a space of convergence, creating an opportunity for social engagement through a central connecting courtyard. Furthermore, the design positions itself as an extension of the high school, emphasizing the importance of the educational drivers of the programme and spatial design.
The design proposes the addition of a new sports field adjacent to the western side of Tsako Tsabo High School, adding an element of play to the programme.

Iteration 1 Critique

Although still in the very early stages of the design process, the design seeks to generate an integrated response between the built and the natural, between architecture and landscape. However, iteration 1 encroaches very closely to the river's edge. Furthermore, iteration one seems to turn its back towards Tsomo street and more consideration should be taken towards activating the edge conditions of the site.



ITERATION 2 - MAQUETTE EXPLORATION

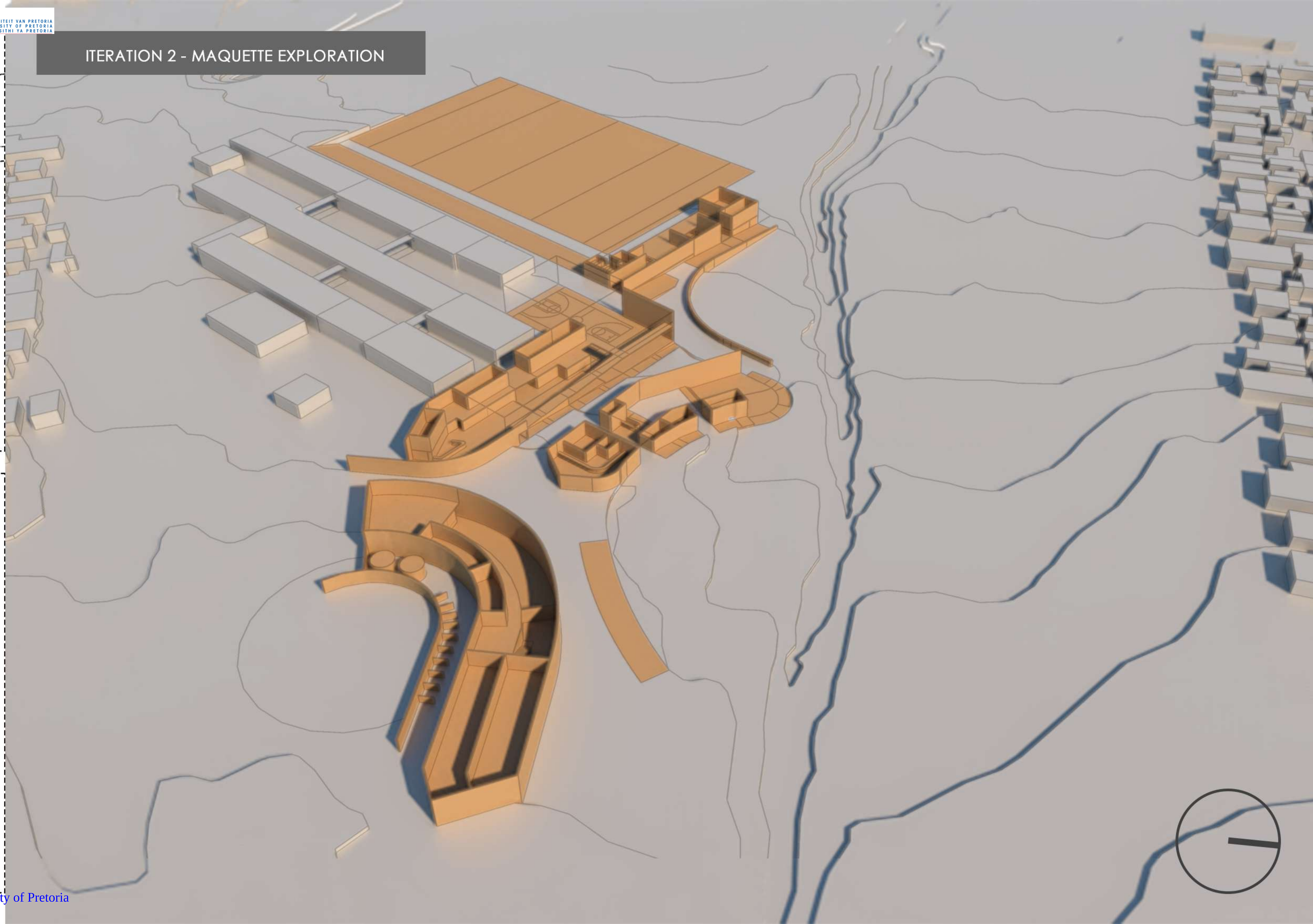


Figure 3.3: (center) Iteration 1 - Bumf Explorations (Author 2021).
Figure 3.4: (right) Digital Maquette Exploration - Iteration 2 (Author 2021)

Iteration 2 - Plan development

Iteration two builds upon iteration one by giving form to the design and programme. The form generated within iteration two is in line with the aim of creating a social landscape and convergence point to facilitate social interaction, as can be seen in the public vs private space diagram of the iteration. Furthermore, iteration two starts to respond to the environmental vulnerabilities of the space and proposes a retaining wall as a flood protection device.

ITERATION 2 CRITIQUE

Although iteration two is beginning to respond to the river's edge condition and floodline, there is no response to the proposed ecological corridor as per the urban vision. Furthermore, the production facility has been designed with very limited production space, which diminishes the viability of the programme. The design still turns its back on Tsomo street and lacks integration with the landscape and its context.

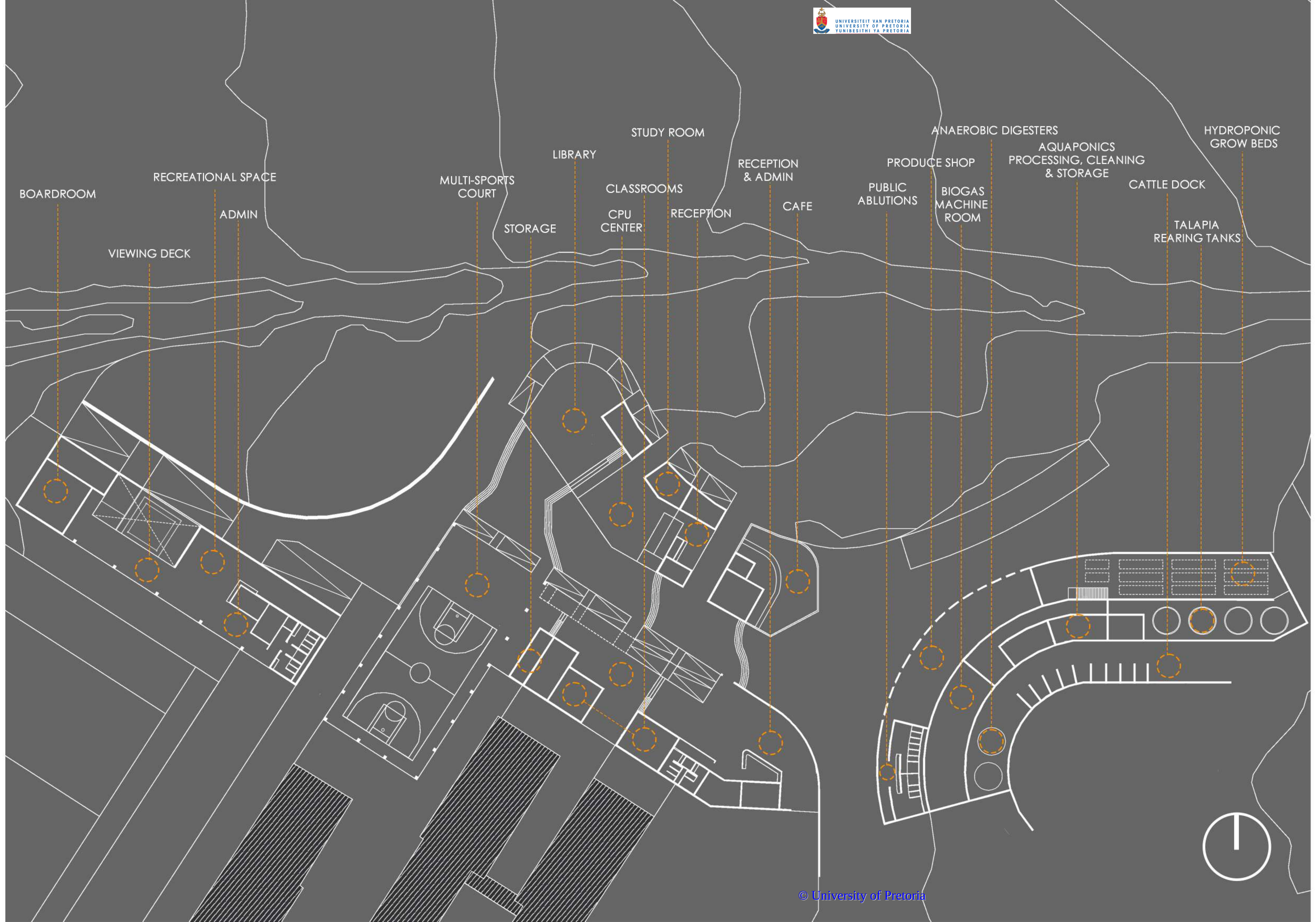
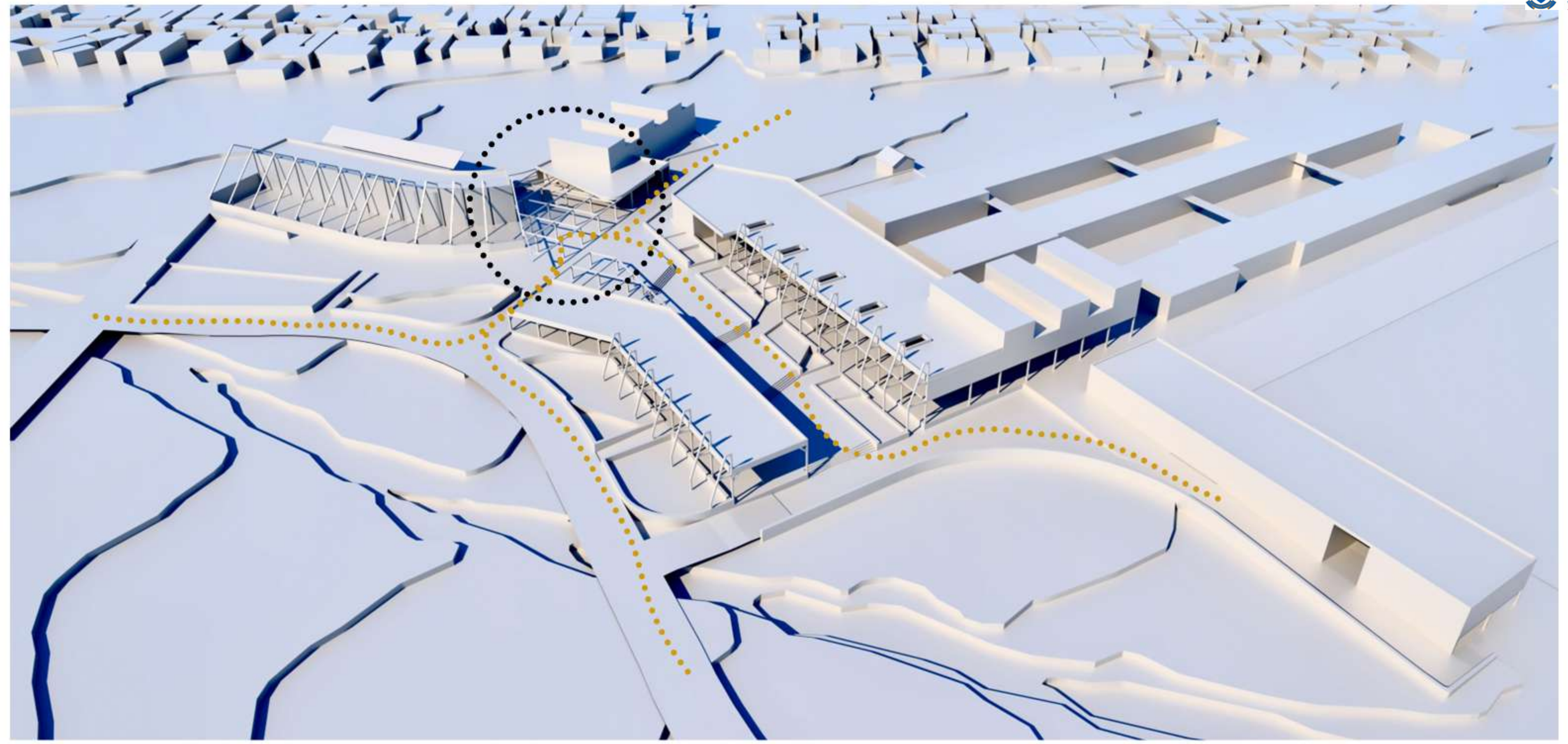


Figure 3.5: Iteration Two Ground Floor Plan (Author 2021)
Figure 3.6: Iteration Two - Public vs Private Space (Author 2021)

ITERATION 3

Iteration three is starting to demonstrate a design and spatial model that is based on whole-systems-thinking and regenerative design strategies. A redevelopment and redesign of the production facility - aquaponics and biogas - along with additional cyclical design strategies such as rainwater harvesting, grey-water recycling, and the filtration of greywater through constructed wetland systems. The water loop can now be utilized in a closed-loop system with the aquaponics facility, rearing tanks, and the additional horticulture agriculture fields. The convergence point within the landscape has now been formalized as a small farm-to-table restaurant. The programme now also includes an auditorium space that connects to Tsako Tsabo Senior School. Additionally, the design starts to consider the ecological corridor as an integral part of the social landscape.



PRIMARY PROGRAMME

Resource Integration Facility

- Anaerobic Digestion (Biogas)
- Aquaculture
- Horticulture
- Constructed Wetland System

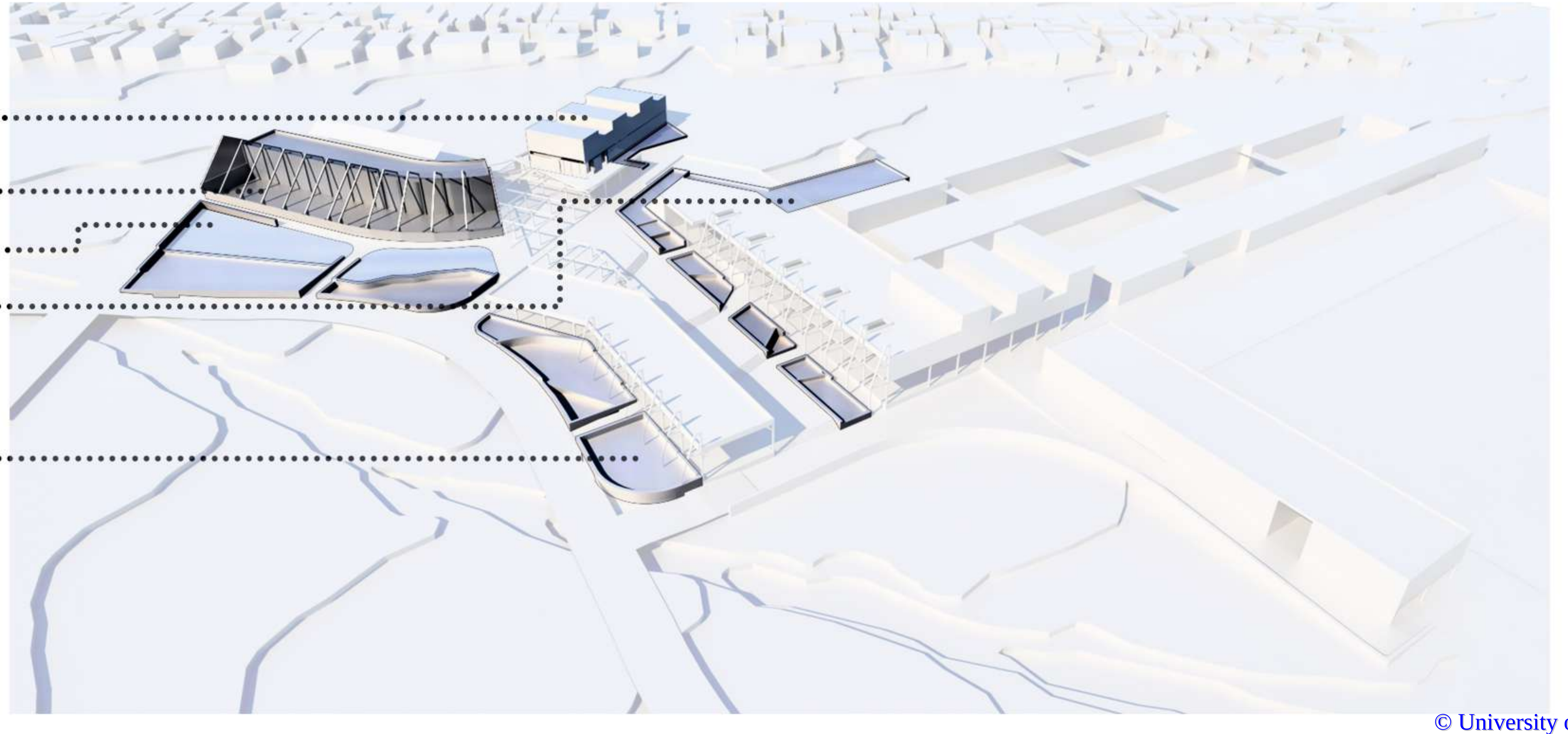


Figure 3.7: Primary Programme (Author 2021)
Figure 3.8: Secondary Programme (Author 2021)
Figure 3.9: Tertiary Programme (Author 2021)

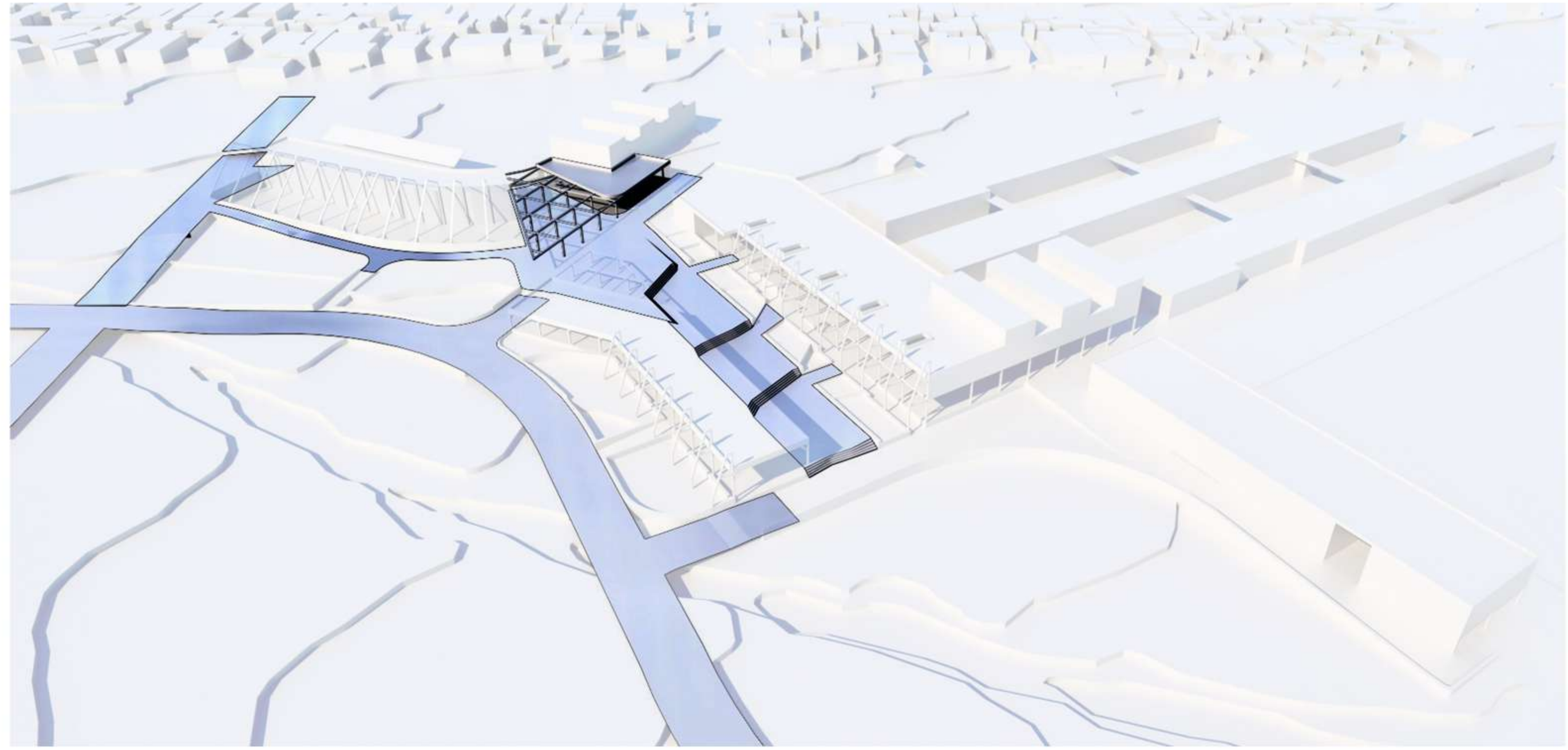
SECONDARY PROGRAMME

- Education Center
- Workshop and Skills Development
- Auditorium

- Public Library
- Computer Center

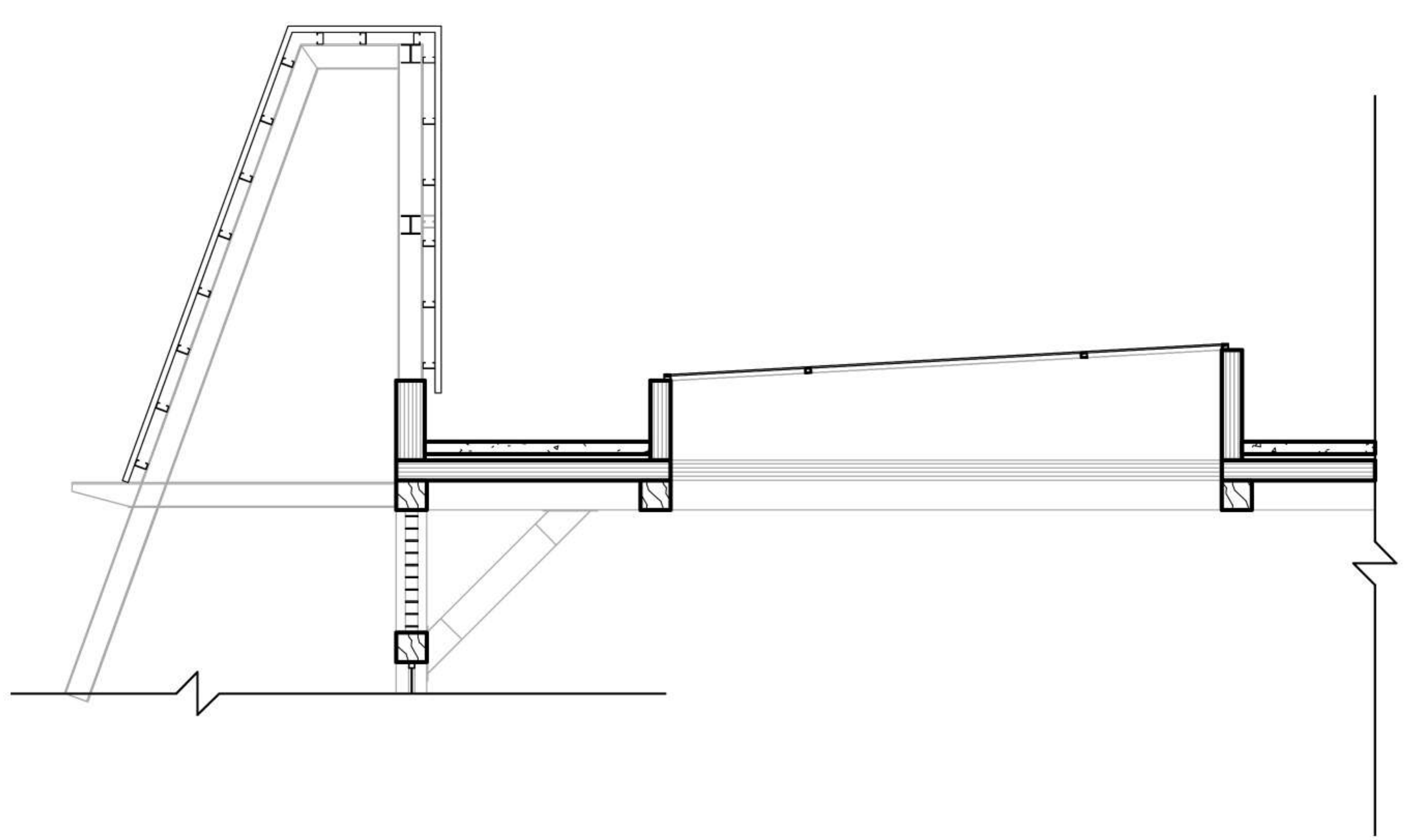
TERTIARY PROGRAMME

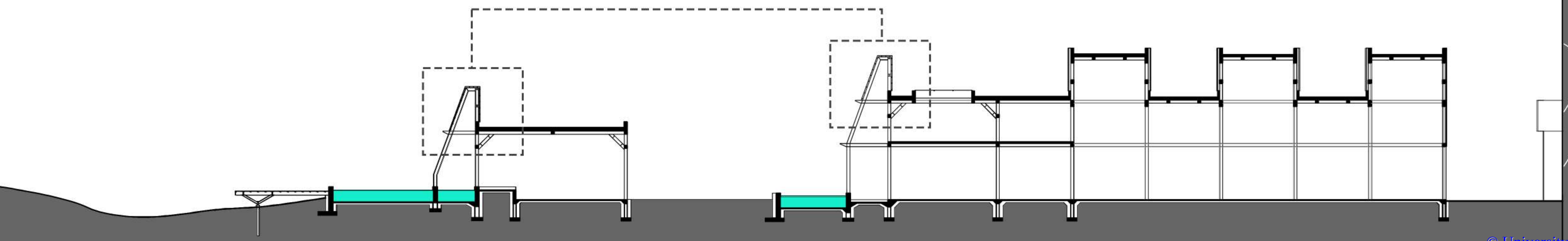
- Didactic Social Landscape
- River Rehabilitation Strategy
- Ecological Promenade

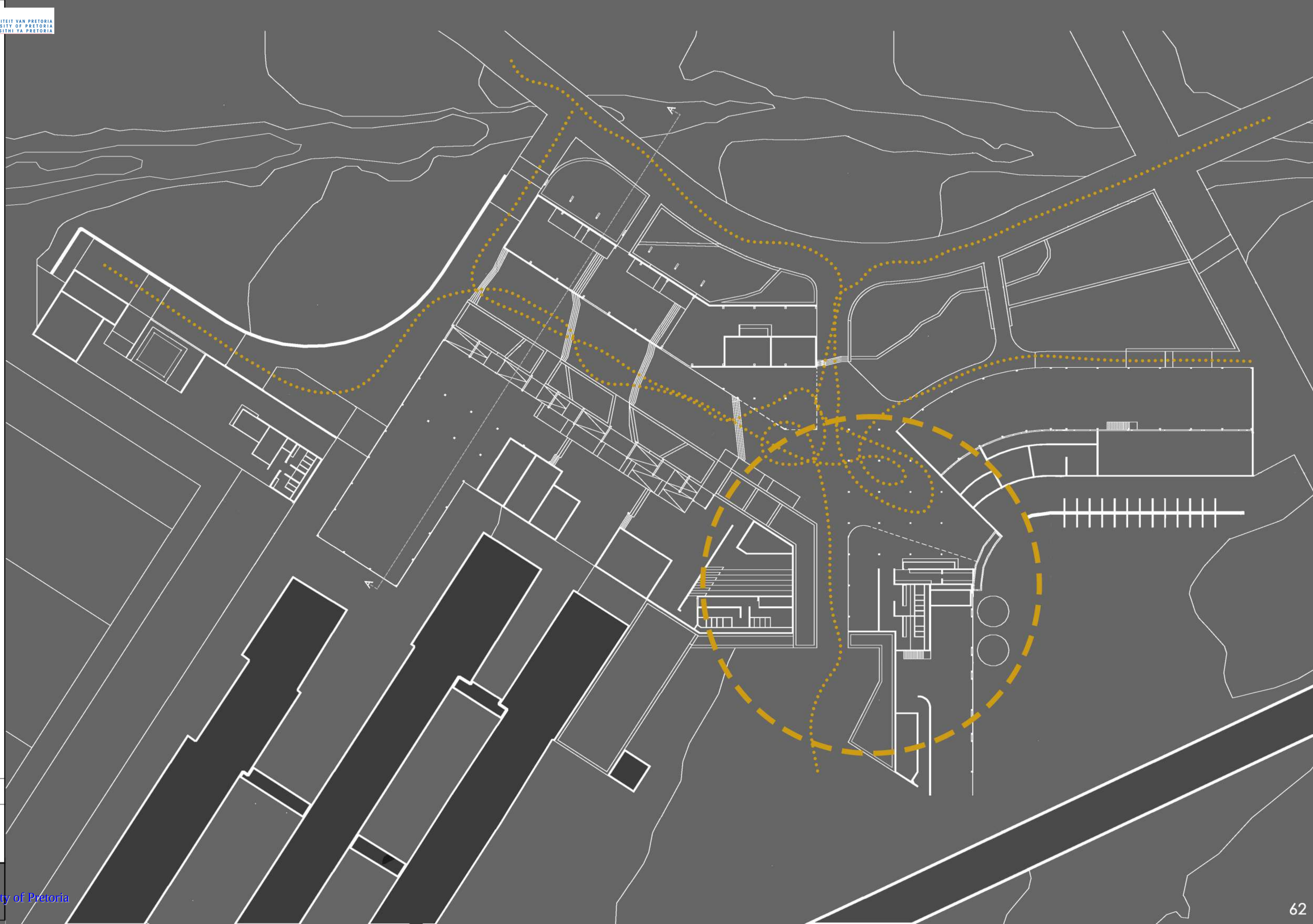


ITERATION 3

Figure 3.10: Ground Floor Plan, Section, and technical Development (Author 2021)







FINAL DESIGN

Figure 3.11: (left) Perspective Render of Final Design in Context (Author 2021)
Figure 3.12 (right): Site Plan - n.t.s (Author 2021)

SITE PLAN

GROUND FLOOR PLAN

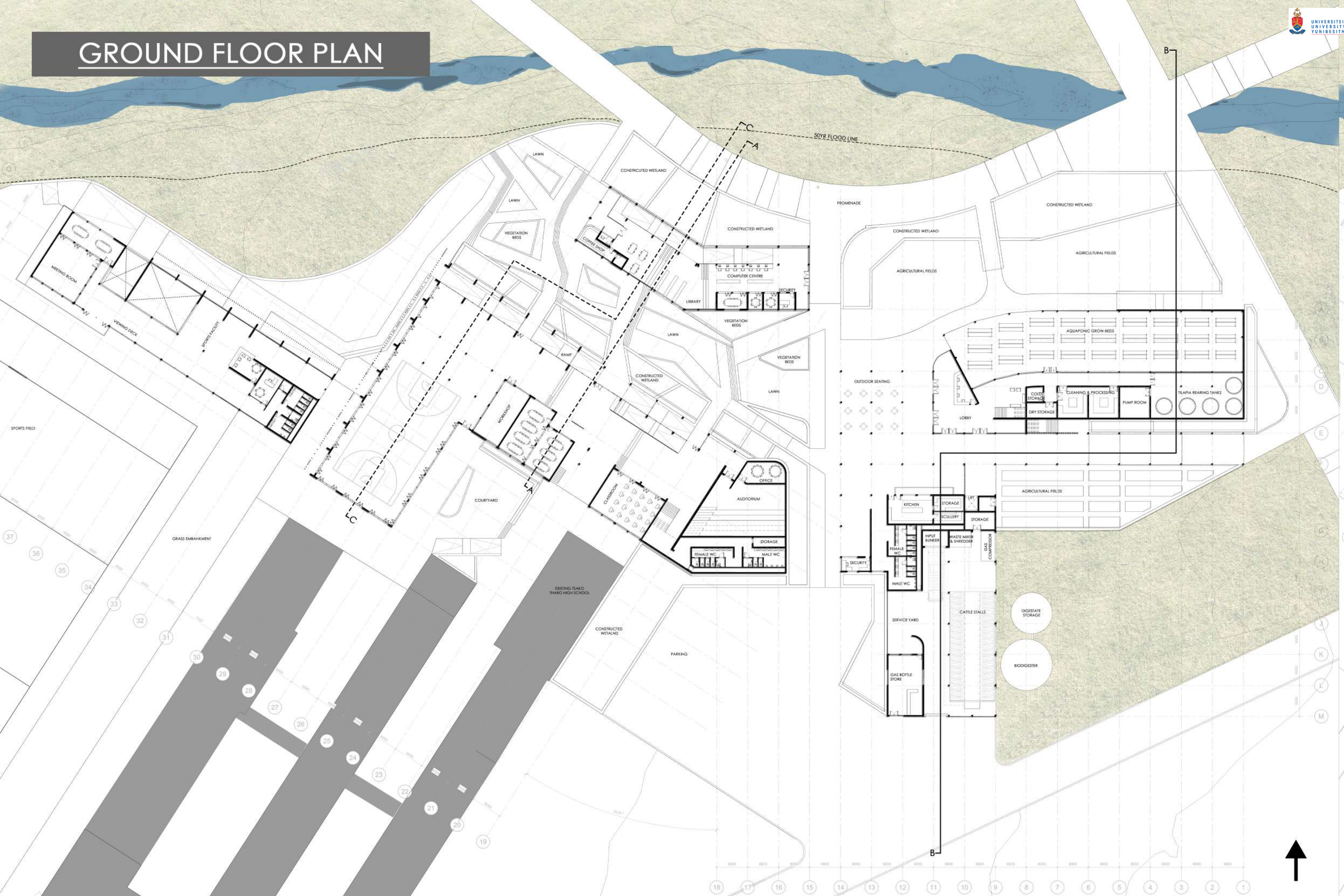


Figure 3.13: Ground Floor Plan - n.t.s. (Author 2021)

FIRST FLOOR PLAN

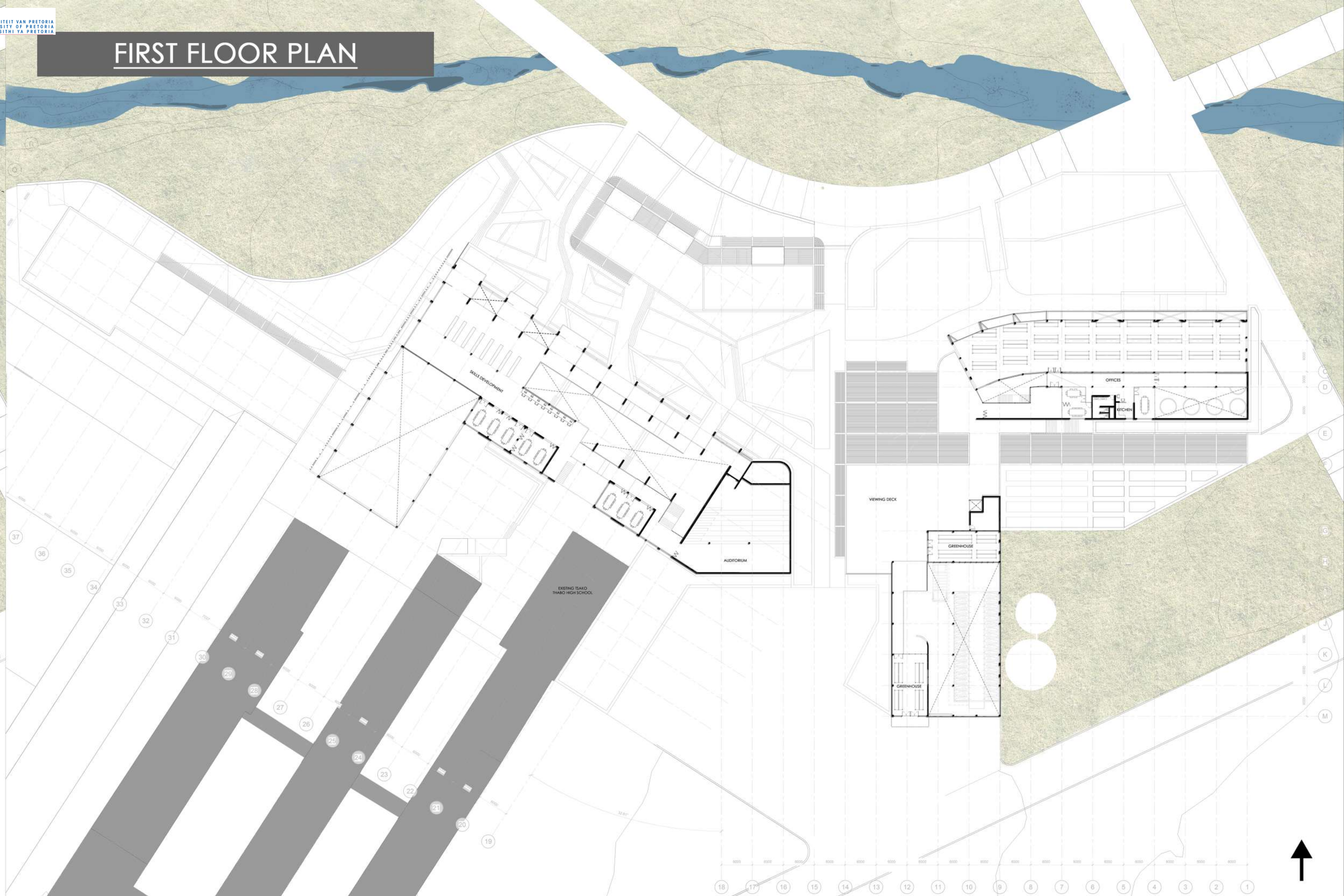
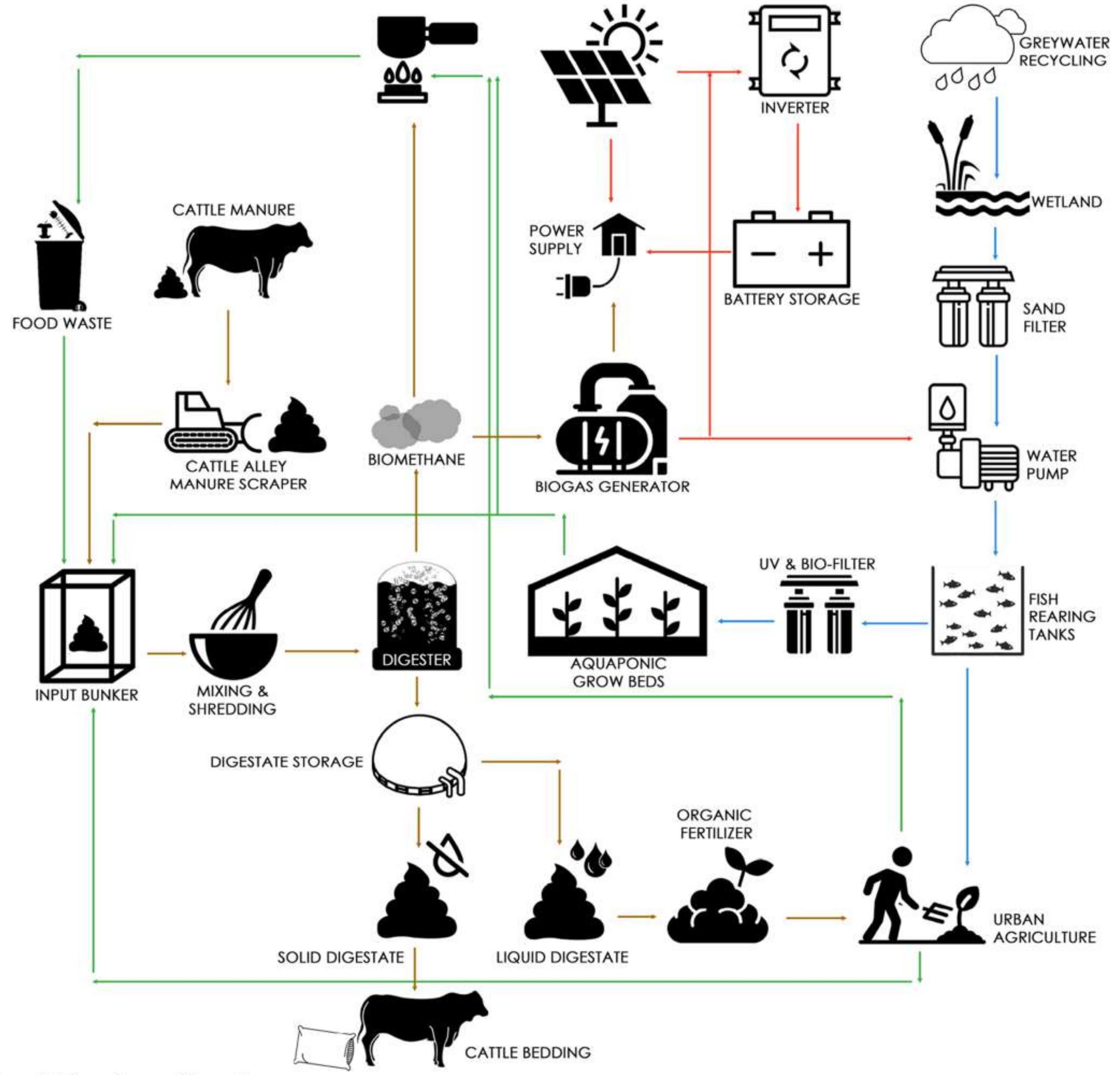
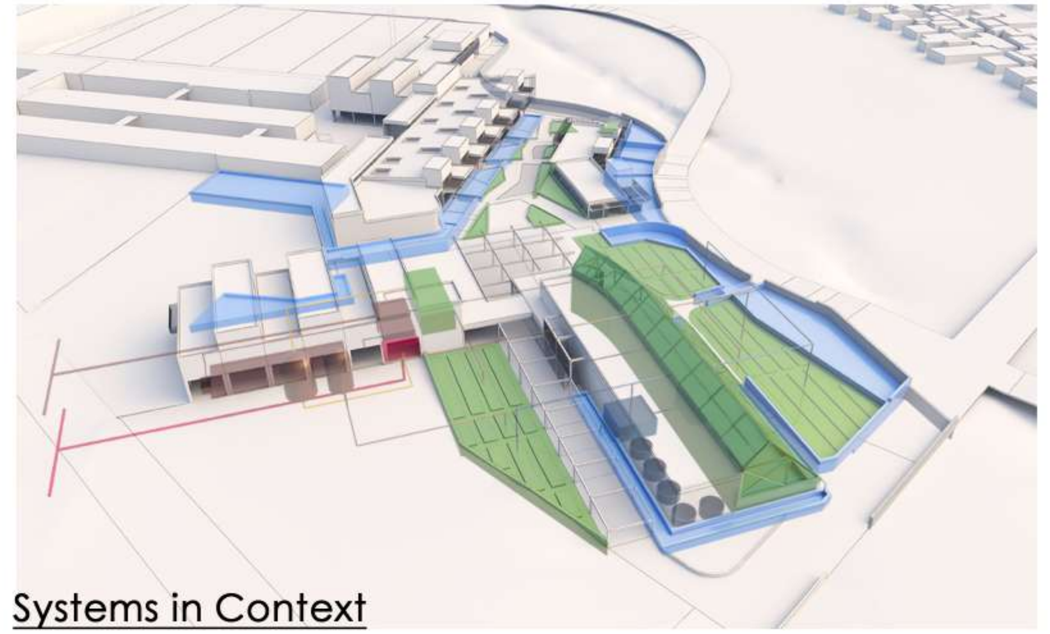


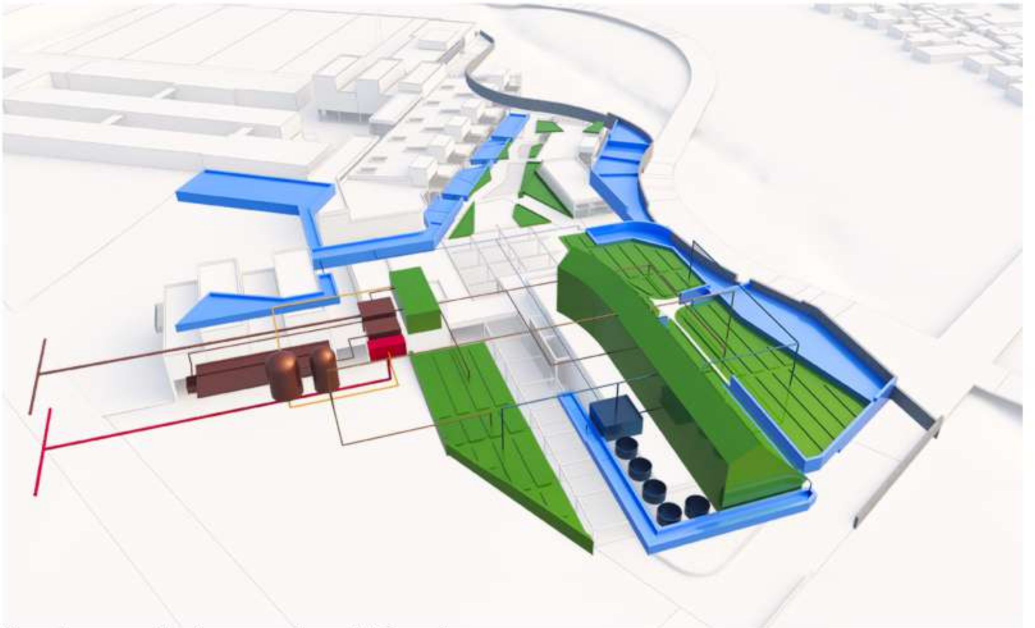
Figure 3.14: First Floor Plan - n.t.s. (Author 2021)



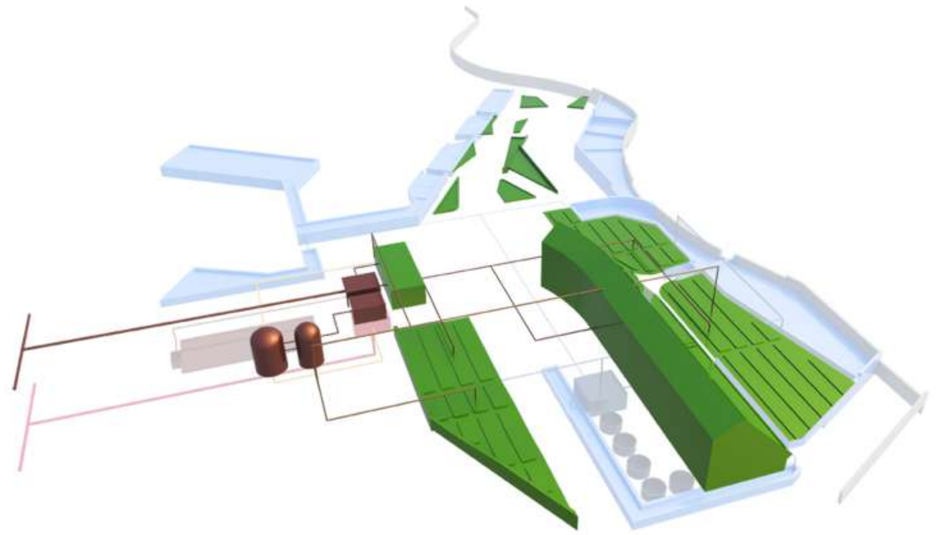
Cyclical Design Strategy



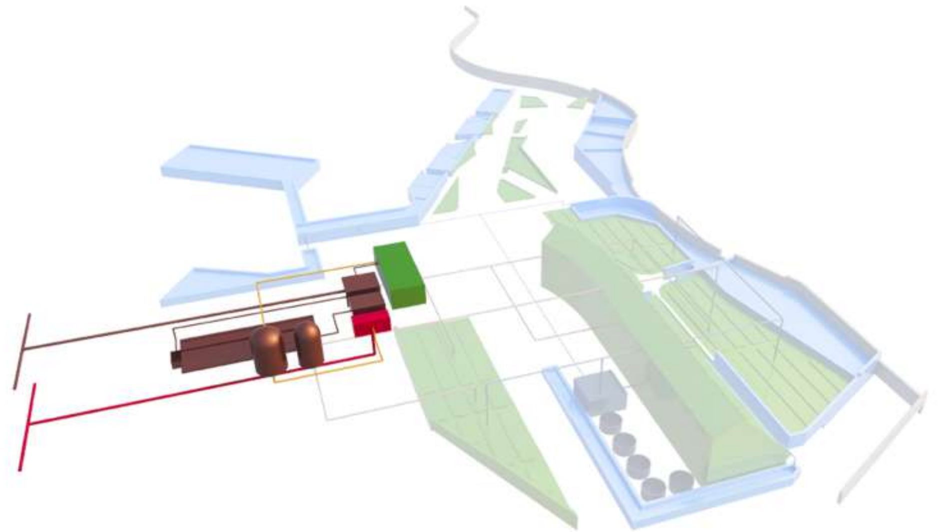
Systems in Context



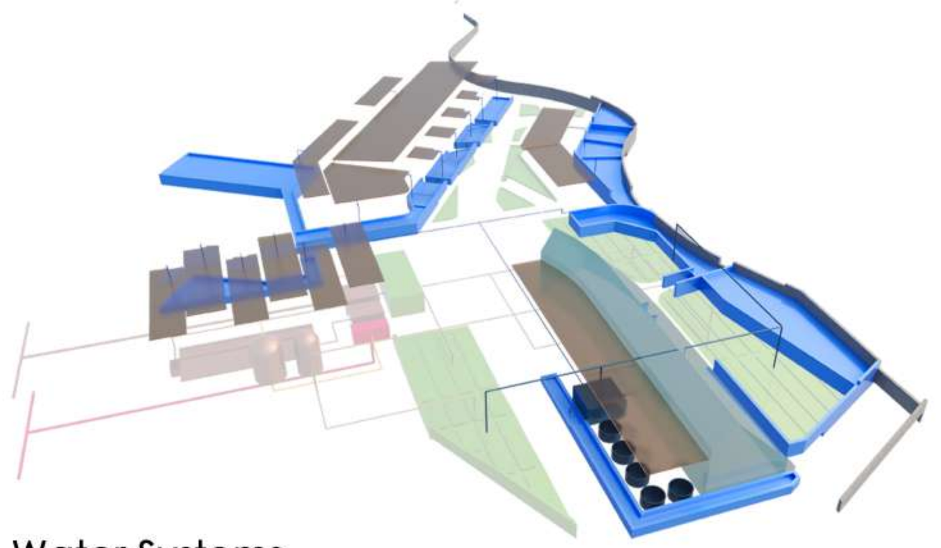
Systems-Integrated Design



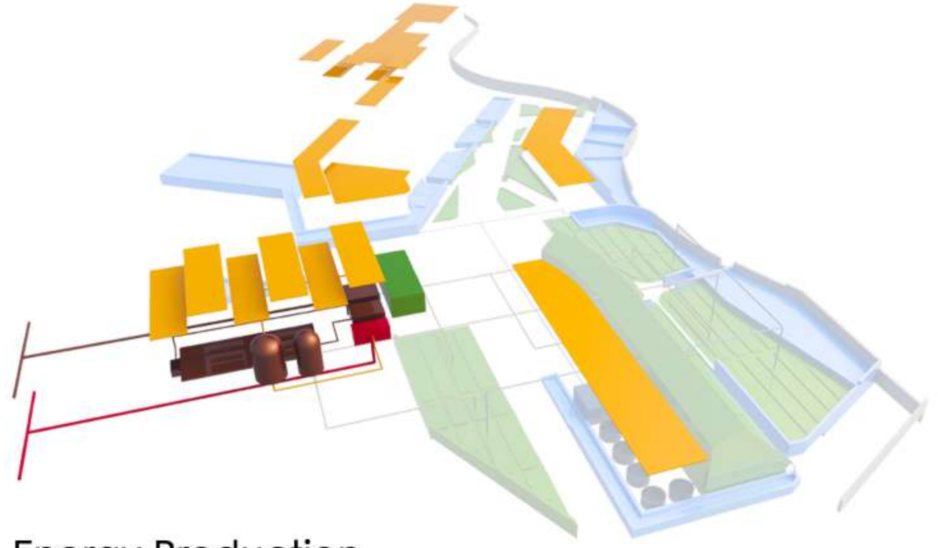
Food Production
- Urban Agriculture



Biomethane Production
- Biogas Compression Turbine & Generator



Water Systems
- Aquaponics, Rainwater Harvesting, Surface Flow Wetland



Energy Production
- Biomethane & Solar Harvesting

Figure 3.15: Cyclical Design Strategy (Author 2021)
Figure 3.16: Systems in Context (Author 2021)
Figure 3.17: Systems-Integrated Design (Author 2021)
Figure 3.18: Food Production (Author 2021)
Figure 3.19: Water Systems (Author 2021)
Figure 3.20: Biomethane Production (Author 2021)
Figure 3.21: Energy Production (Author 2021)
Figure 3.22: Section A-A (Author 2021)

Section A-A

Figure 3.23: Perspective Render (Author 2021)

CONSTRUCTING

Towards a circularity-based, total carbon neutral construction methodology

The purpose of Part 4 is to demonstrate how the principles of circularity can be extended to the construction and technical resolution of an architectural project. Part 4 demonstrates a pathway towards total-carbon neutrality.

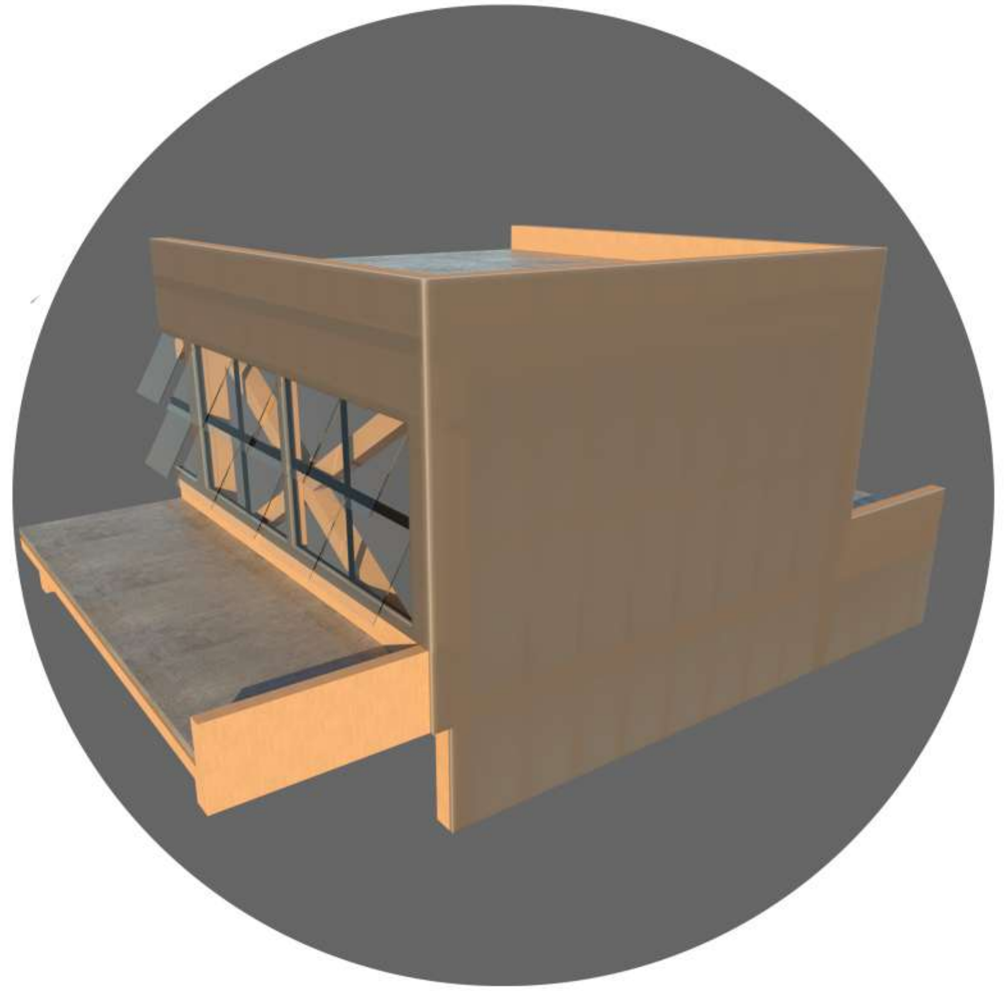
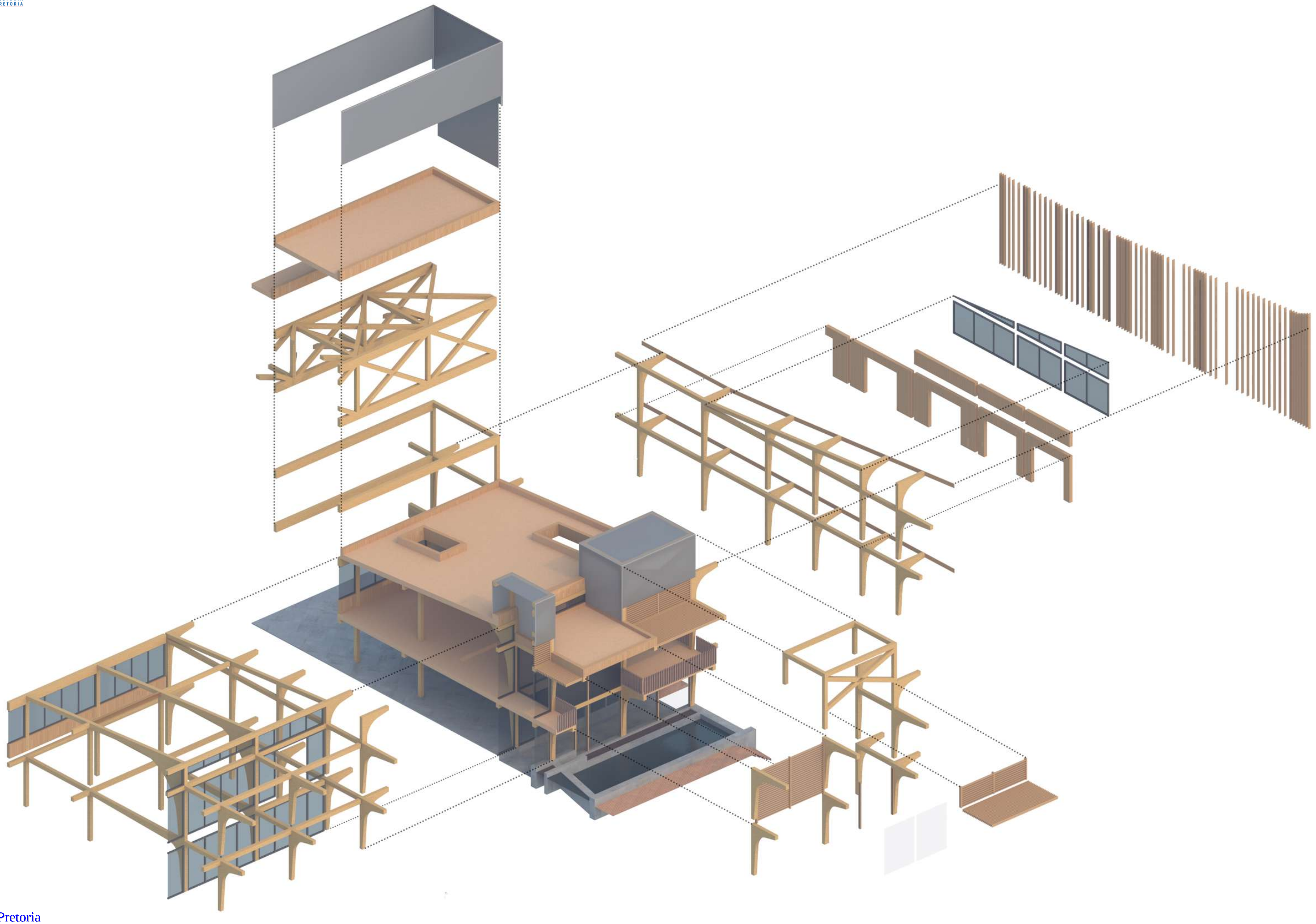
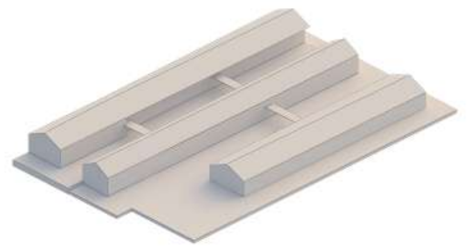


Figure 4.1: (above) Constructing (Author 2021)
Figure 4.2: (right) Exploded Axonometric (Author 2021)

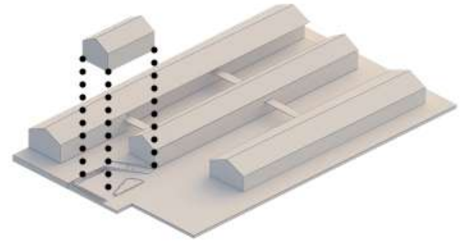


TECHNIFICATION

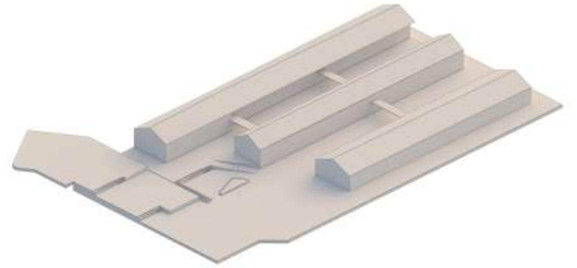
CONCEPT



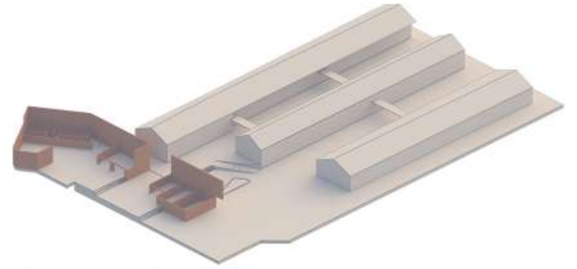
01 -EXISTING SCHOOL CONDITION



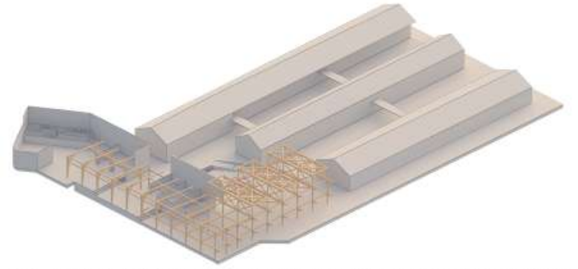
02 - DEMOLITION TO IMPROVE CONNECTION TO SCHOOL.
BRICKS TO BE REUSED IN PAVING.



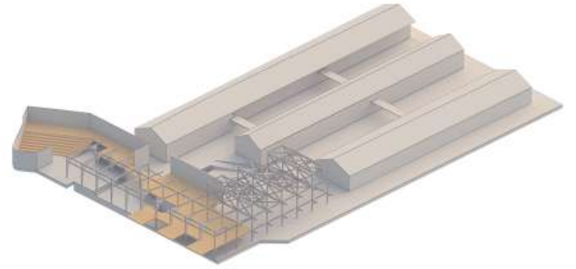
03 - NEW INTERVENTION SLAB CONNECTION TO SCHOOL



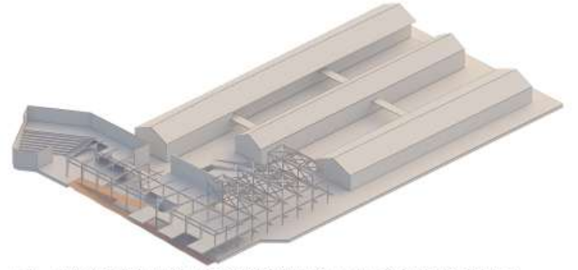
04 - ADOBE BRICK WALLS TO COMPLIMENT EXISTING STEREOTOMIC ARCHITECTURAL LANGUAGE



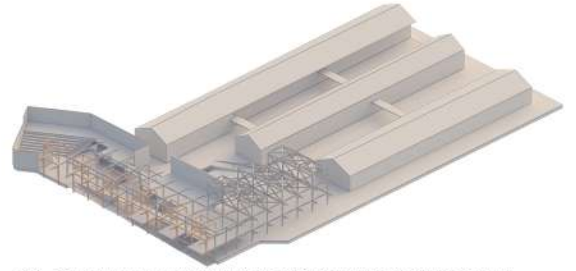
05 - PREFABRICTAED GLULAM ENGINEERED MASS TIMBER FRAME CONSTRUCTION



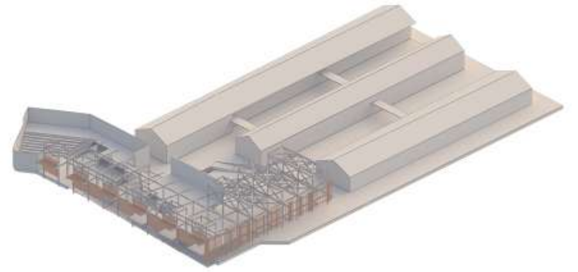
06 - CROSS-LAMINATED TIMBER FIRST FLOOR LEVEL FLOOR PLATE



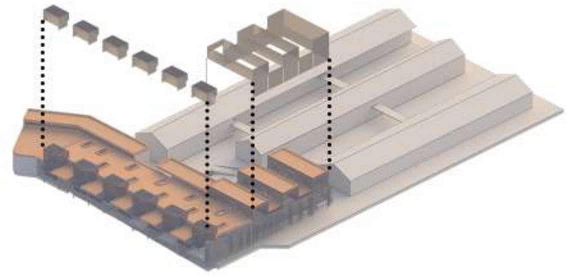
07 - UNIVERSALLY ACCESSIBLE RAMP CONNECTING FLOOR LEVELS



08 - GLULAM MASS TIMBER STRUCTURE FOR DOUBLE FACADE CONNECTION



09 - THERMO-TREATED TIMBER SCREENS CONNECTING TO GLULAM TIMBER STRUCTURE AS SOLAR SHADING DOUBLE FACADE

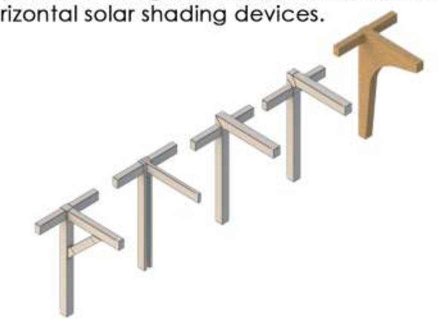


10 - CROSS-LAMINATED TIMBER ROOF PLATE AND PALSUN POLYCARBONATE SHEETING

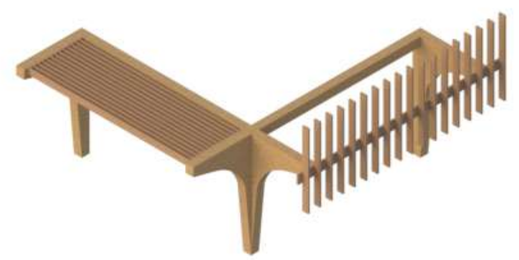
ENGINEERED GLULAM COLUMN

KIT-OF-PARTS CONSTRUCTION

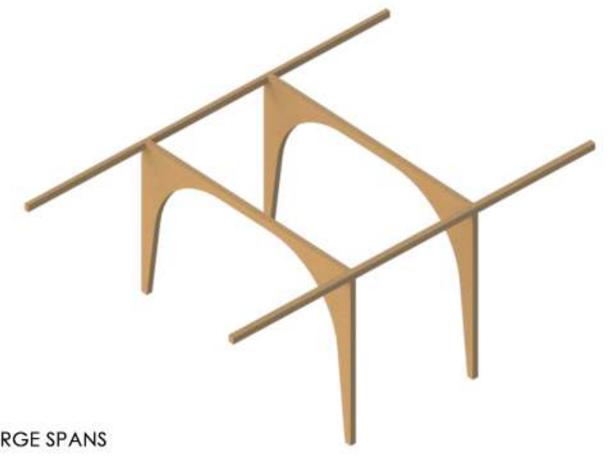
Building on the theoretical framework of the dissertation, the intervention utilizes mass timber and adobe brick construction as a low-embodied energy alternative to the conventional manufactured brick, concrete and steel construction within the South African built environment. An engineered glulam column is developed as a prefabricated construction component. The glulam columns further allow for connection of both vertical and horizontal solar shading devices.



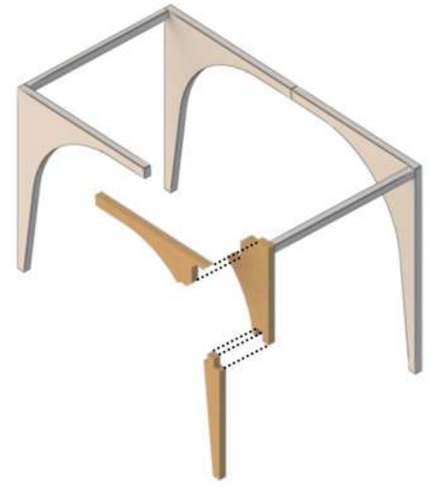
COLUMN DEVELOPMENT



ATTACHMENT OF SHADING DEVICES



COLUMN CONNECTION FOR LARGE SPANS



PREFABRICATED KIT-OF-PARTS

MATERIALITY

PRIMARY STRUCTURE

CLT ROOF SLAB

POLYCARBONATE SHEETING

TIMBER SCREENS

SECONDARY STRUCTURE

ADOBE BRICK WALLS

CLT FLOOR PLATE

CLT WALLS

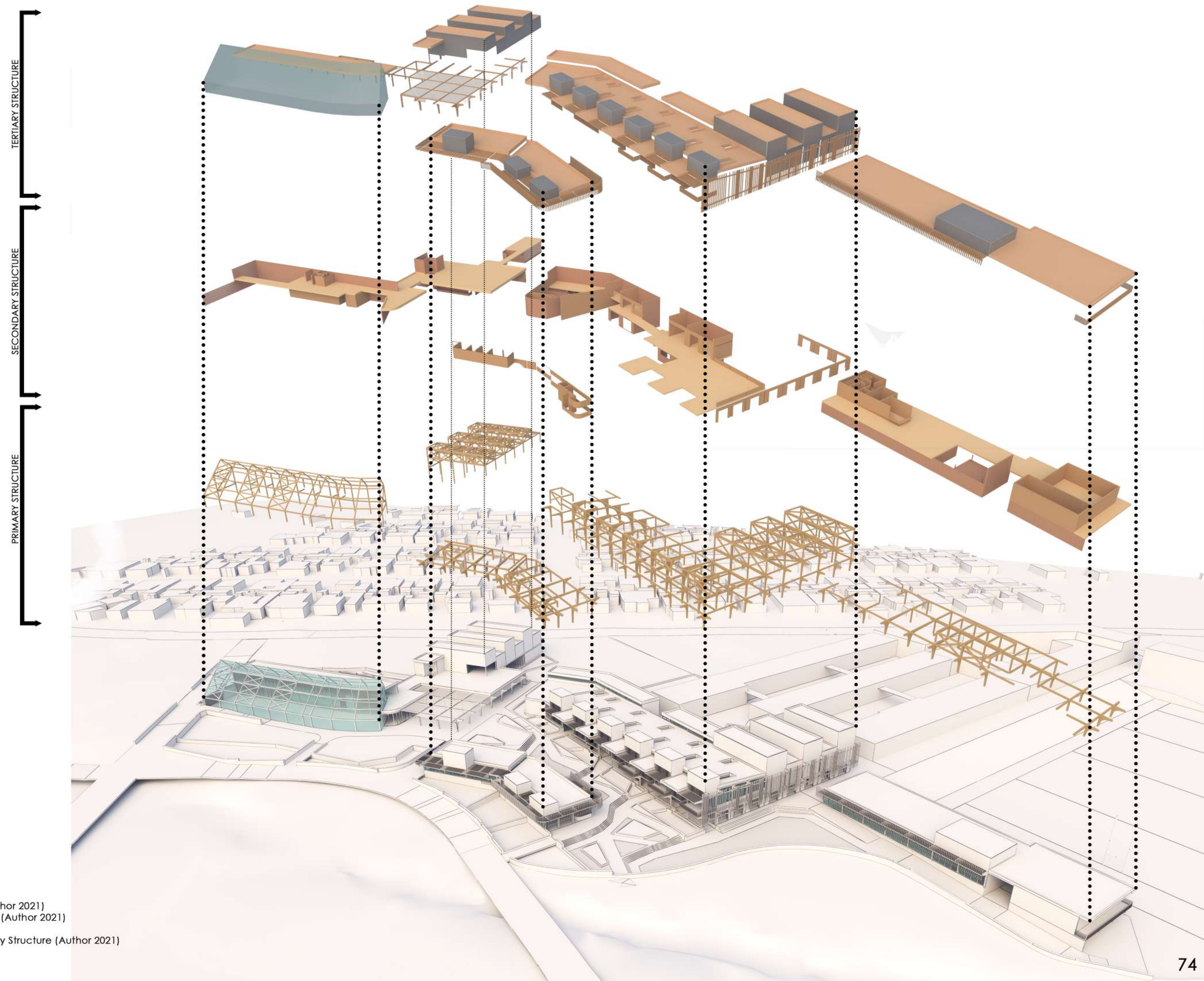
TIMBER CLADDING

TERTIARY STRUCTURE

GLULAM COLUMNS

LVL BEAMS

Figures: From left to right
Figure 4.3: Concept Development (Author 2021)
Figure 4.4: Engineered Glulam Column (Author 2021)
Figure 4.5: Materiality (Author 2021)
Figure 4.6: Primary, Secondary & Tertiary Structure (Author 2021)



TECHNIFICATION

DETAIL 01
- Column-to-Floor Connection
- CLT Floor-Plate Detai

CLT Cassette Floor Plate:

Floor Finish with 20mm tongue and groove Oggie reclaimed oak timber planks

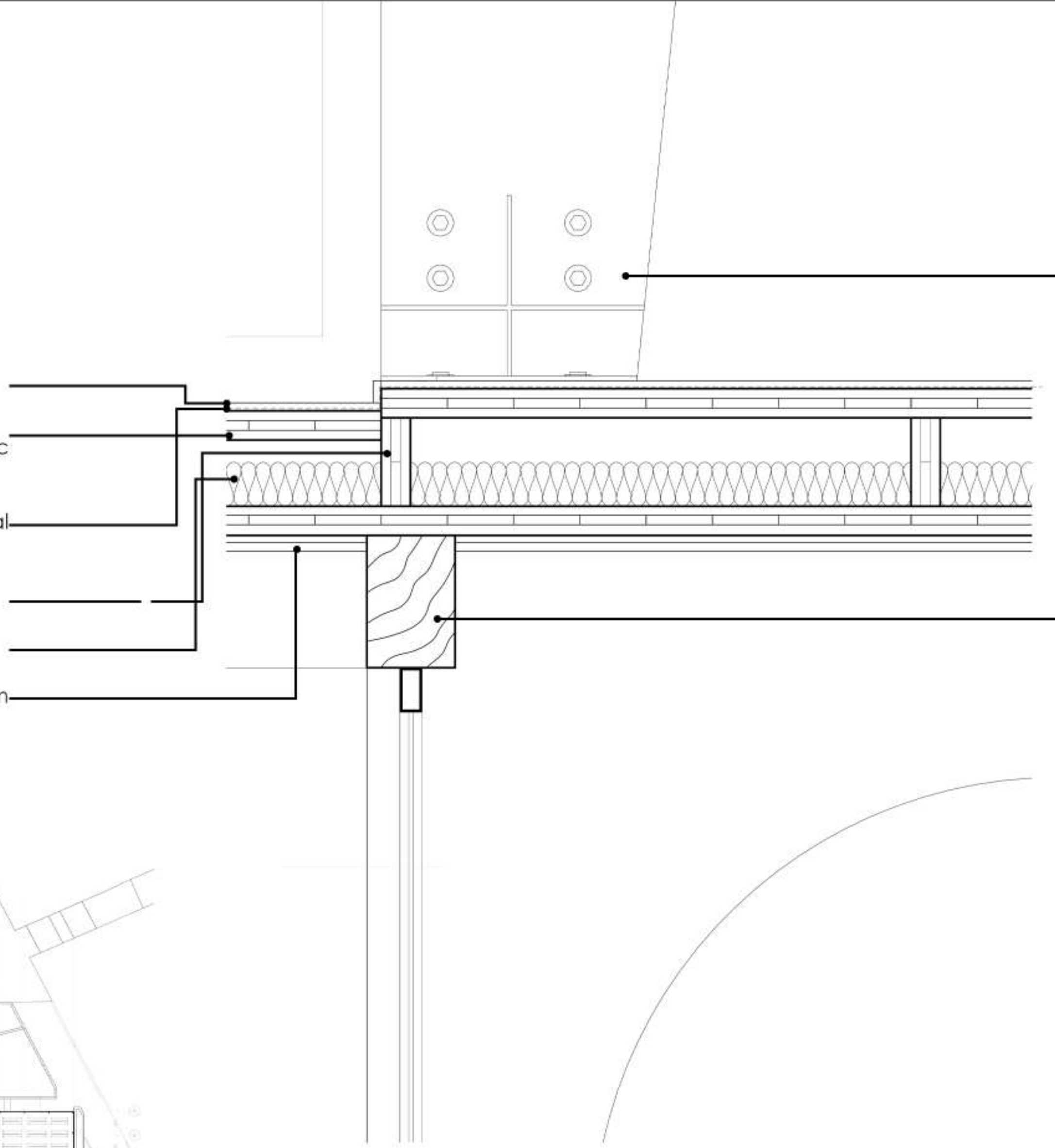
2 X 66mm 3-Ply (3x22mm) CLT Panel screw fixed to 150x66mm CLT Ribs at max. 1200mm c/c with 6mm Rothoblast tek screws.

Top CLT floor panel to be primed with Steico therm primer and BASF Masterseal waterproofing.

200x66mm 3-Ply CLT ribs at 1200mm c/c

100mm ISOTHERM (polyester fibre from recycled PET bottles) insulation laid in cavity.

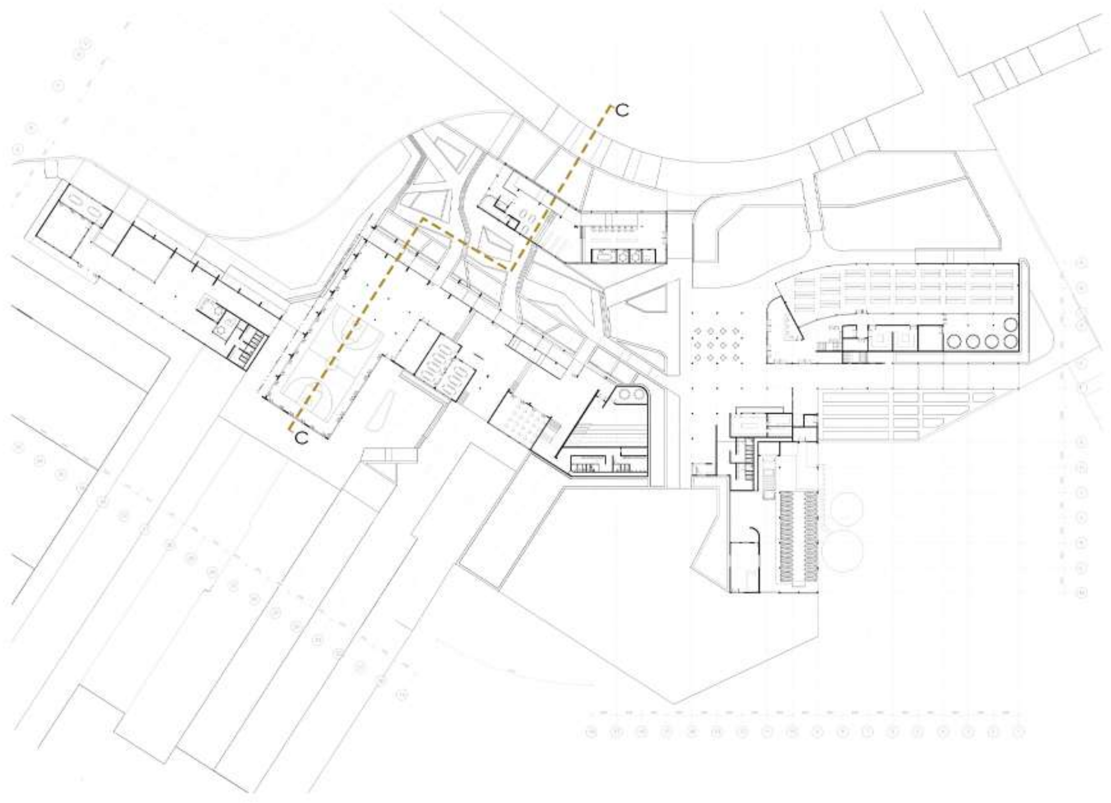
CLT soffit finished with 20x20mm Meranti ceiling slats fixed to 16mm MDF board with 6mm countersunk tek screws.



Engineered GluLam Column:

265mm thick engineered curved GluLam column fixed to CLT floor plate with 10mm thick mild steel knife plate, primed and finished with two coats enamel paint, with 4xM16 bolts

300x200mm LVL beam fixed to 265mm thick engineered GluLam column with Rothoblast dovetail pitzl connectors

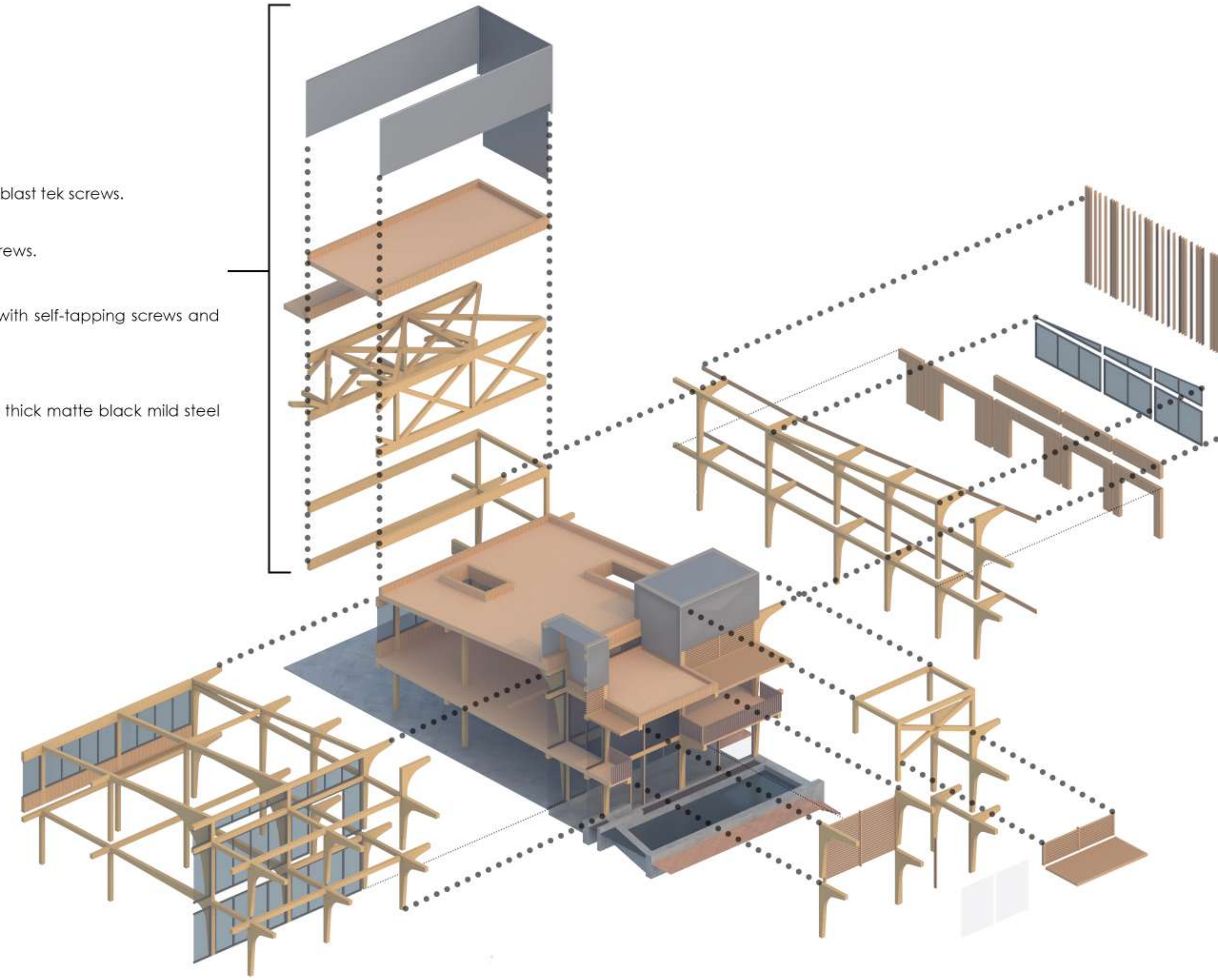


CLT Roof Slab:

(from top to bottom)
BASF Masterseal
Steico therm floor primer
100mm (2x50mm layers) Polyisocyanurate (closed cell rigid foam board) insulation
2 X 66mm 3-Ply (3x22mm) CLT Panel screw fixed to 150x66mm CLT Ribs at max. 1200mm c/c with 6mm Rothoblast tek screws.
150x66mm 3-Ply CLT ribs at 1200mm c/c
100mm ISOTHERM (polyester fibre from recycled PET bottles) insulation laid in cavity.
CLT soffit finished with 20x20mm Meranti ceiling slats fixed to 16mm MDF board with 6mm countersunk tek screws.

Polycarbonate Facade and Structure:

20mm twin wall Palsun polycarbonate panels fixed to 152x50mm SAP timber frame studs at 1000mm c/c with self-tapping screws and sealing washers.
Palsun Polycarbonate Panel system bottom-end flashing cap as per supplier specifications.
152x50mm SAP timber frame stud.
Aluminium Window frame to supplier specifications
300x200mm LVL (Laminated Veneer Lumber) Bracing Beam fixed to 265x265mm GluLam column with 8mm thick matte black mild steel knife plate, primed and finished with two coats enamel paint, with 4xM16 bolts
600x200mm LVL beam fixed to 265x265mm GluLam column with Rothoblast dovetail pitzl connectors.



SECTION C-C

Figures: From left to right
Figure 4.7: Detail 01 (Author 2021)
Figure 4.8: Section C-C (Author 2021)
Figure 4.9: Exploded Axonometric - Detail(Author 2021)

DETAIL 02
- Polycarbonate Facade and Structure
- CLT Roof Slab

Polycarbonate Facade and Structure:
20mm twin wall Palsun polycarbonate panels fixed to 152x50mm SAP timber frame studs at 1000mm c/c with self-tapping screws and sealing washers.

Palsun Polycarbonate Panel system bottom-end flashing cap as per supplier specifications.
152x50mm SAP timber frame stud.
Aluminium Window frame to supplier specifications

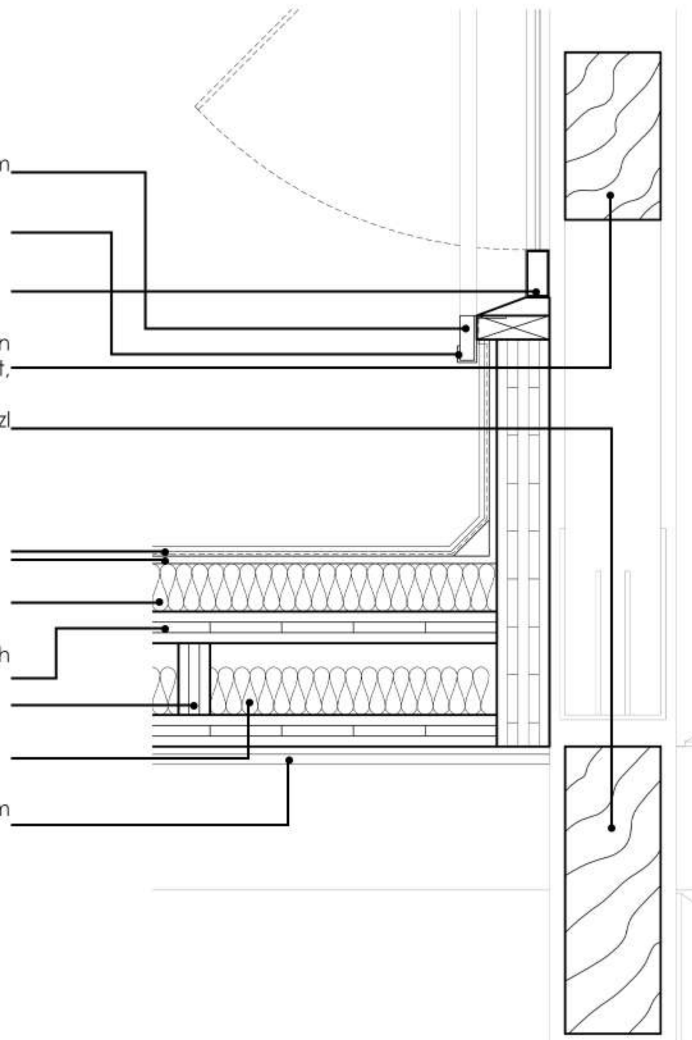
300x200mm LVL (Laminated Veneer Lumber) Bracing Beam fixed to 265x265mm GluLam column with 8mm thick matte black mild steel knife plate, primed and finished with two coats enamel paint, with 4xM16 bolts
600x200mm LVL beam fixed to 265x265mm GluLam column with Rothoblast dovetail pitzl connectors.

CLT Roof Slab:
BASF Masterseal
Steico therm floor primer
100mm (2x50mm layers) Polyisocyanurate (closed cell rigid foam board) insulation

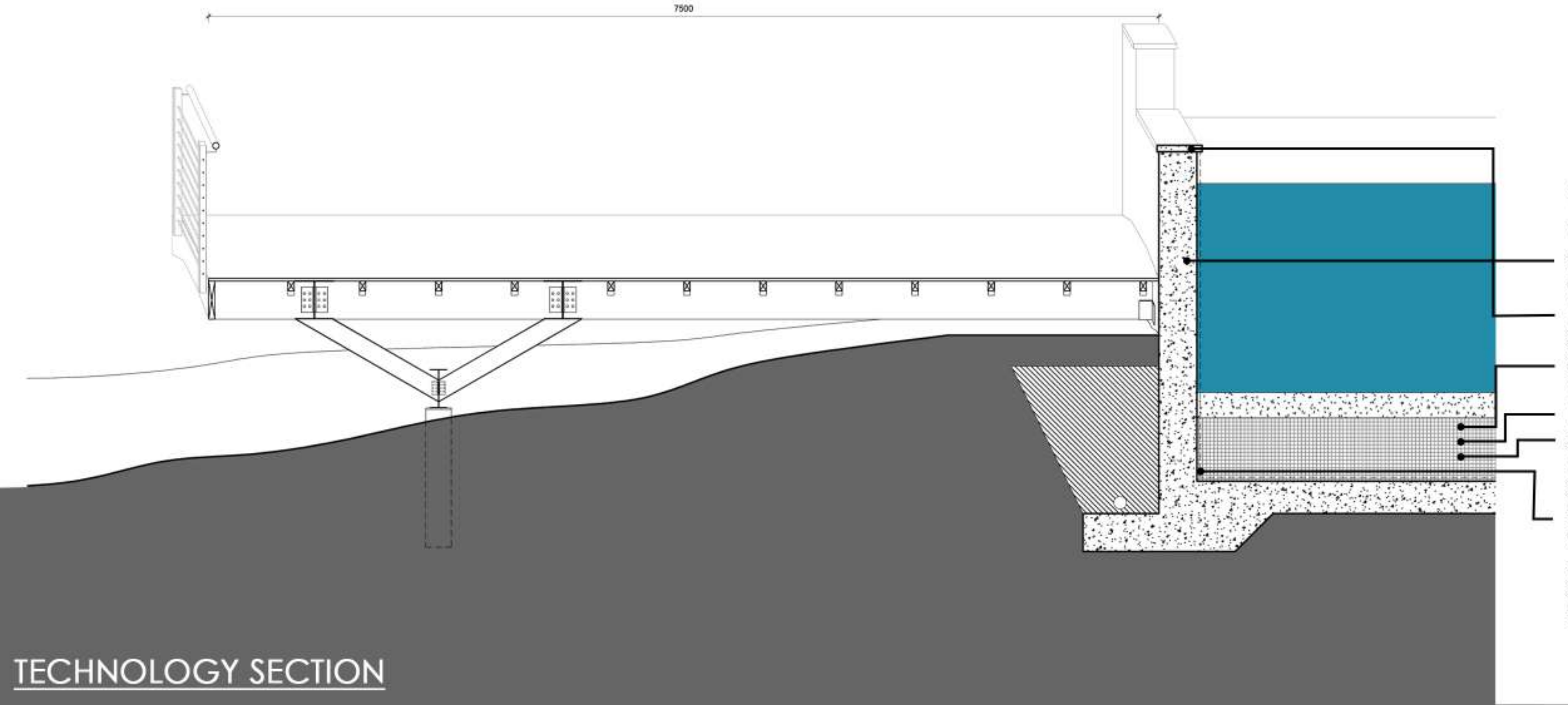
2 X 66mm 3-Ply (3x22mm) CLT Panel screw fixed to 150x66mm CLT Ribs at max. 1200mm c/c with 6mm Rothoblast tek screws.
150x66mm 3-Ply CLT ribs at 1200mm c/c

100mm ISOTHERM (polyester fibre from recycled PET bottles) insulation laid in cavity.

CLT soffit finished with 20x20mm Meranti ceiling slats fixed to 16mm MDF board with 6mm countersunk tek screws.



Promenade Structure:
(From bottom to top)
200mm diameter reinforced concrete micropile to engineer's specification.
10mm thick matte black mild steel base plate bolted to reinforced concrete micropile with 4xM10 chemical anchors
305x133x8mm matte black hot-rolled mild steel i-beam welded to 10mm steel base plate
152x152x8mm matte black hot-rolled mild steel universal (h-section) bracing member fixed to 305x133x8mm i-beam with 100x50x5mm matte black hot-rolled mild steel unequal angle with 6xM8 bolts. Welded to 305x305x10mm matte black hot-rolled mild steel universal (h-section) beam.
305x305x10mm matte black hot-rolled mild steel universal (h-section) beam welded to 152x152x8mm matte black hot-rolled mild steel universal (h-section) bracing member.
300x200mm GluLam beam, treated and finished with a penetrating sealer and light colour paint coating, fixed to 305x305x10mm matte black hot-rolled mild steel universal (h-section) beam at 1200mm c/c with 100x50x5mm matte black hot-rolled mild steel unequal angle with 6xM10 bolts
76x50mm treated and varnished SAP timber battens fixed to 300x200mm GluLam beam at 600mm c/c with 100x50mm matte black hot-rolled mild steel unequal angle and 2xM8 bolts.
20mm tongue and groove Oggie reclaimed oak timber planks treated and varnish with anti-corrosive finish



Constructed Wetland:
300mm reinforced concrete retaining wall to engineer's specification
Precast concrete coping with 10x10mm drip joint
Small and medium gravel layer on top of large gravel layer
Large gravel layer on top of sludge layer
Sludge layer on top of 200mm thick Reno mattresses stacked on top of each other for wetland planting
5mm thick Bentofix geosynthetic waterproofing membrane laid to coping. Waterproof membrane overlaps of 300mm longitudinally and 500mm cross overlaps.

TECHNOLOGY SECTION

Polycarbonate Facade and Structure:
20mm twin wall Palsun polycarbonate panels fixed to 76x50mm SAP timber frame studs at 1000mm c/c with self-tapping screws and sealing washers.

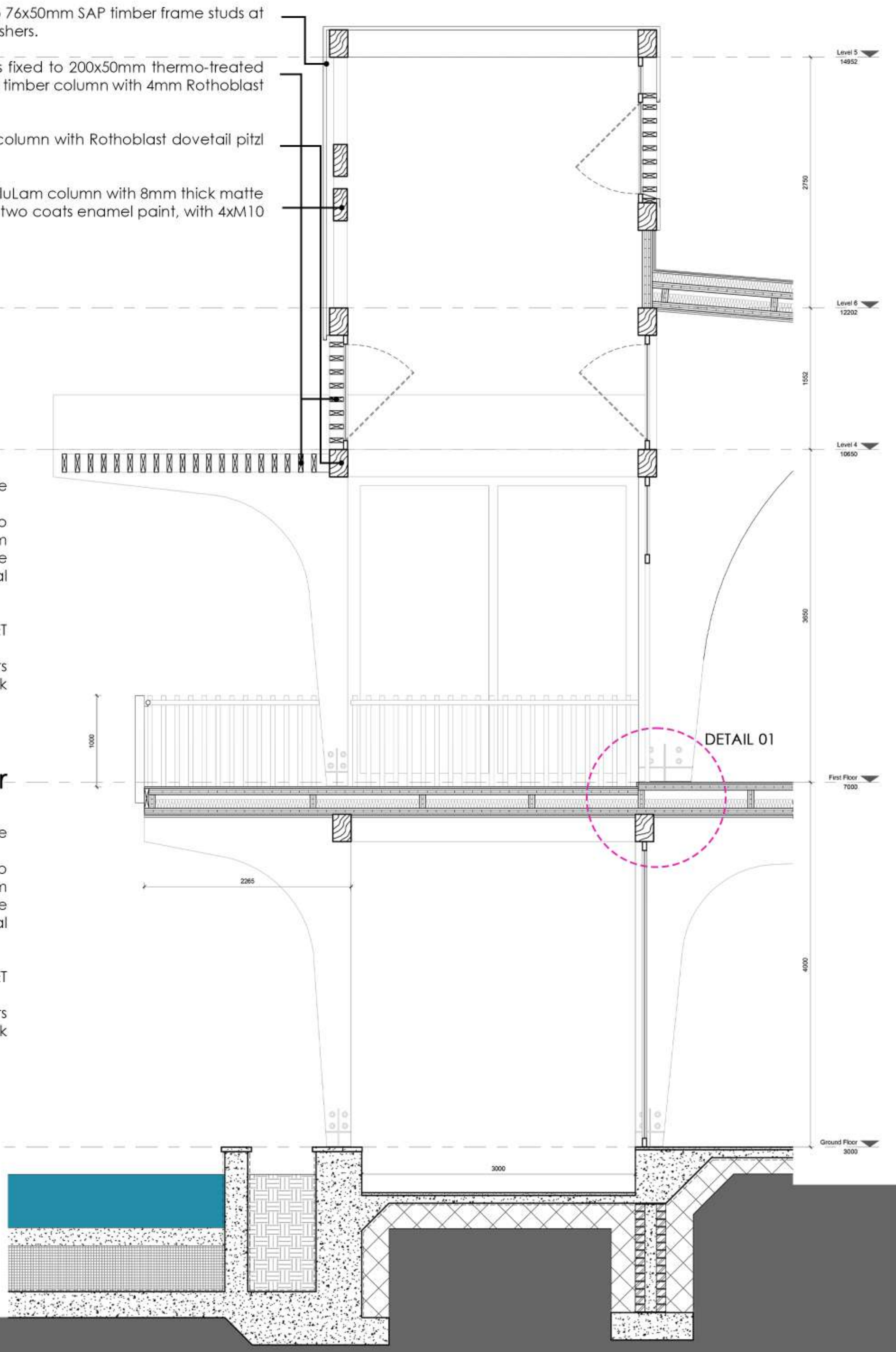
200x50mm thermo-treated LunaWood timber louvres fixed to 200x50mm thermo-treated LunaWood timber frame fixed to GluLam engineered timber column with 4mm Rothoblast tek screws.

300x200mm LVL beam fixed to 265x265mm GluLam column with Rothoblast dovetail pitzl connectors.

300x150mm LVL Bracing Beam fixed to 265x265mm GluLam column with 8mm thick matte black mild steel knife plate, primed and finished with two coats enamel paint, with 4xM10 bolts.

CLT Cassette Floor Plate:
Floor Finish with 20mm tongue and groove Oggie reclaimed oak timber planks
2 X 66mm 3-Ply (3x22mm) CLT Panel screw fixed to 150x66mm CLT Ribs at max. 1200mm c/c with 6mm Rothoblast tek screws. Top CLT floor panel to be primed with Steico therm primer and BASF Masterseal waterproofing.
2000x66mm 3-Ply CLT ribs at 1200mm c/c
100mm ISOTHERM (polyester fibre from recycled PET bottles) insulation laid in cavity.
CLT soffit finished with 20x20mm Meranti ceiling slats fixed to 16mm MDF board with 6mm countersunk tek screws.

CLT Cassette Balcony Floor Plate:
Floor Finish with 20mm tongue and groove Oggie reclaimed oak timber planks
2 X 66mm 3-Ply (3x22mm) CLT Panel screw fixed to 150x66mm CLT Ribs at max. 1200mm c/c with 6mm Rothoblast tek screws. Top CLT floor panel to be primed with Steico therm primer and BASF Masterseal waterproofing.
150x66mm 3-Ply CLT ribs at 1200mm c/c
100mm ISOTHERM (polyester fibre from recycled PET bottles) insulation laid in cavity.
CLT soffit finished with 20x20mm Meranti ceiling slats fixed to 16mm MDF board with 6mm countersunk tek screws.



CLT Roof Slab:
Flashing
BASF Masterseal laid up to under flashing
Steico therm floor primer
100mm (2x50mm layers) Polyisocyanurate (closed cell rigid foam board) insulation. Insulation shaped to create fall of min 1:200 slope towards drainage spout.
2 X 66mm 3-Ply (3x22mm) CLT Panel screw fixed to 150x66mm CLT Ribs at max. 1200mm c/c with 6mm Rothoblast tek screws.
150x66mm 3-Ply CLT ribs at 1200mm c/c
100mm ISOTHERM (polyester fibre from recycled PET bottles) insulation laid in cavity.
CLT soffit finished with 20x20mm Meranti ceiling slats fixed to 16mm MDF board with 6mm countersunk tek screws.

Polycarbonate Facade and Structure:
20mm twin wall Palsun polycarbonate panels fixed to 152x50mm SAP timber frame studs at 1000mm c/c with self-tapping screws and sealing washers.

20mm twin wall Palsun polycarbonate panels fixed to 76x38mm SAP timber frame studs at 1000mm c/c with self-tapping screws and sealing washers.

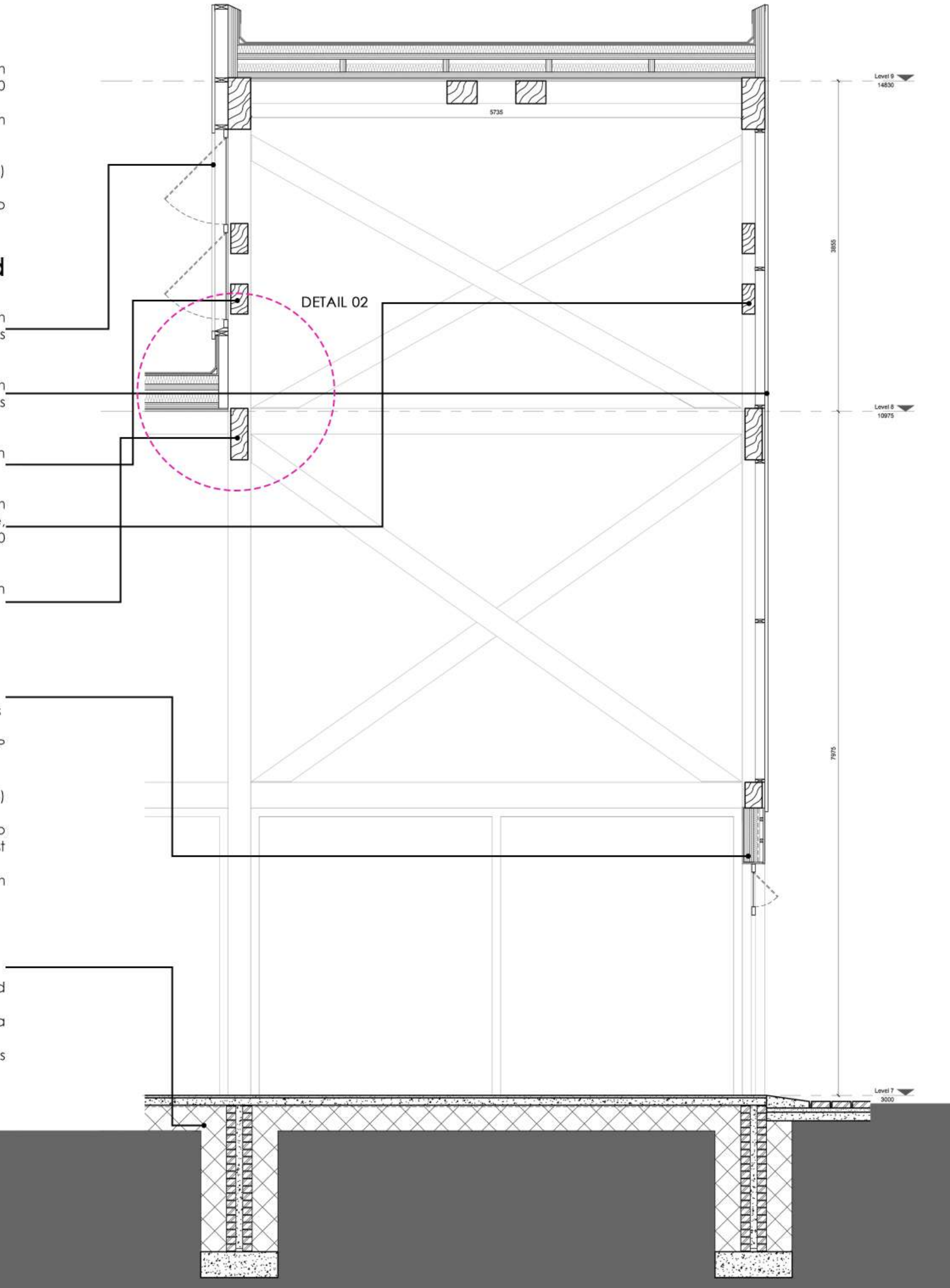
300x200mm LVL beam fixed to 265x265mm GluLam column with Rothoblast dovetail pitzl connectors.

300x150mm LVL Bracing Beam fixed to 265x265mm GluLam column with 8mm thick matte black mild steel knife plate, primed and finished with two coats enamel paint, with 4xM10 bolts.

600x200mm LVL beam fixed to 265x265mm GluLam column with Rothoblast dovetail pitzl connectors

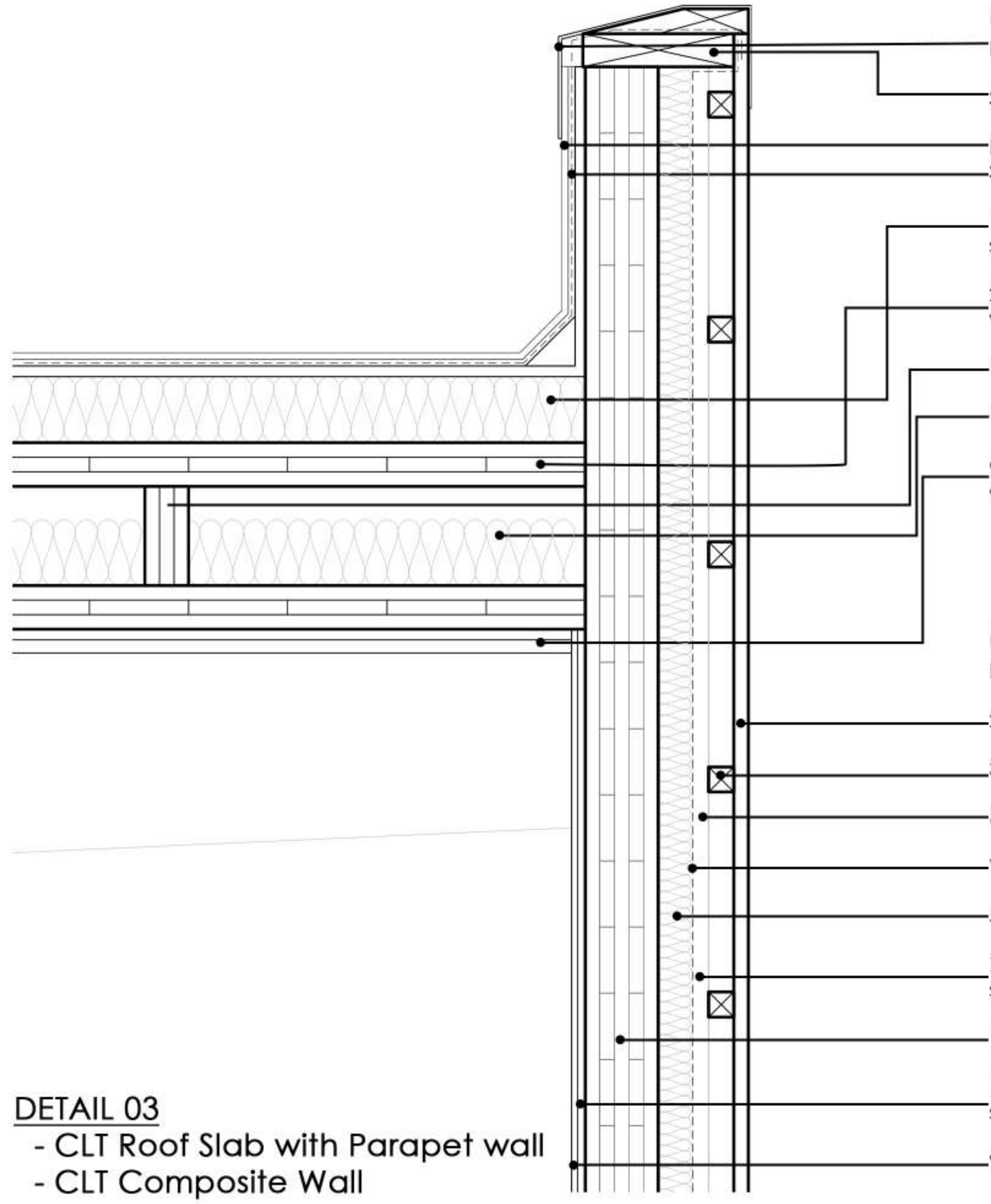
CLT Composite Wall:
From exterior to interior
22mm thermo-treated SAP cladding fixed to 38x38mm SAP slats
64mm Air cavity
38x38mm SAP slats at 500mm c/c screw fixed to 76x38mm SAP timber frame stud
Vertical waterproofing membrane
50mm ISOTHERM (polyester fibre from recycled PET bottles) insulation
76x38mm SAP timber frame stud at 1200mm c/c screw fixed to 110mm 5-ply (5x22mm) CLT structural panel with 4mm Rothoblast tek screws.
12mm Gyprock Firestop rhinoboard fixed to CLT panel with 4mm Rothoblast countersunk tek screw
9mm Nutek cladding panel

Hempcrete Ground Floor Slab:
Floor slab finish with self-leveling epoxy finish on 30mm screed layer.
85mm reinforced hempcrete ground floor slab with min. 250MPa strength to engineer's specification.
250 microns thick 3 layer damp proof membrane with overlaps at min 150mm.
Well compacted fill compacted at layers of max. 150mm



Figures: From left to right
Figure 4.10: Detail 02 (Author 2021)
Figure 4.11: Technology Section (Author 2021)

TECHNIFICATION



CLT Roof Slab:

Flashing

SAP timber wedge on top of 228x50mm SAP timber spacer

BASF Masterseal laid up to under flashing

Steico therm floor primer

100mm (2x50mm layers) Polyisocyanurate (closed cell rigid foam board) insulation. Insulation shaped to create fall of min 1:200 slope towards drainage spout.

2 X 66mm 3-Ply (3x22mm) CLT Panel screw fixed to 150x66mm CLT Ribs at max. 1200mm c/c with 6mm Rothoblast tek screws.

150x66mm 3-Ply CLT ribs at 1200mm c/c

100mm ISOTHERM (polyester fibre from recycled PET bottles) insulation laid in cavity.

CLT soffit finished with 20x20mm Meranti ceiling slats fixed to 16mm MDF board with 6mm countersunk tek screws.

CLT Composite Wall:

From exterior to interior

22mm thermo-treated SAP cladding fixed to 38x38mm SAP slats

38x38mm SAP slats at 500mm c/c screw fixed to 76x38mm SAP timber frame stud

64mm Air cavity

Vertical waterproofing membrane

50mm ISOTHERM (polyester fibre from recycled PET bottles) insulation

76x38mm SAP timber frame stud at 1200mm c/c screw fixed to 110mm 5-ply (5x22mm) CLT structural panel with 4mm Rothoblast tek screws.

110mm 5-ply (5x22mm) CLT structural pane

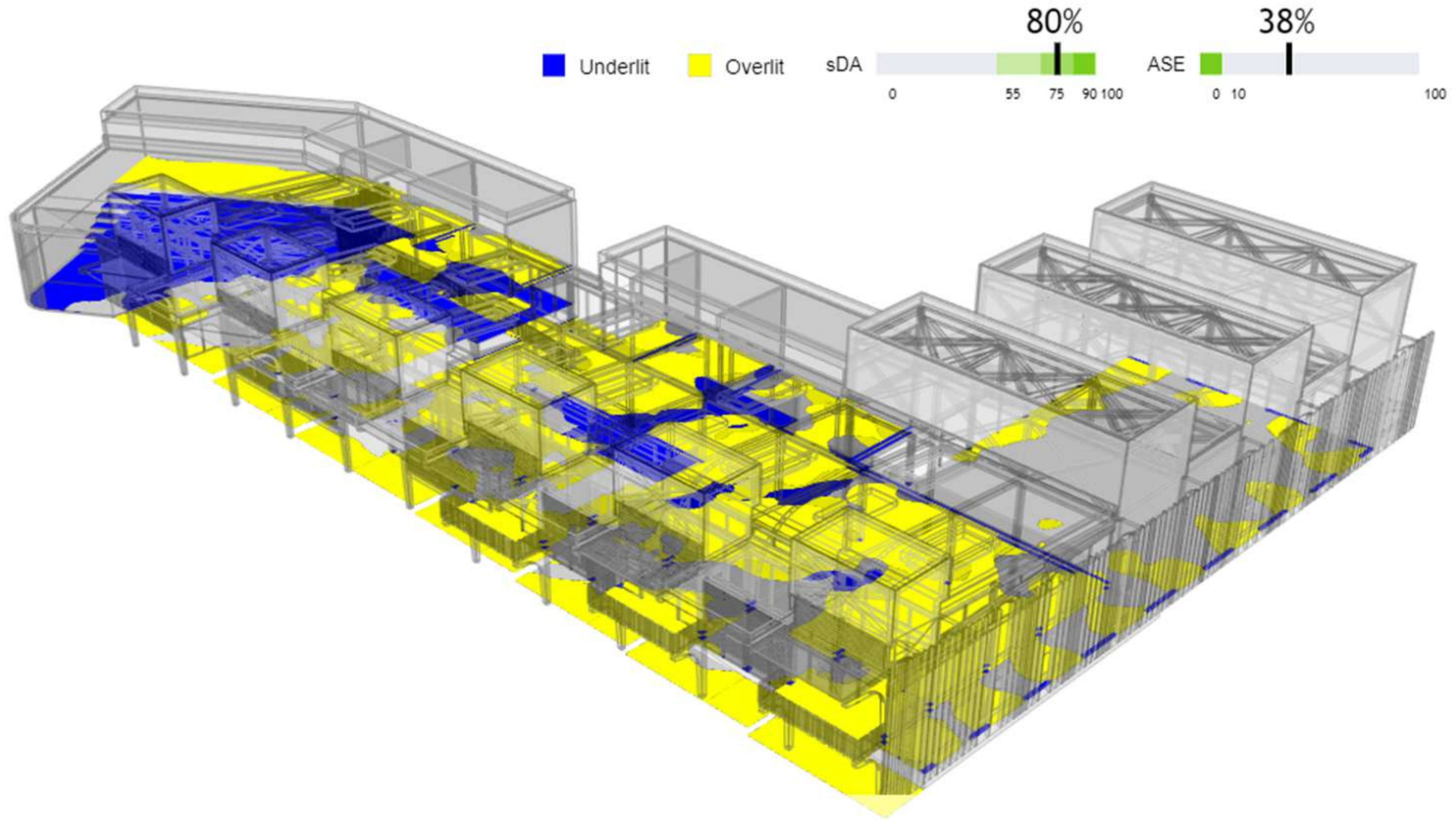
12mm Gyprock Firestop rhinoboard fixed to CLT panel with 4mm Rothoblast countersunk tek screw

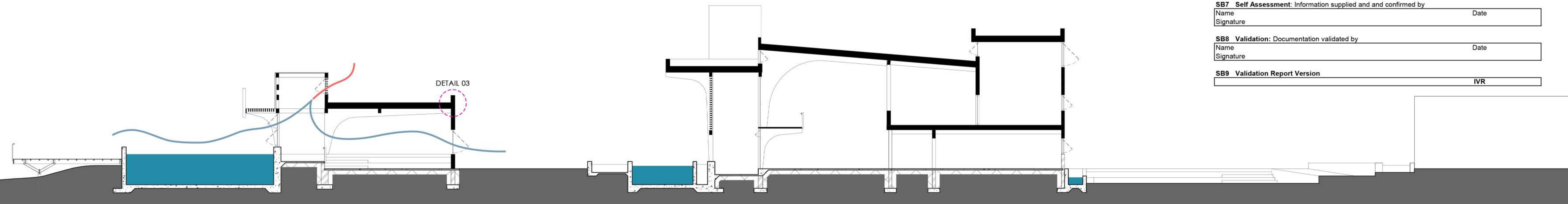
9mm Nutek cladding panel

DETAIL 03
- CLT Roof Slab with Parapet wall
- CLT Composite Wall

Figures: From left to right
Figure 4.12: Detail 03 (Author 2021)
Figure 4.13: Section B-B (Author 2021)
Figure 4.14: Sefaira - Daylight Modeling (Author 2021)
Figure 4.15: SBAT Report (Author 2021)

SEFAIRA - DAYLIGHT MODELING





SECTION B-B
Passive Ventilation

SBAT RATING

SUSTAINABLE BUILDING ASSESSMENT TOOL RESIDENTIAL
1.04

		Achieved
SB	SBAT REPORT	4.5

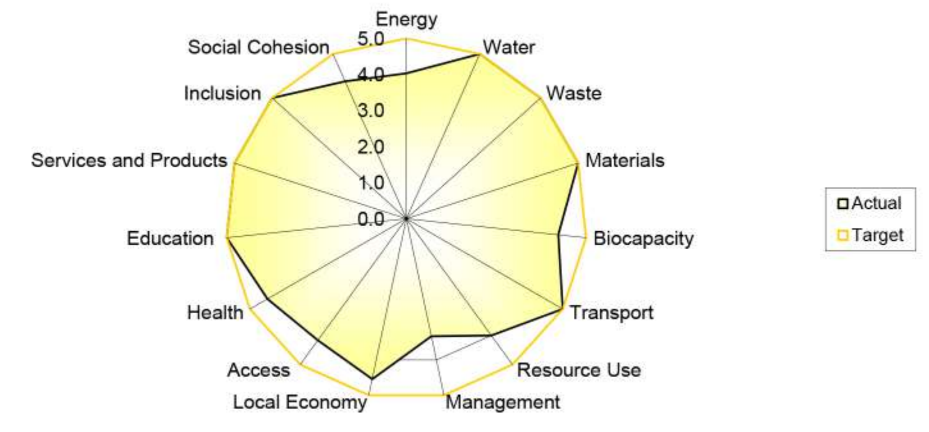
SB1 Project

	0

SB2 Address

	0

SB3 SBAT Graph



SB4 Environmental, Social and Economic Performance	Score
Environmental	4.7
Economic	4.2
Social	4.7
SBAT Rating	4.5

SB5 EF and HDI Factors	Score
EF Factor	4.6
HDI Factor	4.7

SB6 Targets	Percentage
Environmental	93
Economic	84
Social	94

SB7 Self Assessment: Information supplied and and confirmed by

Name	Date
Signature	

SB8 Validation: Documentation validated by

Name	Date
Signature	

SB9 Validation Report Version

	IVR

Figure 4.16: Perspective Render (Author 2021)

PART 5

REFLECTING

Figure 5.1: (above) Render (Author 2021)

ADDRESSING THE RESEARCH QUESTIONS

Developed from the global, urban, and architectural issues, as highlighted within Part 1, this dissertation set out to understand circular-economics and its interconnection with the built environment. The intention of this dissertation is to identify where circularity, and its associated principles, can be injected and integrated within conventional design and construction practices to develop a new circularity-based architectural model that acts as agent of regenerative design and urban cultural-economic resilience.

The research methodology utilized within this dissertation, particularly referring to the waste-stream mapping and the development of the "Mamelodi Doughnut Portrait", identified crucial obstacles standing in the way of developing urban resilience within the study area and achieving circularity within the built environment.

Together with the research methodology, the established theoretical framework set out to unpack programmatic drivers and design informants, taking into account global sustainability goals as well as local resources, systems, and skills, to develop a holistic whole-systems-based approach and design and construction methodology.

THE CIRCULARITY-BASED ARCHITECTURAL MODEL

As agent of regenerative design

Aligned with the United Nations 2030 Sustainable Development Goals, the circularity-based architectural model set out to achieve a minimum of carbon, water, and ecology net zero certification. The architectural intervention's programme was developed to demonstrate and be a didactic manifestation of closed-loop systems design, resource integration, and zero-waste principles.

The design and construction methodology of the dissertation serves as a manifestation of the core principles of circularity in the built environment as well as regenerative design theory. The choice of low-embodied-energy materials as well as the movement towards prefabricated mass timber construction, the carbon footprint of the project is greatly reduced whilst simultaneously acting as a carbon-sink within the environment.

The technological methodology of the dissertation demonstrated the shift towards circularity in the built environment through the use of materials and structural connections that act as a reversible and dynamic kit-of-parts, capable of being disassembled into its most basic components. This dynamic construction methodology allows for a high degree of flexibility of programme and adaptability of space in order to future proof the intervention for changing cultural and environmental conditions. By utilizing prefabricated mass timber as the primary structural system, this dissertation builds upon the concept of "afritech" design and reduces construction time on site, therefore resulting in a lower cost of construction.

AS AGENT OF URBAN CULTURAL ECONOMIC RESILIENCE

The programme and architectural manifestation of the dissertation set out develop urban resilience in many forms whilst breaking the cycle of poverty experienced within the study area. The programme of the architectural intervention creates a holistic and wholse-systems-based integration of internal resources within the study area whilst simultaneously addressing the vulnerability of the study area to system shocks due to the complete dependence on external systems of resources. At the core of the project, specifically the developed programme and the didactic social landscape connecting the intervention, is the active and passive transfer of knowledge. By creating this system of transferring knowledge, the cycle of poverty can be broken through education and skill development, as well as the creation of future-forwards and resilient economic opportunities.

MOVING FORWARD

In conclusion, by manifesting the principles of regenerative design and circular-economics, the project demonstrates a new architectural spatial model, based upon circularity, that provides a new direction for resilient and sustainable architecture that will aid in the development of future-proof architectural interventions.

BIBLIOGRAPHY

- 3XN. 2019. Building a circular future. 3rd ed. Copenhagen: GXN Innovation, pp.30-42.
- Aboginije, A, Aigbavboa, C. and Thwala, W. 2020. Determining the Impact of Construction and Demolition Waste Reduction practices on Green Building Projects in Gauteng Province, South Africa
- Amulya, K, Annie Modestra, J, and Venkata Mohan, S. 2020. Urban biocycles – Closing metabolic loops for resilient and regenerative ecosystem: A perspective, Bioresource Technology. Elsevier Ltd
- ARUP. 2016. City Resilience Index. Understanding and Measuring City Resilience. The Rockerfeller Foundation.
- Berg, P. G. and Nycander, G. 1997. Sustainable neighbourhoods - A qualitative model for resource management in communities, Landscape and Urban Planning, 39(2–3), pp. 117–135.
- Boontharm, D. 2019. Urban Design for Super Mature Society. The Journal of Public Space, 4(4), pp.137-154.
- Boyle, L., Michell, K. and Viruly, F. 2018. A critique of the application of Neighborhood Sustainability Assessment Tools in urban regeneration, Sustainability (Switzerland), 10(4).
- Brand, S. 1994. 'How Buildings Learn'. New York, NY: Viking.
- Cayuela, A, Miller, D, and Waldron, D. 2013. Regenerative Neighbourhoods – scaling up from net positive buildings, Pushing the Boundaries: Net Positive Buildings (SB13). CaGBC National Conference & Expo, pp. 69–82.
- City of Tshwane. 2013. Tshwane Vision 2055. Remaking South Africa's Capital City. Pretoria: Visionary Vangard Designs.
- Dixon, T, Eames, M, Hunt, M. and Lannon, S. 2014. Urban Retrofitting for Sustainability. Mapping the Transition to 2050. 1st ed. Florence: Taylor and Francis, pp.Chapter 2: Sustainable urban development to 2050: complex transitions in the built environment of cities.
- Earthworld Architects. 2021. Future Africa Innovation Campus - 2017 - Earthworld Architects & Interiors. [online] Earthworld Architects & Interiors. Available at: <https://www.ewarch.co.za/post/3096/futureafrica/> [Accessed 10 June 2021].
- Ellen MacArthur Foundation. 2013. Towards The Circular Economy. Economic and business Rationale for an Accelerated Transition.
- ESI Africa. 2019. Built environment consumes 33% of global energy. ESI-Africa.com. Available at: https://www.esi-africa.com/industry-sectors/energy-efficiency/built-environment-consumes-33-of-global-energy/ (Accessed: 14 May 2021).
- Fabbricatti, K. & Biancamano, P. F. 2019. Circular Economy and Resilience Thinking for Historic Urban Landscape Regeneration: The Case of Torre Annunziata, Naples, Sustainability
- González, A. et al. 2013. A decision-support system for sustainable urban metabolism in Europe, Environmental Impact Assessment Review. Elsevier Inc., 38, pp. 109–119.
Harrison, P, et al. 2014. Urban Resilience Thinking for Municipalities. Johannesburg: University of the Witwatersrand.
- Jaca, C., Ormazabal, M. and Prieto-Sandoval, V. 2018. Towards a Consensus on the Circular Economy, Journal of Cleaner Production, 179, pp.605-615
- Laprise, M, Rey, E, and Riera Pérez, M. G. 2018. Fostering sustainable urban renewal at the neighborhood scale with a spatial decision support system, Sustainable Cities and Society. Elsevier B.V., 38, pp. 440–451.
- Lean Built Environment – Afrika. 2019. LEAN Starter Kit. Creating Creative Capacity in Design & Construction. Pretoria: LBE - Afrika, pp.17-19.
- Lendagar Group. 2018. A Changemaker's Guide to the Future. 2nd ed. Denmark: Narayana Press.
- Levy, M. 2020. The art of Urban Generativity. MArch (Research). University of Pretoria, South Africa.
- Mahmoud, R. A. 2017. Smart Solutions in New Cities as main actors in Regenerative Urbanism: The Creation of Resilient Cities through Circular Urban Metabolism and decreasing Ecological Footprints.
- Mang, P. and Reed, B. 2013. Regenerative Development and Design, Encyclopedia Sustainability Science & Technology. Regenesis Group and Story of Place Institute, pp. 1–34.
- Mossin, N. 2020. An architecture guide to the UN 17 sustainable development goals. 1st ed. Copenhagen: Royal Danish Academy - Architecture, Design, Conservation.
- Novakovic, S. 2020. AZURE. [Online] Available at: https://www.azuremagazine.com/article/will-covid-19-spell-the-end-of-urban-density-dont-bet-on-it/ (Accessed: 12 June 2020).
- Perez, E. 2016. The translation of ecological resilience theory into urban systems. Ph.D. Department of Architecture, Faculty of Engineering, Built Environment and Information Technology, University of Pretoria.
- Pomponi, Francesco, and Alice Moncaster. 2017. Circular Economy for the Built Environment: A Research Framework. Journal of Cleaner Production 143: 710–18
- Raworth, K. 2021. Doughnut | Kate Raworth. [online] Kate Raworth | Exploring Doughnut Economics. Available at: <https://www.kateraworth.com/doughnut/> [Accessed 12 June 2021].
- Reed, B. 2007. Shifting from 'sustainability' to regeneration. Building Research & Information, 35(6), pp.674-680.
- Royal Danish Academy. 2020. An Architecture Guide to the UN 17 Sustainable Development Goals. Volume 2. Copenhagen: Royal Danish Academy.
- Statista. 2020. South Africa - Unemployment Rate 2020. Statista. [online] Available at: https://www.statista.com/statistics/370516/unemployment-rate-in-south-africa/ (Accessed 07 February 2020).
- TU Delft - edX, 2021. Course | edX. [online] Learning.edx.org. Available at: <https://learning.edx.org/course/course-v1:DelftX+CESBE1x+3T2020/block-v1:DelftX+CESBE1x+3T2020+type@sequential+block@ef2eec36a0454a67af9a06b31a79aca6/block-v1:DelftX+CESBE1x+3T2020+type@vertical+block@92f1d2d63ba64dcb894918c56309eb11> [Accessed 12 February 2021].
- Ulgiati, S. and Zucaro, A. 2019. Challenges in Urban Metabolism: Sustainability and Well-Being in Cities. Frontiers in Sustainable Cities, 1.
- United Nations FCCC. 2021. Nationally determined contributions under the Paris Agreement. Interim Report. United Nations Framework Convention on Climate Change.
- United Nations. 2021. New United Nations Climate Change Report 'Red Alert' for Planet, Secretary-General Says, Warning Current Emission Plans Not Enough to Adequately Curb Global Temperature Rise. (online) Available at: https://www.un.org/press/en/2021/sgsm20604.doc.htm\ (Accessed 15 May 2021).
- Wandl, A. 2021. Territorial Metabolism: Facilitating Circularity on a Global Scale. Delft University of Technology


Figure 5.2: Render (Author 2021)