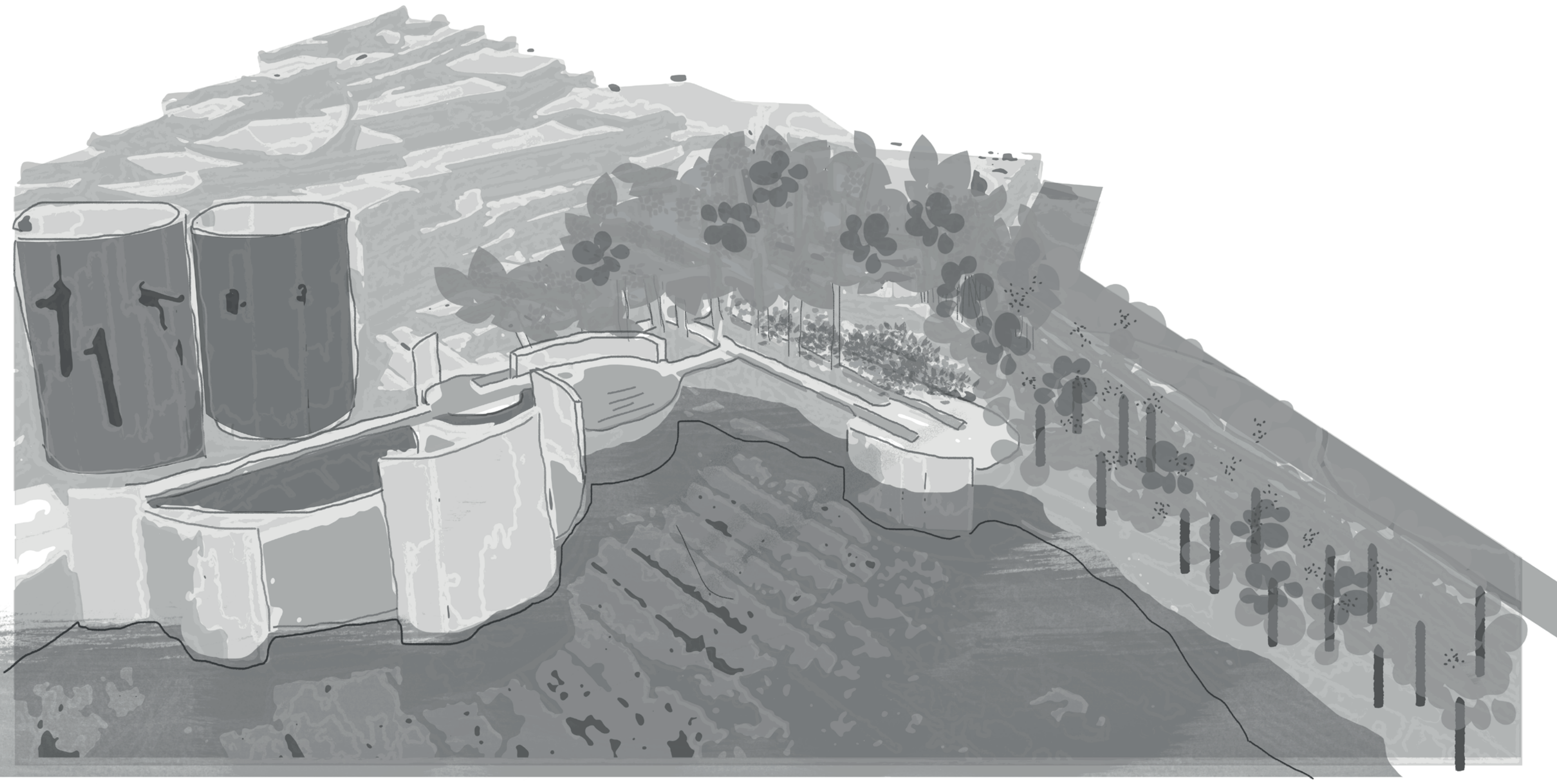
CARBON-CULTURE

An Urban Productive Landscape for Carbon Sequestration in Pretoria West



Dissertation Title: Carbon-Culture: An Urban Productive Landscape for Carbon Sequestration in Pretoria West.

Site Description: Pretoria West Power Station

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Declaration:

In accordance with Regulation 4(c) of the General Regulations (G.57) for dissertation and theses, I declare that this thesis, which I hereby submit for the degree Masters of Landscape architecture (Professional) at the University of Pretoria, is my own work and not previously been submitted by me for a degree at this or any other tertiary institution.

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

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

ABSTRACT

Rapid urbanisation worldwide since the 1950's has led to the depletion of ecosystem carbon pools and a loss of biodiversity, particularly in the urban environment. Urban expansion not only possess many threats to human well-being but also a greater over-arching threat of global climate change. South Africa has a heavy dependence on fossil fuel burning power stations, which ranks it as the fourteenth highest carbon emitter in the world. On top of this, current agricultural practices are detrimental to the environment, lead to lower yields and are a large contributor to South Africa's national carbon emissions. These unsustainable practices also fail to resolve urban food security, an emerging concern in the City of Tshwane.

The United Nations Framework Convention on Climate Change (UNFCCC) gave rise to the 2015 Paris Agreement dealing with greenhouse gas emissions mitigation, adaption and finance. Although South Africa signed the agreement pledging the reduction of national carbon emissions by the year 2035,the current trajectory will not honour this pledge.

The historical landmark of Pretoria West Power Station, a vastly underutilised landscape that has the potential to offset its past transgressions in terms of its impact on the atmosphere, is the focus area for the study. This dissertation investigates and proposed a new approach to the urban productive landscape in the form of a Carbon Farm, through: 1) Effective methods of carbon sequestration, including the mechanisms to aid this; 2) design principles which combat biodiversity loss in the urban environment; 3) design principles for climate change adaption and; 4) how these principles can be combined to form a landscape which addresses human well-being, food security and the rehabilitation of an industrial site.

The Carbon Farm challenges the way industrial landscapes are viewed, from a highly polluted landscape which should be situated on the outskirts of cities, to a landscape which is efficient, clean and attractive to a general populace whilst ensuring that emissions created are absorbed in-situ.

It achieves this using a multi-layered approach inspired by the three-step process of carbon sequestration as a conceptual driver. This is to ensure that the design of the Carbon Farm can facilitate the required levels of production in the form of forestry, agroforestry and algae farming whilst still contributing to human and environmental well-being. The human experience is further enhanced through the addition of a skywalk which takes the user on an elevated journey over the landscape to experience each carbon sequestration method prevalent in the Carbon Farm. This journey then culminates within an existing cooling tower where the user is able to take in the sheer scale and magnitude of the infrastructure used to generate electricity.

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CHAPTER 1- INTRODUCTION

Chapter One focuses on the introduction to the main issues and the selected site as well as the subsequent research question and sub-questions, hypotheses, research methodology, study objectives, delineations, limitations and assumptions of this dissertation.

1.1-INTRODUCING THE PROBLEM

Due to rapid urbanisation in both developed and developing countries, since 1950, there has been a dramatic shift in land-use from arable land to land covered in concrete (Lal, 2012a). This has led to a disturbance in the elemental cycles and the depletion of ecosystem carbon pools1 which has led to the loss of biodiversity, particularly in the urban environment (Shochat et al., 2010; Lal, 2012a) . This rapid urban expansion possesses many threats to human well-being regardless of the overarching issue of global climate change (UCCRN, 2018). The increased population in urban areas in turn, leads to the increased burning of fossil fuels attributed to transport, industry and power production, coupled by the presence of dedicated industrial zones containing various mixed industries each emitting Greenhouse gasses (GHG) into the atmosphere. All these factors lead to an increase in the concentration of carbon dioxide (CO2) and other greenhouse gasses (Lal, 2012b).

Whilst playing a vital role with regards to sustainable development and food security globally the agriculture, forestry and other land-use (AFOLU) sector is also a large contributing factor to global GHG Emissions (Smith et al., 2014). Their roles are however twofold, while the plants release gases in the form of Nitrous Oxide (N2O) and Methane (CH4) into the atmosphere by decomposition of dead biomass and Soil Organic Matter (SOM), respiration and combustion (Smith et al., 2014) they also absorb CO2 and Nitrogen (N) from the atmosphere and soil. Another contributing factor to these emissions is the human activities posed on these lands in the form of maintenance practices such as the use of gasoline powered lawn and garden equipment as well as large scale machinery used for agricultural purposes (Banks and McConnell, 2015), combined with detrimental land-use changes such as altering a natural grassland to an agricultural landscape (Smith et al., 2014).

According to Mcsweeny and Timperly (2018) South Africa is the 14th largest CO2 emitting country in the world and the largest in Africa. This is due mainly to the use of coal powered electricity generators, with the remainder of the 460 million tonnes of CO2 equivalent (CO2e) coming from oil consumption, Agriculture, Forestry and other Land Use (AFOLU) and manufacturing processes mostly present in the industrial zones (Boden et al., 2011). These industrial zones can be found in many of the larger and more developed South African cities.

According to Schrag (2007) there are three methods to lowering CO2 levels, and thus potentially mitigating climate change: a reduction in the world's energy consumption; expanding on the use of energy sources that do not emit CO2 into the atmosphere; and by capturing and storing CO2 in geological repositories in a process known as carbon sequestration2 (CS). The process of CS can be categorised under two different approaches, namely abiotic and biotic the latter of which will be the focus of this dissertation. Biotic CS requires living organisms in order to take place (Lal, 2007). Although various methods of biotic CS exist, such as oceanic sequestration and more experimental methods like bio-fixation of CO2 as discussed by Wang and Lan (2014), perhaps the most appropriate method to the urban context is terrestrial sequestration (TS). TS involves the sequestration of CO2 into the terrestrial carbon pools which are defined by two distinct factors: soil and plants (Lal, 2014).

The efficacy of urban trees or urban forestry in the reduction of atmospheric CO2 is well understood and studies have been done in McPherson and Simpson (1999) as well as Stoffberg and van Rooyen (2012) and Stoffberg et al. (2010) who specifically looked at the effectiveness of *Jacaranda mimosifolia* (Jacaranda), *Combretum erythrophyllum* (River Bushwillow), *Searsia lancea* (Karee) and *Searsia pendulina* (White Karee) street trees specifically in the context of Pretoria. However, it can be deduced that the presence of street trees as well as other trees in urban environments do not currently account for the total emission outputs from vehicular use and industrial processes of South African cities. There may therefore be a need for more focused interventions and practices in urban environments to account for the total amount of carbon emissions not only in South Africa but also globally.

Reaction to Climate Change
A global reaction to climate change comes in the form of the United Nations Framework Convention on Climate Change (UNFCCC) established in 1994 whose purpose is to stabilise the concentrations of GHGs in the atmosphere to a level which would prevent dangerous interference with the Earth's climate system (Parliament of Australia, 2010). From this, rose the 2015 Paris Agreement of which South Africa was a part of, pledging a peak, plateau and reduction of emissions by the year 2035 (Mcsweeny and Timperly, 2018).

As a result of the formation of the UNFCCC, the Reducing Emissions from Deforestation and Forest Degradation in developing countries (REDD+) mechanism was formed, which involves conservation and sustainable management of forests, and the enhancement of their carbon stocks (Rahlao et al., 2012). According to Rahlao et al. (2012) the REDD+ mechanism is one of the more efficient and cost effective mechanisms for mitigating climate change, however, most southern African countries including South Africa are not part of this programme, which can most likely be attributed to their relatively low forest cover and thus low deforestation rate. Regardless of the REDD+ mechanism's environmental benefits, it has inherent socio-economic benefits such as livelihood creation, food security improvement, and recreation opportunities to name a few, however, implementing this mechanism into developing countries needs to take into account the effects on the communities as well as the environment in which it might sit (Silori et al., 2013). Thus as part of the Cancun agreement various safeguards were implemented such as conservation of biodiversity and the protection of natural forests and their ecosystem services (UNFCCC, 2011).

Urban Food Insecurity in South Africa
Global food demand is expected to increase by 50% towards 2030 and then by approximately 70% by 2050 (Alexandratos and Bruinsma, 2012). The impacts of climate change play a heavy role with regards to current and future food security globally but particularly in Africa where agriculture is key to food security and economic growth (Anya et al., 2012). According to a survey done by the South African National Health and Nutrition Examination Survey (SANHANES) found that 28% of urban households are at risk of hunger and 26% are experiencing hunger, in comparison to the rural figures of 32% and 36% respectively. Those statistics clearly indicate that, what was traditionally considered a rural issue, food insecurity is becoming more and more an urban issue and one that needs to be dealt with particularly in the South African context (Battersby et al., 2015).

A Way Forward- Urban Carbon Farming
Carbon farming can be defined as land-based practices or processes which either reduce or eliminate the release of GHG or actively absorb carbon through CS into terrestrial carbon pools primarily in productive landscapes thus having the potential of mitigating climate change (Evans et al., 2015). Bringing productive landscapes into urban areas through the application of urban agriculture is being implemented in many developed as well as developing countries world-wide (Dieleman, 2017). Urban agriculture does not only contribute to food security for urban populations, but can also aid in economic upliftment as well as enhancing social and ecological systems (Dieleman, 2017). However, in a report published by the City of Tshwane (2009) it was stated that the biggest challenges facing the implementation of urban and peri-urban agriculture in the city are lack of access to good quality land as well as the lack of resources and capital. It is however important to note that the application of carbon farming solely fixated on maximising CS and output, for instance the planting of mono-cultures, may lead to a range of detrimental ecological impacts (Evans et al., 2015).

1.2-INTRODUCING THE SITE

The industrial zone of Pretoria, which is the focus area of this study, lies in Pretoria west which is situated on the western outskirts of the Pretoria central business district (CBD) and is one of the oldest suburbs in the city originally established in 1892. Pretoria West is bordered by a suburban area to the west in the form of Proclamation Hill and encapsulates the Tshwane University of Technology (TUT) to the north but the bulk is made up of mixed-use buildings containing industry, commercial activity and residential dwellings. Pretoria West is also adjacent to large industries such as steel works, aggregate and limes mines, and other factories predominantly situated towards the south western edge of the area.

Situated between Proclamation Hill and Pretoria West the Pretoria West Power station is the selected site for this study (Figure: 1). The power station was originally built in 1924 due to an increasing demand for energy supply to the city. Subsequent to this, in 1952, a new station was built adjacent to the original, which was left empty and allowed to decay. The newer power station remains in operation to this day but is however going to be decommissioned in the near future due to the fact that it is financially infeasible to continue running the station, even amidst statements made by the municipality's mayoral committee in 2015 that it was going to be upgraded (Bothma, 2015). This closure will lead to job loss and will add to the economic detriment which is currently being experienced in Pretoria West. The new power station building would then meet the same fate as its neighbouring building and fall into disrepair and deteriorate. The remainder of the site consists of: a large water body which is supplemented by the Daspoort Waste Water Treatment Plant 6.5 kilometres north-east of the site and is used for cooling excess steam and treating ash; ash settling ponds; and vast open spaces dominated by invasive plant species. The site is closed off from public access, presumably due to its derelict nature, causing a barrier between the western suburban area the industry to the south and the CBD to the east. The site however has vast potential for acting as: a hub of activity which links the suburban area to the west the industry to the south and the CBD and an environmental mitigator which can enhance the well-being of the current and future city dwellers.

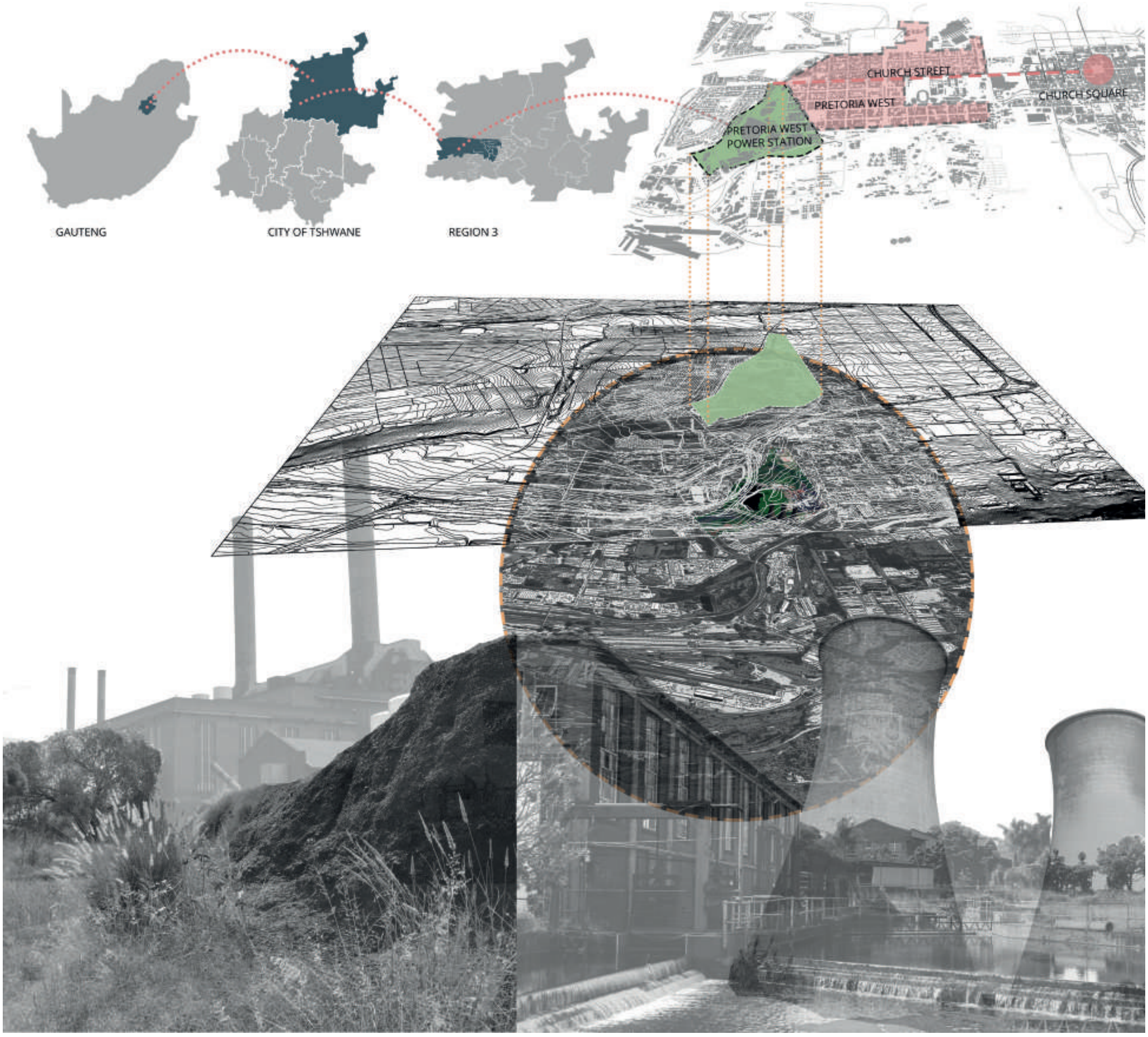


Figure-1: Pretoria West Power Station context map including images of existing infrastructure in the form of the buildings and cooling towers.

1.3-PROBLEM STATEMENTS

The Reducing Emissions from Deforestation and Forest Degradation (REDD+) Programme, is a cost effective and efficient way of mitigating climate change, however, South Africa is currently not part of this programme due to a relative low forest cover (Rahlao et al., 2012).

Current productive landscape practices are detrimental to biodiversity and have high carbon emissions contributing to climate change (Swift et al., 2004; Cole et al., 1997; Smith et al., 2014).

The application of urban and peri-urban agriculture in Tshwane is hindered by lack of access to land as well as capital and resources which has an effect on urban food security (City of Tshwane, 2009).

The study aims to establish how the idea of a carbon farm, could become a new typology for urban productive landscapes in South Africa, that addresses the above mentioned issues of carbon sequestration, climate change, food security and biodiversity enhancement that is required in urban environments.

1.4-RESEARCH QUESTION

What are appropriate landscape design guidelines for addressing urban carbon emissions and food insecurity in Tshwane?

With "appropriate" the author wishes to underline the following location specific aspects relevant to Tshwane:

- The climatic and micro-climatic conditions of the area;
- The locally indigenous flora and fauna;
- The socio-economic and well-being issues of the surrounding communities.

1.5-HYPOTHESES

By implementing the REDD+ mechanism as a small-scale approach combining existing and new urban forestry within Pretoria West the intervention can mitigate emissions from surrounding industries, adapt to an inevitable change in climate and improve ecosystem services thus improving overall site health and human well-being.

By implementing agroforestry principles as part of the REDD+ mechanism, the intervention can contribute to: improving urban food security, reducing $CO2$ emissions prevalent in agricultural practices and the rehabilitation of the site.

Carbon farming processes should incorporate critical considerations for climate change and biodiversity loss, while optimizing carbon sequestration. These considerations have the potential to holistically address the environmental imbalances found in industrial urban conditions while retaining contextual identity and aesthetic experience, which may aid in the improvement of human well-being.

1.6-SUB-QUESTIONS

How effective is urban forestry in reducing the amount of atmospheric $CO2$ in the urban environment?

How can urban agriculture contribute to food security whilst aiding in the reduction of atmospheric $CO2$ in the urban environment?

a) What are guidelines for species selection to maximise carbon sequestration?

What are design guidelines and species selection criteria against climate change?

What are design guidelines and species selection criteria against biodiversity loss?

How can the application of a carbon farm in an industrial environment contribute to:

a) Human well-being and economic upliftment in the area?
b) The rehabilitation of a toxic site?

1.7-RESEARCH METHODOLOGY

Research Paradigm: This dissertation can be placed within the post-positivist paradigm where it is heavily based on the natural sciences and attempts to search for ways to generalise the prediction of the sequestration potential of a carbon farm implemented within a particular environment.

Approach: The research design for this dissertation will involve the acquisition and analysis of secondary data.
Using secondary data though the available literature, the dissertation will attempt to hypothetically predict how much carbon can be sequestered by a series of CS techniques applicable to the selected site. The dissertation will attempt use desktop studies to ensure appropriate plant species selection in terms of their applicability towards the above mentioned themes namely: climate change mitigation; carbon sequestration maximisation; biodiversity enhancement and aesthetic experience in order to have a set of guidelines for the future implementation of carbon landscapes.

Secondary Data will be obtained by the following methods: Analysis of census data to understand the demographics of the study area in terms of the average income, average rate of employment, general type of employment and average age which will shed light on possible programmatic requirements of the intervention. The study makes use of secondary mapping data which can be overlaid to understand the surrounding land uses and distances to certain amenities, looking specifically at the types of industries which fall within the study area and how much carbon these industries emit per unit of output. Current emissions data are available for the particular industries. Desktop studies will be undertaken to analyse the various methods of carbon sequestration that have been locally and internationally used and how these can be adapted to work within the South African urban context. This point in the study will also include an analysis, based on secondary data, of which plants and trees, both indigenous and exotic, will meet the requirements of the above-mentioned themes. Further secondary data analysis will aid in obtaining data regarding root carbon pools of particular tree species through the use of root-to-shoot ratios.

1.8-AIMS AND OBJECTIVES

The study aims to establish how the idea of a carbon farm, combining urban forestry and agroforestry, could become a new typology for urban productive landscapes in South Africa.

The Study has the following objectives:

- To discover guidelines for the implementation of carbon farms within the urban context of South Africa.
- To create a landscape intervention that can actively sequester carbon whilst still managing to rehabilitate the toxic nature of the site.
- To discover guidelines for the selection of plant species which can be used as a template for future implementation of restorative carbon landscapes which enhance carbon sequestration and biodiversity whilst still being able to cope with the effects climate change.
- Discover ways in which a carbon farm can contribute to the social and economic upliftment of a dwindling industrial area.
- To discover the various methods of carbon sequestration and how they can be applied to particular sites, should the site area not be large enough to facilitate the required number of trees.

1.9-DELINIATIONS

The site is located in Pretoria West and is defined by Church Street to the north, Buitekant Street and Delfos Road to the east, Roger Dyason Road to the south and Quagga Road to the west, it is also split in two by Charlotte Maxeke Street but is bridged through the use of a railway line. The implementation of the intervention will be on the entire site on a masterplan scale.

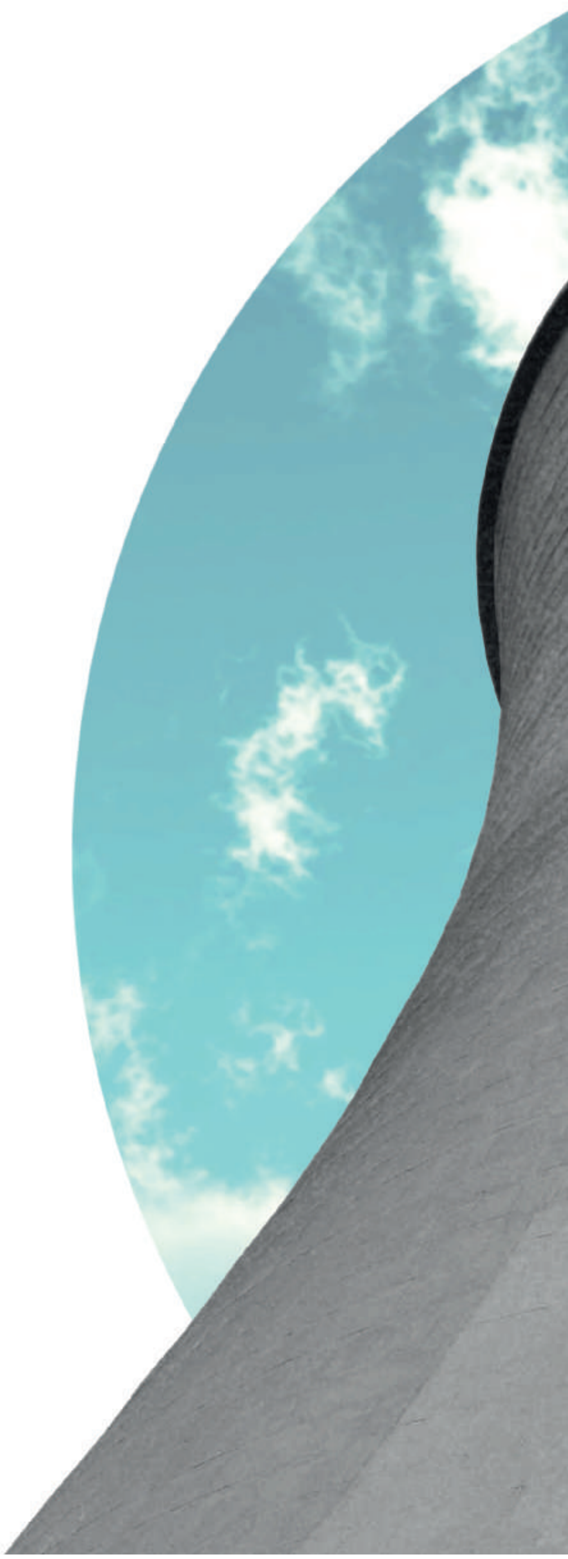
1.10-LIMITATIONS

The site is security controlled and very difficult to gain access to on a regular basis. On site there are structures which are declared unsafe and are therefore not accessible. Due to strict access it was not possible to obtain soil samples from the site in time for this study therefore some envisioned primary data samples were excluded from the study.

1.11-ASSUMPTIONS

- It is assumed that the coal powered aspect of the Pretoria West Power station will be decommissioned in the next few years.
- It is assumed that the water being pumped into the dam from the Daspoort waste water treatment plant is safe for human interaction and will continue to flow to the power station.
- It was assumed that the surrounding industries have a similar product output per annum in order to obtain an average carbon emissions for these industries.

CHAPTER OVERVIEW:



CHAPTER 2- THEORY REVIEW

This chapter's main focus is on answering the sub-questions as raised in chapter one through reviewing the relevant literature. The objective of this chapter is to answer the four research sub questions and their combined relevance to the context of Pretoria West.

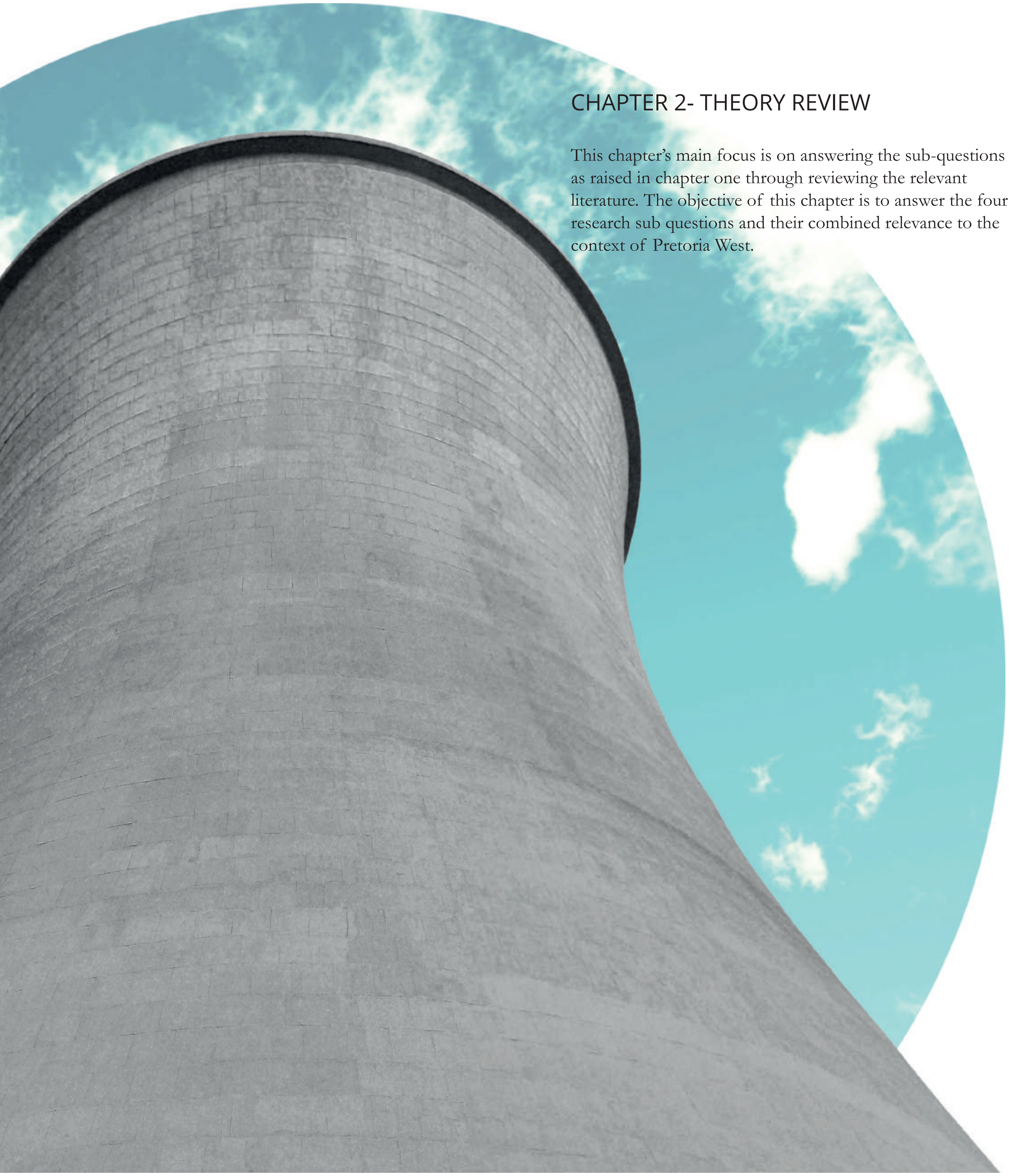


Figure-2: Conceptual image introducing the issues faced due to an ever increasing urban population- the transition between arable land to urban land and the hazards created.

2.1-INTRODUCTION

From the literature it is clear that the impacts that humans have on the concentrations of atmospheric gases are leading to an imbalance between what is being emitted by day-to-day usage of fossil fuel burning vehicles and what is being absorbed through carbon sequestration. According to McPherson and Simpson (1999) human activities such as the use of vehicles as well as air-conditioning add GHGs, namely CO2 and CH4, to the atmosphere at roughly 3% of the annual natural emissions. Although this may seem like a small percentage it is enough to ensure that the natural sinks are thrown out of balance and thus there is an excess of these GHGs in the atmosphere (McPherson and Simpson, 1999). This is exacerbated by ever-increasing urban population which leads to continued urban development and infrastructure as well as detrimental land-use change, loss of wetlands and deforestation world-wide which in-turn has a negative effect on ecosystem services (Muñoz-Vallés et al., 2013; Grimm et al., 2000; Haines-Young and Potschin, 2010). According to Haines-Young and Potschin (2010) in 2010 60% of global ecosystem services were being degraded or are being used in an unsustainable manner, this has a major impact on development, the alleviation of poverty and adaption to long-term environmental change.

Current agricultural practices are a large contributing factor to land degradation and do not sufficiently address food insecurity, particularly in urban environments. According to Waldén et al. (2019) sub-Saharan Africa has the highest rate of land degradation in the world which is largely due to low amounts of nutrients and soil organic carbon (SOC). Land degradation can lead to loss of biodiversity and cause negative micro-climatic conditions which has the potential to facilitate desertification and increase climate change effects by increasing GHG emissions (Hillbrand et al., 2017). This in combination with poor agricultural management practices leads to low yields and thus reduces food security. This is particularly prevalent in urban areas of Sub-Saharan Africa due to the fact that it is the most rapidly urbanising region in the world (Battersby, 2012).

As mentioned in chapter one, South Africa, as part of the 2015 Paris Agreement, has pledged that the country's emissions are to peak, plateau and decline by 2035. However, according to the Climate Action Tracker (CAT), an independent scientific analysis produced by three research organisations tracking climate action, South Africa, if the current low economic development continues, will only reach their peak by 2030 meaning that the plateau and decline periods will be extended and the decline can only be expected by the year 2040 (Mcsweeny and Timperly, 2018) (Figure: 3). On top of this, the CAT has stated that South Africa's pledge is inconsistent with limiting global climate change and predicts that South Africa's emissions will increase to 90% above the 1990 levels (355 MtCO2e per annum) by 2030, excluding land use, land-use change and forestry (LULUCF) (Mcsweeny and Timperly, 2018). It is therefore important to urgently consider ways in which carbon in urban areas can be reduced in South Africa.

The purpose of this literature review is to explore ways in which the amount of atmospheric CO2 can, and is currently being, reduced in urban environments around the world and whether these techniques would able to contribute to the economic upliftment and human well-being of the urban environment and its population through improving ecosystem services in South Africa.

The review firstly considers the role of urban forestry as an approach to mitigating climate change through carbon sequestration and will then look at how agroforestry in an urban area can be an approach to dealing with urban food insecurity. Subsequently it considers what decisions can be made and what strategies can be followed in order to enhance their prospective impacts.

The review is concluded by combining these factors into a summarised table to discover guidelines for implementing a landscape which will set out to achieve the objectives laid out in Chapter One.

2.2 THE POTENTIAL OF URBAN VEGETATION IN SEQUESTERING CARBON

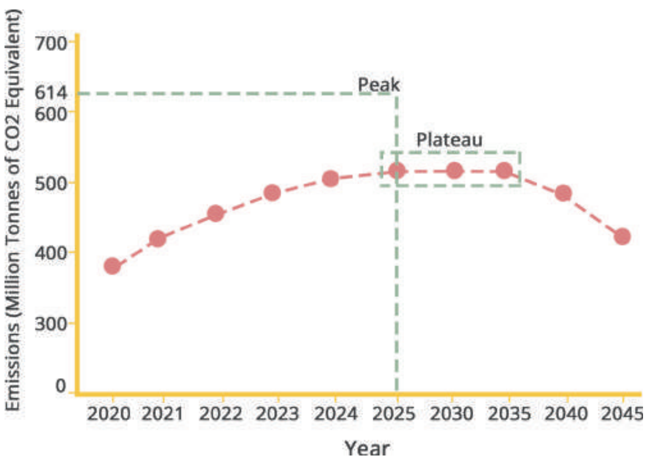
Vegetation has the ability to slow down the accumulation of atmospheric carbon within the urban environment (Nowak et al., 2002; Muñoz-Vallés et al., 2013). Of all terrestrial vegetation, trees have the greatest sequestration potential, particularly in the urban environment, to act as sink for CO2 and are unmatched by any other form of vegetation due to their size and life expectancy (McPherson and Simpson, 1999).

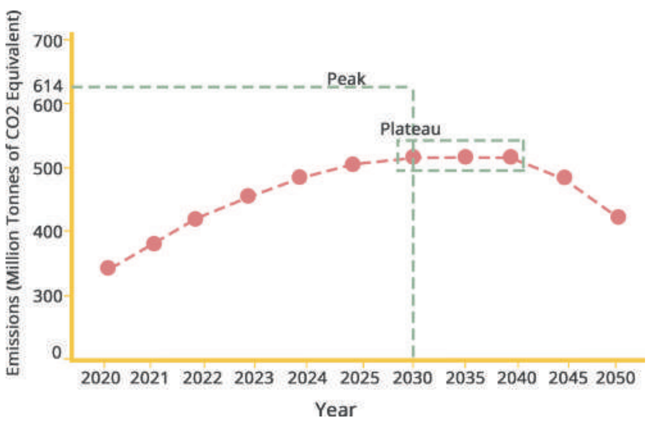
The structure of a forest is able to accommodate many different vegetation layers and is therefore considered to have the best carbon sequestration potential. The amount of carbon sequestered by urban forests depends heavily on regional and local factors (McPherson et al., 2013). The regional context influences include, amongst other attributes, the climate, soil types, potential vegetation as well as urban morphology whereas the local determinants of urban carbon storage include: species composition, age structure, the density of stands, urban tree management practices as well as land-use (McPherson et al., 2013). Sequestration rates also depend on tree growth and mortality which in-turn depends on species composition, age structure and the overall health of the forest (McPherson and Simpson, 1999).

South Africa has a relatively low forest cover which amounts to roughly 1.3% (±1.3mil.Ha) (Rahlao et al., 2012)(Figure: 4). Of that 1.3%, 1.1% are commercial plantations, 0.5% intact indigenous forests and 35% indigenous woodlands and savannahs (Rahlao et al., 2012). This low percentage of forest cover is part of the reason South Africa is not part of the REDD+ programme. However, in Gauteng there is roughly 37 000Ha of indigenous forest land coupled with roughly 77 900Ha of land occupied by non-natural and planted trees (Schäffler et al., 2013). The city of Tshwane alone contains 56% (20 600Ha) of Gauteng's indigenous forest cover and 24% (18 800Ha) of the non-natural and planted tree cover (Schäffler et al., 2013) (Figure: 5). These areas have the potential to become significant carbon sinks in what is South Africa's most densely populated province with 25.4% of the population with a predicted influx of roughly 1 048 440 migrants between 2016-2021 (Stats SA, 2018).

Various studies have been done into the carbon storage and sequestration potential of urban forests for example Nowak and Crane (2002) who calculated carbon storage by urban trees in the United States of America as well as Stoffberg (2006) who calculated carbon sequestration potential by street trees in the City of Tshwane. Urban forests, because of lower tree cover store less carbon per hectare in trees (25.1 tC/ha) than forest stands (53.5 tC/ha) with a gross sequestration rate of 0.3 kgC/m² (Nowak and Crane, 2002). However, on a per unit tree cover basis, the storage of carbon by urban trees equated to 9.25 kgC/ha compared to forest stands' 5.3 kgC/ha which can be attributed to a larger proportion of large trees and relatively fast growth rates due to the urban forest structure being more open when compared to a forest stand which tend to be more densely planted (Nowak and Crane, 2002).

Figure-3: Indicating South Africa's pledged emissions target versus the predicted emissions targets as per CAT predictions.





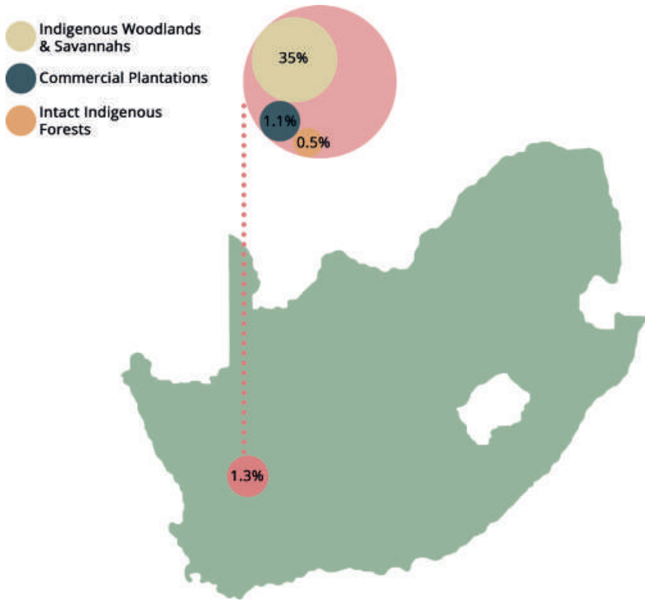
According to Nowak et al. (2002) tree species which are planted in urban environments need to live a minimum number of years (species dependant) to compensate for the initial carbon emissions involved in the planting, establishment and tree removal. If this does not occur, sustaining the tree population will lead to overall emissions of carbon throughout their life cycle.

On top of direct storage and sequestration of atmospheric CO2 in urban areas, urban forestry can affect atmospheric carbon concentration in various additional ways. Firstly the maintenance of urban trees through the use of fossil-fuel burning machinery such a chain saws, trucks and chippers directly emit carbon back into the atmosphere (Nowak et al., 2002). When fossil fuels are used to manage or maintain urban vegetation the emissions from the machinery will inevitably offset the nett carbon gain through time, the point where this offset is reached is referred to, by Nowak et al. (2002), as the “last positive point” (LPP). Therefore, the greater the value of the LPP the more effective the vegetation and/or maintenance practices are, at reducing the concentration of atmospheric carbon (Nowak et al., 2002). One passive method of prolonging the LPP is through the strategic planting of trees to reduce a building’s energy usage resulting in less carbon emissions from fossil-fuel-based power plants (Nowak et al., 2002). Another strategy of prolonging the LPP is through the use of wooden products, such as timber for structural material or cladding, for long-term carbon storage that can potentially offset carbon emissions from maintenance practices (Nowak, 2000).

From the information above it is clear to see that although urban forests influence the amount of atmospheric carbon within urban environments they are not the overall solution. It is possible to slow down the accumulation of atmospheric carbon however, reaching the LPP is inevitable. Further, more deliberate, strategies are required to take place along with urban forestry to increase the nett amount of sequestered carbon within the urban environments. On top of this it is necessary to consider how vegetation is able to adapt to the imminent change in climate without losing its function and thus its contribution to ecosystem services and human well-being.

In summation, the following factors need to be considered in order to maximise the potential of urban forestry for carbon sequestration:

a) Climate, soil type, stand density, urban morphology and species composition- These will influence the species selection, growth rate and life expectancy of the tree.
b) Age Structure of the forest- This will inform decision making as to where the most suitable areas for harvesting trees are as well as planting of new trees.
c) Maintenance Practices- If fossil fuel burning machinery is used for urban forest planting, establishment and removal, the emissions will eventually offset the amount of CO2 absorbed unless the machinery dramatically increases growth rate and life expectancy of the tree.
d) Placement of urban trees- by placing trees in strategic positions around buildings, the energy use of that building can be reduced which in-turn can reduce CO2 emissions from power plants.



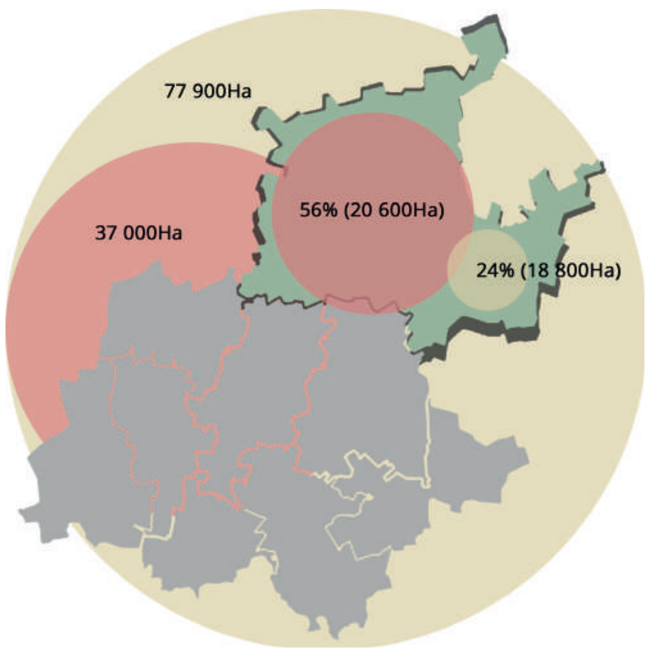


Figure-4:(Top): Indicating the total percentage of forest land cover in South Africa and what the percentage entails.
Figure-5:(Bottom): Indicating Gauteng’s forest land cover area and the area of non-natural and planted trees with the percentage distribution within Tshwane.

Landscape design guidelines to maximise carbon sequestration.

In order to maximise the carbon sequestration potential of urban vegetation a series of guidelines can be followed particularly when implementing new vegetation or conserving vegetation which already exists. As mentioned above, a tree's effectiveness in terms of sequestering carbon depends on its growth rate and mortality which in turn depends on species composition, age structure and the overall health of the tree (McPherson and Simpson, 1999).

It is therefore important to select tree species which are fast growing but still have a relatively long lifespan in order to maximise their total intake of CO2. Nowak (2000) and Nowak et al. (2002) have listed certain strategies to help increase carbon sequestration and thus mitigate climate change, the strategies regarding species selection include: maximising the use of low volatile organic compound (VOC) emitting trees; utilising long lived trees; utilising low maintenance trees; avoiding the use of trees which are pollutant sensitive; utilising evergreen trees for particulate matter reduction and utilising trees which are able to be harvested for long term timber products. It is important to note however that although there is advocation for fast growing mono-cultural forests which can include exotic species to sequester carbon at high rates, their storage can be seen short term as their capacity to do so for long term periods may be hindered due to the ever changing climate (Seddon et al., 2019). In order for a forest to sequester carbon over a long term period it is necessary for the species to be able to resist, recover or adapt to these changes (Seddon et al., 2019).

When it comes to growing these species, it is found that amenity forests i.e. forests grown and left to reach full maturity, tend to store more carbon than plantations grown for timber (Cannell, 1999). However, this excludes the calculation of carbon stored within the harvested timber products, which if counted ensures that the carbon storage is more, provided that the harvested timber decays slowly (Cannell, 1999). Timber which has been harvested or salvaged from trees tend to on average store carbon for fifty years before eventually decomposing (McPherson and Simpson, 1999).

In an urban environment, the soils which support the wide variety of green spaces represent a significant pool of organic carbon, even though the soils are often artificial or modified (Renforth et al., 2011). It was noted in Renforth et al. (2011) that in the United Kingdom, soil carbon storage in arable and horticultural soils has been estimated at being between 36-53% lower than that of public grasslands and garden lawns which can be attributed to maintenance practices such as watering. Soil type is an important factor when it comes to carbon sequestration (Cannell, 1999). The higher the fertility of the soil the greater the support for rapid tree growth, however the overall sequestration of a site is noticeably better when the trees planted are able to create carbon rich soil rather than being planted in carbon rich soil (Cannell, 1999).
In summation, the following factors need to be considered in order to maximise the potential of carbon sequestration in vegetation:

a) Plant and tree species should be fast growing and have long lifespans
b) Tree and plant species must be low VOC emitting.
c) Trees and plants must be low maintenance and must not be sensitive to pollutants.
d) Evergreen trees are preferred for particulate matter reduction.
e) Species should be selected based on their ability to produce timber products.
f) Mono-cultures are to be avoided due to climate change adaption.
g) Maintenance practices such as watering can enhance carbon storage in soils.
h) Enhancing soil fertility can increase tree growth rates.
i) Establishment of plantations should take place in soils which have a lower carbon content.

"A silo-based sectoral approach, in which agriculture, forestry, climate change, biodiversity conservation, water management, energy supply, devolution of governance and reduction of inequity are seen as separate targets is not going to deliver on the promises made. A coherent approach to all land uses (including agriculture and forestry) is needed."
- Meine van Noordwijk

2.3-COMBINING CARBON SEQUESTRATION AND FOOD INSECURITY.

Land practices that combat land deterioration and increase both carbon sequestration and food production would be beneficial to overcome the predicted challenges of urbanization. Agroforestry shows great potential for meeting these three goals. Agroforestry can be defined as the deliberate growing of woody perennials (trees and shrubs) in the same area and at the same time as agricultural crops, which are spatially mixed and form part of a temporal sequence (Viswanath and Lubina, 2016; Elevitch et al., 2018). Agroforestry goals are materialised in two ways: 1) a diverse and multi-layered food production system; 2) a resource conservation and ecologically restorative land-use (Elevitch et al., 2018).

Agroforestry, according to Hillbrand et al. (2017), can provide a wide array of ecosystem services beyond that of provisioning services and can contribute towards landscape restoration through improving soil productivity, enhancing the control of erosion and increasing the availability of water in soils (Hillbrand et al., 2017). The ecosystem services enhanced by agroforestry can include: supporting services in the form of pollination and carbon cycling as well as regulating services in the form of wind protection, enhanced water quality and nitrogen fixation. If these systems are well designed and managed, they can aid in ecosystem restoration thus contributing to biodiversity enhancement as well as climate change mitigation and adaption (Hillbrand et al., 2017).

There are a number of recognised agroforestry practices which include: alley cropping; contour hedge growing; forest farming; living fence, multi-storey cropping, riparian forest buffering, silvoarable systems, silvopasture and wind break (Elevitch et al., 2018). The most applicable to this dissertation in dealing with urban industrial sites, will be briefly discussed below based on Elevitch et al.'s (2018) study:

Alley Cropping: Also known as inter-cropping involves planting single or multiple rows of trees with crops in alleys between the tree rows. This practice can reduce run-off and soil erosion, improve the efficiency of nutrient uptake, sequester carbon and increase biodiversity.

Forest Farming: Practice of cultivating high-value, shade tolerant speciality crops under the canopies of a forest which is being managed to provide necessary micro-climatic conditions for understory crops such as mushrooms and medicinal herbs. This can be achieved by either thinning of an existing woodland or by adding a new layer to the structure of an existing system. Products produced by forest farming are typically not for timber use.

Riparian Buffer: Strips of permanent vegetation consisting of trees, shrubs herbs and grasses that are planted and managed adjacent to waterways and water bodies. The intention here is to buffer water bodies from potential negative impacts of surrounding croplands by reducing erosion and runoff of nutrients and sediments, improving water quality and increasing biodiversity.

Elevitch et al. (2018) set out criteria for agroforestry systems. The criteria called for these systems to be highly integrated, densely planted, multi-storied and contain multiple species. Integrated in that they include trees, shrubs and other perennials within the cropping system, there must be >40% cover by trees and shrubs allowing transition time from open field. Dense in that the density of planting is high, stacked or multi-storied, there must be >5 woody perennials per $100m^2$. Multi-storied so that there are many layers to improve light inception, there must be >2 woody perennial layers per $200m^2$. Multi-specie in that there is a use of multiple plant species which improves biodiversity and thus resilience of the system, there must be >8 plant families, genera, species and/or woody perennials per $100m^2$ present through the life of the agroforest (Figure: 6).

Further review by Elevitch et al. (2018) into the above mentioned criteria with regards to certain agricultural and forestry certification and standards found a list of criteria which need to be adhered to in order for an agroforestry system to be successful. The list is based on the United States Department of Agriculture (USDA) Natural Resource Conservation Service, which, although is not within a South African Context, still has applicability. The list is summarised, according to the applicable criteria, in the Table 1:

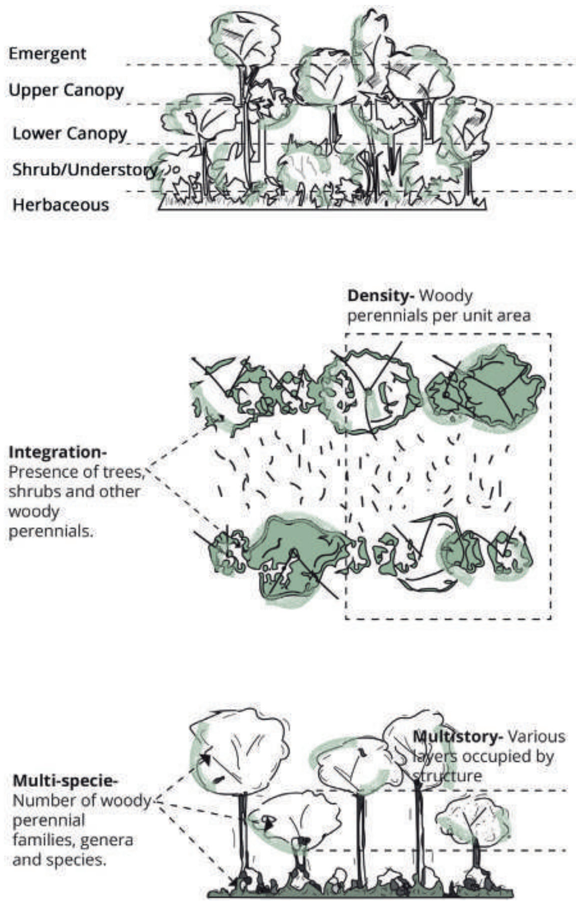


Figure-6: Indicating the principles of agroforestry as set out by Elevitch et al's study.

Criteria Measurement	Mixed Agroforest Specification for Pacific Islands Area (*Can be compared to humid areas of the Eastern Coast of South Africa)*	Riparian Forest Buffer for Around Water Bodies	Silvopasture for Kentucky *(Similar Köppen-Geiger climate classification as Pretoria (Cfa))*
1) Plants per unit area	Tree and Shrub counts must be > 1050/ha of which tall stature trees must be > 62/ha	Location and layout density of the buffer should complement natural features. Initial densities should be based on potential height, crown characteristics and growth form	Use trees and shrubs that are adapted to climate, soil and biological conditions of the site.
2) Layers represented in the tree/ shrub structure	High diversity in planting arrangement. **Minimum** of two layers (Tall and short trees)	Manage dominant tree canopies to maintain growth of overstory and understory species. Thinning and burning may be necessary to allow light to reach forest floor to maintain a good cover of grasses and forbs.	Manage tree and shrubs as needed to provide appropriate light conditions. Pruning is needed to achieve the desired canopy type for production of fruits, nuts and timber.
3) Number of woody perennials	a) 6 or more Woody plants depending on field size; b) <50% that produce non-timber forest products (any number of timber-producing trees are allowed; c) Minimum of 20% as native species **Limitations:** Individual plant genera that produce non-timber forest products may be planted in pure or contiguous clumps not to exceed 5 trees or 20 shrubs.	No Single species will make up more than 50% of the total number of species planted. Favour trees and shrubs which have multiple values i.e. timber, fruit, florals, nesting and aesthetics.	N/A

Table 1: a list of criteria which need to be adhered to in order for an agroforestry system to be successful (Elevitch et al., 2018).

The table reveals that for agroforestry to be successful in a number of different climatic areas it needs to be densely planted with a number of structural layers and multiple species which need to be managed in order to ensure proper light conditions for the understory vegetation. The selected species must be well adapted to the climatic conditions and growth form and overall size are important factors for species selection. Agroforestry systems must also favour woody species in the form of trees and shrubs.

On top of the environmental benefits of agroforestry, it can also contribute towards income generation. By growing high-value trees along with understory crops, it has the potential of providing alternative sources of income other than that of the actual crop itself (Hillbrand et al., 2017). Examples of these types of mixes that have been successfully implemented include Macadamia-nut trees with coffee plants in the understory in Hawaii and Sesbania spp. (Used for wood-fuel and nitrogen fixation) which provides sufficient shading for passion fruit vines in West Africa. A study done by Waldén et al. (2019) demonstrated how agroforestry systems (AFS) are able to mitigate climate change, through carbon sequestration, whilst improving food security as well as enhancing the local economy. In the study, AFS were compared to traditional monoculture plantations and were found to have improved yield, due to a wider variety of food producing crops, thus increasing revenue from an average of $289 for mono-cultures to an average of $1025 for the AFS, this does not factor in carbon revenue from carbon sequestration which for mono-cultures ranged between $90US to $300US and for AFS between $590 to $870. This indicates that the application of agroforestry can contribute to the local economy whilst improving the crop yield and thus increasing food availability of the intervention area.

In summation, the following factors need to be considered in order to create a successful agroforestry system:

a) Integration- The system will need to include trees, shrubs and other perennials in order to increase resilience against climate change, there is also the potential of carbon sequestration within the integrated system. (>40% Cover by trees and shrubs)
b) High Planting Densities- This aids in building soil by increasing organic matter production and can also reduce erosion and increase soil holding capacity. (>5 woody perennials per $100m^2$.)
c) Multi-storied- This results in higher biomass production due to a higher total light interception when compared to single storied configurations. This also has the ability to create diverse habitats which in-turn increases biodiversity. (>2 woody perennial layers per $200m^2$)
d) Multiple species- Increased species diversity increase overall biodiversity of the system and has an effect on the resilience of the system. (>8 plant families, genera, species and/or woody perennials per $100m^2$)
e) Tree and shrub count must be >1050/ha and the layout thereof must compliment natural features and must be adapted to climate, soil and biological conditions.
f) There needs to be at least two layers in the planting structure of the system and these layers must be maintained in

a way that appropriate light conditions are ensured for the understory vegetation.

g) Of the minimum six woody perennials, per site depending on size, no more that 50% of them should be non-timber product producing and a minimum of 20% of the species need to be indigenous. Of these species no more than 50% shall be made up of the same species.

2.4-LANDSCAPE DESIGN GUIDELINES FOR CLIMATE CHANGE.

As mentioned above, the application of agroforestry systems as well as urban forestry has the potential to mitigate climate change through carbon sequestration, however this does not mean that climate change will be abated. As pointed out by Cannell (1999), global reforestation and afforestation efforts set out by the Intergovernmental Panel on Climate Change (IPCC) will only accumulate 12-15% of the projected cumulative fossil fuel and deforestation emissions. It is therefore necessary to select plant species which can adapt to a changing climate without losing their ability to provide ecosystem services thus having the potential to maintain their positive effect on human well-being.

According to Hunter (2011), the ability of ecosystems to deliver services defines whether or not they are healthy. The healthy functioning of an ecosystem depends highly on the interaction between species and their abiotic environment which may be affected by the changing climate (Parmesan, 2006; Haines-Young& Potschin, 2010). Climate change has been attributed to higher average temperatures as well as extreme fluctuations in temperatures and rainfall (Hunter, 2011). According to a report published by the Climate System Analysis Group (CSAG) and African Climate Development Initiative (ACDI) University of Cape Town (2017), Gauteng may experience an increase in temperature of 1-2ºC between 2016-2035 and as much as 6ºC predicted by some climate change models between the years 2080-2100. However, this report eludes to uncertainty with regards to rainfall prediction, indicating that between the years 2080-2100 a majority of models show significant drying whilst the minority showing an increase in rainfall.

Climate change has also been associated with a change in distribution of plant and animal species as well as their phenology (Parmesan and Yohe, 2003). There is therefore a need for ecosystems to be adaptable to a changing climate so that the impacts of climate change on the ecosystem services are dulled.

According to Hunter (2011) there are three components that should be utilised to ensure adaptability within an ecosystem those components will be discussed below:

1. Plasticity (Figure: 7)- This describes the effectiveness of a species' performance across different environmental conditions such as: change in temperature, soil moisture, urban pollution tolerance, drought and flood tolerance. The higher a plant's plasticity the greater its ability to persist under a greater flux of environmental conditions.
2. Ecological resilience (Figure: 8)- This describes the ability of an ecosystem to remain functional whilst facing environmental disturbance. This depends on the way that biodiversity is grouped in accordance to ecosystem function. The number of species which contribute to an ecosystem function a) functional redundancy and the range of the reaction to environmental change of the species contributing to that ecosystem function b) response diversity, play a critical role in determining ecological resilience.
3. Structural Diversity (Figure: 9)- This describes the spatial complexity of a plant's form and structure. This is generally applied to a collection of plants rather than the plant itself. The structural diversity is directly proportional the physical diversity or architectural form within the collection of plants. Biodiversity is supported by structural diversity.

It is however important to note that although the above mentioned components may ensure adaptability, if used in isolation may be in detriment to other aspects such as biodiversity, for example, where planting design includes a high level of plastic species, the list of available species will decrease (Hunter, 2011). This can be balanced by enhancing other aspects such as functional redundancy and response and structural diversity.

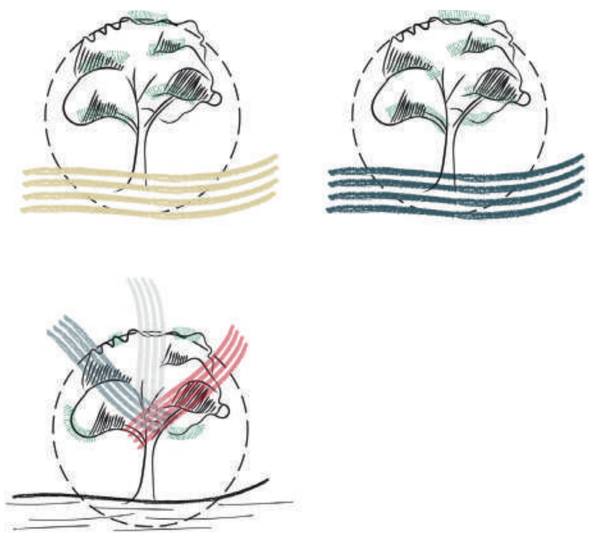


Figure-7: Principles of plasticity- drought tolerance, flood tolerance, change in temperature, soil moisture and urban pollution.

2.5-LANDSCAPE DESIGN GUIDELINES FOR ENHANCING BIODIVERSITY IN URBAN AREAS

A key element in enhancing ecosystem functioning which in-turn enhances ecosystem services is biodiversity (Swift et al., 2004; Taylor& Hochuli, 2015; Haines-Young& Potschin, 2010).

Biodiversity is defined as the variability amongst living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological populations of which they are a part. This includes variations within species,

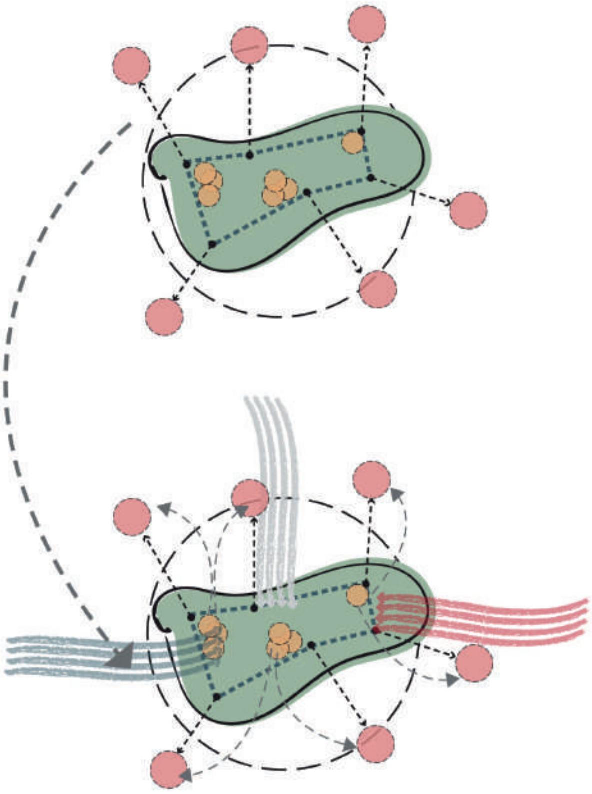


Figure-8: (Top): Diagram indicating ecosystem ecological resilience, the ability ecosystem to remain functional whilst facing environmental disturbances.
Figure-9: (Bottom): Diagram indicating structural diversity of planting.

between species and of ecosystems (Swift et al., 2004).

Swift et al. (2004) states that there are four key types of value which enhanced biodiversity is able to provide and they will be discussed below:

1. Intrinsic value- This refers to the ingrained value of biodiversity to humans or the value that biodiversity has on its own. This includes social, aesthetic and ethical benefits.
2. Ecological Value- As mentioned above, biodiversity also contributes to ecosystem functions and the preservation of ecological structure and integrity.
3. Utilitarian value- This refers to the value of the components of biodiversity such as the subsistence and/or commercial benefits of species to one or multiple societal sectors. This may be found in scenarios such as commercial farmers, subsistence farmers and governmental organisations and can materialise in high value agricultural crops as well as other types of goods.
4. "Serendipic" value- This refers to the yet unknown value that biodiversity may have to future generations. For instance, the presence of a certain micro-organism may have a yet undiscovered application potential for industrial products.

As we can see from the above, biodiversity has several values and is therefore important to conserve and/or enhance to provide a wide range of benefits. In order to do this there are a few guidelines that need to be taken into account.

According to Shochat et al. (2010) communities which have higher evenness, i.e. when individual species are equally distributed among one-another in a community, have higher diversity when compared with a community with similar number of species but with unequal distribution of these species. Rookwood (1995) argues that in order to enhance biodiversity and thus evenness amongst communities it is necessary to take a wider approach to open space planning by integrating multiple open space planning objectives into one system. This can be done by designing connected open space corridor systems which allow for habitat creation as well as sufficient area to support populations of species which are linked to each other via these corridors. When doing this it is important to minimise or remove barriers between these corridors (Rookwood, 1995). Brown (2013) states that in order to increase and sustain biodiversity the system needs to provide habitat for cover and foraging; natural patterns and processes that species are adapted to; and reduce threats to wildlife survival such as habitat sinks, invasive species, inappropriate land uses adjacent to habitats as well light pollution. Brown (2013) identifies ten spatial design elements as derived from landscape ecology, namely: 1) percentage of project area preserved; 2) Area of landscape within development; 3) Percentage area of priority habitats avoided; 4) Percentage historic habitat types present; 5) Percentage structural layers present in landscape; 6) Number of target plant species within structural layers; 7) Habitat patch area; 8) Habitat corridor width; 9) Distance gap between patch or corridor and 10) Network consistency, these are summarised in Table 2.

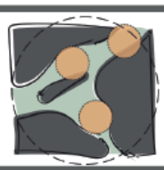
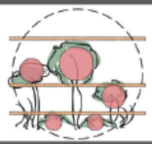
Indicator Categories			Sample Metrics	Assumptions
1	Habitat Area		% of project area preserved	Total Landscape area= foundation for biodiversity. More area= more potential for biodiversity
2	Habitat Area		Area of landscape within Development	Landscape footprint is related to many other community sustainabilty indicators and urban design considerations. Percentage landscape area often required by codes- foundation for potential biodiversity in more urban areas.
3	Habitat Variety		% area of priority habitats avoided	Priority habitats are often the most important biodiversity indicator considered.
4	Habitat Variety		% historic habitat types present	Variety of native habitat types provide an indication of the overall biodiversity that may exist on a site
5	Habitat Quality		% Structural layers present in landscape	Absence or presence of vegetation and structural layers as compared to layers present in native ecosystems is assumed to inidcate value for native biodiversity.
6	Habitat Quality		Number of target plant species within structural layers	Existing or planned species composition when compared to that of a native ecosystem is asssumed to indicate overall biodiversity
7	Habitat Patch/ Corridor size and shape		Habitat patch area	Larger patches have less edge relative to area= more interior habitat conditions for native biodiversity. Larger patches = more area for natural processes.
8	Habitat Patch/ Corridor size and shape		Habitat corridor width	Corridors provide movement + migration of species between patches. Wider the corridor the greater the interior conditions and ecological characteristics of a patch.
9	Habitat Connectivity		Distance gap between patch or corridor	Closer the patches and corridors the higher the biodiversity for both. Visual continuity, species mobility, dispersal strategies and adjacent land-use can also impact biodiversity.
10	Habitat Connectivity		Network consistency	Biodiversity value can increase or decrease depending on habitat quality of broader network. Higher quality adjacent to lower quality= more valuable than low quality adjacent to low quality.

Table 2: Five main strategies to enhance biodiversity adapted from Brown (2013).

2.6-HOW CAN THE APPLICATION OF A CARBON FARM IN AN INDUSTRIAL ENVIRONMENT CONTRIBUTE TO HUMAN WELL-BEING AND ECONOMIC UPLIFTMENT IN THE AREA WHILST ALSO CONTRIBUTING TO THE REHABILITATION OF A TOXIC SITE?

In order to address the main research question, the answers from the literature review need to be combined into an approach that could work for a partially toxic post-industrial site in an economically challenged environment.

Industrial and urban environments are rife with air pollutants from production practices as well as degraded soils due to mono-functional land-use and detrimental land-use changes (Muñoz-Vallés et al., 2013).

In their basic capacity trees are able to reduce the urban heat island effect by improving shading, evaporative cooling and interception which thus has an impact on the human comfort levels in the urban environment (Derkzen et al., 2017). This can be achieved through the correct application of urban forestry. However, trees are also able to restore degraded soils through biomass production, nitrogen fixation and dense networks of roots among others aspects (Hillbrand et al., 2017). This in turn makes it possible for ecosystem services, in the form of supporting, provisioning and regulating services, to each have a positive impact on the natural environment as well as the human environment in which they are situated (Hillbrand et al., 2017; Elevitch et al., 2018).

The Pretoria West area that surrounds the industrial site has been economically challenged, especially due to the closing of a number of the industrial programmes including the power plant on the site. As indicated in the discussion about agroforestry above, a characteristic of agroforestry is its ability to generate new sources of income within the environment it is placed (Hillbrand et al., 2017). The idea of different plants performing different functions provides a wide array of opportunities for provisioning services such as food production but can also include the production of high-value trees for use in timber products (Hillbrand et al., 2017).

The failure of land rehabilitation in current urban and agricultural practices, is caused mainly by the weakness and inaccuracy of the applied technologies, limited funding and lack commitment from institutions (Nuddin et al., 2019). As mentioned above, agroforestry is able to prevent erosion, improve soil fertility, preserve water systems and protect biodiversity (Moreno et al., 2018). The multi-strata approach to an agroforestry system allows for ecological succession to take place which aids in the succession of plant species that contain certain characteristics of successional stages which have the ability to diversify functions, promote tree growth and crop productivity (Young, 2017). In this way species which may aid in the absorption of ground toxins will have opportunity to succeed.

If we consider the application of urban forestry and agroforestry as well as the subsequent guidelines for carbon sequestration, biodiversity and climate change stated above, the idea of a carbon farm in an urban environment can pose many positive contributions to human well-being as well as economic upliftment whilst contributing to site rehabilitation (Figure: 10).

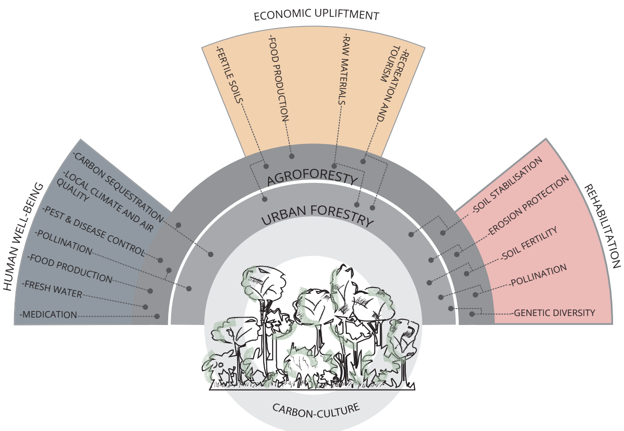


Figure-10: The concept of carbon culture as an approach to improving human well-being, contributing to economic upliftment as well as the rehabilitation of a toxic site.

CASE STUDY: PUR Projects- Sidama Project, Wonsho Woreda, Ethiopia
Trees Planted: 225 787.
Wonsho Woreda remains one of Ethiopia's most deforested areas and is highly threatened by unsustainable agricultural practices, illegal timber logging and sales and the use of firewood (PUR Project, 2016). Most of the farmers in the region rely on coffee production for income generation but live below the poverty line. Low densification of coffee plantations combined with poor agricultural management practices leads to low coffee yields and therefore low income (PUR Project, 2016). On top of this, the effects of climate change are already noticeable in the form of heavy droughts and irregular rains, which all increase the impact of coffee yields and quality (PUR Project, 2016).

The project was undertaken by PUR projects in conjunction within the Bokasso cooperative which consists of a series of small-scale farmers with an average surface area of one hectare. This cooperative is supported by Trabocca, a company which sells coffee globally. The project was also later funded by the Louis Dreyfus foundation (PUR Project, 2016).
Project Objectives:
Planting trees in and around coffee fields to help increase resilience to climate change, preserve water resources and soils, reduce erosion, and therefore ensure optimal growing conditions. Agroforestry trees will provide food for the community in the form of fruit trees, fuel wood, environmental benefits in the form of carbon sequestration, increase in soil quality and water hold capacity while increasing coffee yields and quality, and ensuring its long-term availability. In 2016, additional activities were developed with coffee farmers in order to increase food security, improve coffee production and health.

Figure-11:(Left) Diagram and photos indicating the planting and community engagement strategies applied to the Sidama project.

2.7-CONCLUSION AND FINDINGS

This literature review looked at how successful the application of urban forestry is at reducing the amount of atmospheric carbon dioxide through carbon sequestration and concluded that although it is a viable method it will merely prolong the LPP. It then looked at and listed certain landscape design guidelines which could further enhance the carbon sequestration potential in terrestrial vegetation. Section 2.2 concluded that because a changing climate is inevitable, there is therefore a need for systems to become adaptable in order to deal with the variable future climate. It then looked at how agroforestry systems can be applied in order to combat food insecurity by ensuring a diverse range of food producing plant species instead of the traditional mono-cultural crops. It also showed that agroforestry systems do not only contribute to food security but also aid in climate change mitigation in the form of carbon sequestration as well as economic upliftment by ensuring that the planting of woody perennials can provide alternative sources of income in the form of timber production. It then looked at how these two tactics can be enhanced through designing for biodiversity and climate change. Finally, the literature review considered how the aspects of urban forestry for carbon sequestration and agroforestry for food production can be combined onto a partially toxic post-industrial site in order to aid in the rehabilitation process and simultaneously address human well-being and economic upliftment of the surrounding areas (Figure: 12).

The findings in terms of landscape design principles are divided into four categories, namely: spatial (Figure: 13); environmental; time and maintenance (Table 3) and are summarised as follows:

Figure-12:(Right) Diagram indicating how the application of urban forestry combined with agroforestry with subsequent enhancements through designing for biodiversity, climate change as well as carbon sequestration has the potential to lead to a new typological approach to productive landscapes in urban areas which provide adverse benefits such as: climate change mitigation; climate change adaption; increased urban biodiversity; economic upliftment; food security and rehabilitation.

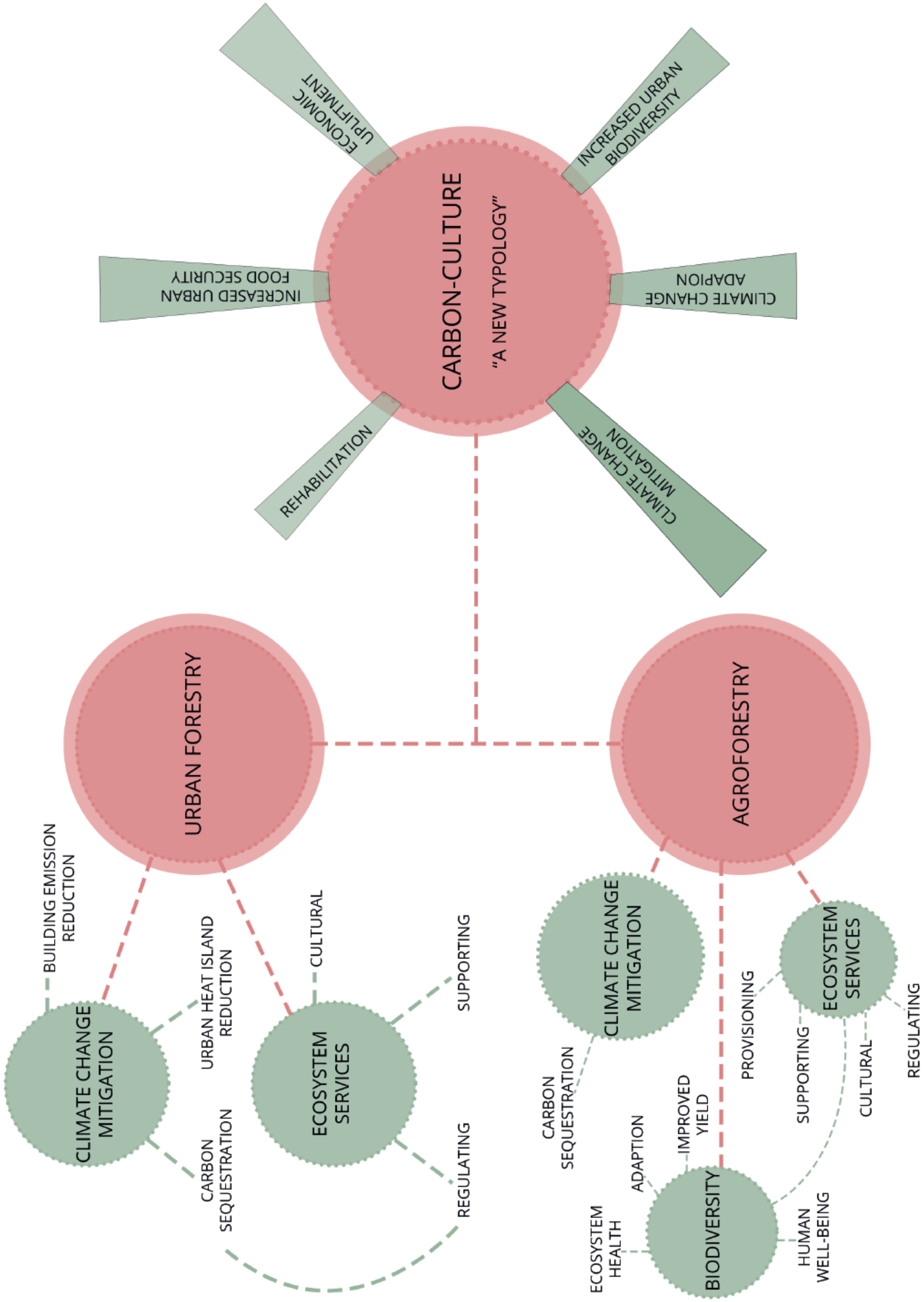

CARBON-CULTURE
"A NEW TYPOLOGY"
ECONOMIC UPLIFTMENT
INCREASED URBAN BIODIVERSITY
INCREASED URBAN FOOD SECURITY
CLIMATE CHANGE ADAPION
REHABILITATION
CLIMATE CHANGE MITIGATION
URBAN FORESTRY
AGROFORESTRY
CLIMATE CHANGE MITIGATION
BUILDING EMISSION REDUCTION
URBAN HEAT ISLAND REDUCTION
CARBON SEQUESTRATION
ECOSYSTEM SERVICES
CULTURAL
SUPPORTING
REGULATING
CLIMATE CHANGE MITIGATION
CARBON SEQUESTRATION
ECOSYSTEM SERVICES
PROVISIONING
SUPPORTING
CULTURAL
REGULATING
BIODIVERSITY
ECOSYSTEM HEALTH
ADAPTION
IMPROVED YIELD
HUMAN WELL-BEING

Table 3: Indicating the environmental; time and maintenance conclusions of the literature review.

Environmental Implications	Conclusions
% of landscape area	Total landscape area needs to be maximised
% of priority habitat preserved	Identified natural habitats to be maintained and enhanced.
Mixed rather than monocultures	Plant and tree mixes to be maximised as much as possible
Soils with low initial carbon content	Plantations to be established in soils which have a lower carbon content in order to make the greatest impact
Soil fertility	Increasing soil fertility through rehabilitation will ultimately improve overall productivity of intervention.
Allowing succession	Facilitating succession of pioneer species will aid in the removal of soil toxins.
Riparian buffer as a means to buffer water bodies form agricultural practices	Riparian buffer agroforestry practices can be utilised around water bodies in order to prevent negative impacts of activities
Time Implications	**Conclusions**
Long lived species	Tree and plant species should live for sustained periods of time to maximise CS and Storage.
Fast Growing species	Species should be selected according to their growth rates
Carbon storage in timber	Species should be selected according for their use in timber products
Minimum number of years trees need to survive to account for planting, establishment and removal.	Practices to ensure tree species live for as long as possible to offset emissions
Temporal sequence of planting	Planting specifically for food should be rotated according to optimal growth seasons.
Forest farming after forest has fully established	Once forest has been fully established thinning can take place to allwo for forest farming practices to take place.

Spatial Implications	Conclusions
Trees to be placed strategically to minimise building emissions	Deciduous trees to be placed by building areas on site
Species to be spatially mixed	This can elude to both plant selection as well as spaces created by the intervention (create diverse spaces)
Alley Cropping as a spatial informant	The practice of alley cropping has specific spatial implications which can be applied both systematically and spatially to the intervention.
Planting to be multi-storied	This can be implemented spatially as well as systematically (Spaces at various level linked to heights of trees and plants)
Planting to be integrated	Integrated planting and integrated spaces within the landscape.
Planting to be structurally diverse	Utilising the structure of plants to define and frame spaces and views within the landscape.
Evenness	Plant species to be evenly distributed within landscape
Connectedness	Zones within the landscape to be connected both for movement of users as well as migration of species on site and urban scale
Size of patches	Landscape typological patches to be large enough to maximise function as well as biodiversity on site and urban scale
Width of corridors	Corridors linking patches/zones to be wide enough to facilitate function and movement on site and urban scale.
Distance between patches	Where possible, distances between patches/zones to be minimised both on site scale and urban scale
Stand density	Where plantations are implemented stand density is to be as dense as possible to ensure maximise CS in that zone. Where ammenity forests are implemented density of trees to decrease to maximise CS potential of each tree
Complementing natural features.	Utilising plating to compliment both the industrial landmarks as well as the natural features such as stream and lake.
Maintenance Implications	**Conclusions**
Watering to improve growth	Sustainable irrigation practices to be designed into site in order to facilitate rapid initial growth
Use of non-fossil fuel based equipment	Maintenance equipment to be hyridised or manual. This may increase employment and facilitate stewardship
Maintenance must increase lifespan	Maintenance practices must ensure the extension of plant and tree lifespans. This will increase carbon storage potential
Trees and plants to be low maintenance	Where possible tree and plant species must be low maintenance thus decreasing the for possible use of fossil-fuel based equipment

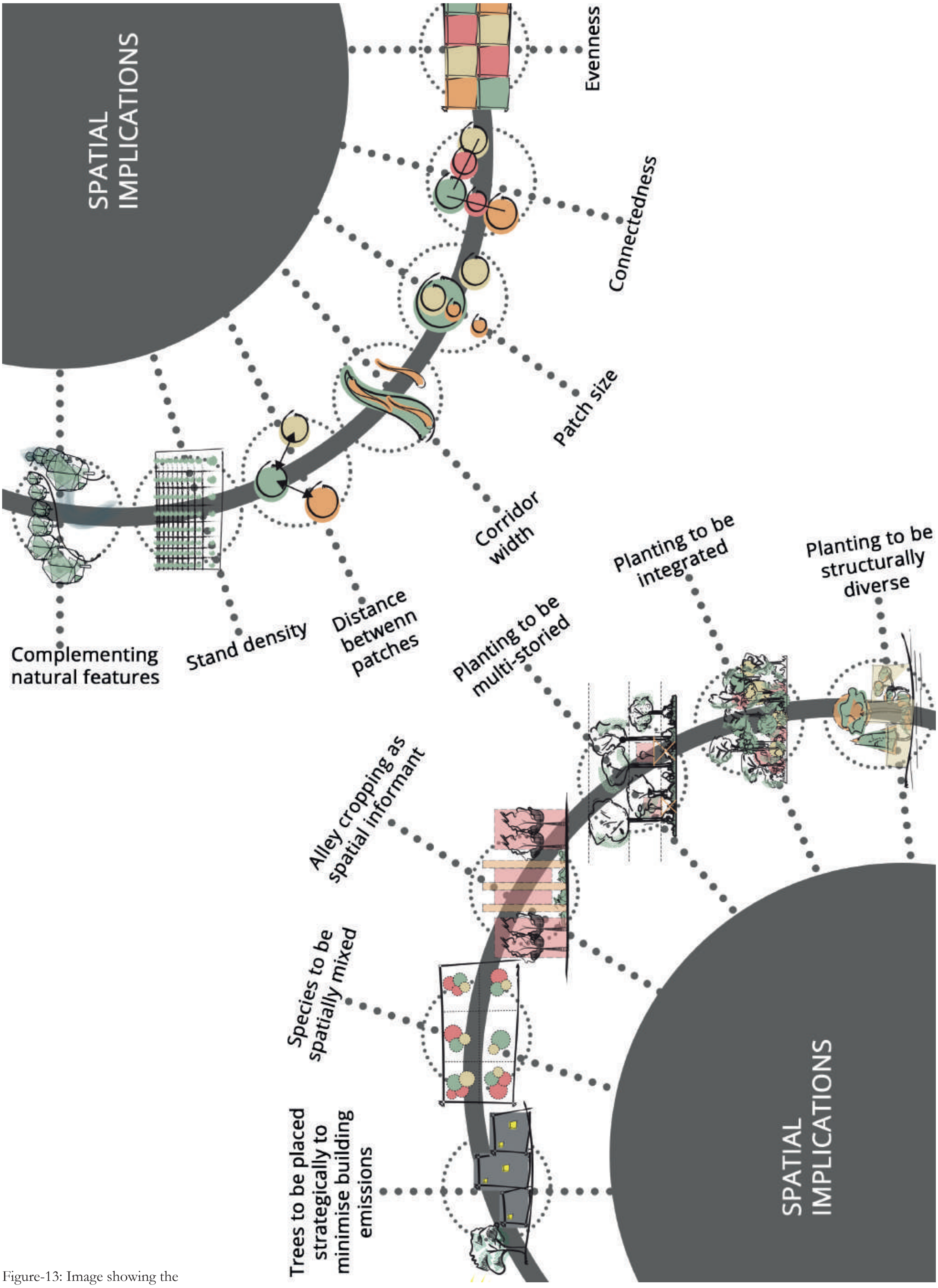


Figure-13: Image showing the spatial conclusions of the literature review.

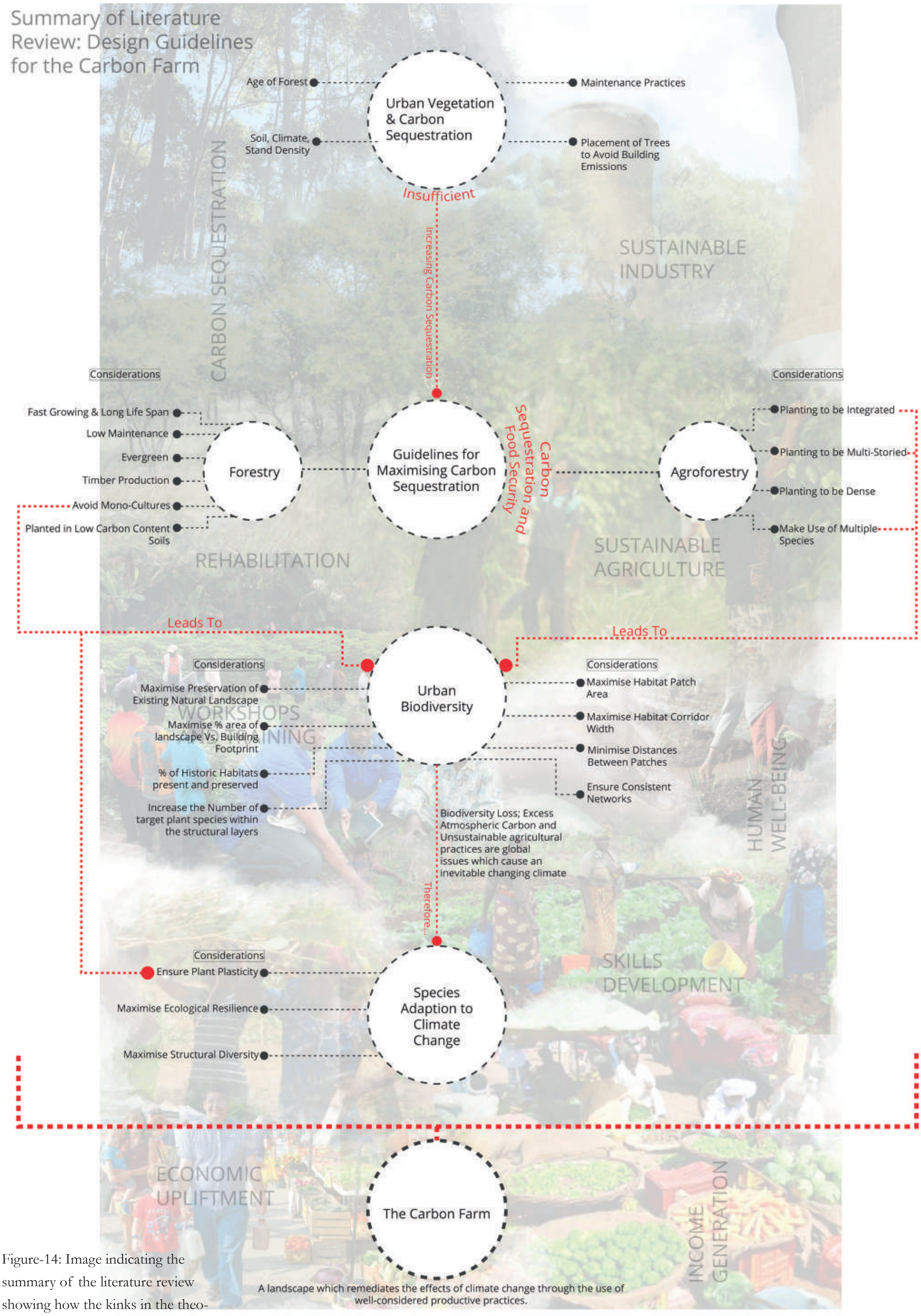


Figure-14: Image indicating the summary of the literature review showing how the kinks in the theory resulted in the formation of the Carbon Farm.

CHAPTER 3- THE SITE

This chapter delves into a short historical analysis of the site followed by its urban context and then the detailed analysis of the site itself. The chapter concludes with various opportunities and constraints for the development of the site going forward.

3.1-HISTORICAL ANALYSIS

In 1892 the original electricity supply for Pretoria was from a station located in Francis Baard Street (Formally Schoeman Street). As the urban population of Pretoria increased so did the demand for electricity and thus the station was moved to the outskirts of the city onto a larger area which is now the current location of the Pretoria West power station. The new station was built in 1922 (Davey, 2010). Following this, in 1928, the outskirts of Pretoria was further bolstered by the addition of the South African Iron and Steel Corporation Limited (ISCOR), later Arcelor-Mittal, by the South African parliament (Davey, 2010). ISCOR and the power station aided the establishment and definition of the western outskirts of Pretoria organised along Buitekant Street which was later planted with a row of palm trees, (which exists to this day), in order to further define the edge (Davey, 2010). The station itself was in due-course expanded and additional structures were built in the form of coal bunkers and coal stores.

Once the station had reached its electrical supply limits a new set of buildings were commissioned (Station A). The new station was an expansion of one of the boiler buildings but soon reached capacity as well. Thereafter Station B was commissioned and completed in 1954. Following the completion of Station B, Station A was abandoned and allowed to fall into disrepair it still stands to this day, as a reminder of the past (Figures:15-19).

A. Beginnings of Proclamation Hill
B. Beginnings of Pretoria West Power Station (1922)
C. Expansion of Proclamation Hill
D. Expansion of Station A
E. First cooling tower
F. Further expansion of Proclamation Hill
G. Addition of sports fields
H. Completed coal bunker for Station B
I. Completed Station B (1954)
J. Two additional cooling towers added
K. Addition of Palm Trees along Buitekant Street (Circa. 1950)

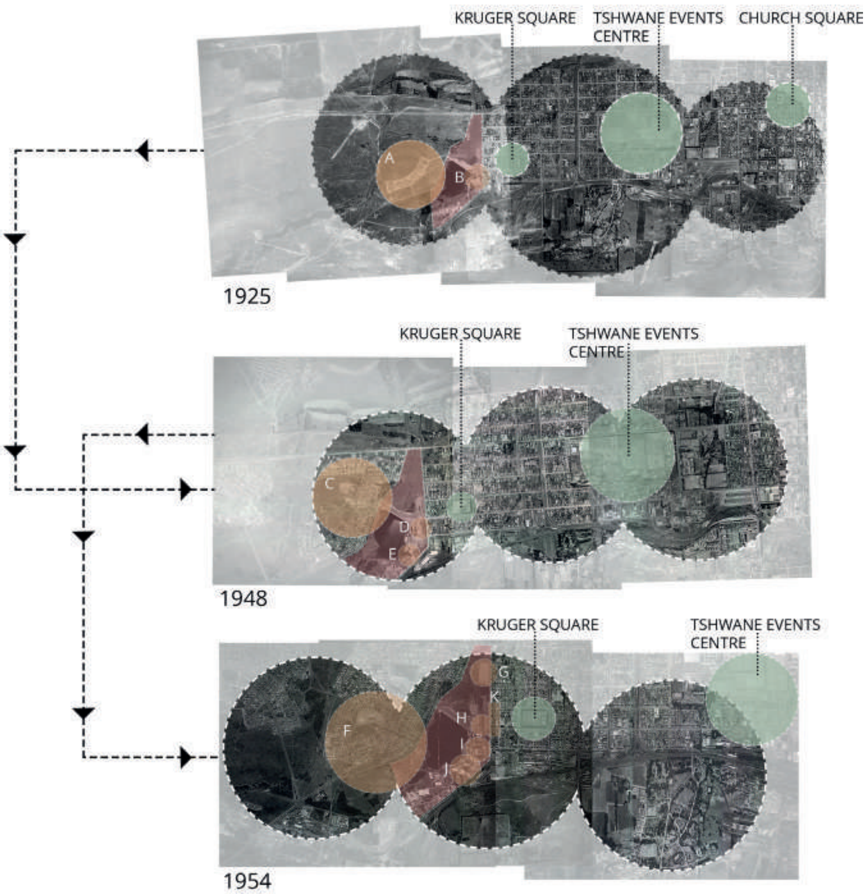


Figure-15: Showing the historical evolution and development of the Pretoria West Power Station and the surrounding suburbs

HISTORICAL PHOTOGRAPHS

Figure-16: Showing a completed Station B Circa 1932 (Courtesy of the Pretoria West Power Station Archives)

Figure-17: Showing a construction of coal bunker on northern section of the site with station A and B in the distant background. (Courtesy of the Pretoria West Power Station Archives)

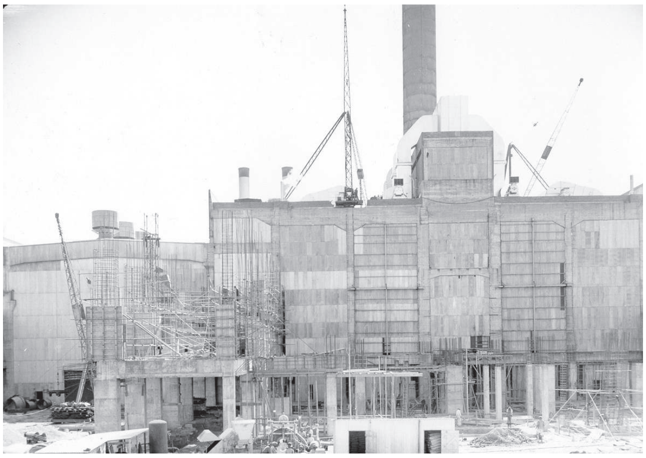


Figure-18: Showing construction of Station B. (Courtesy of the Pretoria West Power Station Archives)

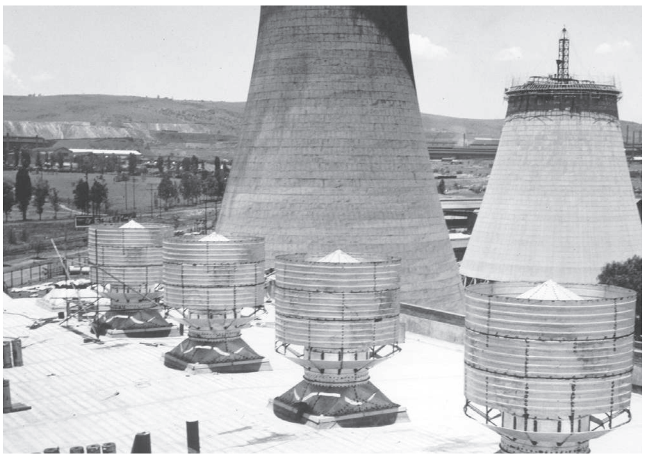


Figure-19: Showing additional cooling tower being constructed. (Courtesy of the Pretoria West Power Station Archives)

CURRENT PHOTOGRAPHS

Figure-20: Taken from atop current power station looking west showing extent of water hyacinth invasion on site dam.

Figure-21: Taken from atop current power station looking south showing existing three cooling towers.

Figure-22: Showing dilapidated nature of station B on the left of the image.

Figure-23: Taken from atop current power station looking north over coal bunker on the northern section of the site.

The current condition of the power station campus, even though partly operational, is in a state of disrepair and lacks basic maintenance on both the existing built fabric as well as the landscape which surrounds it. Station B has also been stripped of all re-sellable infrastructure and steel and therefore the structure has been condemned and is inaccessible. This general lack of maintenance and the presence of non-operational infrastructure and buildings gives the campus a sense of neglect. This furthers the need for intervention to prevent what can be seen as an iconic infrastructural landmark, in the history of the development of Pretoria, from becoming completely condemned and lost to the future development of the city (Figures: 20-23).

3.2-CONTEXT ANALYSIS

The Pretoria West Power Station is situated 4.5 kilometres west of Church Square along Church Street. The station is surrounded by various mixed-use developments, with a particular focus on high density industrial and commercial use, to the east and south with low density residential to the west and north. It is defined by Church Street to the north, Buitekant Street and Delfos Road to the east, Roger Dyason Road to the south and Quagga Road to the west, it is split in two by Charlotte Maxeke Street. It is also situated within close proximity to public transport in the form of train stations and bus stops. The site is surrounded by various open spaces in the form of public parks as well as natural servitudes (Figure: 24).

Figure-24: The Pretoria west power station and its proximity to Pretoria CBD as well as metro bus stops.

Figure-25: Looking south towards the Vibro Aggregate Mine, over the SAPS Tshwane Police Academy.

Figure-26: The View Looking south-east towards Freedom Park and the Voortrekker Monument.

Figure-27: The View Looking east towards Pretoria CBD along Carl Street.

Figure-28: The View Looking west towards the suburb of Proclamation Hill.

3.2.1-POPULATION DENSITY

The population density map (Figure: 29) indicates a relatively low population density in Proclamation Hill, approximately 6-25 people per hectare, when compared to the Pretoria West area, approximately 101-1093 people per hectare. The highest densities are found to the north/ north-west and east of the site in Phillip-Nel Park/ Danville and Pretoria West areas respectively. As urbanisation rates continue to increase so too the urban population of Tshwane which is expected to increase by 2.5% from 2 738 000 to 3 219 000 between the years 2018-2030 (United Nations Department of Economic and Social Affairs Population Division, 2018).

3.2.2-SURROUNDING LAND-USE

The surrounding land-use shows a strong grouping between what is industrial, residential and commercial with the exception being Pretoria West which is relatively mixed-use in nature (Figure:30). The site itself has a strong industrial nature which tends to increase in a south to south-easterly direction. There is also a strong residential land-use to the north and west within close proximity to all the industrial processes (refer to section 3.2.6) which may have a negative impact on human health and well-being.

3.2.3-OPEN SPACE NETWORKS

There are three notable public open spaces within a two kilometre radius of the site (Figure:31),However, they are rather underutilised and ill-maintained thus making them less favourable for use. The smaller spaces are not linked to form green corridors and thus the environmental benefits are limited to the confines of each space with the exception of the servitude spaces which are linked to a bigger system via the waterways.

3.2.4-SURROUNDING STREET ANALYSIS

The surrounding streets are mainly focused and designed for vehicular use and therefore create physical barriers for pedestrians beyond that of the fences that surround the site. There are very few safe pedestrian crossings and the edges of the site create barriers in the form of walls and fences, therefore there is not a sufficient amount of pedestrian flow, over and along the streets (Figure:32).

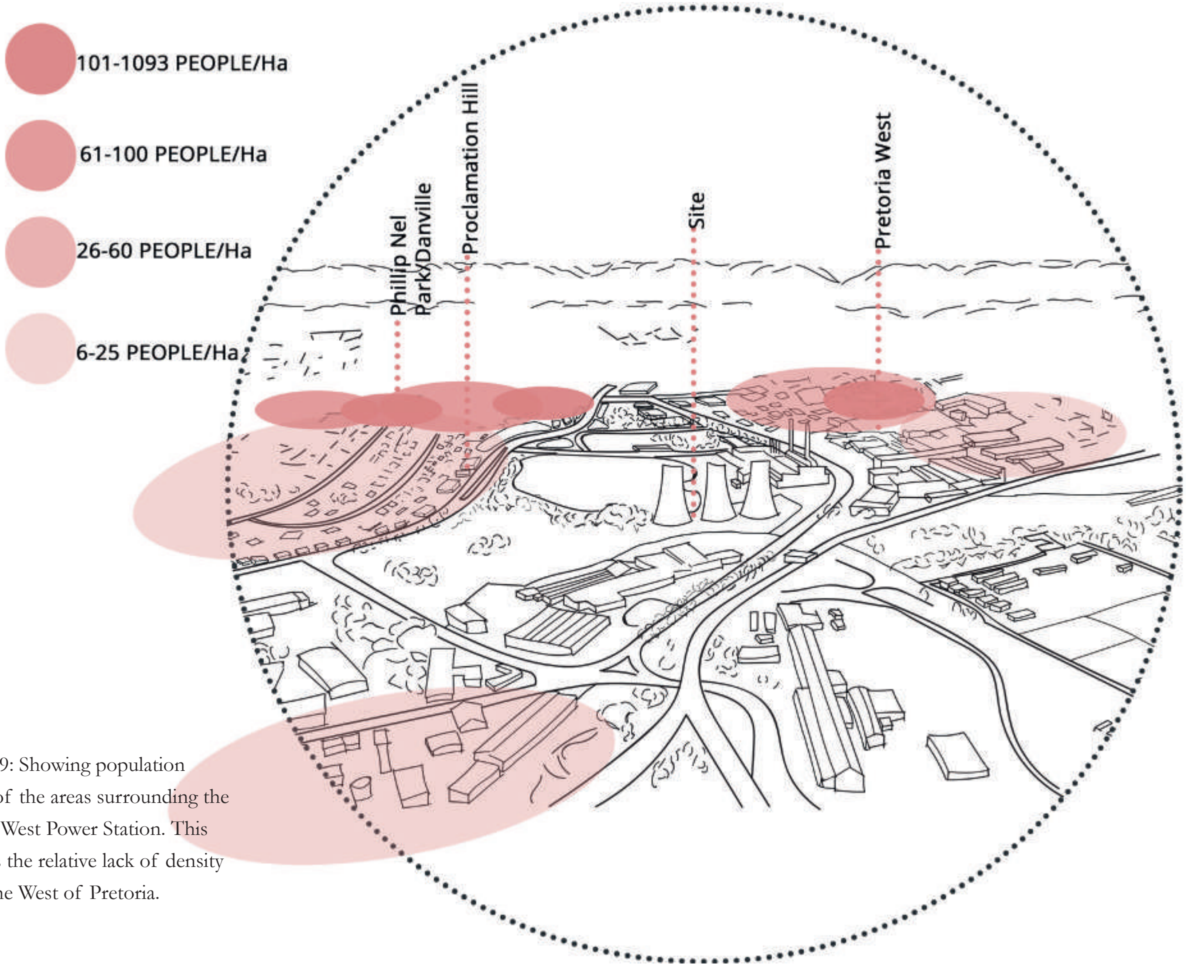


Figure-29: Showing population density of the areas surrounding the Pretoria West Power Station. This indicates the relative lack of density within the West of Pretoria.

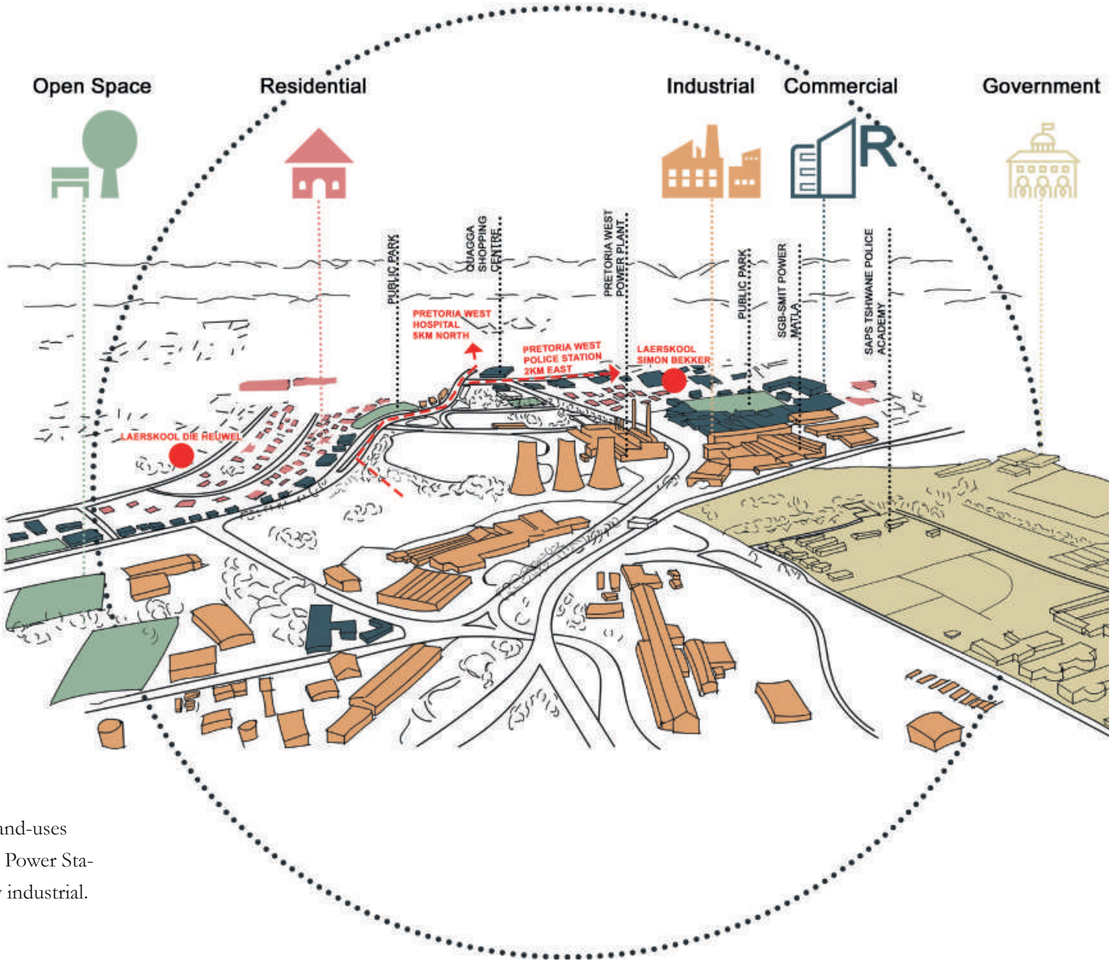


Figure-30: Showing the land-uses around the Pretoria West Power Station being predominantly industrial.

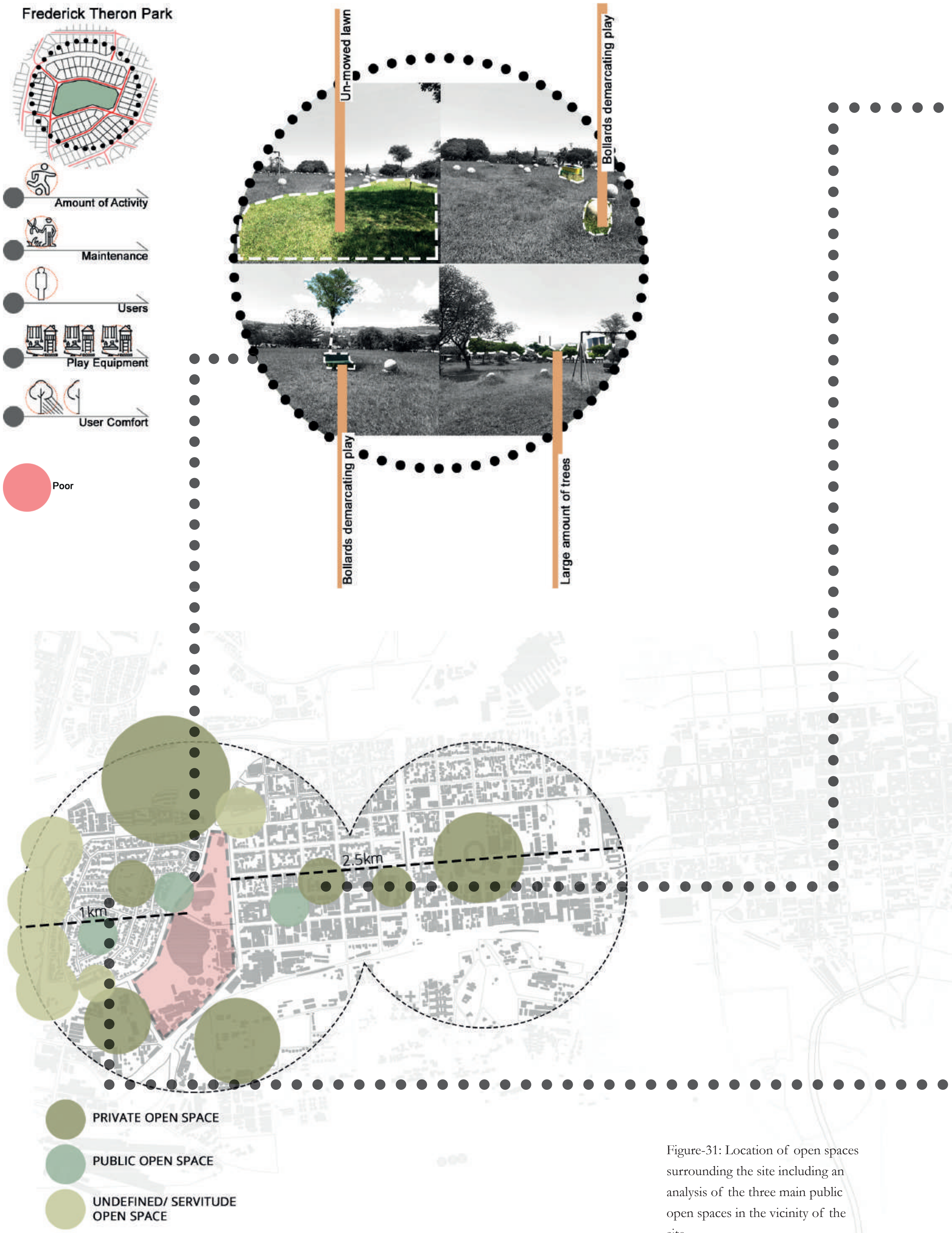
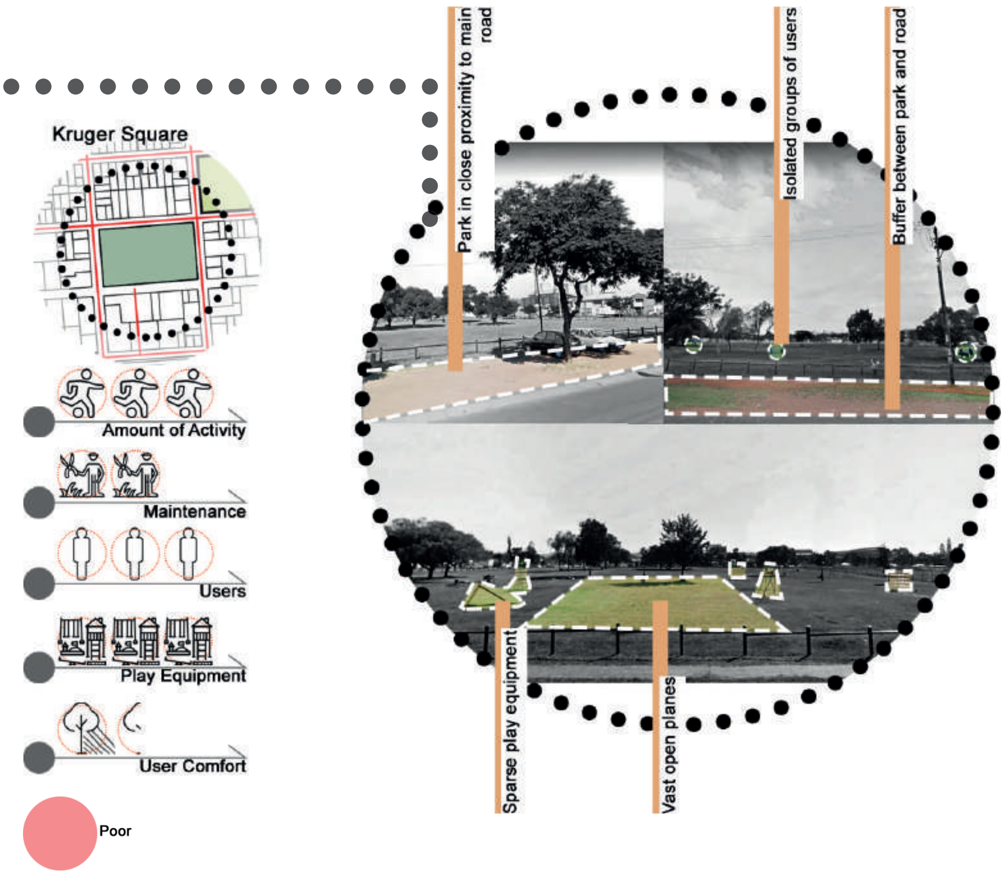
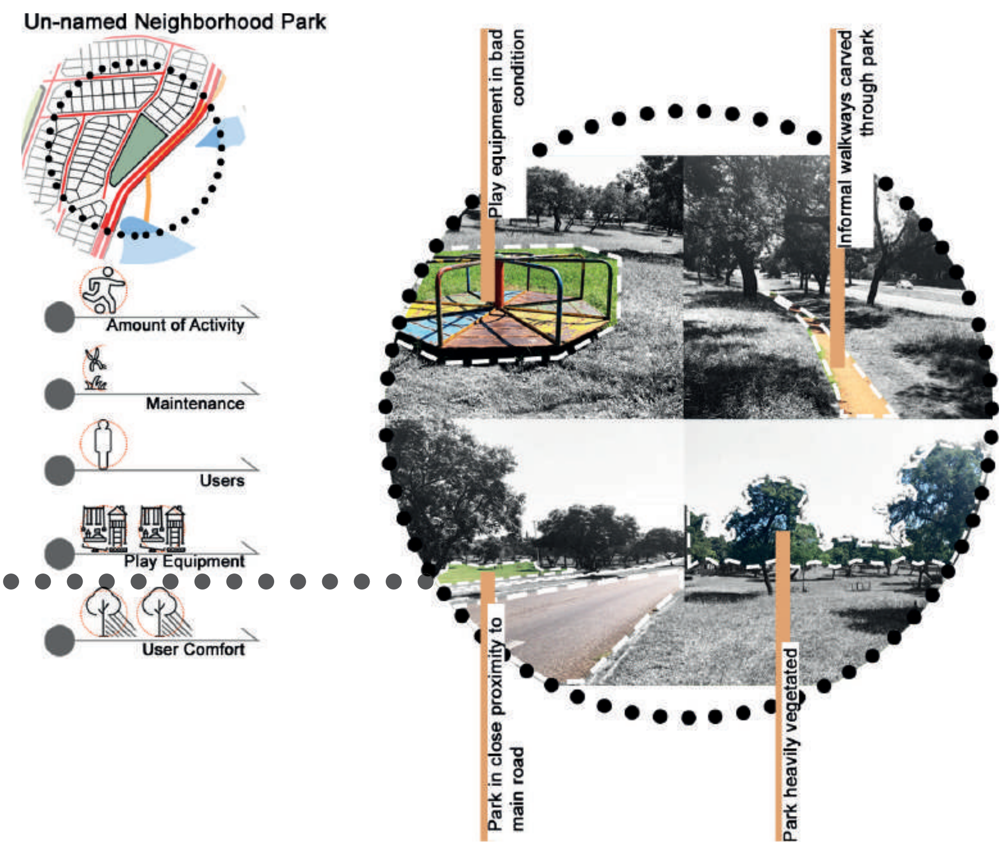


Figure-31: Location of open spaces surrounding the site including an analysis of the three main public open spaces in the vicinity of the site.


Kruger Square
Amount of Activity
Maintenance
Users
Play Equipment
User Comfort
Poor
Park in close proximity to main road
Isolated groups of users
Buffer between park and road
Sparse play equipment
Vast open planes


Un-named Neighborhood Park
Amount of Activity
Maintenance
Users
Play Equipment
User Comfort
Play equipment in bad condition
Informal walkways carved through park
Park in close proximity to main road
Park heavily vegetated

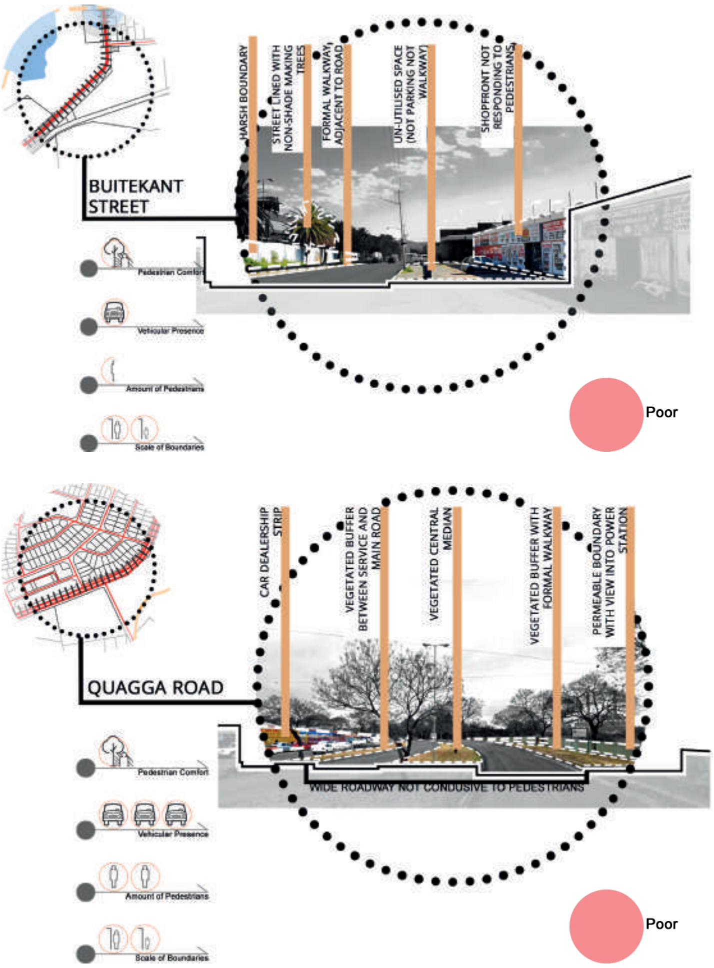
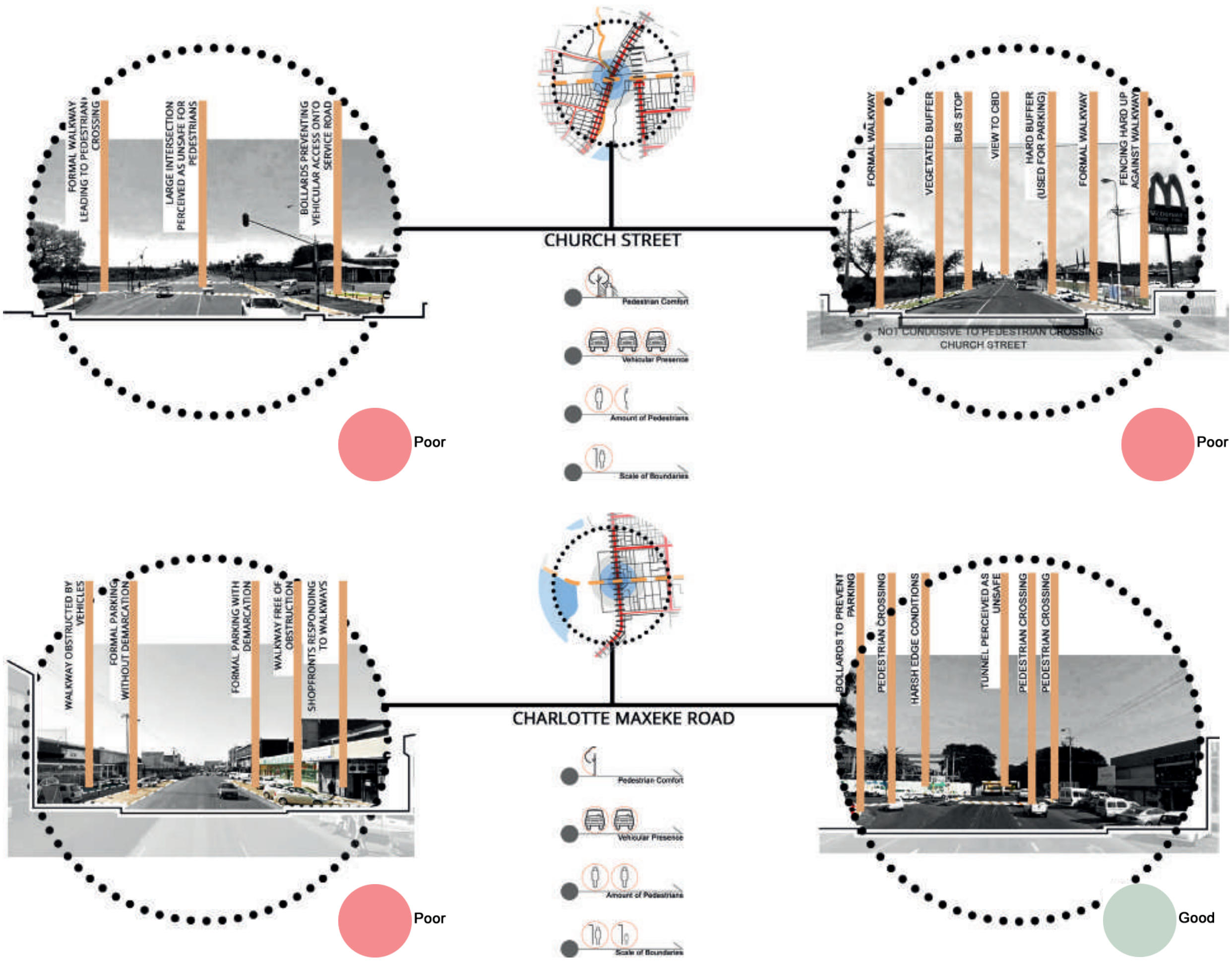


Figure-32: Analysis of streets surrounding the site indicating the lack of pedestrian interface, limiting the flow of pedestrians around the site.



3.2.5-TSHWANE REGIONAL SPATIAL DEVELOPMENT FRAMEWORK

The Tshwane RSDF 2018 (Figure:33) indicates a future proposed bus rapid transit (BRT) route along Charlotte Maxeke Street which then turns down Quagga Road. It also indicates a local node situated at the Quagga shopping centre just north of the site (refer to section 3.2.2). The site is connected to the CBD via two existing activity streets in the form of Church and Soutter Street, and is located within close proximity to a proposed transit oriented development node to the east of the site.

Terms from Tshwane Regional Spatial Development Framework.

- Local Node: a place where both public and private investment tends to concentrate. Nodes are usually associated with major road intersections, or with public transport facilities It offers the opportunity to locate a range of activities, from small to large enterprises and is often associated with mixed use development.
- Activity Streets: Local collector roads supporting lower order land uses in a linear fashion along its length. Direct access to land uses is provided compromising mobility for activity.
- Transit Oriented Development Nodes: Transport-oriented development (TOD) is a mixed-use residential or commercial area designed to maximise access to public transport. A TOD node typically has a centre with a transit station or stop (i.e. a train station, metro station, BRT stop, or taxi rank), surrounded by relatively high-density development with progressively lower-density development spreading outward from the centre.

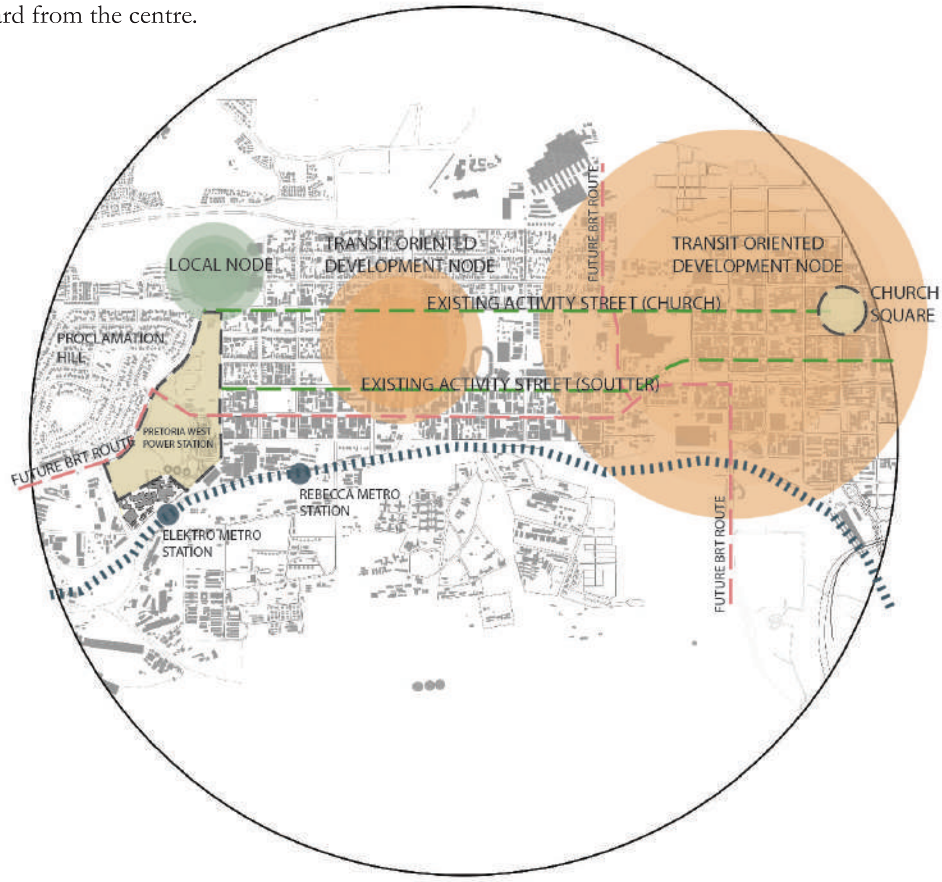


Figure-33: Tshwane Regional Spatial Development Framework (RSDF) 2018. Indicating the proposed BRT route moving past the site as well as the close proximity to a local node.

3.2.6-SURROUNDING INDUSTRIES

There are in excess of six major industries surrounding the site, each contributing to the CO2 concentrations in the area. The dissertation focuses on six industries in particular based on the available emissions data. These are specifically: a tissue conversion plant; a ferro-alloy production plant; an aggregate mine; a brick factory; a steel production plant and a polyurethane foam factory (Figure: 34). Based on the assumption that each of these produce a similar amount of product per annum the total CO2 emissions equate to roughly 34 000 Tonnes of CO2 equivalent per annum.

3.2.7-EXISTING TREE DENSITIES

The total amount of existing trees in the areas which surround the site contribute to the overall carbon sequestration of the area as well as the overall beneficial effects of urban forestry (Figure: 35). The total number of *Jacaranda mimosifolia* street trees within Pretoria West and Proclamation Hill was taken from Stoffberg and van Rooyen (2012) and the total amount of non-street trees was calculated as an estimate using a sample area and extrapolating the density to the overall areas. Based on this it is estimated that the total number of both street trees as well as non-street trees in private gardens, open green spaces and parking lots within the confines of Pretoria West and Proclamation Hill equates to roughly 8000 trees which is not sufficient to sequestrate the industrial emissions from the six industries highlighted earlier.

Figure-34: Mapping of the six industries which are found to the south of the site indicating their total carbon emissions per annum.

TOTAL TONNES OF CO2 EQUIVALENT PER ANNUM
(ASSUMING 10 000 TONNES OF PRODUCT IS PRODUCED BY EACH PER ANNUM)
= 34 914 tCO2e

3.3-SITE ANALYSIS

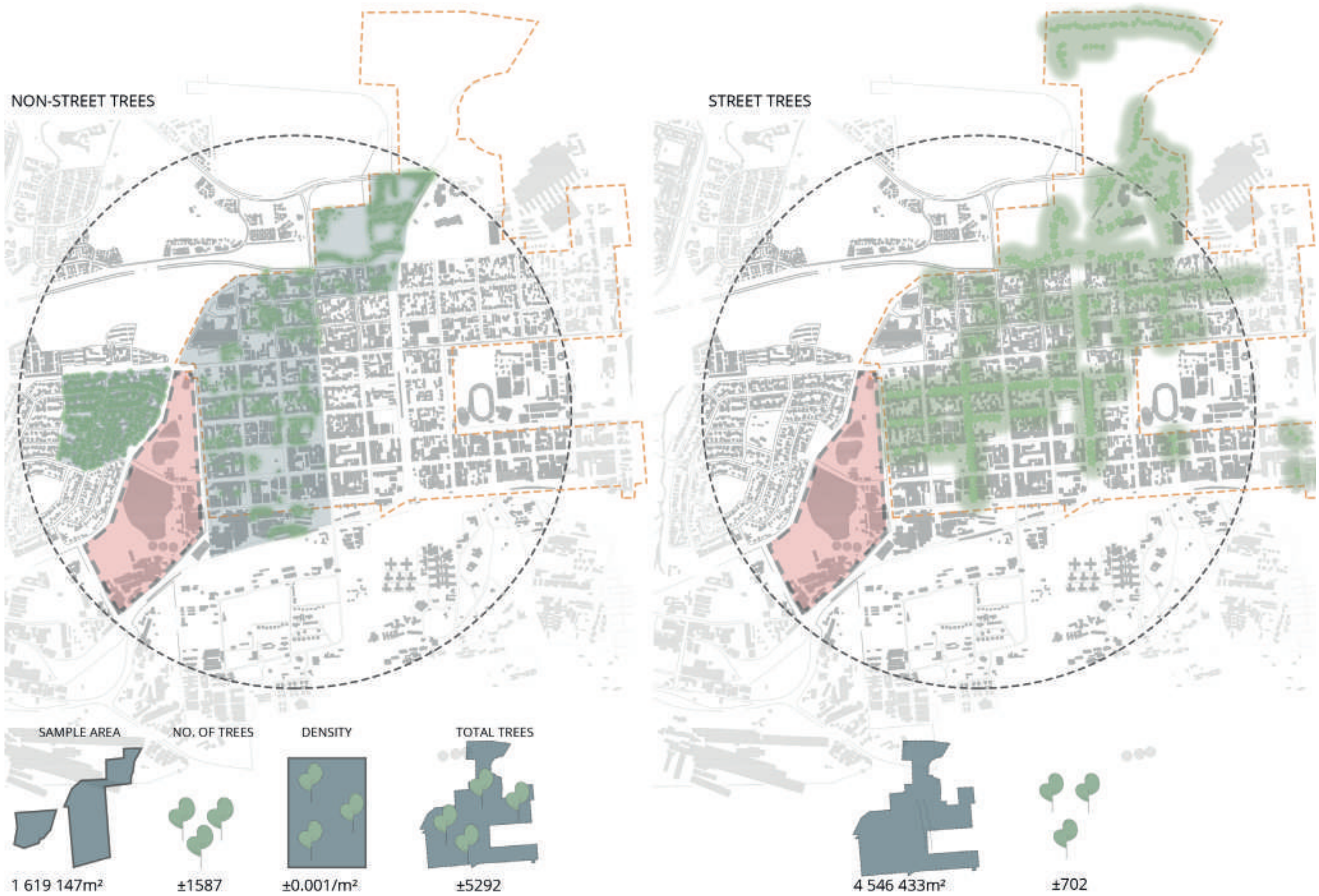
The Pretoria West Power Station's grounds are roughly 45 Hectares with roughly 16 hectares being north and the remaining 29 Hectares falling south of Charlotte Maxeke Street.

The majority of the grounds are made up of various vegetation zones (Figures: 35-41) largely dominated by invasive grass, tree and plant species such as *Pennisetum clandestinum* (Kikuyu Grass), *Eucalyptus grandis* (Saligna gum) and *Ipomoea indica* (Morning Glory) to name a few. The large dam on the site as well as the stream leading into it are also infested with *Eichhornia crassipes* (Water Hyacinth) which can be incredibly detrimental to the aquatic life prevalent in these water bodies. There are however, indigenous tree and grass species prevalent on site as well in the form of *Vachellia karroo* (Sweet Thorn) and *Cenchrus ciliaris* (Blue Buffalo Grass) amongst others.

Regardless of the invasive or indigenous nature of the vegetation on the site it is important to note that each of these vegetation types has an inherent carbon sequestration potential and the removal of them especially through the use of fossil-fuel based machinery can release their stored carbon back into the atmosphere.

It is therefore important to determine a balance between what needs to removed immediately, because the negative impacts far out-weigh the positive ones, and what can be removed gradually through time as to ensure their carbon storage amounts can be accounted for through the introduction of various other sequestration techniques.

Figure-35: Indicating the tree cover densities of the areas surrounding the Pretoria West Power Station.



3.3.1-VEGETATION ZONES

The site can be broken up into seven separate vegetation zones (figure: 36). These vegetation types each have a different rate of carbon sequestration, for example it can be deduced that the semi-disturbed grassland area (Figure: 41) has less carbon stored in biomass than the dense tree areas (Figure: 37), however it may contain a greater soil carbon content stored beneath it than the dense tree area. It may therefore be necessary to leave some of these areas undisturbed at least in the beginning stages of the intervention establishment in-order to ensure that the carbon released into the atmosphere. Other vegetation zones come in the form of: highly disturbed grassland (Figure:40); semi-maintained grassland or lawn (Figure: 39 and 42); dense reeded area (Figure: 38); seasonally wet area and sports fields.

Figure-36: Existing vegetation zones which are currently found on the site.

Figure-37: Dense tree Area (Zone 1- East)

Figure-38: Dense reeded area (Zone 2- South)

Figure-39: Semi-maintained grassland (Zone 3- East)

Figure-40: Highly disturbed area (Zone 4- West)

Figure-41: Semi-disturbed grassland (Zone 5- Central)

Figure-42: Semi-maintained grassland (Zone 3 East)

3.3.2-SITE MOVEMENT AND BUILDINGS

The movement on site is restricted mainly to staff and visitors of the power station because of strict access control. There are however, multiple entrances to the site which are currently non-operational except for the two located on Charlotte Maxeke street and the ones located on the northern parts of Buitekant street. The main site movement is in the form of private vehicles which enter on Charlotte Maxeke street and move to the various parking zones thereafter the movement is in the form of pedestrians walking to the various buildings of employment namely the administration building, the original workshops and the residential facilities (Figure:43 and 44). Currently station a and station b are non-operational and are in the process of falling into disrepair (Figure: 21 in section 3.1). The grounds which stretch from the built fabric to the western edge of the site are heavily overgrown with a combination of grasses such as *Eragrostis curvula* (weeping love-grass) and invasive species such as *Ipomoea purpurea* (common morning glory).

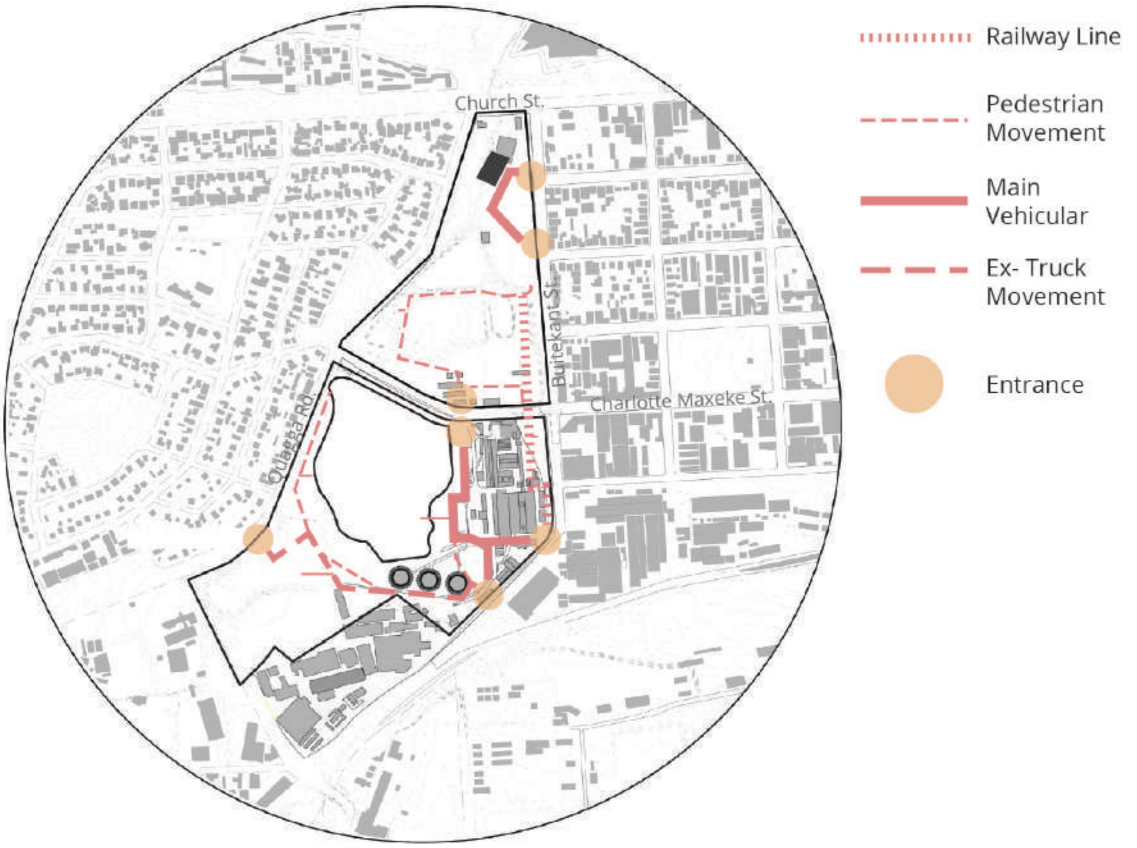


Figure-43:Indicating overall pedestrian and vehicular movement through the Site

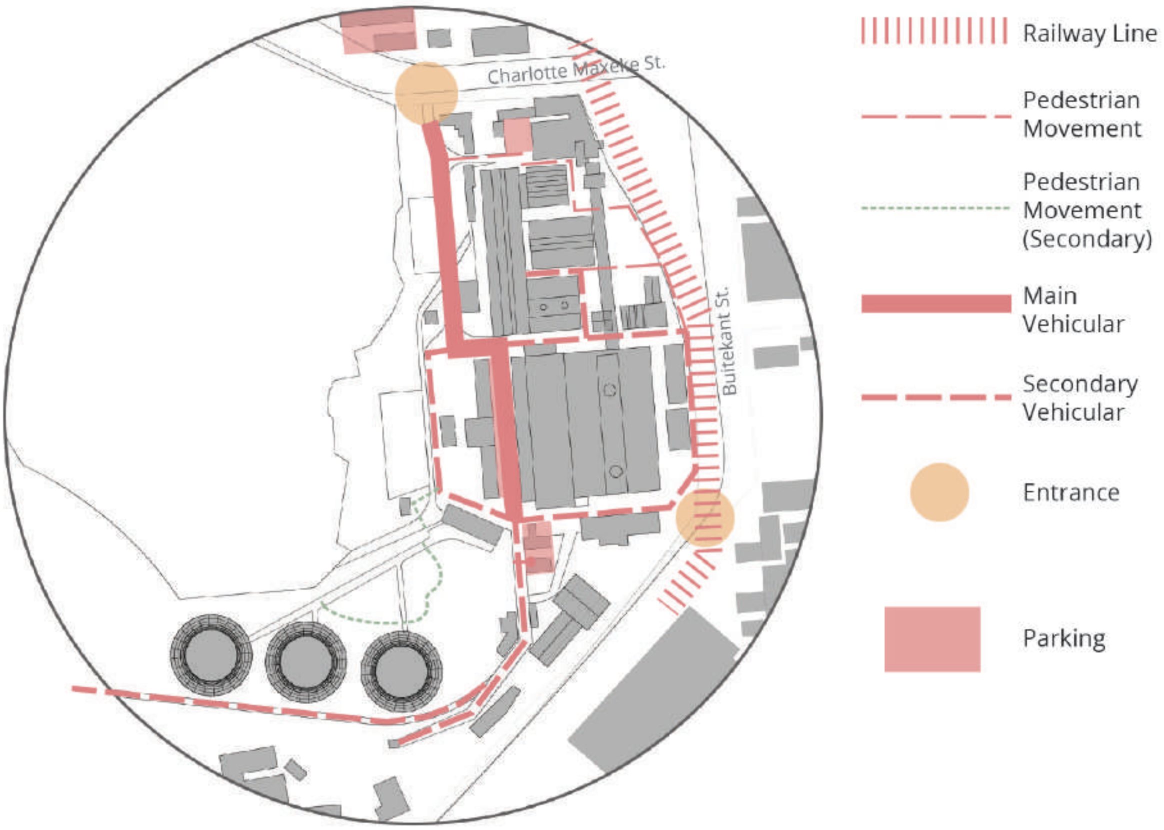
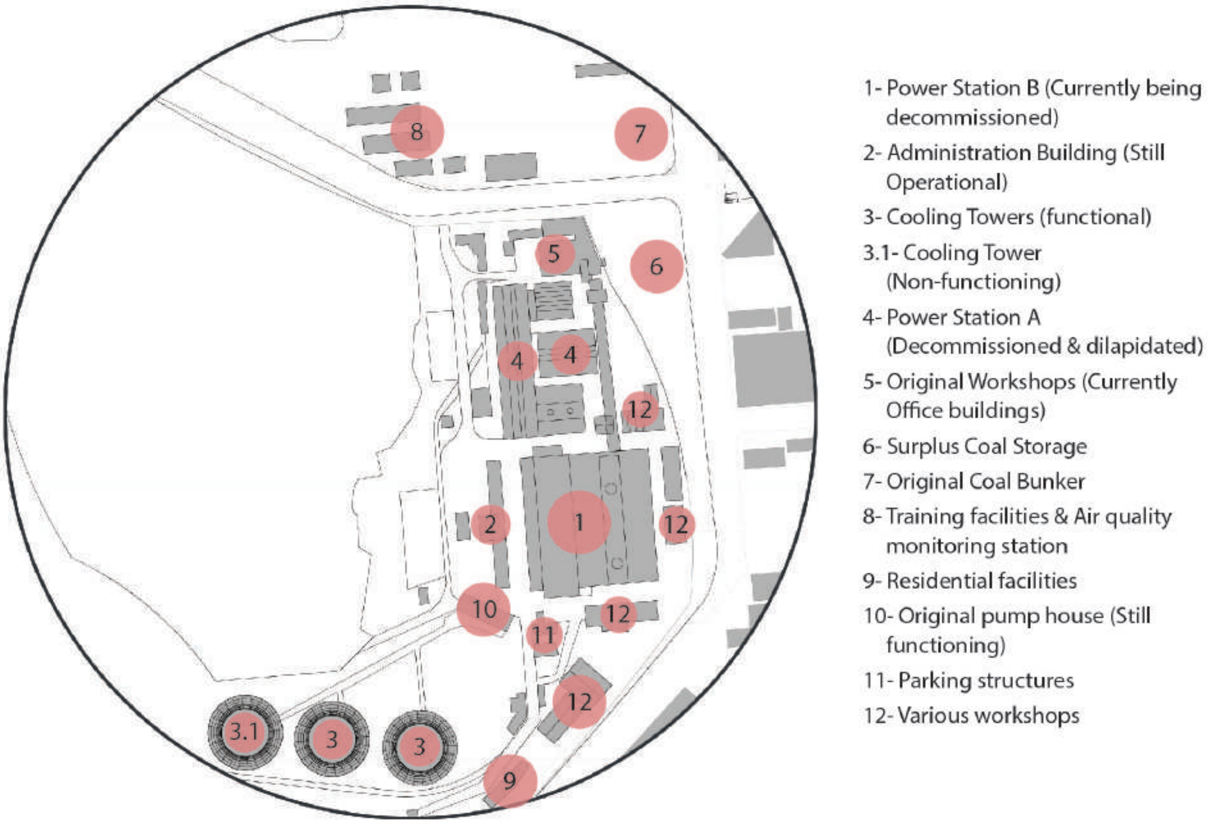


Figure-44:(Above):Indicating site movement along with existing built fabric.

Figure-45:Indicating the types and locations of the existing buildings and infrastructure.



3.3.3-SITE HYDROLOGY

The site is defined by a number of hydrological systems both natural and man-made (Figure: 46). These systems were originally implemented to service the requirements of the power station and are therefore currently not being utilised to their full potential due to the non-operational nature of the power station. The topography of the site falls from south to north and in some occasions both west to east and east to west creating a small valley inwards into the site. This allows a flow of water into the dams and natural stream. The main dam is supplemented by the natural stream as well as water which is pumped form the Daspoort Waste Water Treatment Plant. Overflow from the dam is allowed to flow under Charlotte Maxeke and into the natural stream situated on the northern part of the site. This stream eventually flows into the Skinner Spruit and then into the Apies River.

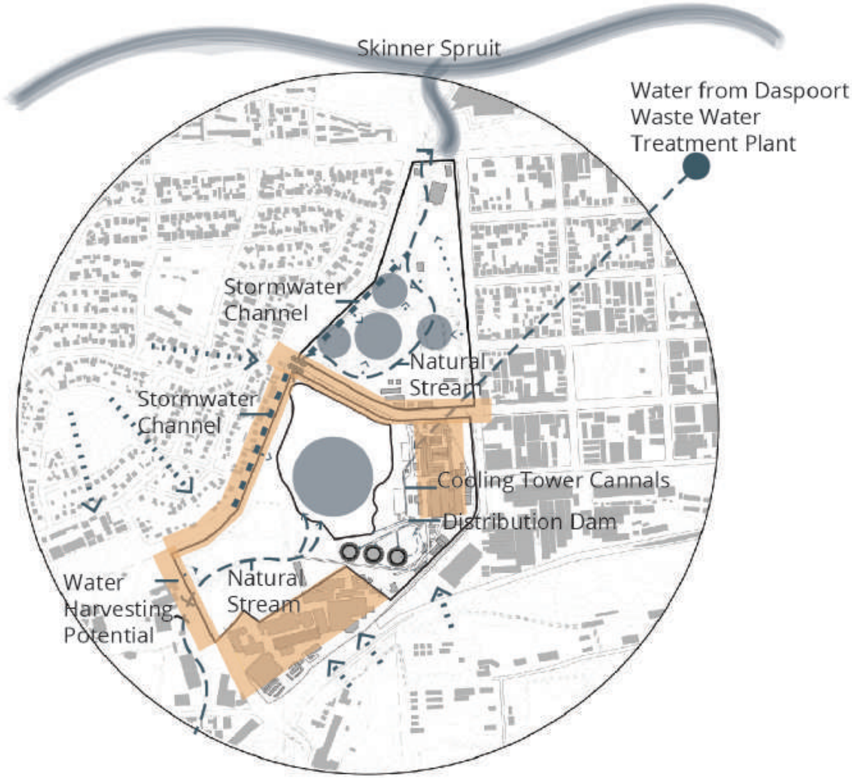
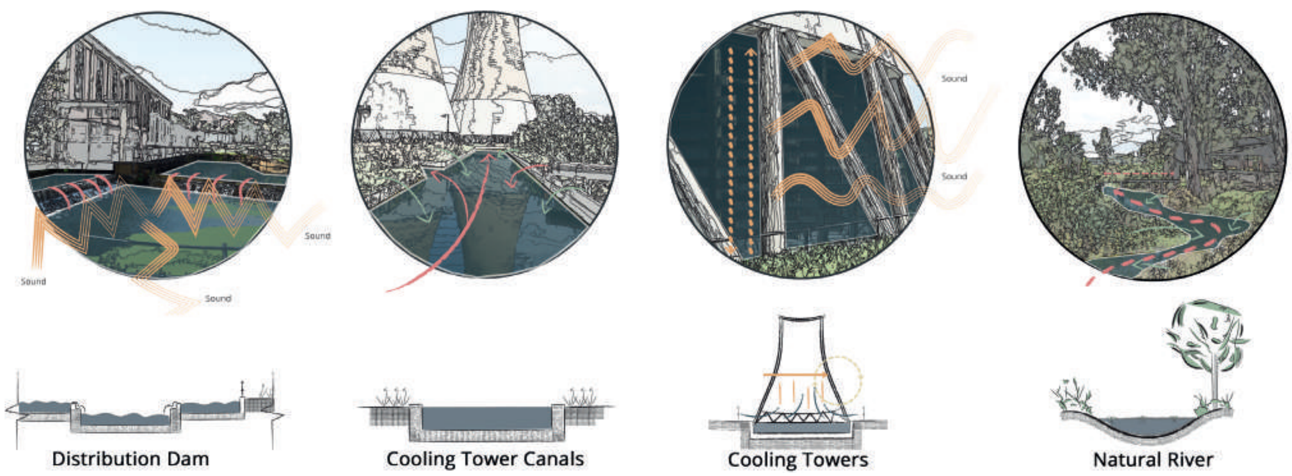


Figure-46:Indicating the four different hydrological typologies found on the site currently and where on the site they are located.



3.3.4- OTHER CONSIDERATIONS:

3.3.4.1-EXISTING TREES, OVERHEAD POWER-LINES AND COAL HEAPS

The Site as it stands has an inherent carbon storage in biomass of the existing trees, this can be calculated by using a formula published in a document compiled by the Intergovernmental Panel on Climate Change (IPCC) in 2003. There is approximately 6.15Ha of tree cover on the entire site which equates to roughly 17.84 Tonnes of carbon per hectare (Figure: 47). It is also important to note the areas of highest tree coverage in order to indicate where areas of carbon concentration are and where there is opportunity to expand on tree densities. The overhead power-lines will also need to be taken into consideration with regards to tree planting and servitude areas (Figure: 48). According to Eskom, no tree or structure may be planted or placed within a 10 metre servitude of a pylon or within a certain distance (voltage dependant) from the centre-line of the overhead electrical cables (Le Roux, 2011). What also needs to be taken into account is the coal dump area of about 21 523m² situated on the southern corner of the site, this equates to roughly 38 742m³ of coal which needs to be moved or removed and rehabilitated (Figure: 48).

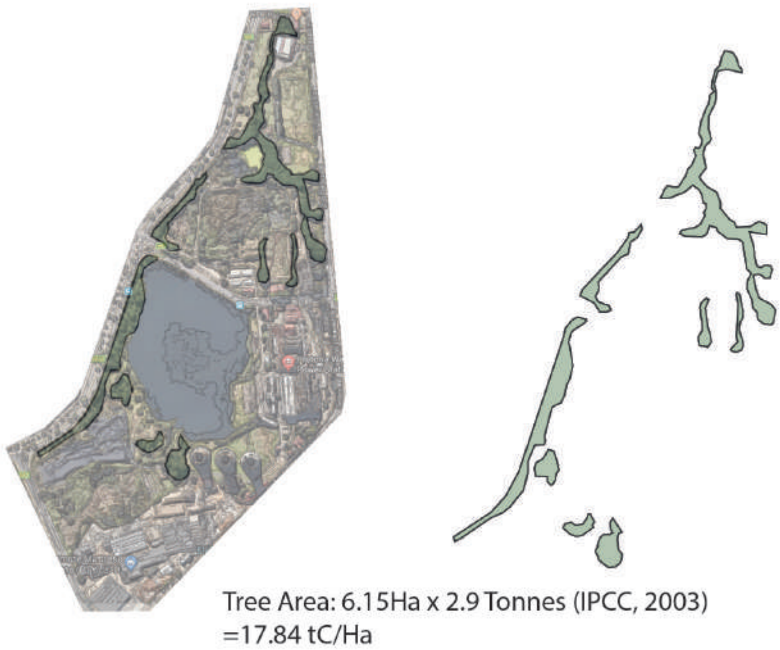


Figure-47: Indicating the extent of the existing tree cover on the site as well as the estimated amount of carbon stored within them.

Figure-48:Indicating the existing tree cover as well as overhead powerlines on the site.

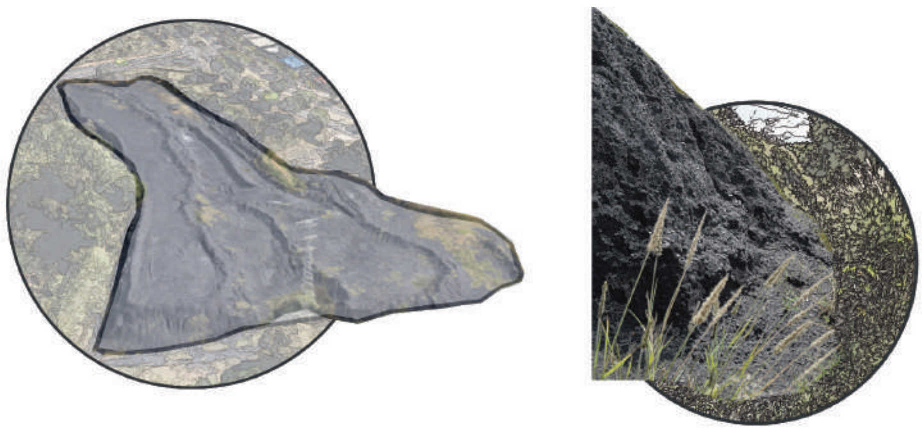


Figure-49:Indicating the extent of the coal heap situated within the landscape as well as the estimated volume of the coal.

3.3.5-SWOT ANALYSIS

In order to come to terms with the opportunities and constraints of the site, a SWOT analysis was undertaken which highlights the strengths, weaknesses, opportunities and threats respectively. These aspects are discussed below:

Strengths:

- The site is located at an important node between Pretoria CBD and Proclamation Hill.
- It is located along various high activity streets such as Church and Soutter Street.
- The site has a large water body that is being supplemented from an external source.
- The vast open-spaced nature of the site makes it possible to implement multiple programmes.
- The existing built fabric has a very particular materials palette which can be used within the proposed landscape design to create coherence in the design language.
- The existing structures are large and iconic and are able to create focii in the vast landscape.
- The industrial nature of the existing buildings allow for industrial programmes to be placed within them.
- The site is situated close to existing and future proposed transport infrastructure.

Weaknesses:

- The site is riddled with invasive plant species and polluted by coal and ash.
- The size of the site may necessitate long distances for pedestrians to traverse from west to east and north to south vice versa.
- The site is fenced in for health and safety issues related to the power station and some areas may have to remain fenced in for health and safety purposes.
- The built infrastructure on the site is imposing on a human scale.
- The perceived negative connotations of industrial areas may be detrimental to the image of the site.
- The surrounding industries cause daily air pollution on the site and the site surrounds.

Opportunities:

- There is the opportunity of bringing multiple transport modes into the site due to its vastness.
- The mixed-use nature of the surrounding context gives opportunity for various different users of an intervention.
- There is the opportunity of opening the site up onto the high activity streets leading into the CBD.
- The size of the site allows mass amounts of planting which can offset the emissions of the surrounding industries.
- The site is split in two by Charlotte Maxeke Street which can allow one section to be used for more productive purposes and the other for more social purposes.
- The existing structures can be retrofitted with new structures that enhance carbon sequestration.
- The existing water bodies and structures can be used for irrigation as well as ecological corridors.
- Sounds created by water systems can be used to enhance user experience.

Threats (To the Carbon Farm):

- The shallow gradient of the stream may mean the water stagnates.
- Tearing up the soil and existing plant cover will release stored carbon back into the atmosphere.
- Implementing industrial programmes onto the site may negatively offset the proposed carbon sequestration techniques.
- Access and circulation of general public may be difficult to control on a vast productive landscape.
- Management of proposed agricultural land may be difficult to facilitate.
- Machinery used for installation and maintenance of landscape may offset carbon sequestration techniques.

These aspects played an important role in the development of the design along with the selection the precedent studies which are discussed in the next chapter.

Figure-50:Photo Map of the Pretoria West Power Station. Photos are taken in 2019.


Photo A


Photo B

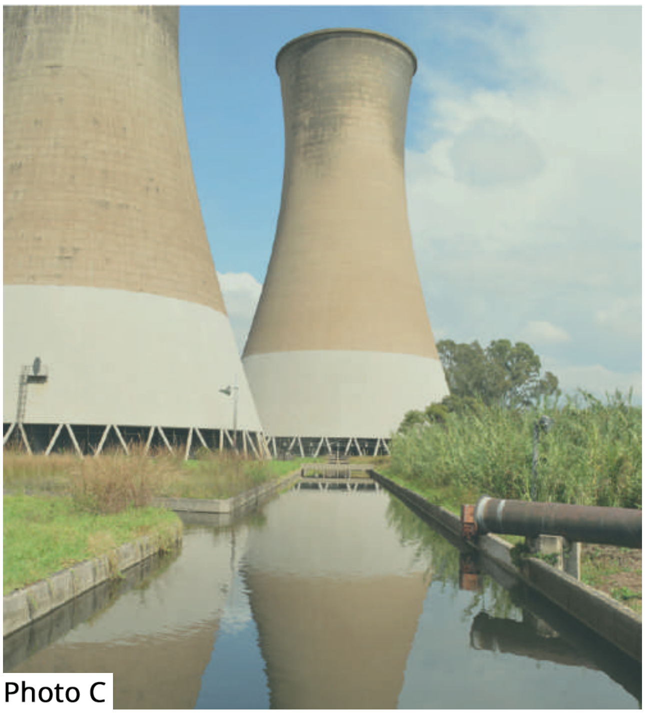


Photo C


Photo D


Photo E


Photo H


Photo F


Photo I


Photo G


Photo J

CHAPTER 4- PRECEDENT STUDIES

The purpose of these precedent studies is to find projects which are focused on similar types of problems and consider how they have been dealt with on different scales and in different countries across the world in both professional practice as well as in the educational realms. The precedents may guide form, programme, phasing and space creation but do not necessarily have to have the same programmes, size or applications. At the end of each study the key takeaways will be summarised as to how the concepts and ideas from the precedents can be utilised further in the design approach in this dissertation once applied to the contextual realities.

4.1-FUTURE HOPELY: HUTANO, MVURA, MITI-
LEONARDO ROBLETO COSTANTE,
UNIVERSITY OF PENNSYLVANIA 2013 (Student project)

The following aspects of this project are noteworthy and applicable to this study:

- The project establishes a framework for the growth of Hopley Farms, an informal settlement in Harare.
- A territorial growth pattern, rainwater management and an agroforestry system are linked.
- Places of socialization and exchange, multi-scalar options of rainwater harvesting, and a cooperative agroforestry system
- Social hubs as points of social encounter, defined by crossings of existing paths.
- Pedestrian paths and a few main roads that allow for simple forms of public transportation
- A reforestation campaign that utilizes indigenous and non-invasive species.

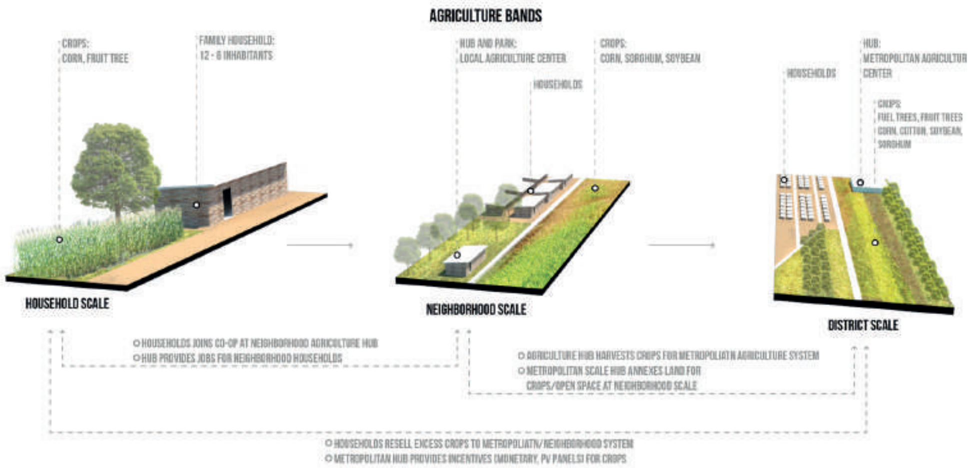


Figure-51: Showing the approach to the different typologies of the agricultural strips.

Figure-52:Figure: Project perspective of social hub at the intersection of major movement corridors

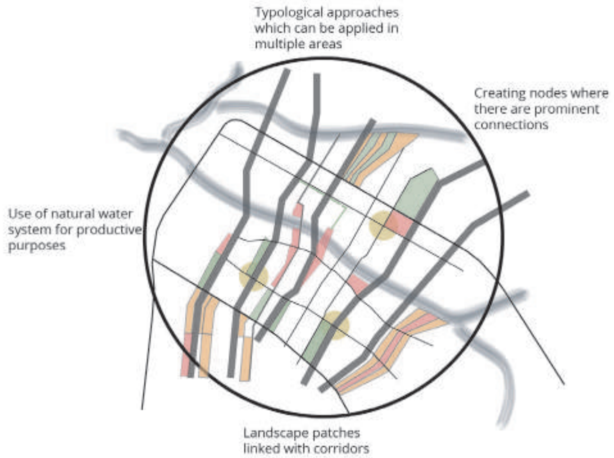


Figure-53: Parti diagram of project

Key Takeaways

- Using the river as an ecological corridor to enhance ecosystem services.
- Allowing the topography of the site to dictate placement of programmes and form.
- Using areas where paths intersect and social nodes of exchange and interaction.

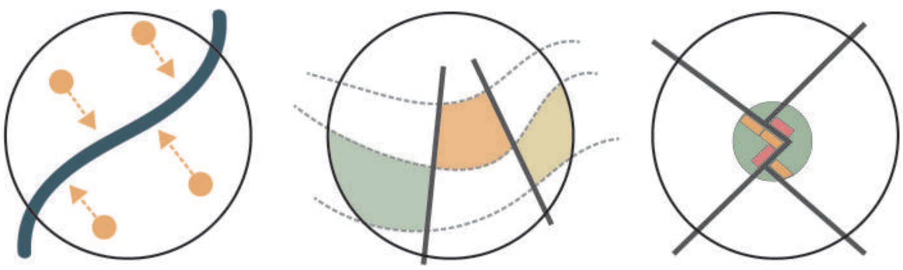
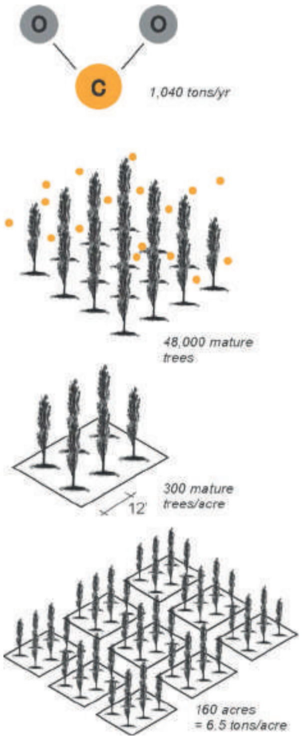


Figure-54:Figure(left): Diagrams of key takeaways from the precedent.

4.2-50 000 TREES- SARAH MOOS, UNIVERSITY OF CALIFORNIA 2013 (Student Project)



The following aspects of this project are noteworthy and applicable to this study:

- Designed to sequester CO2 emissions, an urban forest emerges on space beneath a freeway interchange in San Francisco, California.
- Derives its form and planting regimen from scientific studies on carbon sequestration.
- Capitalizes on existing infrastructure to devise irrigation, storm water reduction, and pedestrian access.
- Planting trees 3 meters apart and cycling the trees every 6 years through a process of growth, partial forest removal, and both afforestation and diversification.
- To minimize CO2 emissions in the construction and maintenance of the emerging forest, funding and materials are locally sourced within the San Francisco Bay Area. Hybrid machinery is specified for tree maintenance and cycling.

Figure-55: Sketch Plan of project showing the interaction of the infrastructure and the tree plantations.

Figure-56:Diagram showing planting strategy according to the width of the predetermined grid.

Figure-57:Figure: Section perspective of walkway through tree plantation showing irrigation structure and pedestrian walkways.

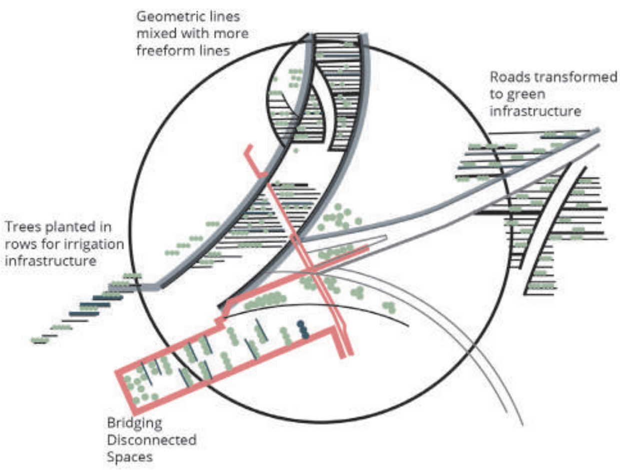


Figure-58: Parti diagram of project

Key Takeaways

- Tree planting is structured according to how the irrigation infrastructure operates
- Incorporating varying layers of infrastructure which overlap and interact.
- Using tree spacing to create separate plots which can be duplicated across the site.

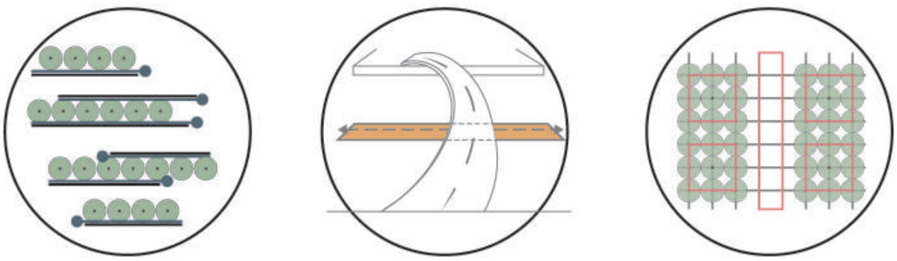


Figure-59:Figure(Left): Diagrams of key takeaways from the precedent.

4.3-Biblioteca Degli Alberi (Library of Trees)-
Studio Giorgetta
Milan, Italy 2008-2018 (Professional Practice)

Figure-61: Photo of open lawn space defined by plant beds.

The following aspects of this project are noteworthy and applicable to this study:

- Urban connector, cultural campus and botanical garden.
- Paths drawn from various areas (residential, commercial, governmental).
- Paths and patches are used to overcome height differences.
- Each patch has different programme and growth pattern.
- Use of isolated circular forest patches to create focii in the landscape.
- Place where people can meet, enjoy and educate themselves.
- It becomes a place for activities such as sports and learning and connects the areas and their inhabitants which surround it.

Figure-60: Aerial view of implemented project.

Figure-62: Photos of completed project including water body, vista towards heritage building created by use of trees and small scale agricultural boxes.

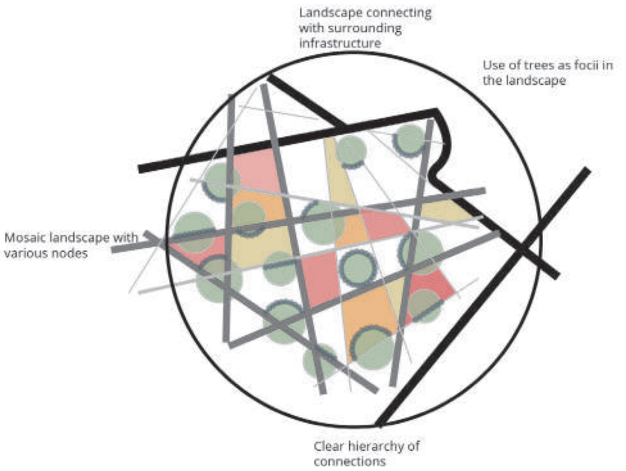


Figure-63: Parti diagram of project.

Key TakeAways

- Using the landscape as urban connector for social exchange.
- Using landscape patches at varying heights to define space and programme.
- Using various foci in the landscape for way-finding .

Figure-64:Figure(Left): Diagrams of key takeaways from the precedent.

4.4-The Metro Forest Project
Landscape Architects of Bangkok
Bangkok, Thailand 2013 (Professional Practice)

Figure-65:(Above): Photos if completed project including skywalk and gallery cut into the landscape.

The following aspects of this project are noteworthy and applicable to this study:

- An ecological regeneration project designed as an outdoor exhibition space to allow for environmental awareness.
- Aimed to reverse the trends of suburban sprawl, urban heat island, and flood-prone developments.
- Raised berms were designed, to provide porosity and prevent compaction.
- The layout of the species was grouped according to rates of succession.
- For the initial planting, a density of approximately 4 trees/m² or a spacing of 50 centimeters was used.
- The remaining planted areas, were sparser to help control sight lines, open views, and provide open space area around the exhibition centre.
- In the early stages of succession, guests spend a majority of their time atop the skywalk + observation tower.

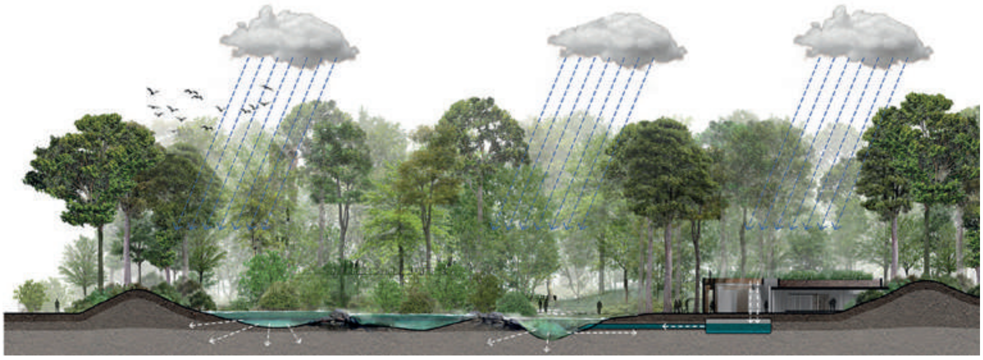
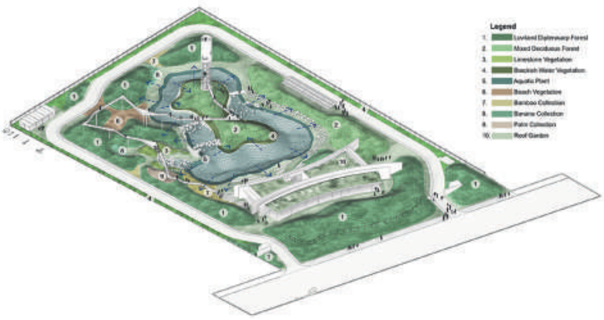


Figure-66:Figure(Left): Section through intervention showing how the site slopes towards inner waterbody

Figure-67:(Below) Aerial view of the implemented project indicating various systems.



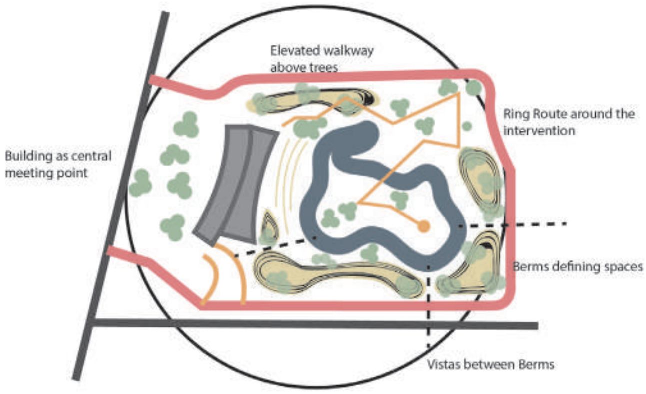


Figure-68: Parti diagram of project.

Key TakeAways

- Implementing a skywalk amongst tree canopies to create a varying spatial experience.
- Using land-form to control movement and vistas throughout the landscape.
- The Landscape terraces and falls towards the water body and allows varying levels of pedestrian movement on these terraces.

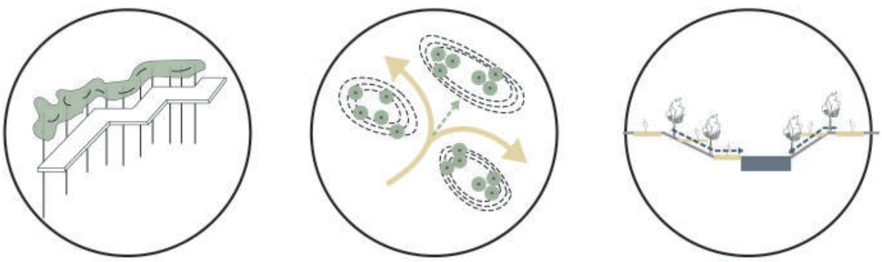


Figure-69:Figure(Left): Diagrams of key takeaways from the precedent.

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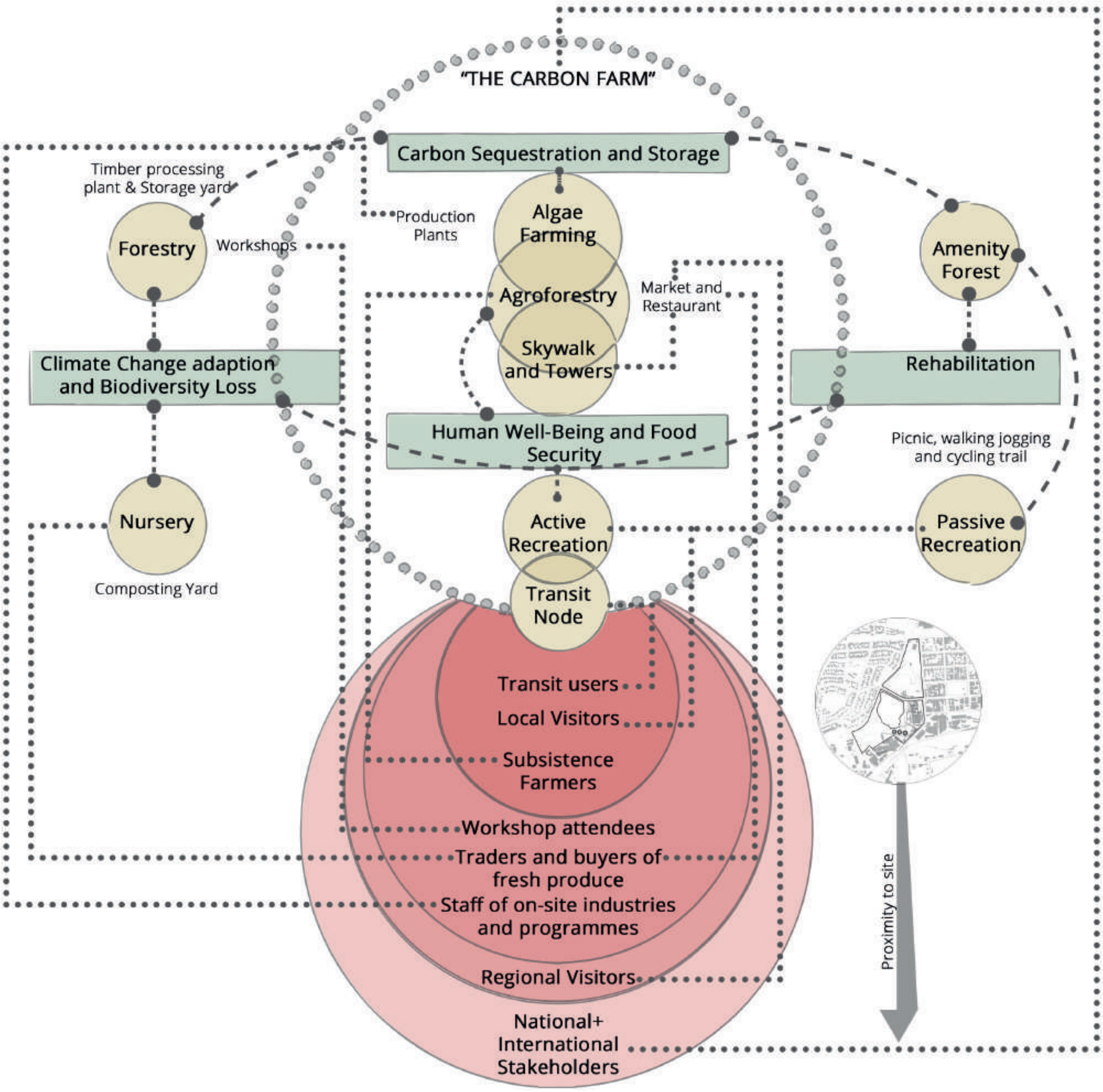
CHAPTER 5- PROGRAMMES AND USERS

This chapter focuses on the various end users of the intervention as well as the programmes which accommodate and engage them. The programmes proposed by the intervention are based on a number of factors such as: site location and access, surrounding site uses, site climate and ecology as well as the surrounding community, researched and documented in the previous chapters. This chapter looks specifically at how the programmes respond to the opportunities raised by the research question and sub questions posed in chapters one and two. Emphasis is placed on the main challenge of carbon sequestration, and how these programmes address this as well as how the end users of the landscape are engaged by the specific programmes.

5.1-SITE PROGRAMMES

There are a number of programmes which are hierarchically proposed for the site in order to address the over arching challengers and opportunities identified and raised in the previous chapters, namely: the need for focussed carbon sequestration; food security improvement; biodiversity enhancement; climate change adaption; human well being and economic upliftment as well as rehabilitation and possible restoration (Figure: 70).

Figure-70: The relationship between programmes and users and the distance the users are expected to travel to engage with the respective programmes. The diagram also indicates how each of the programmes respond to the research questions raised in chapters one and two.



5.1.1- Forestry

For the site to sequestrate enough CO2 to offset the emissions of the surrounding industries highlighted in Chapter three, it needs to be intensely planted with trees (Figure: 71). In order to facilitate this, the carbon farm is divided into tree plantation zones, which are planted and harvested in cycles, and alternative zones of permanent indigenous trees in order to enhance habitat and biodiversity. This is done so that there is a multitude of trees sequestrating CO2 at different rates and over different periods of time with different social and ecological benefits.

Sub Programmes: Timber processing plant and storage yard

Coupled with the forestry is the need for an area where the harvested timber can be processed and stored. The harvested timber is a way to store the carbon sequestered by the trees during their life span and provide more space for more sequestration. A timber processing plant and storage yard is located within the existing built fabric of the site. The forestry and the processing plant are linked via a small-scale railway line which ties in with the existing railway line that enters the site from Delfos Road. The timber is utilised in the workshop zones where woodwork and carpentry skills development take place as well the manufacturing of cladding and structural timber for long term carbon storage in buildings.

5.1.2- Agroforestry

Improving food security within the urban areas which surround the site necessitates an approach to food production which can tie in and happen alongside the principal programme of forestry. As explored in chapter two, the carbon farm therefore incorporates zones of controlled agroforestry (Figure:72). The approach to the agroforestry is two-fold, on the northern section of the site, north of Charlotte Maxeke Street, is heavily focused on the large-scale production of food for sale and distribution to retail institutions with excess food being distributed to feeding programmes. This is to be managed by NGOs such as POPUP. The southern section of the site provides opportunity for small scale agroforestry which allows the average person to undertake subsistence farming. For a small fee- individuals are able to rent a plot or multiple plots whereby they will have control over what and how much they plant and what they do with the produce. The procurement and management of these small-scale plots will be managed by the NGOs such as POPUP.

Sub Programmes: Market place and restaurant.

As part of the agroforestry programme, there is also both a market space, which will allow the small-scale farmers to sell their produce to the general public, as well as a restaurant which makes use of the fresh produce grown on the site. These programmes will contribute to the economic upliftment of the area.

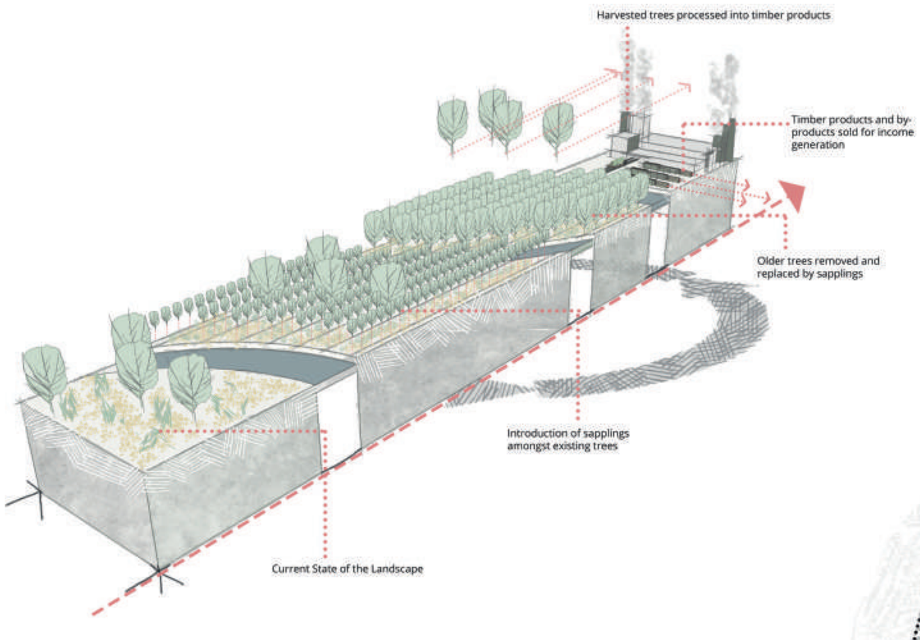


Figure-71: The process of the forestry programme as well as its proposed locations on the site.

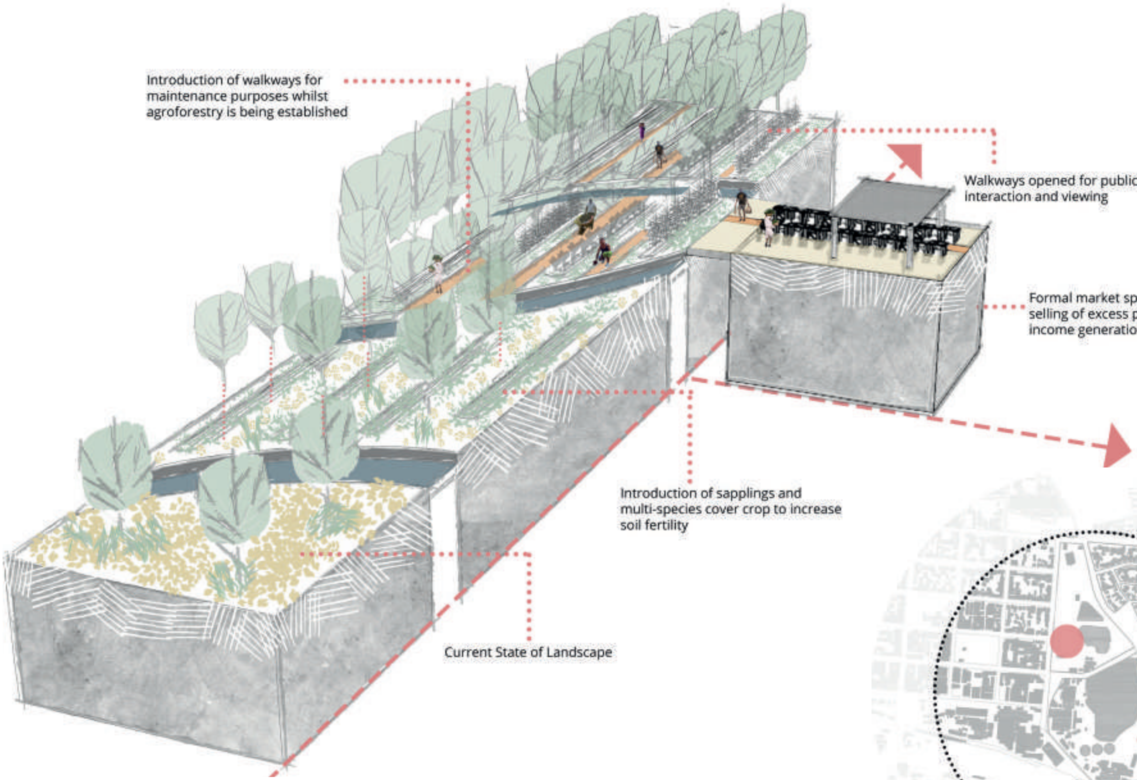


Figure-72:The processes of the agroforestry programme indicating how the site evolves from its current state into its agroforesrty state, including the programme's proposed locations on the site.

5.1.3- Amenity Forest

The amenity forest zone is indigenous and includes habitat for a variety of different species. In addition, it is implemented to fulfil the need for passive recreation zones within what is essentially a highly dynamic and controlled productive landscape (Figure:73). The amenity forest addresses the need for biodiversity enhancement and climate change adaption highlighted in chapter 2 (see table 2). This zone will be rehabilitated to an extent where indigenous vegetation will eventually dominate over what is already there in the form of exotic species using assisted natural regeneration (ASR) and will eventually be left to its on devices with minimal maintenance efforts other than mechanical removing of exotic species. ASR consists of low-cost forest restoration method which can convert deforested lands to more productive forests. The method aims to accelerate, rather than replace, natural successional processes by removing or reducing barriers to natural forest regeneration such as soil degradation, competition with weedy species, and recurring disturbances (Shono et al., 2007).

Sub Programmes: Picnic zones, walking, jogging and cycling trail

The amenity forest zone houses part of the walking, jogging and cycling trail as well as small passive open spaces along the extent of the dam. The trail forms part of a loop which facilitates jogging walking and cycling throughout the site.

5.1.4 Active Recreation: Jogging, cycling, swimming and rowing

In contributing to human well-being, the carbon farm incorporates various modes of activity as a legacy to the triathlon event that used to take place, in part, on the site. The carbon farm has a dedicated jogging, cycling and walking trail which loops its way through both the southern and northern sections of the site. It also has a dedicated swimming area cordoned off from the larger part of the dam which will be used for rowing and kayaking (Figure:74).

Sub Programmes: Bicycle and kayak rental facility

To further facilitate these activities the carbon farm incorporates a bicycle and kayak rental facility which will be managed by a private partnership. There are also changing rooms and ablutions for the intervention's users.

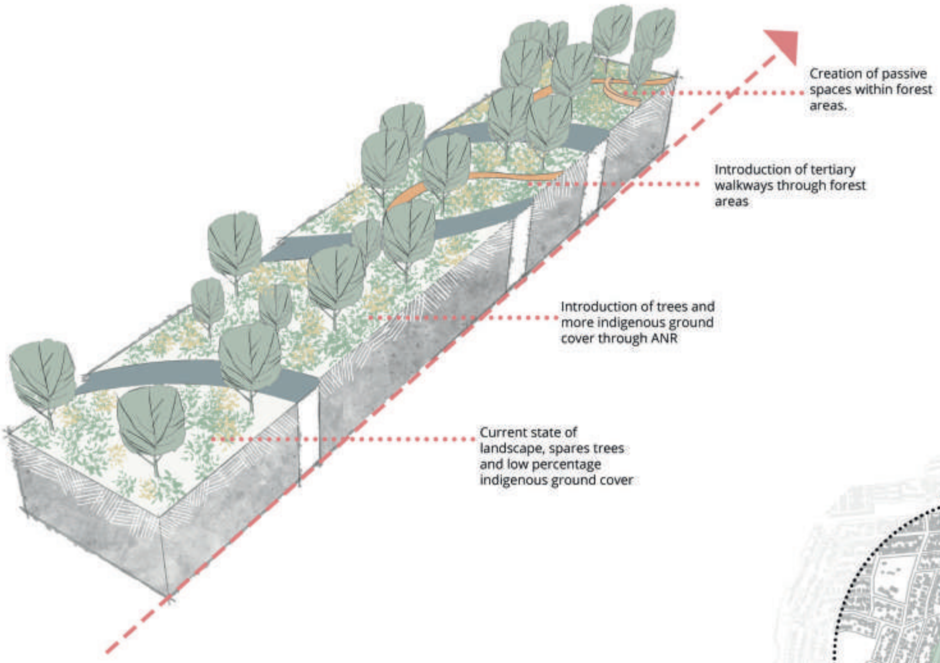


Figure-73: The process of the amenity forest programme indicating how the assisted natural regeneration takes place and the walkways are introduced including the proposed locations on site.

5.1.5-Nursery

The carbon farm utilises a variety of plant and tree species with specific focus on carbon sequestration and agroforestry. The nursery therefore provides the public with the opportunity to purchase these species, excluding the exotic *Pinus* and *Eucalyptus* species, for private use. The species grown by the nursery are also used to supplement the needs of the small-scale farmers as well as the other planted areas of the intervention (Figure:75).

Sub Programmes: Composting Yard

Along with the nursery is a composting plant which utilises waste produced by the agroforestry both small scale and large-scale as well as general landscape waste. The product will be bagged and sold by the nursery to the public and will also be used to supplement the small-scale farmers. This will ensure recycling of all organic matter on site including: litter and debris from forestry, agroforestry and general landscape maintenance, organic food waste from the restaurant, timber by-product of the timber processing plant and workshops and the by-product of the harvested algae.

5.1.6-Algae Farming

Along with the forestry, the carbon farm also grows and harvests algae in order to further improve its performance in terms of carbon absorption. The algae is grown in a transparent tube system which is visible to the public creating a spectacle whilst still fulfilling its primary objective of carbon absorption (Figure: 76). The algae once grown will be harvested and utilised for bio-fuel production as well as for food, furthering the intervention's production of food resources.

Sub Programmes: Algae and bio-fuel production plants

An algae farming and processing plant is located on site and connected to the tubular algae growing structures. The plant facilitates the drying of the algae for food as well as for the beginning stages of the process of breaking down of the cell walls to extract the oil which is found inside. Once the oils have been extracted, the dried algae is then utilised to supplement the composting yard. This oil is then used as part of the production of bio-fuel within the bio-fuel production plant. These programmes are located within the existing built fabric of the site.

5.1.7-Skywalk and towers

In order to enhance the carbon farm's novel appeal, thus further attracting visitors on a more widespread scale, it incorporates three towers which respond to the existing cooling towers (Figure:77). These serve a dual purpose, they firstly function as the structure which hold up the algae tubes and secondly function as viewing towers giving the user a view over the landscape as

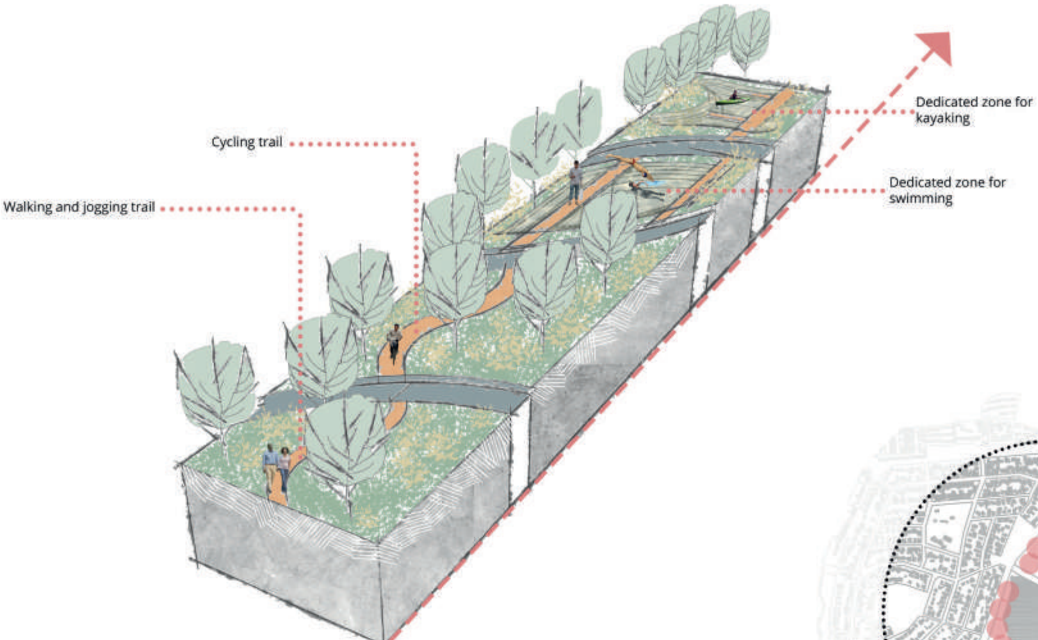


Figure-74: Displaying the Active Recreation: Jogging, cycling, swimming and rowing as well as the proposed locations on the site.

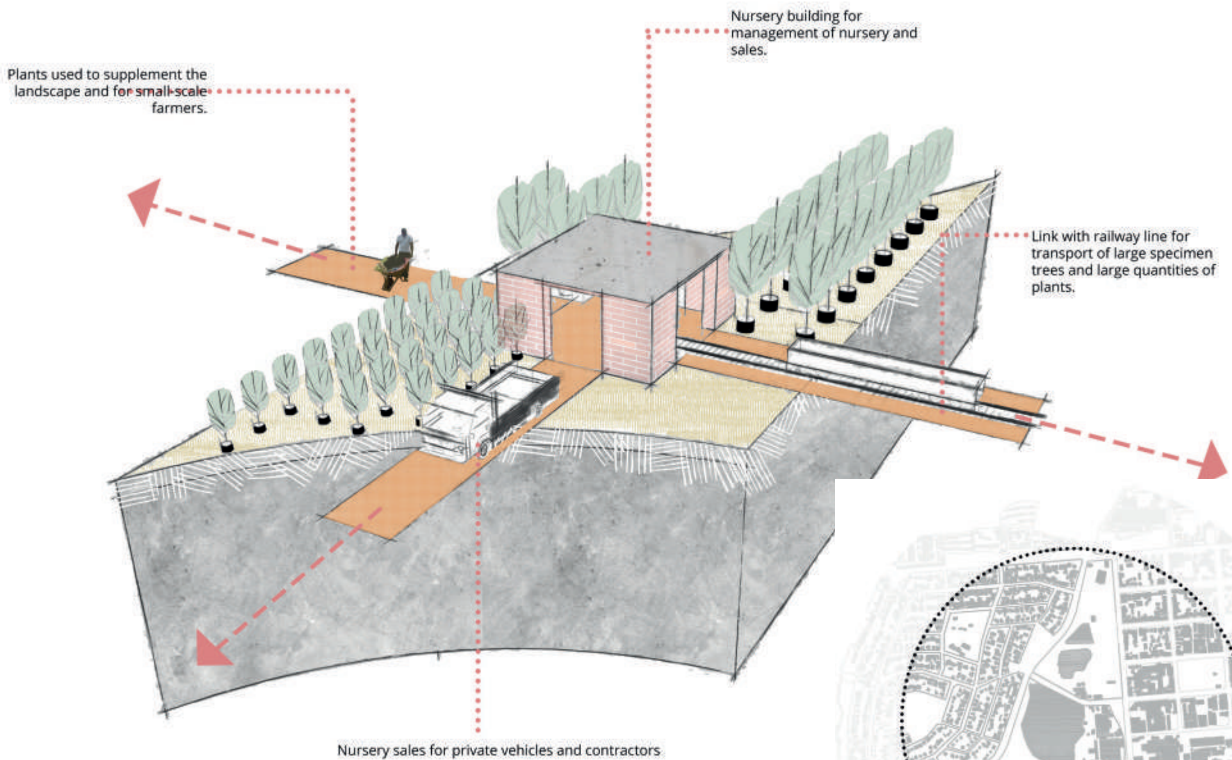


Figure-75:Explaining the processes of the nurseries purpose as well as its proposed location on the site well as the areas which surround it. The towers' platforms are linked by a skywalk which takes the user on a journey over the tree canopies giving them a different spatial experience to that of the ground level walkways.

5.1.8-Transit node

In order to facilitate various visitors to of the carbon farm, it acts as a transportation node. Incorporated within its boundaries is a train station which is linked to the greater metro-railway line as well as two BRT stations located along Charlotte Maxeke Street and Quagga Road as part of the future BRT route as highlighted in the Tshwane RSDF 2018 (See section 3.2.5). There is also space provided for parking private vehicles.

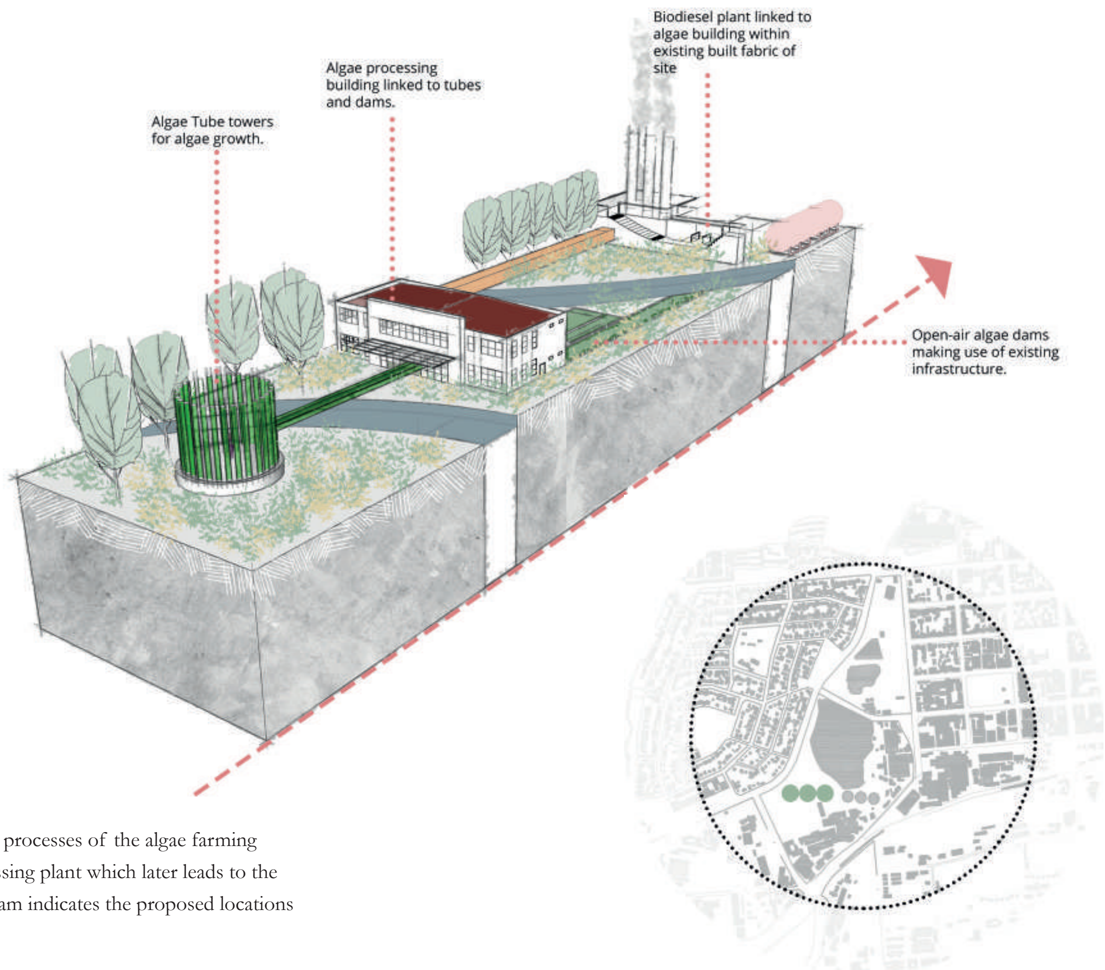


Figure-76: Explaining the processes of the algae farming including the algae processing plant which later leads to the biodiesel plant. The diagram indicates the proposed locations of the algae towers.

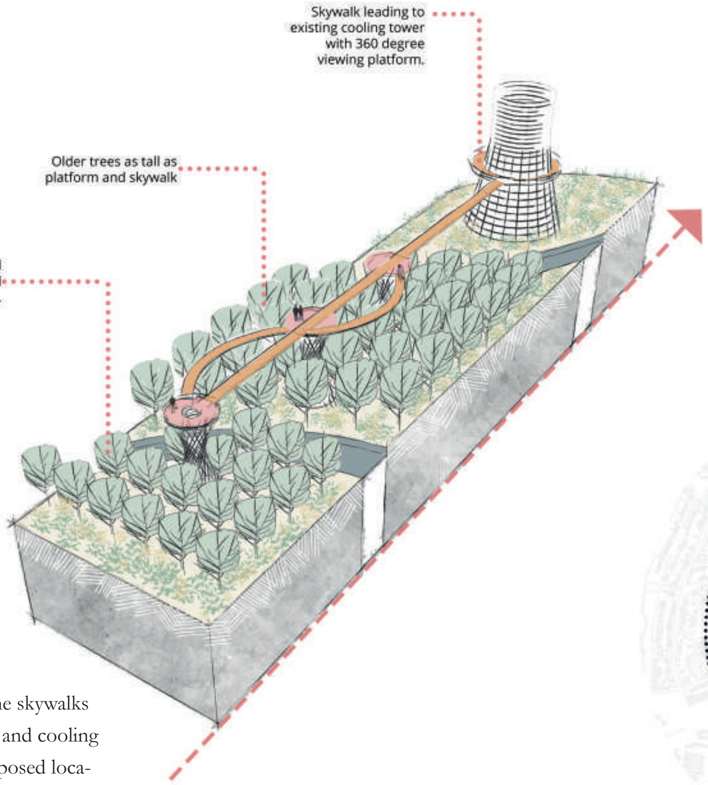


Figure-77: Displaying the skywalks linking the algae towers and cooling tower as well as the proposed location on the site.

5.2-CLIENTS

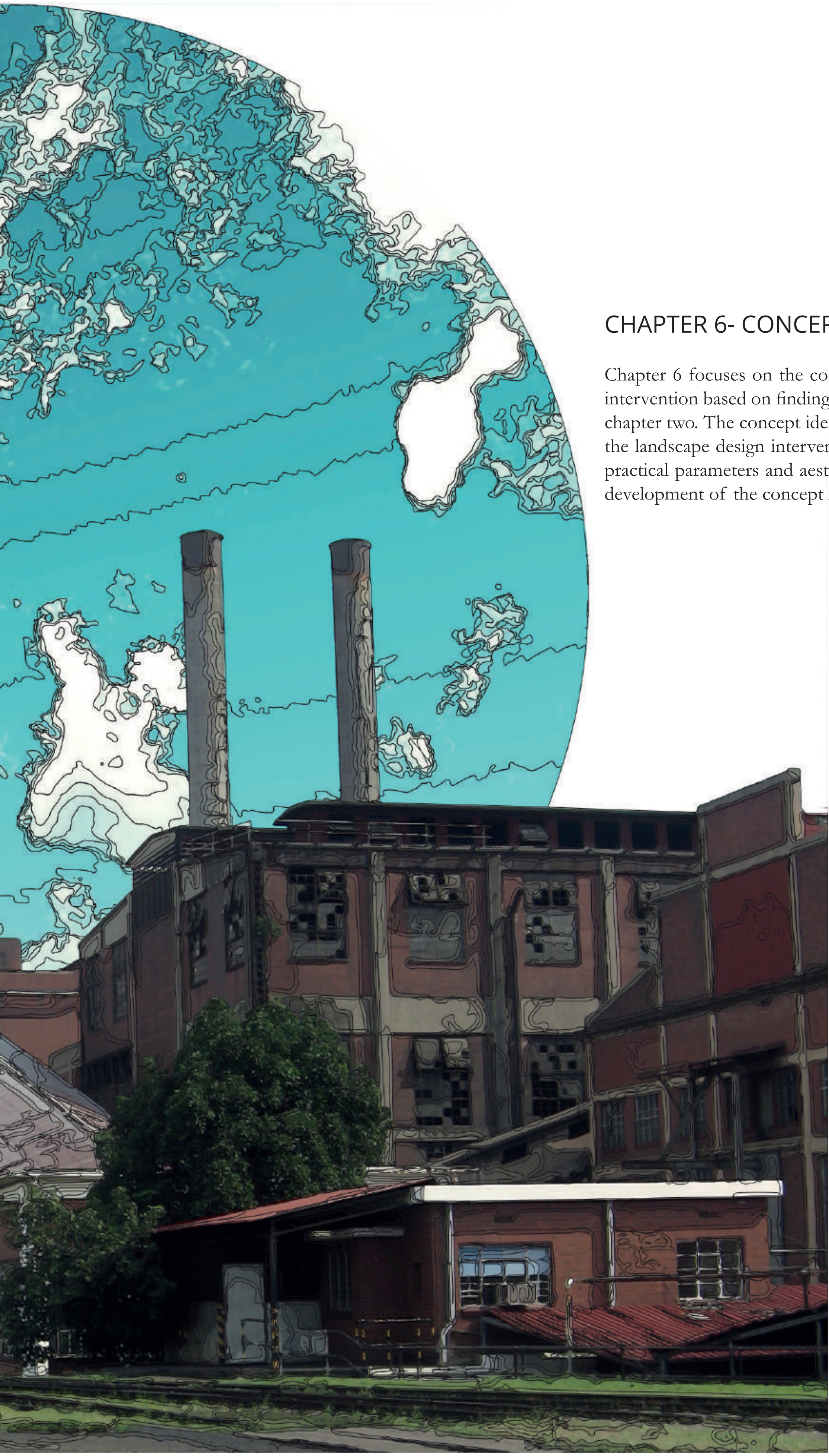
The project client is the South African Department of Agriculture, Forestry and Fisheries (DAFF) who undertake the management of the forestry; the South African Department of Trade and Industry who drive the on-site industries with the South African Renewable Energy Council as managers of the algae farming and processing as well as the biodiesel plant. The City of Tshwane as owners of the property under-see the general maintenance of the Carbon Farm. The management of the agroforestry is undertaken by the NGO POPUP under the supervision of DAFF.

5.3-SITE USERS

The size and location of the site gives the potential for access and use by a variety and multitude of users. Due to its close proximity to Proclamation Hill and Pretoria CBD the carbon farms cater for visitors who live and or work in the surrounding areas as well as people visiting the intervention from other regions of Tshwane and Gauteng. The carbon farm also caters for users that wish to learn about and develop skills in fields such as subsistence farming and wood working as well national or international stakeholders who wish to become partners and facilitate these practices on the site itself.

The list of defined users is as follows:

- Subsistence Farmers.
- Local visitors (From within Pretoria West and Proclamation Hill), including families, young and old visitors who wish to utilise the recreational open space on a day-to-day basis.
- Regional Visitors (From the greater Tshwane and Gauteng Regions).
- Workshop attendees.
- Traders and buyers of fresh produce.
- Labourers for on-site industries and programmes.
- Transit users.
- National and international stakeholders.



CHAPTER 6- CONCEPT

Chapter 6 focuses on the conceptual approach to the design intervention based on findings from the literature presented in chapter two. The concept idea that gave inspiration and life to the landscape design intervention is discussed along with the practical parameters and aesthetic ambitions which drove the development of the concept into its design manifestation.

6.1-CONCEPT IDEA- THE CARBON FARM AS A SYSTEM.

From a landscape of exploitation and pollution to a landscape of carbon absorption.

The design concept of the intervention is a diverse and multi-layered landscape which, at its core, remains highly productive whilst ensuring that the needs of the context, such as food security, as well as global environmental needs, such as carbon offsetting, are balanced and adhered to.

Thus, the idea behind the landscape intervention is to guide a new approach to the urban productive landscape, one which combines elements of biodiversity enhancement, climate change adaption and carbon sequestration, to directly benefit the environment as well as the people who reside within it.

For years the Pretoria West Power Station has played a major role in the growth of Pretoria by providing the city with electricity to the detriment of its environment. Be that as it may, the power station remains an iconic landmark within Pretoria West and therefore needs to be respected and remembered for what it was as the world continues to move towards a greener future.

The iconic landmarks which populate the power station's site are given a new life through the addition of various programmes and are further used to inspire and enhance the multi-layered and diverse landscape which moves rapidly from the past into the future.

6.2- THE PROCESS OF CARBON SEQUESTRATION AS AN ANALOGY

The process of carbon sequestration can be broken up into three stages namely: 1) Absorption of emitted carbon from the atmosphere; the conversion of that absorbed carbon into biomass which leads to; 2) growth and the 3) storage of that carbon within the biomass and soil. These stages and their role in the formation and development of the design concept will be discussed below:

1) Absorption:
The term absorption refers to an uptake of energy, energy which can manifest on multiple levels. The site, as it was, produced energy, in the form of electricity by the burning of fossil fuels which emitted CO_2 into the atmosphere that now needs to be absorbed.

Energy however, can also translate, in a more metaphorical sense, as something which can be experienced by the user of a landscape. This can be achieved through the creation of dynamic and ever-changing spaces and a fluctuation of users over different times of the day and different days of the year.

The findings from the literature in chapter two indicated that of all terrestrial vegetation, trees have the greatest sequestration potential, particularly in the urban environment, and are unmatched by any other form of vegetation due to their size and life expectancy. Trees are therefore identified as an important design component when challenged with the absorption of carbon from atmosphere.

Absorption as a concept idea can therefore manifest programmatically, in the shape of trees in forestry, which can create a sense of energy in the landscape through rotational harvesting and planting. By doing so, the landscape is able to continually absorb carbon at different rates and over different periods of time. The creation of active spaces of high energy and passive spaces within the forested landscape give the user the experience of being absorbed by the landscape. The vastness and scale of the forestry offer an escape from the high activity areas of the site (Figure: 78).

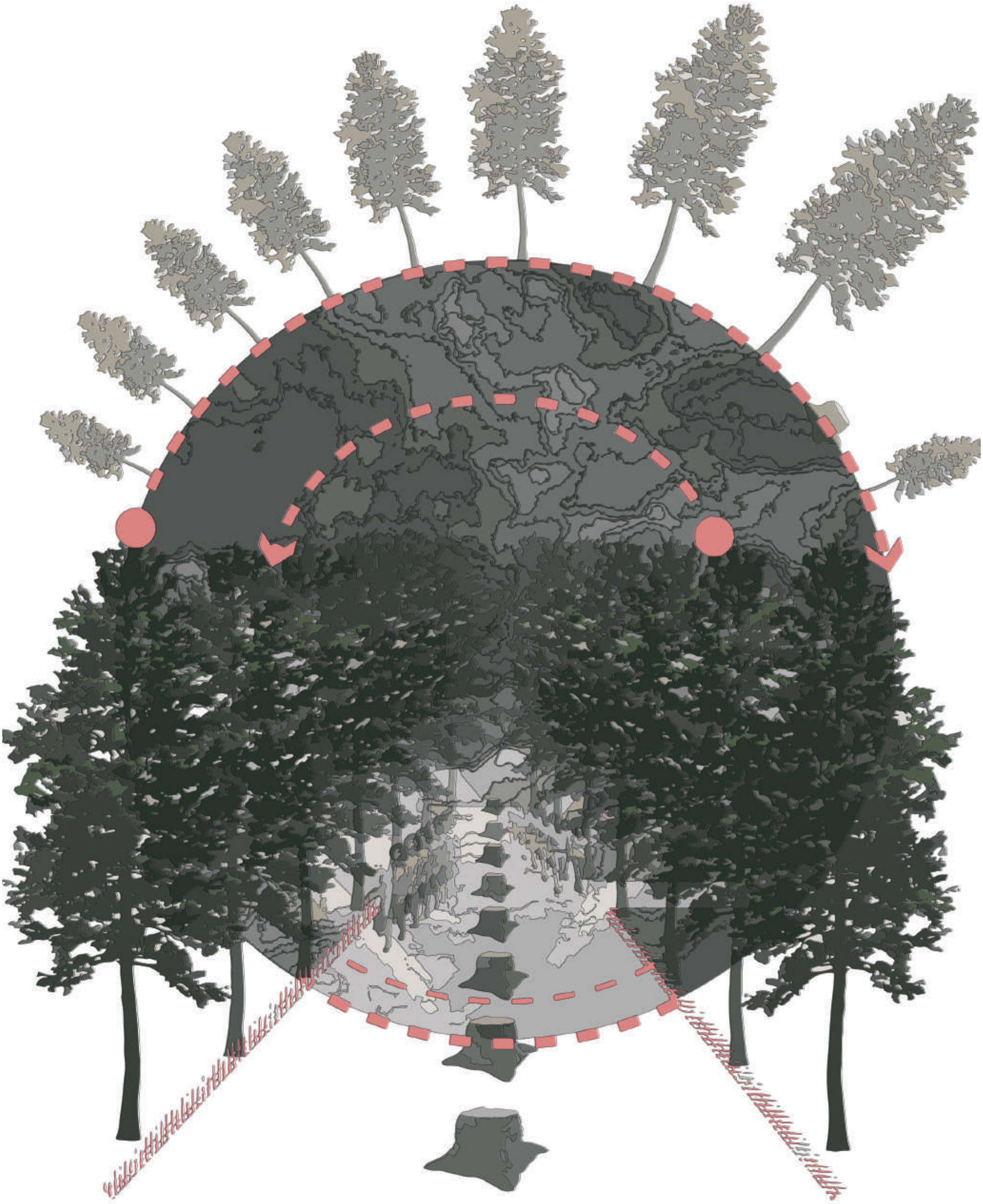


Figure-78: Conceptualising absorption and how energy can be experienced through the use of terrestrial vegetation

Absorption of Carbon Through Forestry

2) Growth:
Growth is directly related to change. As something grows, its form, height and nature may change. As the landscape grows, so too the amount of carbon which is stored within it. Growth in landscape design manifests itself through literal growth of the vegetation, both implemented and existing as well as how the transition is made between what was existing to what will exist in the future in terms of vegetation types.

In the design this could be experienced on multiple levels, through multiple perspectives and along a series of time-lines. By allowing the user to move on both the ground and tree canopies they experience this growth on multiple levels and from multiple perspectives. The use of a combination of tree and plant species both deciduous and evergreen further enhances the concept of growth as a change over time.
In the design- growth manifests programmatically within the production of food through agroforestry, the production of timber through forestry and the production of algae within the algae tubes.

To enhance the idea of growth, the built structures within the proposed landscape are designed to facilitate the growing of plant material on, along and up them. This will give the impression that the structures grew for the landscape and will also give them the ability to absorb CO2 (Figure: 79).

3) Storage:
The final stage of the carbon sequestration process is the storage of carbon facilitated by growth. Storage, at the end of the process, is in the form of biomass, roots and soil. Programmatically, storage manifests in the landscape through the creation of a product, namely timber through forestry. This timber is utilised in the construction of the intervention's structures along with the possibility of timber products being used off-site. This will ensure longevity of stored carbon for as long as the timber is maintained.

Materials selection could also further the idea of storage within the landscape. By using timber as cladding, decking and structure, the intervention creates another layer of storage above that of soil and roots. Stone and soil gathered from the site during excavation processes is used in the construction of permanent structures, such as retaining walls (Figure: 80).

6.3- THE FINAL CONCEPT

The design uses the analogy of the three stages of carbon storage in terrestrial vegetation as conceptual inspiration for the design of a variety of spaces, series of experiences and a selection of materials. The design physically and programmatically adheres to the principles required for biodiversity enhancement, climate change adaption and carbon sequestration set out in chapter two (Figure:81). This includes thirteen aspects namely: the need for planting to enhance natural features; tree stand density; proximity between landscape

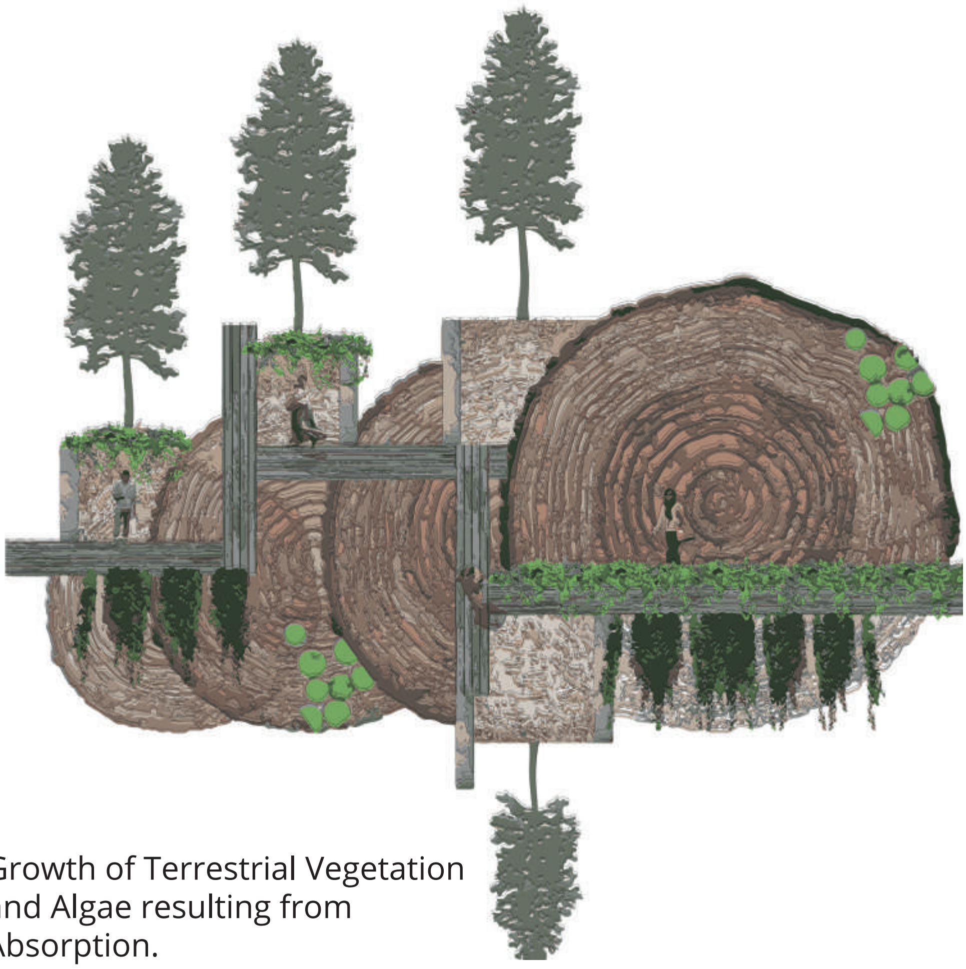


Figure-79: Conceptualising growth through different forms of vegetation from different perspectives.

patches; corridor width; landscape patch size; connectedness of patches; patch evenness; structural diversity of planting; integration of planting; multiple storeys of planting; the use of alley cropping in agroforestry; the need for plant species to be spatially mixed and the use of trees for building climate control.)

This landscape, when combined, creates the concept of the carbon farm. In the final design proposal, the Carbon Farm ultimately manifests as a Ground plane which is highly productive and active (Absorption), a Middle plane with spaces of low activity and contemplation (Growth) and the sky plane, which sits above the landscape allowing the user to take in the vastness whilst at the same time, experiencing the process and appreciating the artefact (Storage).

The Carbon Farm proposes a layer of high productivity and activity on the ground plane combined with passive spaces of low activity the absorption of CO_2 from the atmosphere via vegetation; The growth of that vegetation to produce crops and timber through agroforestry and forestry respectively, and the storage of carbon within the site and the materials used to construct it.

The Carbon Farm creates a landscape which celebrates the act of carbon sequestration through ensuring the user, both as a visitor and a community farmer, and the environment, benefits at multiple levels, from multiple perspectives and over an extended period of time.

Figure-80: Conceptualising storage through varying materials which have the ability to store carbon physically and visually.

Storage of the Absorbed Carbon in: Soil; Biomass and Vegetation.

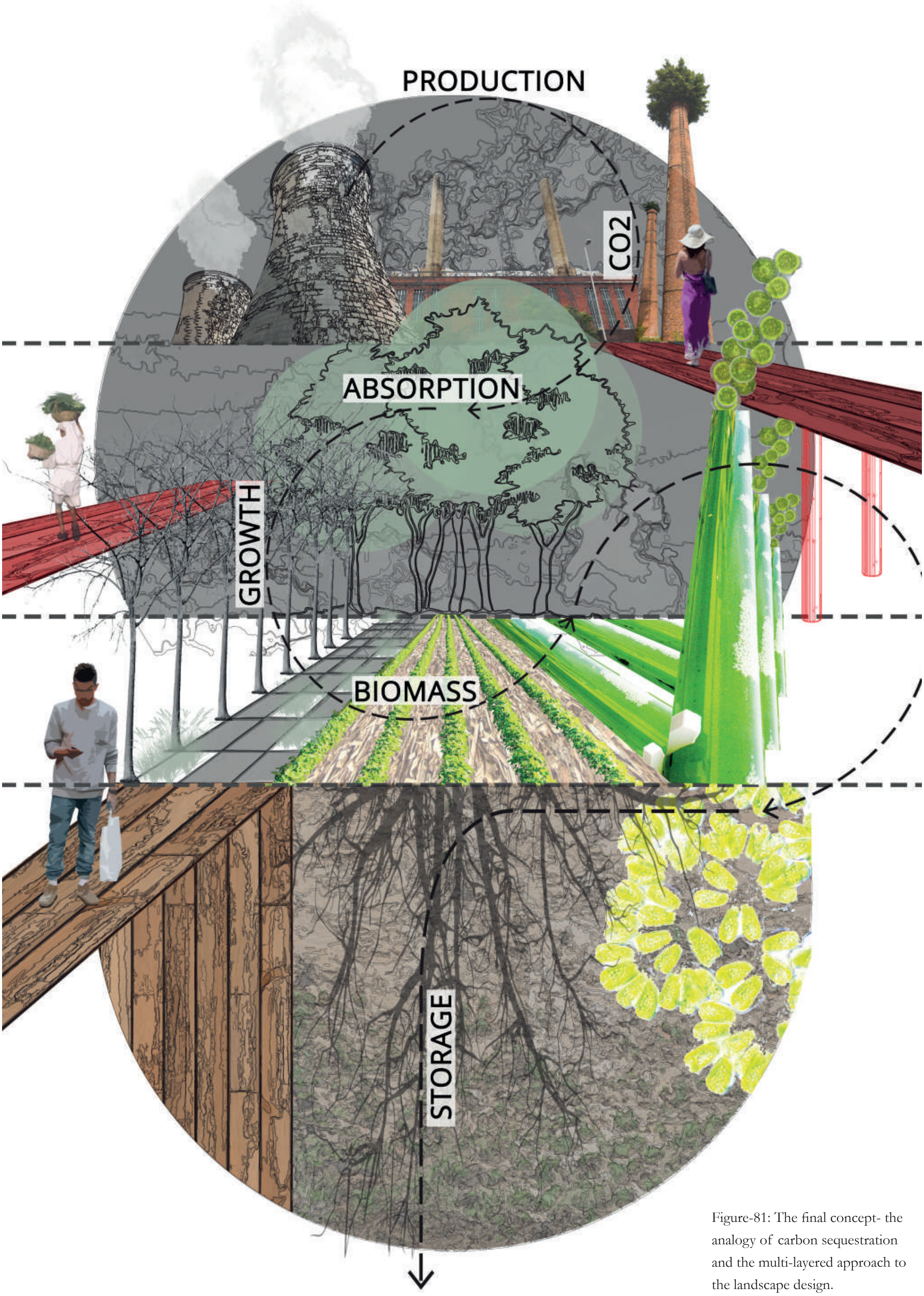
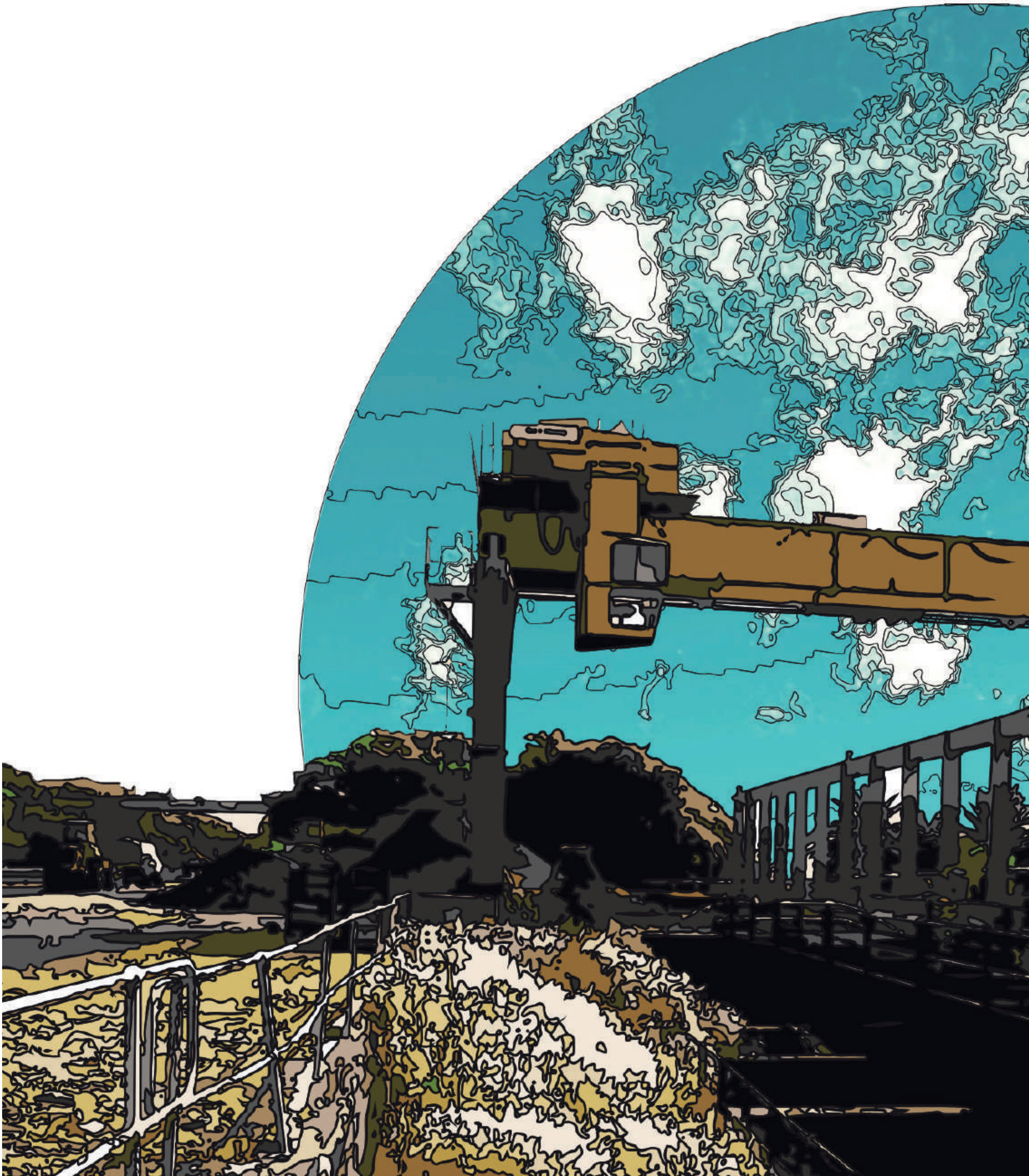


Figure-81: The final concept- the analogy of carbon sequestration and the multi-layered approach to the landscape design.



CHAPTER 7- DESIGN DEVELOPMENT

Chapter 7 focuses on the goals and strategies which shaped the development of the landscape design. The goals and strategies are formed through a combination of factors highlighted in previous chapters: Theory, site analysis, precedents, programmes and users as well as concept. The Chapter illustrates the rationalised approach to the final product, a completed landscape design.

7.1- DESIGN GOALS

The design of the carbon farm developed around the various systems required for sequestration. It is in essence a productive landscape, with various systems that function as an interconnected whole. The decisions guiding the approach to the systems design are based on a number of factors including the literature in chapter two as well as the urban and site analyses in chapter three and the precedent studies in chapter four.

The following four design goals were formulated in order for the carbon farm to respond to the aspects highlighted in the previous chapters:

1. Offset: Combine time, process and ecology to offset emissions from the surrounding industries whilst creating a memorable landscape.
2. Uplift:
   a) Connect- To connect Pretoria West with Proclamation Hill and beyond by creating a node of exchange: Transportation exchange; goods exchange and skills exchange.
   b) Access- Give access to resources and land to undertake agroforestry thus increasing food self-sufficiency in an ever-increasing urban population whilst also providing opportunity for income generation and skills development.
3. Social and ecological well-being: To illustrate the possibilities of the mutual benificiality between: carbon sequestration; biodiversity and climate change, and sustainable food production and industrial processes in order to improve ecology and human well-being.
4. Awareness: Increase overall awareness of the benefits of carbon sequestration and the need for sustainable urban forestry management.

7.2- STRATEGIES

In order to achieve these goals, five overarching strategies have been highlighted and applied to the site in order to form a basis of the development of the design. These strategies are as follows:

Strategy 1- Forestry Grids: Utilising a grid system to maximise the number of trees plantable per available area of the site. The grids follow the forestry industry standard of 2m x2m intervals. The site is divided into areas and the trees are planted in five-year intervals and rotated every 25-30 years when the trees have reached maturity. This is to ensure a continued carbon sequestration while certain areas are being harvested (Figure: 82).

Strategy 2- Ecological corridor: utilising the natural river and dam as ecological corridors to which the ecological patches respond in order to ensure the Carbon Farm has potential to enhance biodiversity. (Figure: 83).

Strategy 3- Transport Node: Integrating multiple modes of transport adjacent to and through the intervention. This is

Figure-82: Strategy 1- The forestry grid system used to maximise the tree planting potential on the site.

achieved by incorporating a commuter train station within the Carbon Farm's boundaries, adding BRT stops on Charlotte Maxeke and Quagga road and including parking for private vehicles within the site boundaries. This also entails the creation of entrances into the site to allow for pedestrian and bicycle movement through the site. (Figure: 84).

Strategy 4- Landscape Patches: The largeness of the site gives the opportunity of creating a series of landscape patches based on function and programme. The site will be broken up into a series of patches with varying programmes which will be linked through various walkways and site lines to create a diverse landscape experience (Figure: 85). The landscape patches include: a) forestry, b) agroforestry, c) recreational spaces and d) ecological patches. The planting strategy for these patches will be briefly discussed below:

a) Forestry: The trees utilised in the forestry areas are purely for productive purposes and need to be fast growing in order to ensure the possibility of high turnover in terms of harvesting and replanting; Thus, exotic tree species in the form of *Pinus* and *Eucalyptus* species are used. On the fringes of these areas there is opportunity for under-story vegetation such as *Sansevieria* species and other shade loving drought tolerant species.
b) Agroforesty: These areas include a mixture of both trees and food crops. The trees' purpose are to creating the desired micro-climates needed for specific crops, such as lettuce and spinach crops as well as other leafy green crops. The trees themselves also enhance the fertility of the soil reducing the amount of erosion and nutrient loss. The agroforesty zones will be split into a 5m x 5m grid with a communal tree such as a *Ceratonia siliqua* which is situated between each set of plots. Trees such as the *Ceratonia siliqua* are selected based on their ability to create micro-climates beneath them as well as their ability to produce fruits.
c) Recreational Spaces: These consist of lawn commons as well as piazzas situated throughout the landscape. The planting strategy for these areas will be of a more ornamental nature whilst still adhering to the requirements for carbon sequestration and biodiversity set out in chapter two. Here will be a mixture of both deciduous and evergreen plant and tree species with varying flowering times and flexible tolerances in order to ensure the needs of climate change adaption are met.

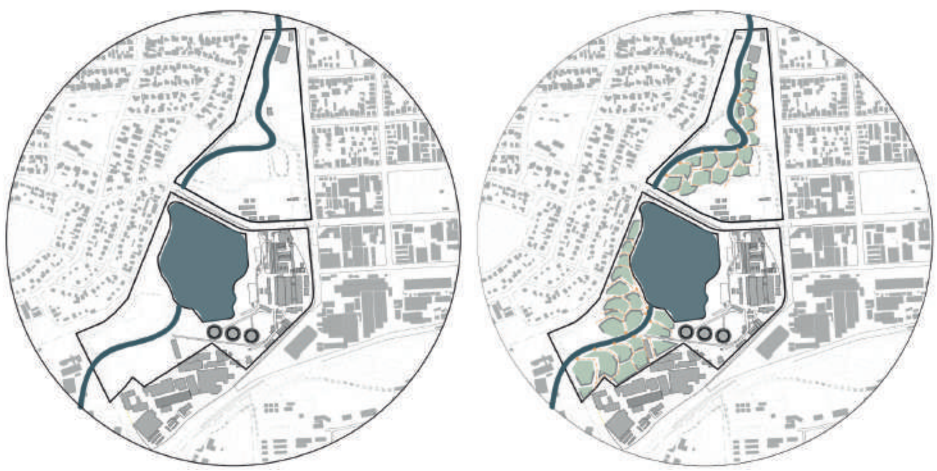


Figure-83: Strategy 2- Using the river as an ecological corridor to guide the placement of indigenous plant buffers to enhance biodiversity.

d) Ecological Areas: These patches are situated mainly along the natural rivers and dams located on the site and will therefore consist of a highly biodiverse mixture of plant and tree species including an allowance for a riparian buffer zones particularly along the rivers and edges of the dam. The planting strategy consist of species indigenous to sub Saharan Africa and will also adhere to the requirements set out in chapter two in terms of biodiversity enhancement climate change adaption and carbon sequestration.

Strategy 5- Ensuring that the carbon farm functions on multiple levels. Firstly to ensure its primary productive functions and in secondly to showcases and creates awareness of carbon sequestration. Layering of functions is achieved through the incorporation of an elevated walkway that takes the user on a route above the landscape to allow them to experience the Carbon Farm form a different perspective. Another way layering is achieved is by dropping the service routes for the productive landscapes at critical intersections where the productive layers and the general use layers intersects. This allows for the productive activities such as harvesting and transporting to take place while general users can continue to safely traverse the landscape.(Figure: 86).

To accommodate the above five strategies, a functional diagram was developed and applied to the site in order to hierarchically order the programmes as well as the overall access and movement on the site (Figure: 87).

Figure-84: Strategy 3- Transport Node- Integrating multiple modes of transport including BRT stops, public parking and a train station.

Figure-85: Strategy 4- Landscape Patches- forestry, agroforestry, Recreational and ecological and how they are spatially mixed and linked through movement routes and site lines.

Figure-86:Strategy 5- Layer- The Carbon Farm functioning on multiple levels including production amenity movement on multiple levels and how these overlap.

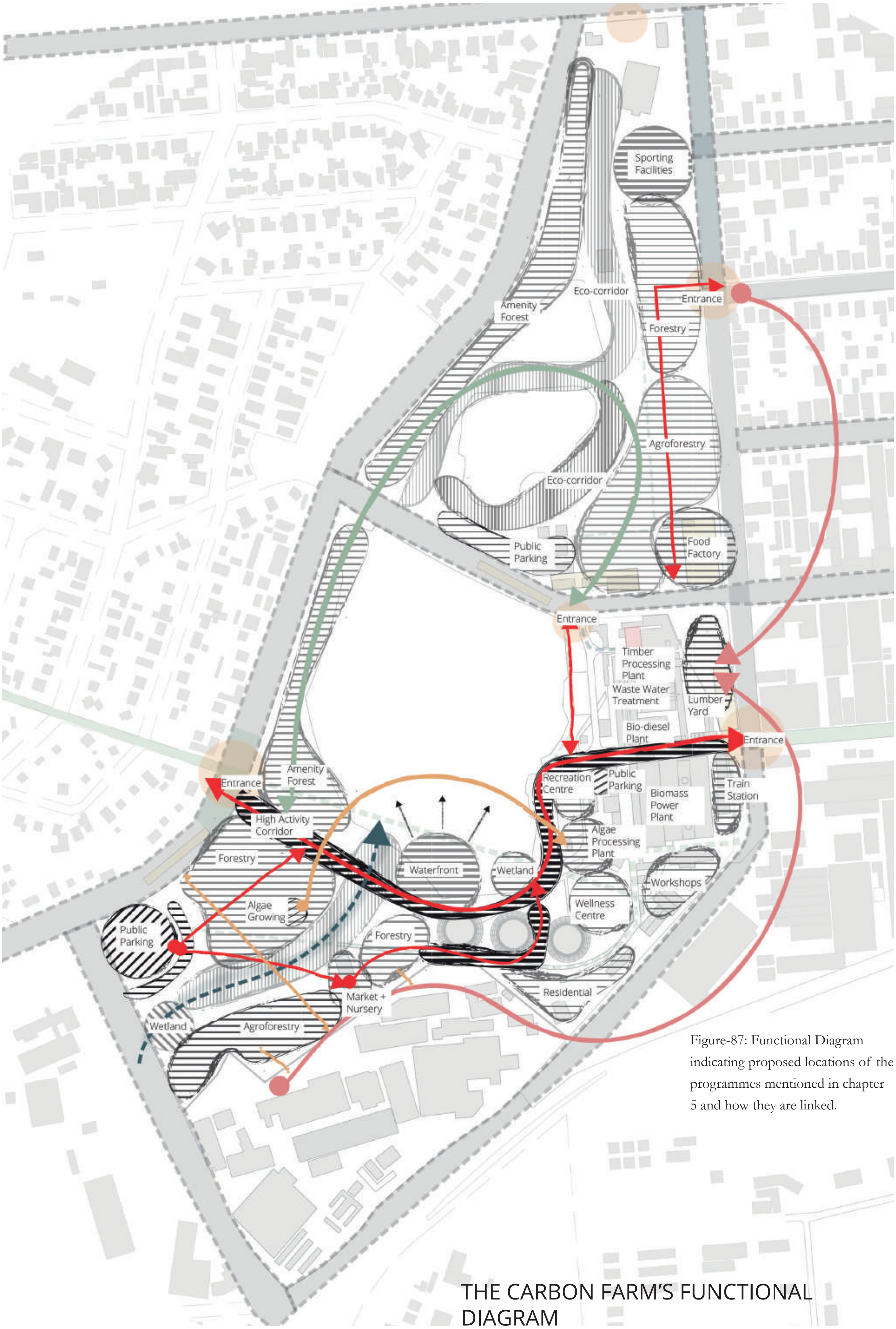


Figure-87: Functional Diagram indicating proposed locations of the programmes mentioned in chapter 5 and how they are linked.

THE CARBON FARM'S FUNCTIONAL DIAGRAM

7.3- DESIGN FORM GENERATION

The strategies that fed into the functional diagram were also subjected to an overlay approach to assist with the form generation of the design. Different layers were selected to inspire and give form to the site, including: 1) the existing infrastructure and built fabric; 2) movement routes, through, around and within the site; 3) a series of landscape patches varying in size and form containing the programmes and functions; 4) the topography of the site; 5) Sight lines; and finally, 6) a grid which unifies and connects all of these layers. These layers and their application to the site to generate form will be discussed below.

1) Existing infrastructure: The site as it stands has a considerable amount of existing infrastructure in the form of water channels, three cooling towers, the station buildings as well as the accompanying workshops and administration buildings (See chapter 3 figure 44). This infrastructure is re-utilised to house new programmes thus giving new life to the deteriorating buildings and allows the industry to take place despite allowing access to the general recreational user of the landscape. The existing railway line which enters the site on Delfos road allows the transportation of materials harvested from the landscape (timber and algae) to be taken to their respective processing buildings. (Figure: 88).

Figure-88:Existing infrastructure and main movement patterns as the initial overlay layer.

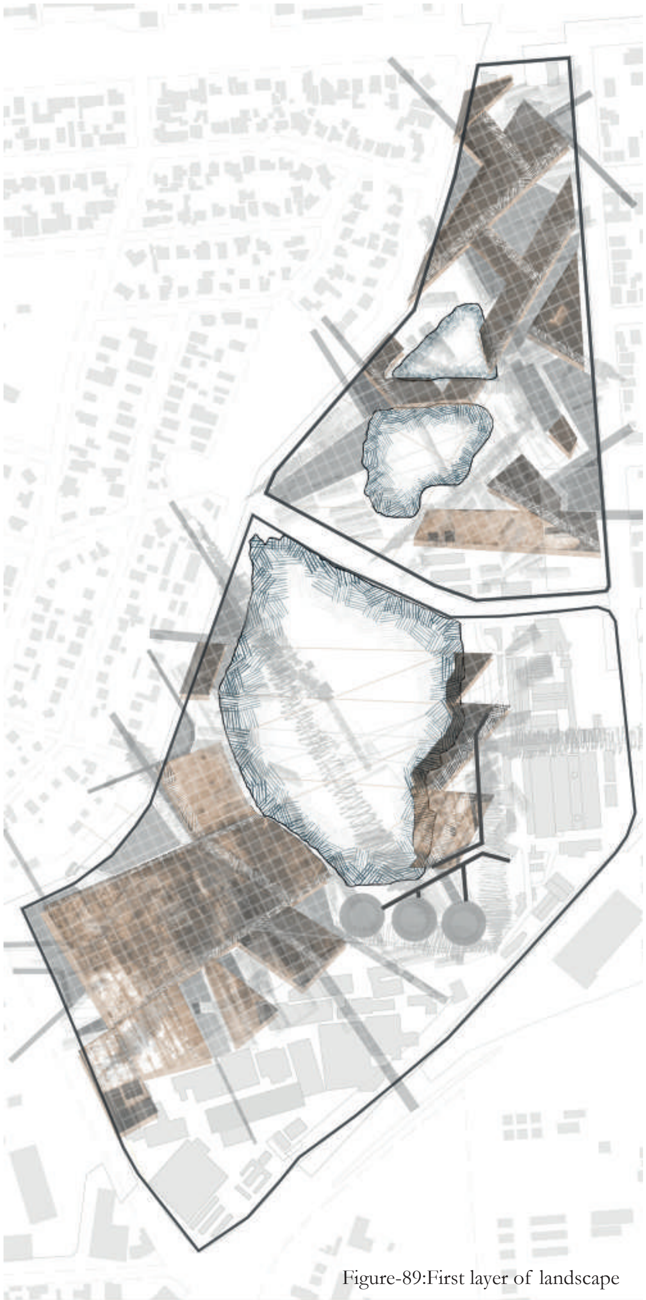


Figure-89:First layer of landscape patches added to site.

2) Movement through the site: The site movement is based on getting a user to and from certain important identified entrances to the Carbon Farm where transport is available namely: Quagga Road, Delfos Road and Charlotte Maxeke Road. The movement was planned in a way that allows a user to walk through the site from west to east or vice versa to gain access to the train station located on the eastern side and or the BRT stops located on Quagga and Charlotte Maxeke Road. This main movement route also links the public parking area located on the southern portion of the site to the rest of the carbon farm. From this main route stems a series of secondary and tertiary movement networks which tie the landscape patches together.
3) Landscape Patches: The creation of landscape patches varying in size and form allows the Carbon Farm to facilitate a diverse experience for the general landscape recreational user whilst still allowing it to function on a productive level. These patches take their inspiration from patterns and patches found in agricultural landscapes when viewed from an aerial perspective. The form of these patches, however poetic, is based on their functional dynamics in terms of harvesting and irrigation. A similar approach is followed with the design of the Carbon Farm's productive patches.(Figures: 89,90,91).
4) Site Topography: The site as it currently stands is relatively flat, except for the southern portion of the site which has previously filled in the form of a berm screening the coal heap from Roger Dyason Road. The rest of the site slopes towards the

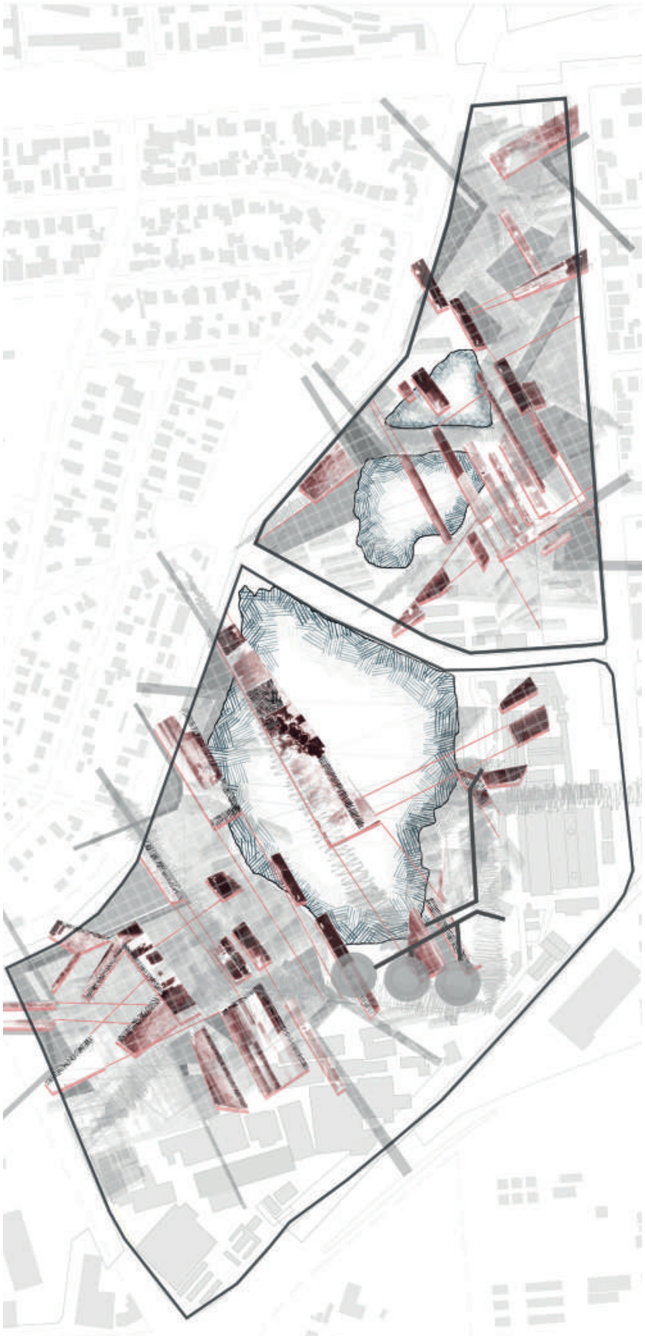


Figure-90: The second layer of landscape patches are added onto the site.

Figure-91: The third layer of landscape patches are added to the site.

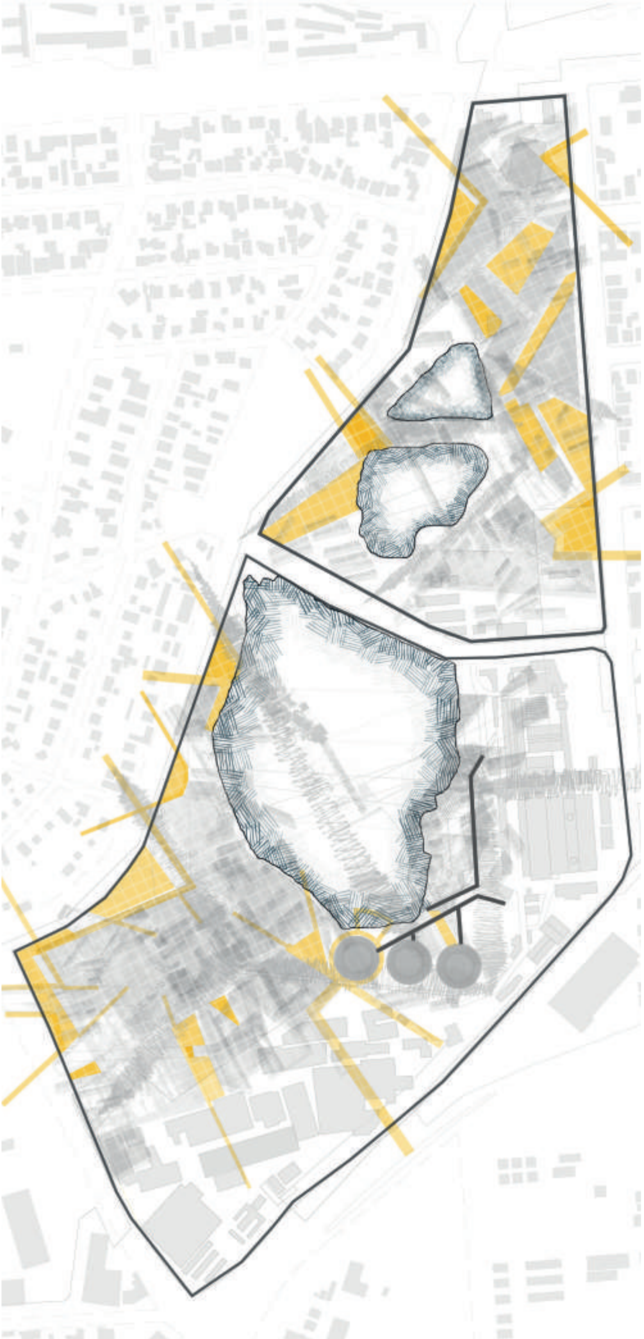


Figure-92: The predicted site lines to possible vistas which surround the site are overlaid.

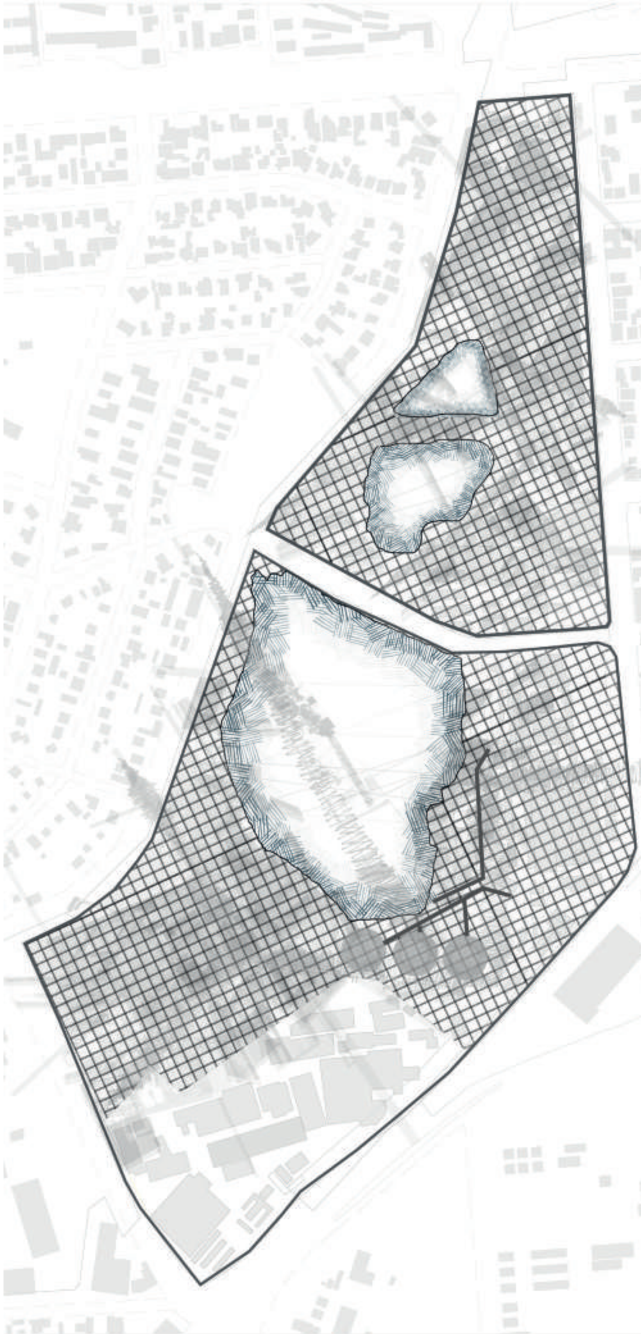


Figure-93: The forestry grid is overlaid onto the site to ensure maximum tree planting potential.

river and the dam allowing a natural flow of water into the dam. The gentle nature of the slope however means that the river stagnates in certain areas. The site's levels are manipulated in the Carbon Farm in order to: a) allow the river to flow more directly towards the dam preventing stagnant spots; b) ensure that water which falls on the walkways flows into any forested or landscaped area; c) ensure that water from the river can flow into the water storage channels and dams.

5) Sight Lines: The location of the site as well the verticality of both the existing and proposed structures made it possible to appreciate views of both the on-site structures as well as the surrounding landmarks such as Salvokop and the Voortrekker monument and the Pretoria CBD. It also provided the opportunity to view the extent of the productive processes happening on site such as the forestry and agroforestry. These views and vistas can be experienced along the proposed elevated walkway route. (Figure: 92).
6) The Grid: The grid, as mentioned above, is based of a 2m x 2m forestry industry standard and is orientated in a northerly direction for maximum sun exposure throughout the day. This orientation also allows the maximum number of trees per surface area based on the unique shape of the site. The grid intervals are increased and decreased according to the nature of the walkways and spaces, and acts as a unifying element within the large expanse of the landscape. This increases the legibility of the site (Figure: 93).

Conceptual Image for Design Iteration 1

Figure-94: Combined layers to generate a conceptual image which lead to design iteration one.

7.3.1 CRITICISMS OF DESIGN ITERATION 1

Design iteration one (Figure: 95) includes large forestry and agroforestry patches spread out within the landscape. The main circulation is achieved by an organically shaped walkway which runs throughout the site which did not create a legible landscape due to the fact that there was no distinction between primary, secondary and tertiary movement routes. An elevated walkway is incorporated which begins within the amenity forest area, spans over the dam and ends at the third cooling tower. Although the grid is evident, it is not, in this case, used to unify elements of the productive landscape or the movement through it. There is therefore very little unity with the current iteration which also does not respond as well as it could to the concept set out in chapter 6.

This iteration was then further developed to overcome these shortfalls.

Design Iteration 1

Figure-95: Interim design iteration based on aforementioned layers as part of the design development which culminated into a final masterplan design (N.T.S).

In order to instil more hierarchy and unity into the design the essence of the previous iteration was used as a base. Greater emphasis is placed on creating hierarchy of movement particularly the west to east movement routes which are developed as service roads that service both the forestry and agroforestry patches (Figure: 96). Iteration two also makes greater consideration towards the existing infrastructure in the form of the cooling towers by placing three new towers in the landscape with a similar footprint. These towers allowed a new narrative to be present within the landscape whilst still functioning as the structures which hold the algae growing tubes. Continuing with the overlaying approach, the circular form of the algae growing towers inspired the addition of a new programmatic layer in the form of algae cells (Figure: 97).

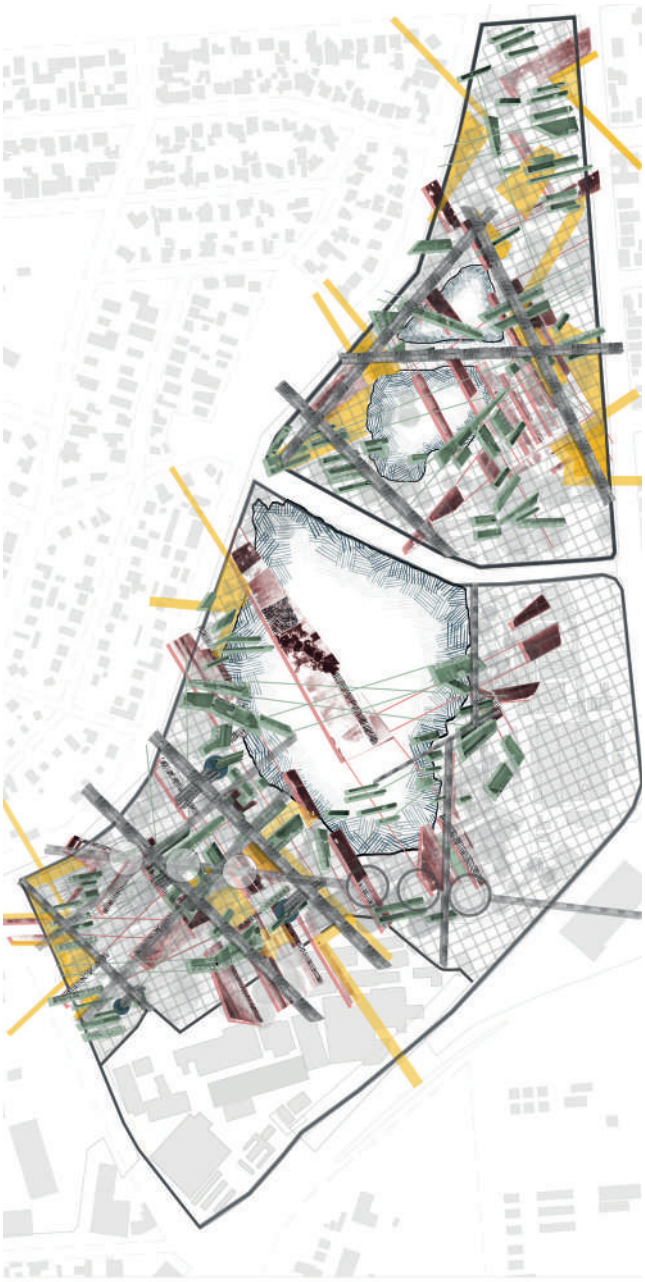


Figure-96: The addition of the three new towers on the cooling towers' axis with improved movement hierarchy.

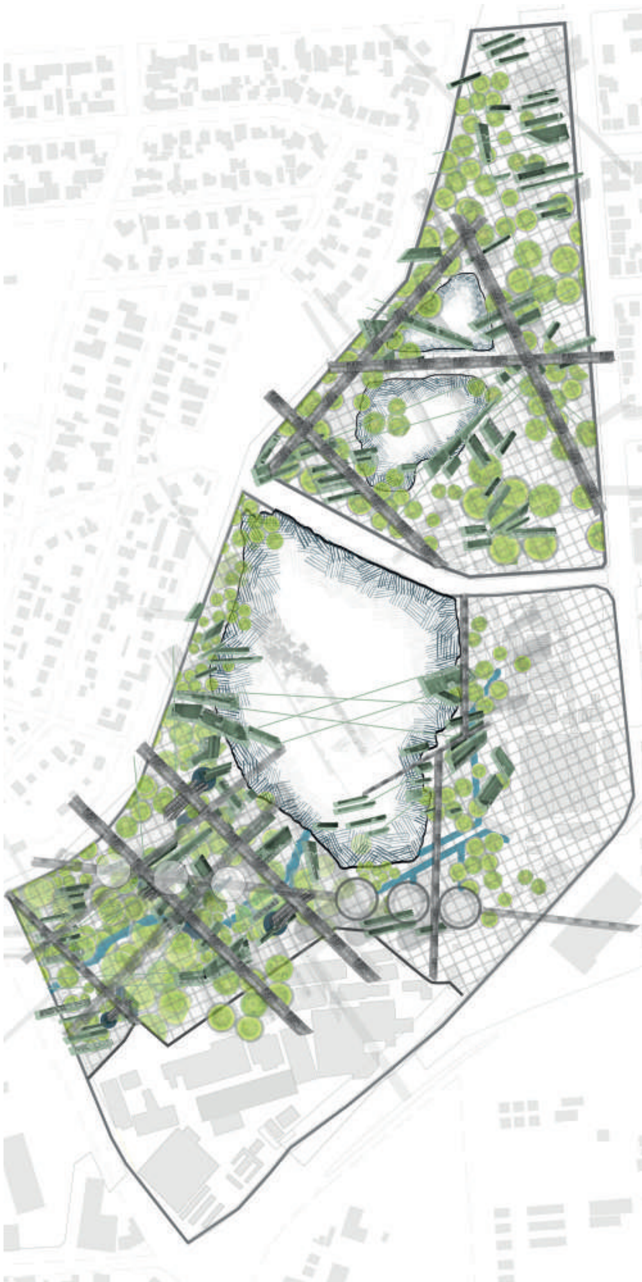


Figure-97: Overlaying the algae cells as a new programmatic layer.

7.3.2 CRITICISMS OF DESIGN ITERATION 2

The basis for the new design iteration, although having more movement hierarchy still lacks unity. Once again, the grid is evident but not a dominant feature of the design. Further exploration was needed in order to allow the grid to unify the design.

Figure-98: Layers combined to form a new conceptual image for further development of design iteration two.

Conceptual Image for Design Iteration 2

This design exploration sought to begin with the new towers and the grid as a starting point (Figure: 99). From there the dominant movement routes were overlaid and rationalised as well as the inclusion of off-stream water channels in order to get the water from the river to the algae towers without having to pump (Figures: 100 and 101). From there, the agro-forestry patches were added according to the size of the grid intervals, then the spaces in-between were filled with forestry patches (Figures: 102 and 103). The grid at this point was incredibly dominant with the threat of creating monotony within the landscape. The algae cells were then re-introduced as a new layer in order to break the dominance of the grid, creating a completely difference spatial experience (Figure: 104). The form of the cells later inspired what became the new iteration of the skywalk, which now meanders its way through the forestry patches and in-between the algae towers eventually ending up at the third cooling tower (Figure: 105).

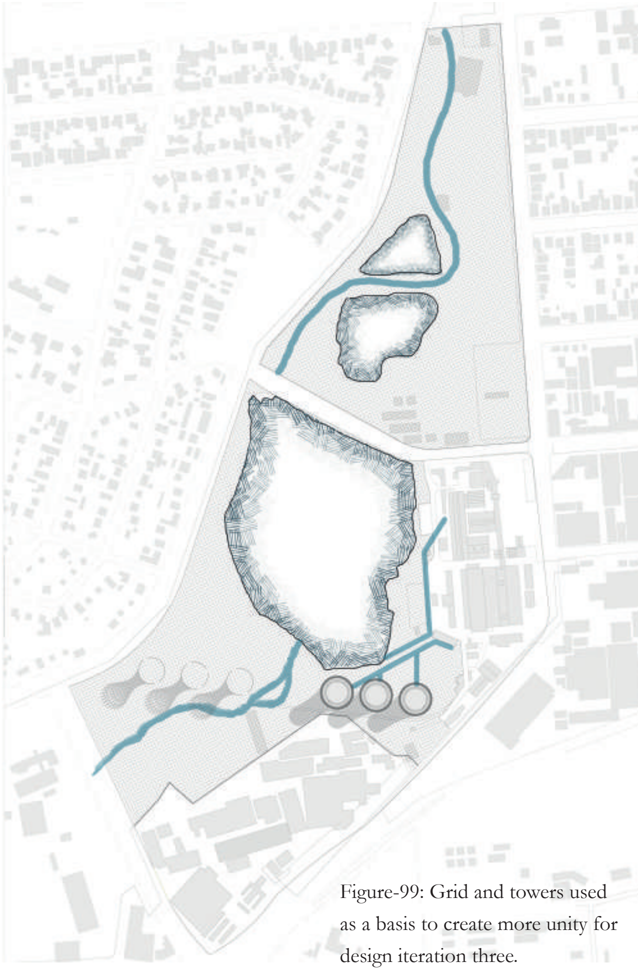


Figure-99: Grid and towers used as a basis to create more unity for design iteration three.

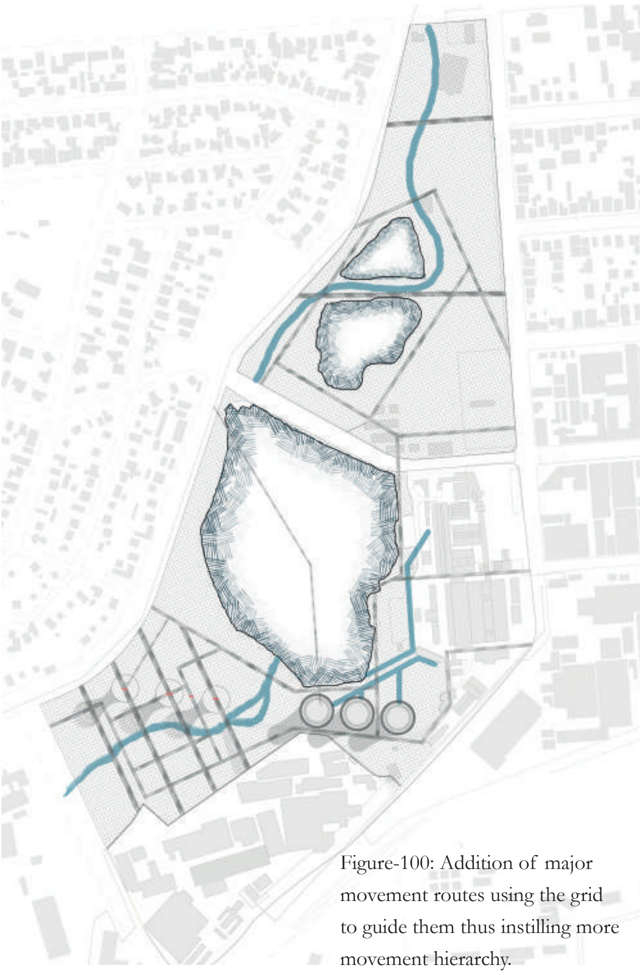


Figure-100: Addition of major movement routes using the grid to guide them thus instilling more movement hierarchy.

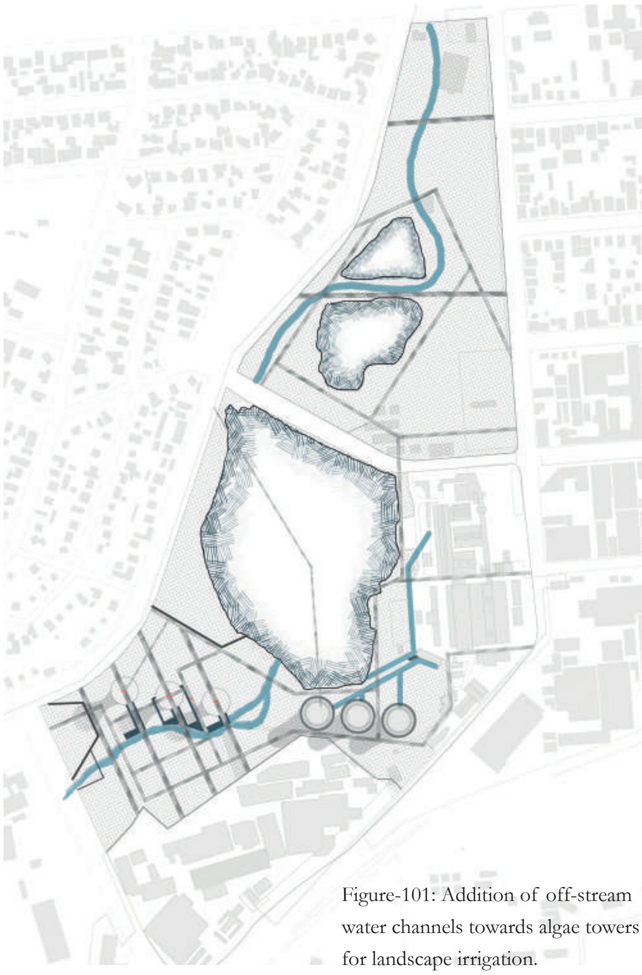


Figure-101: Addition of off-stream water channels towards algae towers for landscape irrigation.

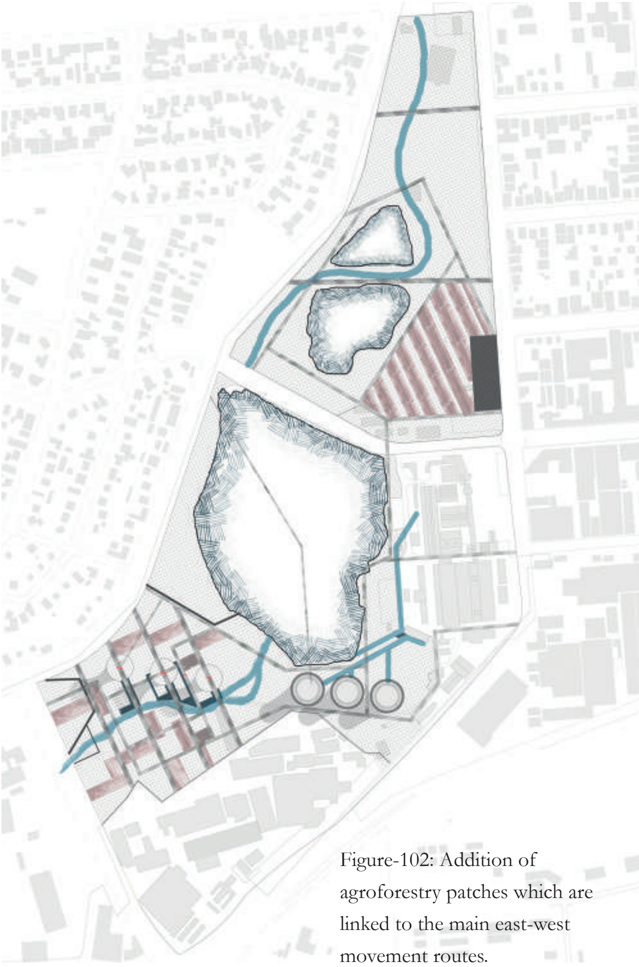


Figure-102: Addition of agroforestry patches which are linked to the main east-west movement routes.

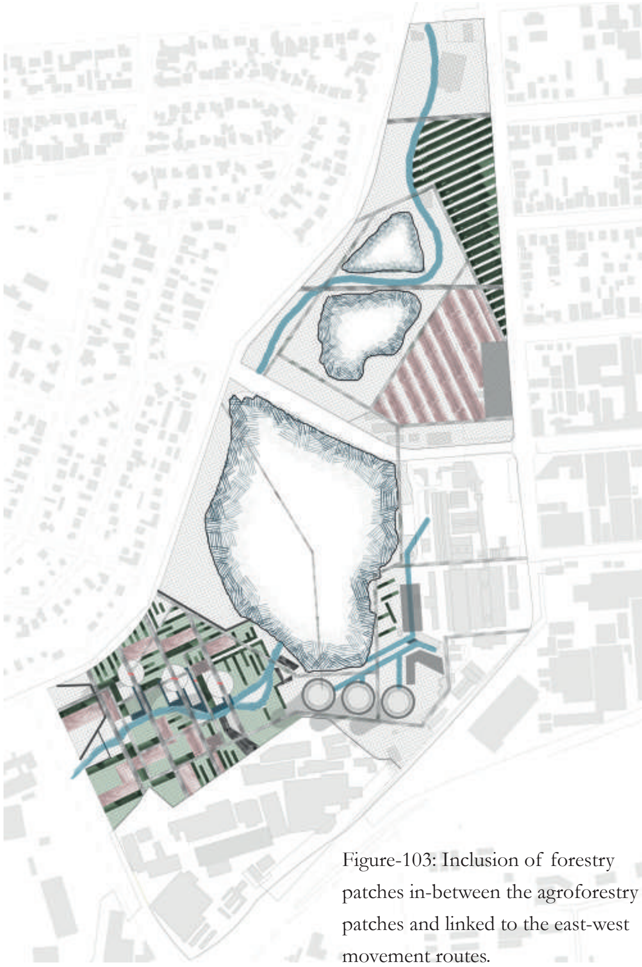


Figure-103: Inclusion of forestry patches in-between the agroforestry patches and linked to the east-west movement routes.

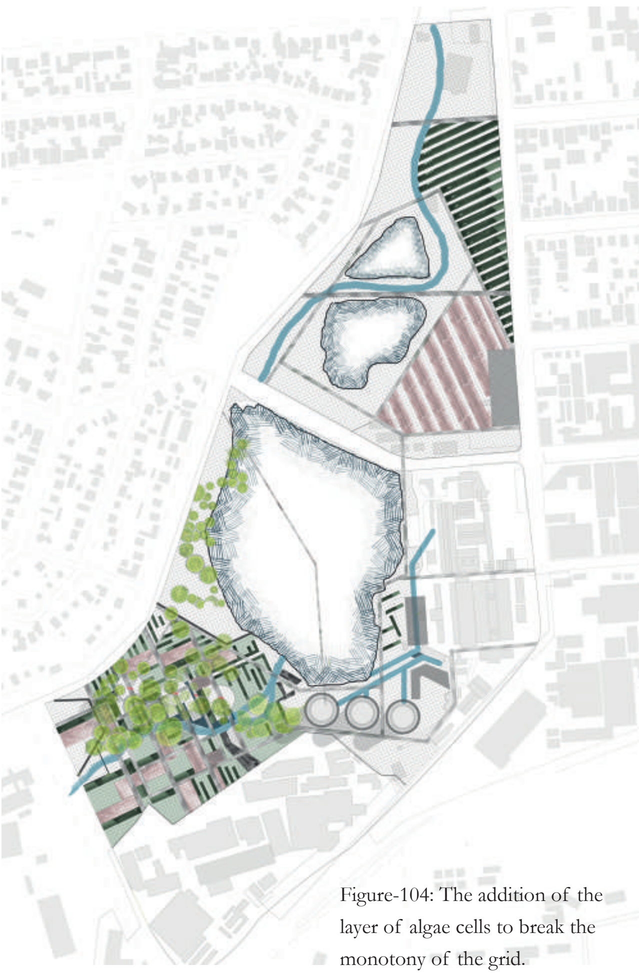


Figure-104: The addition of the layer of algae cells to break the monotony of the grid.

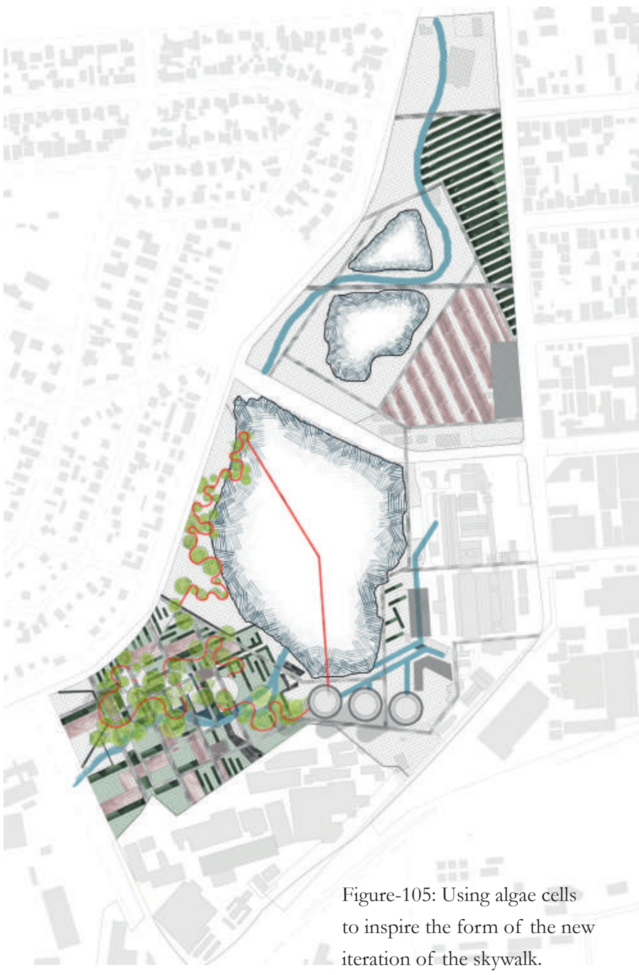


Figure-105: Using algae cells to inspire the form of the new iteration of the skywalk.

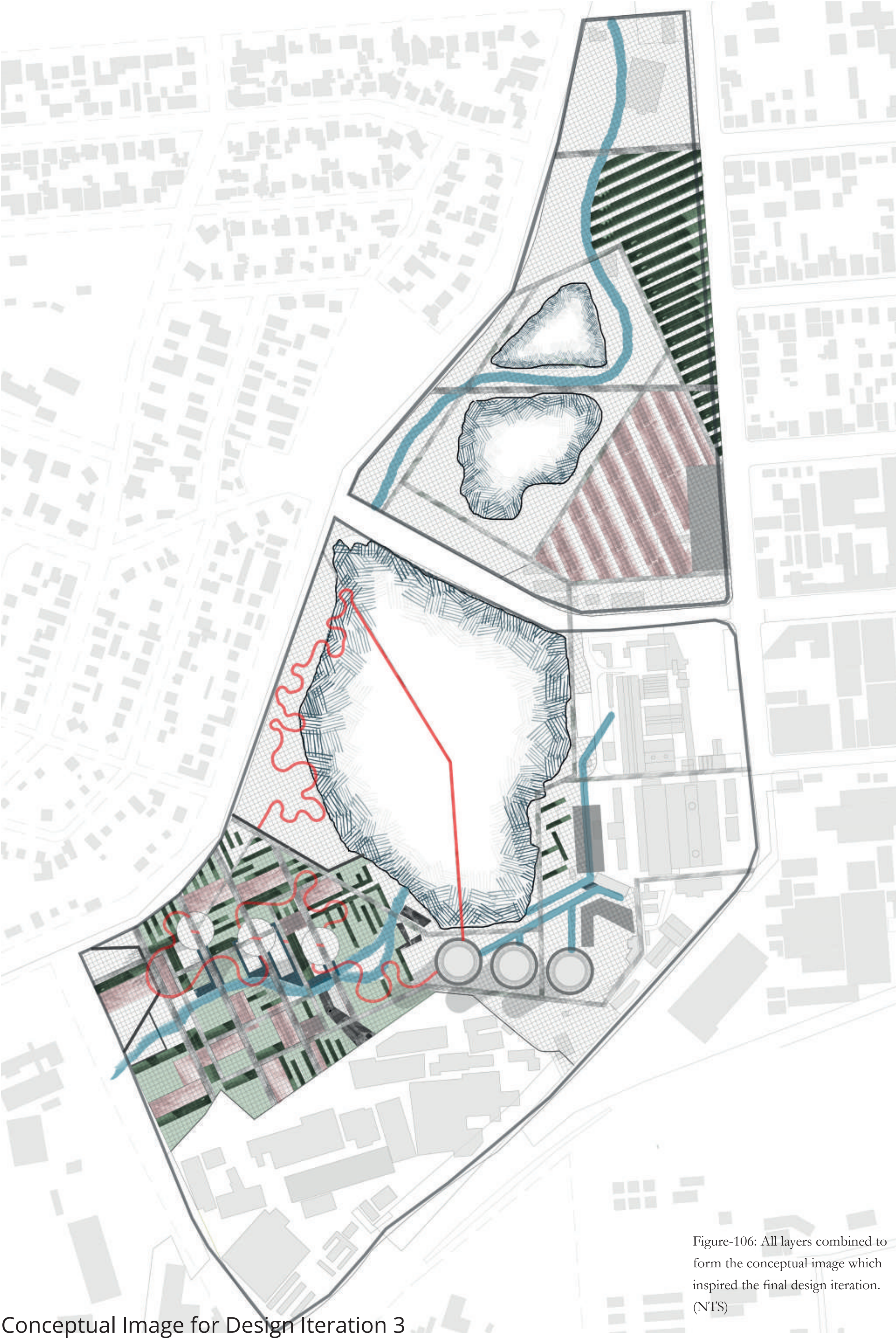
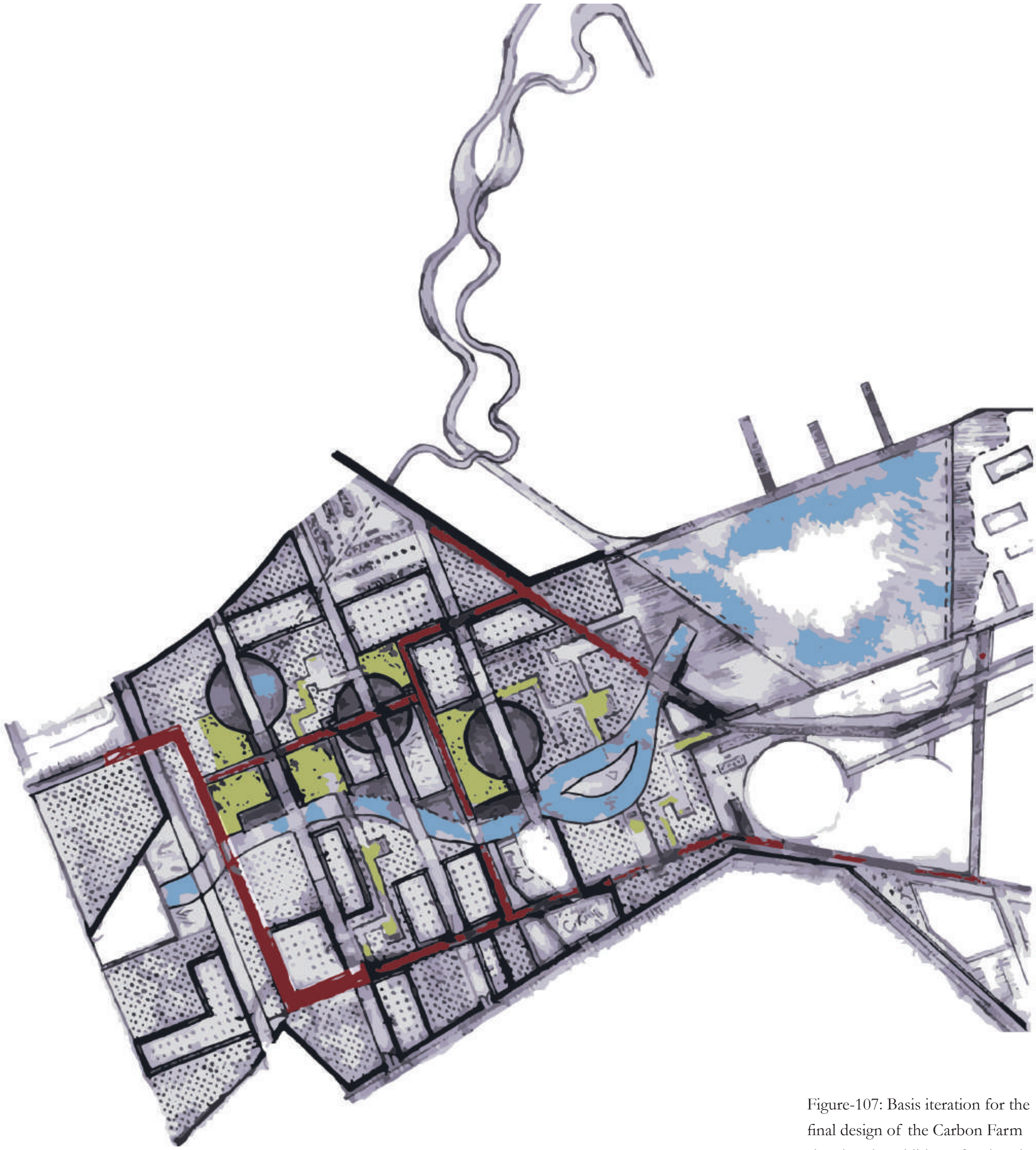


Figure-106: All layers combined to form the conceptual image which inspired the final design iteration. (NTS)

Conceptual Image for Design Iteration 3

This third major iteration of the design became the basis for the final design of the Carbon Farm (Figure: 106). At this stage, the inclusion of the swimming area within the dam as well as the decking over the dam facilitating the other recreational activities came to fruition (Figure: 107). Further additions to the previous iterations included the nursery and composting area as well as the tertiary walkways which make their way through the forestry patches linking open spaces in the form of piazzas, a series of lawn commons as well as the primary walkways.



Design Iteration 3

Figure-107: Basis iteration for the final design of the Carbon Farm showing the addition of swimming area and tertiary walkways.

MASTERPLAN OF FINAL DESIGN ITERATION (NTS)

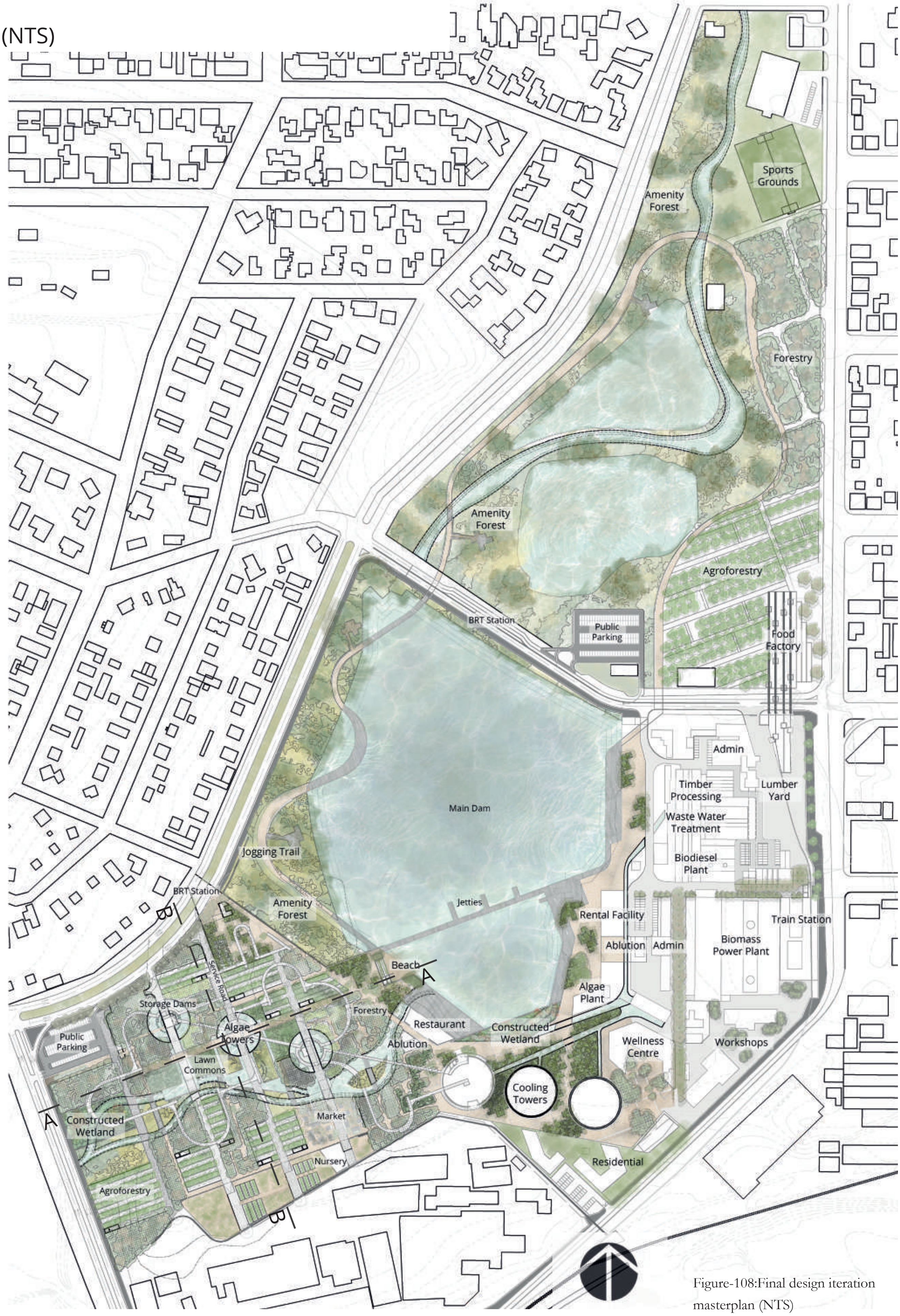
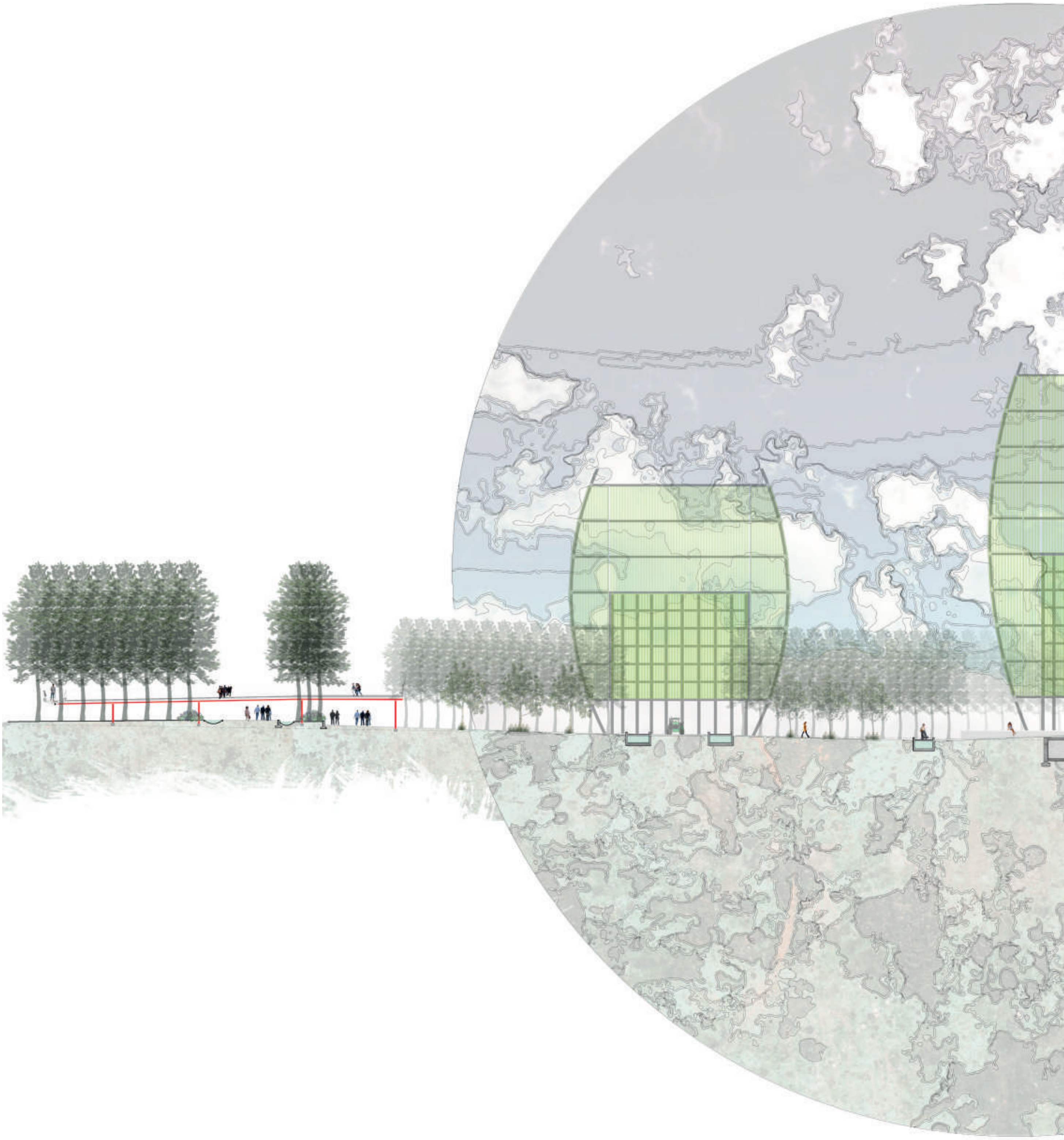


Figure-108:Final design iteration masterplan (NTS)



SECTION A-A (NTS)

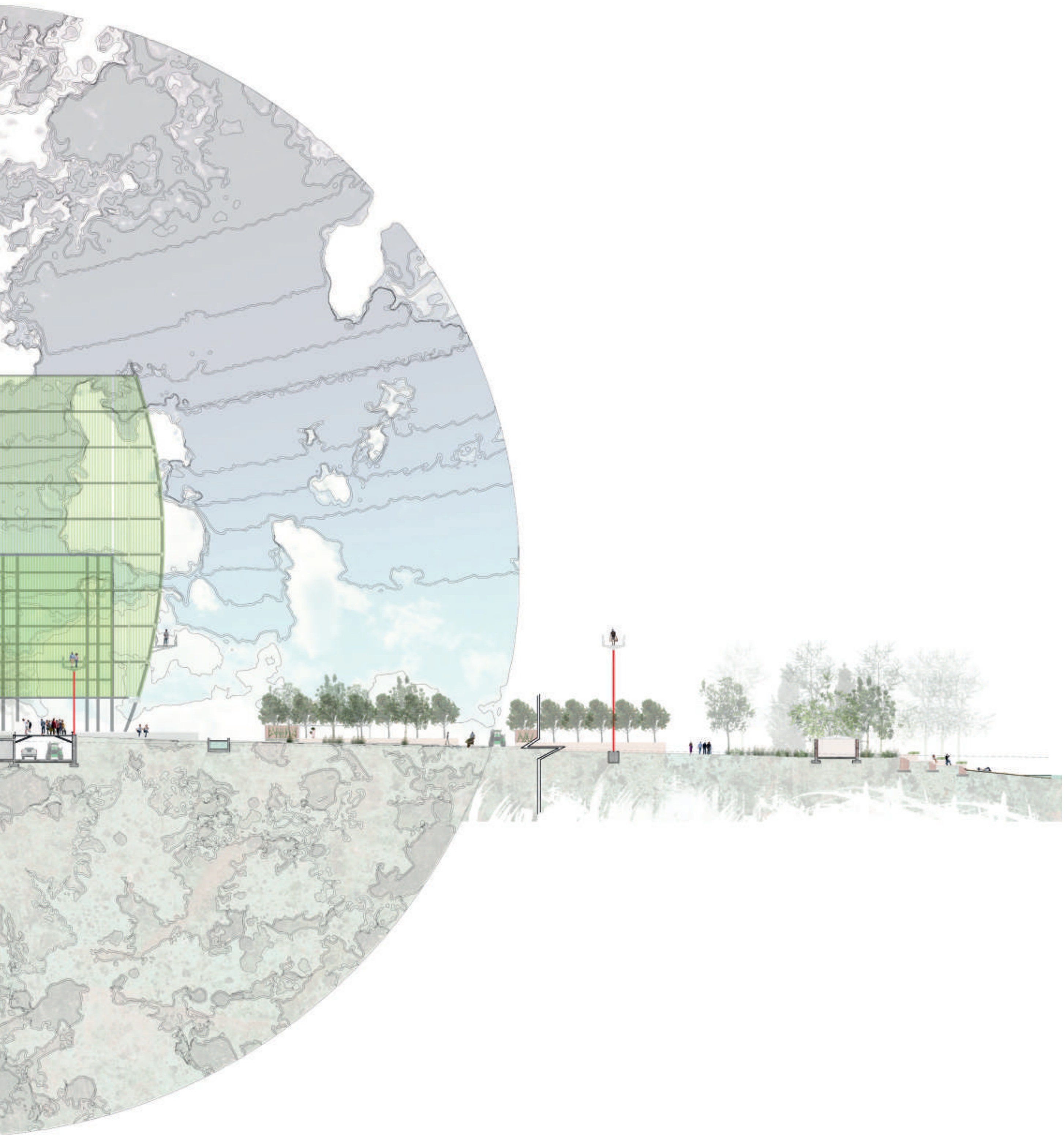
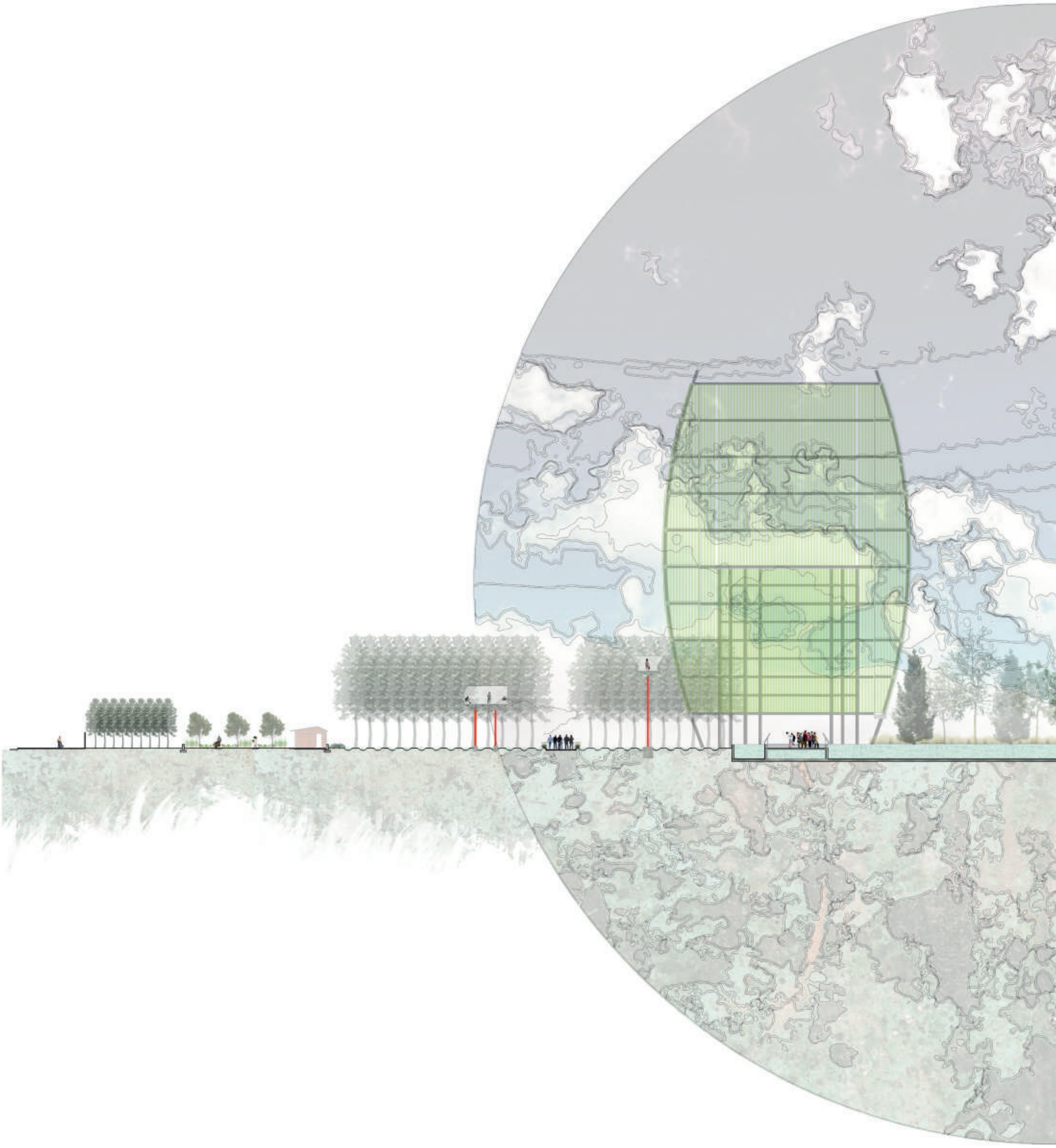


Figure-109:Section A-A cutting through the north-south axis of the site.



SECTION B-B (NTS)

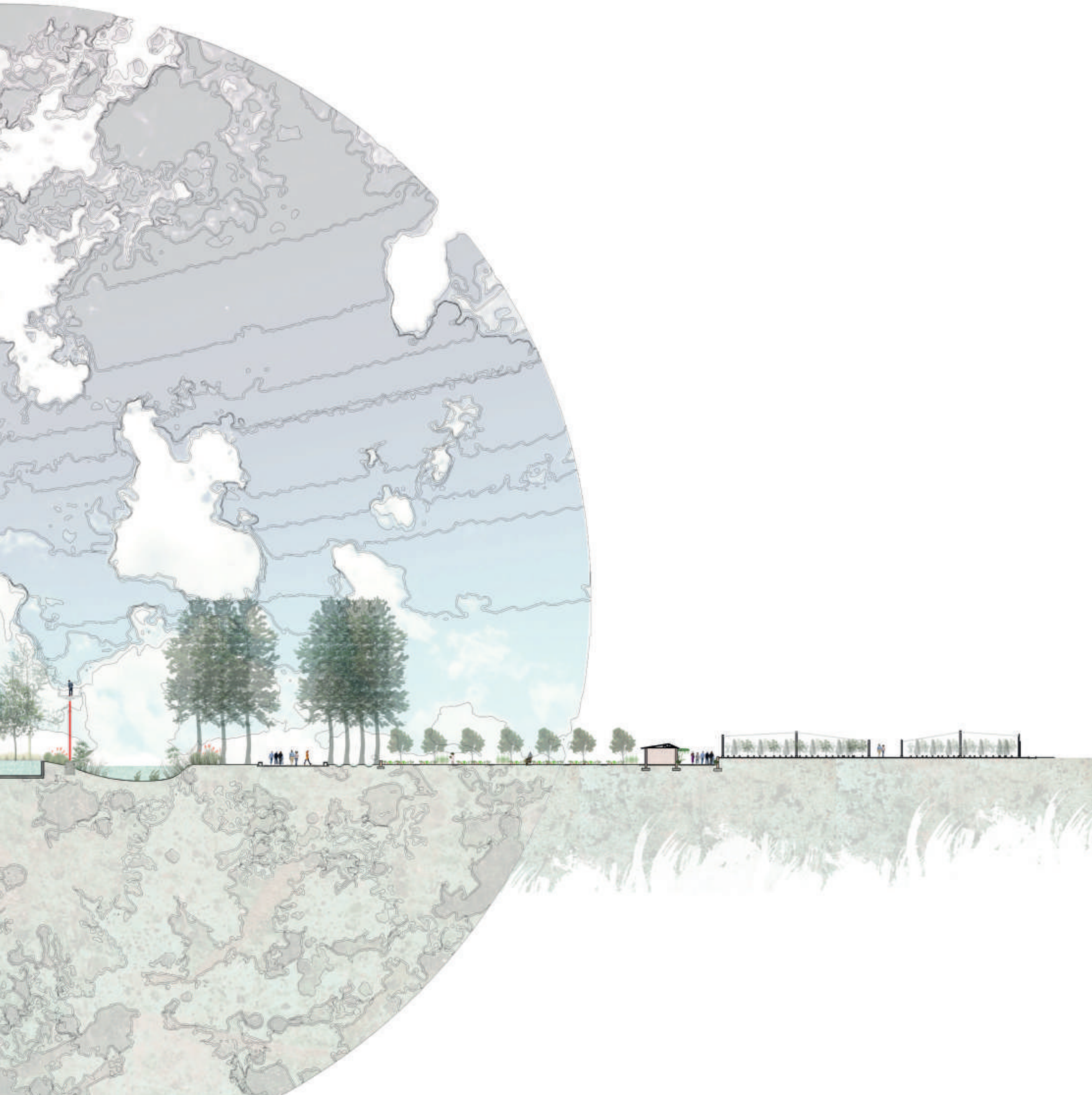


Figure-110:Section B-B cutting through the east-west axis of the site.

7.4- SYSTEMS DEVELOPMENT

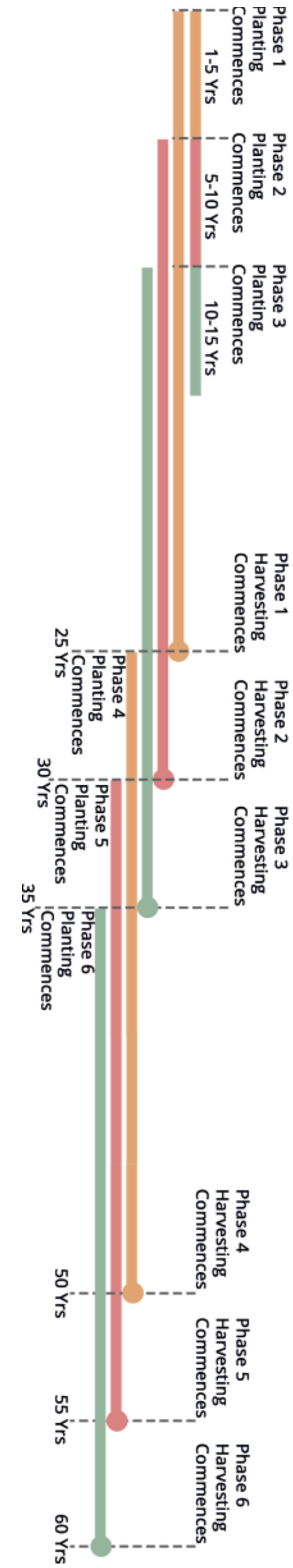
The Carbon Farm is heavily reliant on the systems within the landscape to function as a whole. After having set out the location of the above-mentioned programmes in terms of their respective locations on the site, these programmes were systematically and spatially linked to their respective sub-programmes. The four main systems namely: 1) Forestry; 2) Agroforestry; 3) Algae Growing and 4) Water will be discussed below.

1) Forestry System (Figure: 111)- The main driver behind the addition of the forestry system is the maximisation of carbon sequestration potential in order to absorb the carbon emissions from the surrounding industries (See chapter 3 figure 32). The forestry attempts to address the bulk of this requirement.

Harvesting:
As mentioned above, the forestry system will begin with a five-year planting interval following which the trees will be harvested every twenty-five years. Harvesting of the trees will be done according to the full tree (FT) method highlighted in Längin et al. (2010). This involves the felling of the tree to an acceptable maximum stump height, thereafter all the biomass above the stump is transported to roadside, or in the case of the Carbon Farm to the railway line on the eastern edge of the site (Figure:112).

Processing:
From there the timber will be transported via the railway line to the timber processing plant where it will be processed into timber products such as structural timber and cladding.

Post Processing:
Offcuts and waste, including the stumps, from the forestry will be used in the educational workshops, composting heap and biomass powered electricity plant, depending on the grade of the material, all located within the confines of the Carbon Farm.



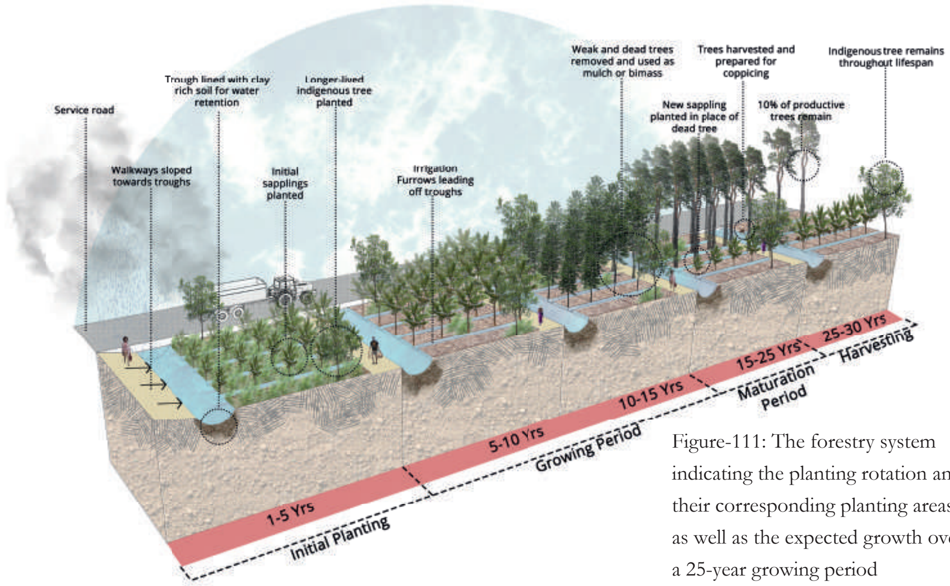


Figure-111: The forestry system indicating the planting rotation and their corresponding planting areas as well as the expected growth over a 25-year growing period

Phase 1 Planting Zones (1-5 Yrs)

Phase 2 Planting Zones (5-10 Yrs)

Phase 3 Planting Zones (10-15 Yrs)

Phase 4 Planting Zones (25-30 Yrs)

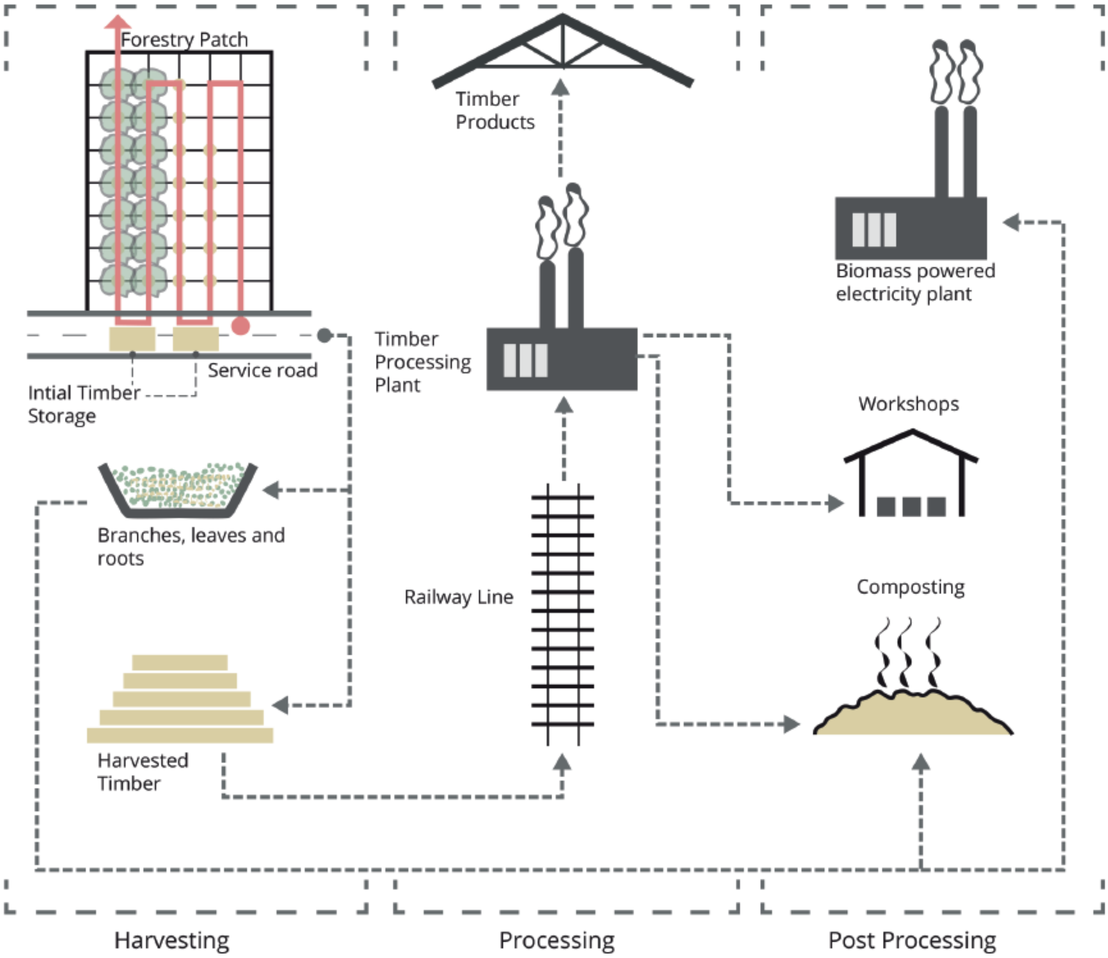


Figure-112: The forestry harvesting process and the various sub-programmes linked to it.

2) Agroforestry System- The agroforestry system is essentially broken up into two major sections. The section south of Charlotte Maxeke Road is occupied by small-scale community farmers who are able to lease a minimum of a 5x5m² plot on which to grow their produce (Figure: 113). These plots are situated within larger agroforestry tiles, each tile is provided with a unit for storing tools as well as a covered break area and a domestic irrigation supply in the form of a series of taps gravity fed from a water storage tank. The section north of Charlotte Maxeke Road is focused mainly on mass production of produce for retail supply.

Produce grown by the community farmers can either be used for personal consumption or sold in the fresh produce market situated in the Carbon Farm. Waste from both the small- and large-scale agroforestry systems will be used in both the composting heap as well as the biomass powered electricity plant.

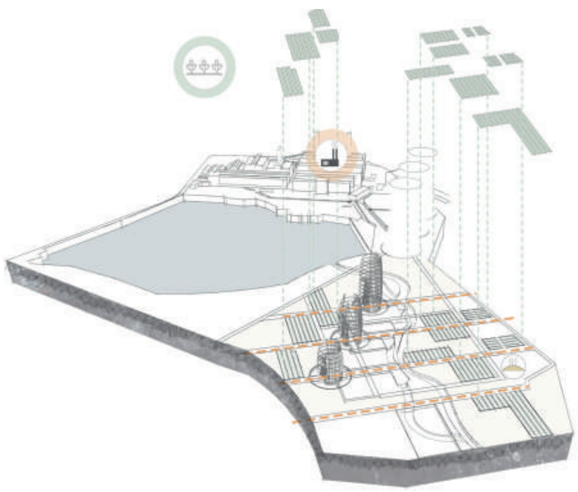
3) Algae Growing System (Figure: 114)- Algae is an effective absorber of carbon due to its rapid growth and can double its biomass within twenty-four hours (Bajhaiya et al., 2010). A controlled and effective method of growing algae for later harvest is using photobioreactors which in essence are closed tubular systems filled with a growth medium, water, and exposed to a light source, the sun or artificial lighting (Cañedo and Lizárraga, 2016). The purpose of these systems is to avoid contamination found in open systems as well as to increase the surface area to volume

ratio thus increasing light energy efficiency (Cañedo and Lizárraga, 2016).

Harvested algae can have many applications such as aiding in bioremediation and as a nitrogen fixing fertilising agent (Bajhaiya et al., 2010). This is initially helpful for rehabilitative purposes of the coal heap area (see chapter 3 figure 48). However, the bulk of the algae will be utilised specifically for the production of biofuels within the biofuel plant as well as for food purposes.

The Process:
The algae are grown in a vertical tubular fence system fixed to the three algae towers located within the Carbon Farm. Two of the towers, the eastern and central tower, are utilised to grow algal species such as *Chlorella* and *Desmodesmus quadricaudatus* for the production of bio diesel (Saad et al., 2019). The remaining tower is utilised to grow algal species such as *Chlorella* and *Spirulina* for human consumption (Vigani et al., 2015).

The algae tubes are fed by a feeding vessel which is supplemented with a combination of required nutrients, namely nitrogen, phosphorous and potassium (N, P, K) and water to form a growth medium. This growth medium is then pumped to fill the fence systems. The fence systems are in four-meter-wide by five-meter-high modules which are fixed to the structure of the towers. The fence modules are independent but are linked through central inlet and outlet tubes. The inlet and outlet tubes are fed from the control buildings



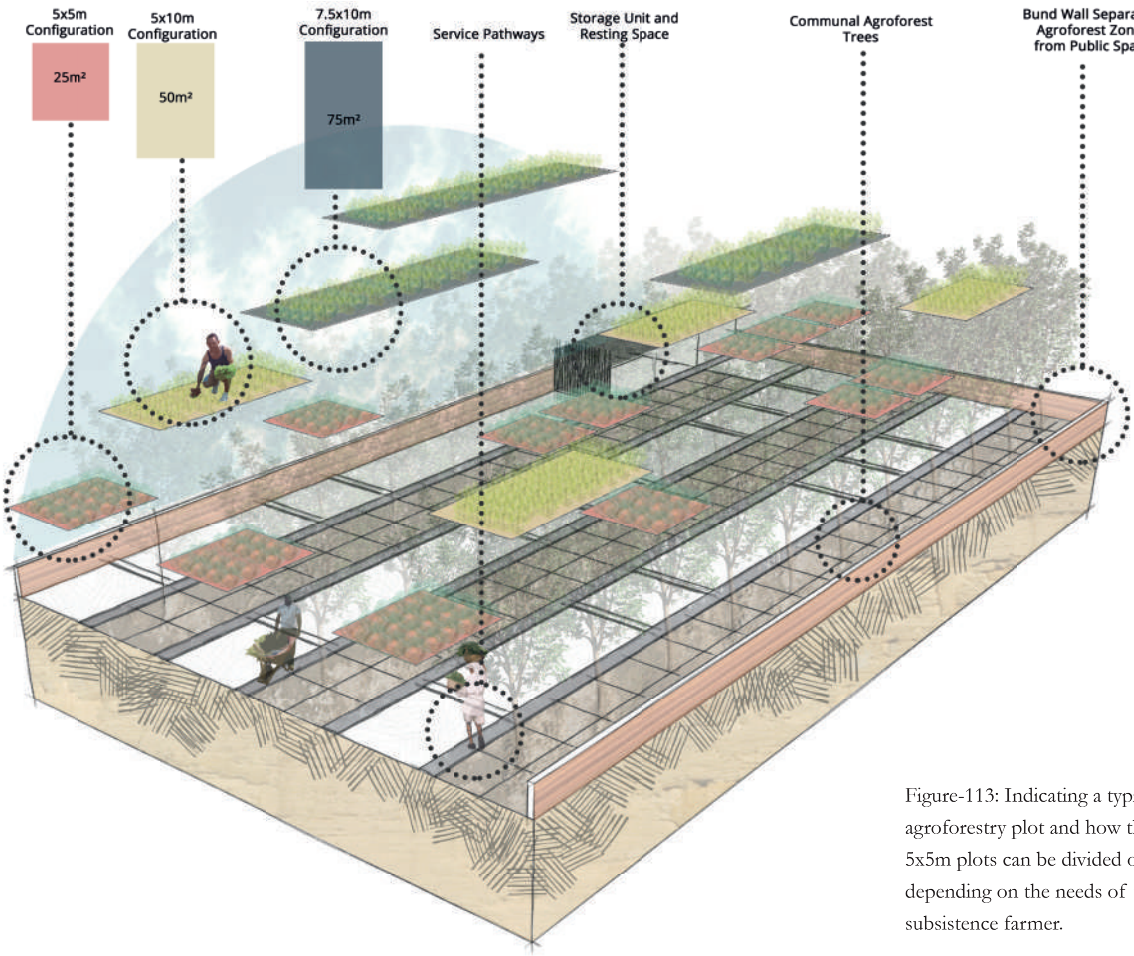


Figure-113: Indicating a typical agroforestry plot and how the 5x5m plots can be divided or joined depending on the needs of the subsistence farmer.

situated within each tower. Once the Algae is ready for harvesting each fence module is drained independently by gravity via outlet tubes into the control building where it passes through a filtration system which separates the water from the algae. The water is then reintroduced into the system and the harvested algae is taken to the algae processing plant. The algae processing plant then dries the algae both for biofuels and food, and extracts the oils found in the *Chlorella* and *Desmodesmus quadricaudatus* for biofuel production. Later the oils extracted from the *Chlorella* and *Desmodesmus quadricaudatus* species are taken to the bio-fuel plant and the food species to the food factory building respectively (Figure: 114).

The dried by-product from the oil extraction is then utilised in the compost heap as well as the biomass powered electricity plant. Emissions from the electricity and timber processing plant's exhaust chimneys is then captured and introduced into the photobioreactor system where it is absorbed by the algae, ensuring a reduction in emissions during the production of electricity.

4) Water- Water in productive landscapes is a crucial element when it comes to sustaining growth. The water systems currently on site (see chapter 3 figure: 45) are enhanced for the purposes of sustaining the Carbon Farm.

The River and Dam System:
Currently the river is a narrow and relatively shallow stream which enters the site on Roger Dyason road and flows in a northerly direction from a heavily urbanised catchment area.

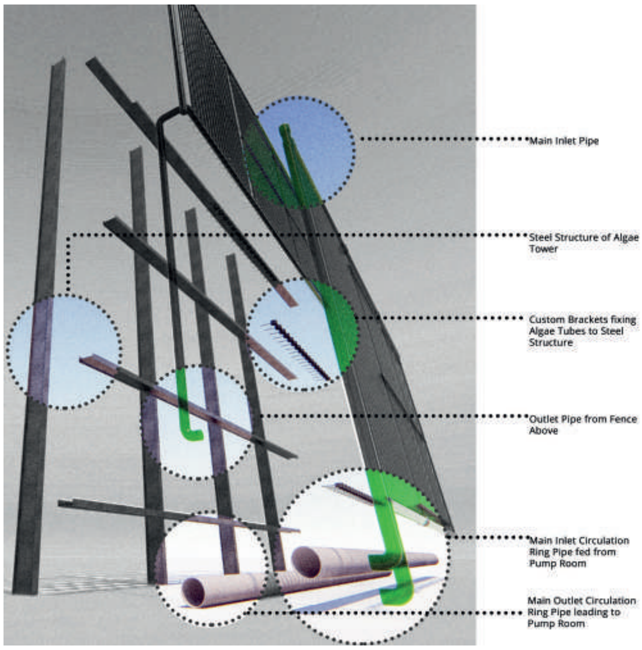
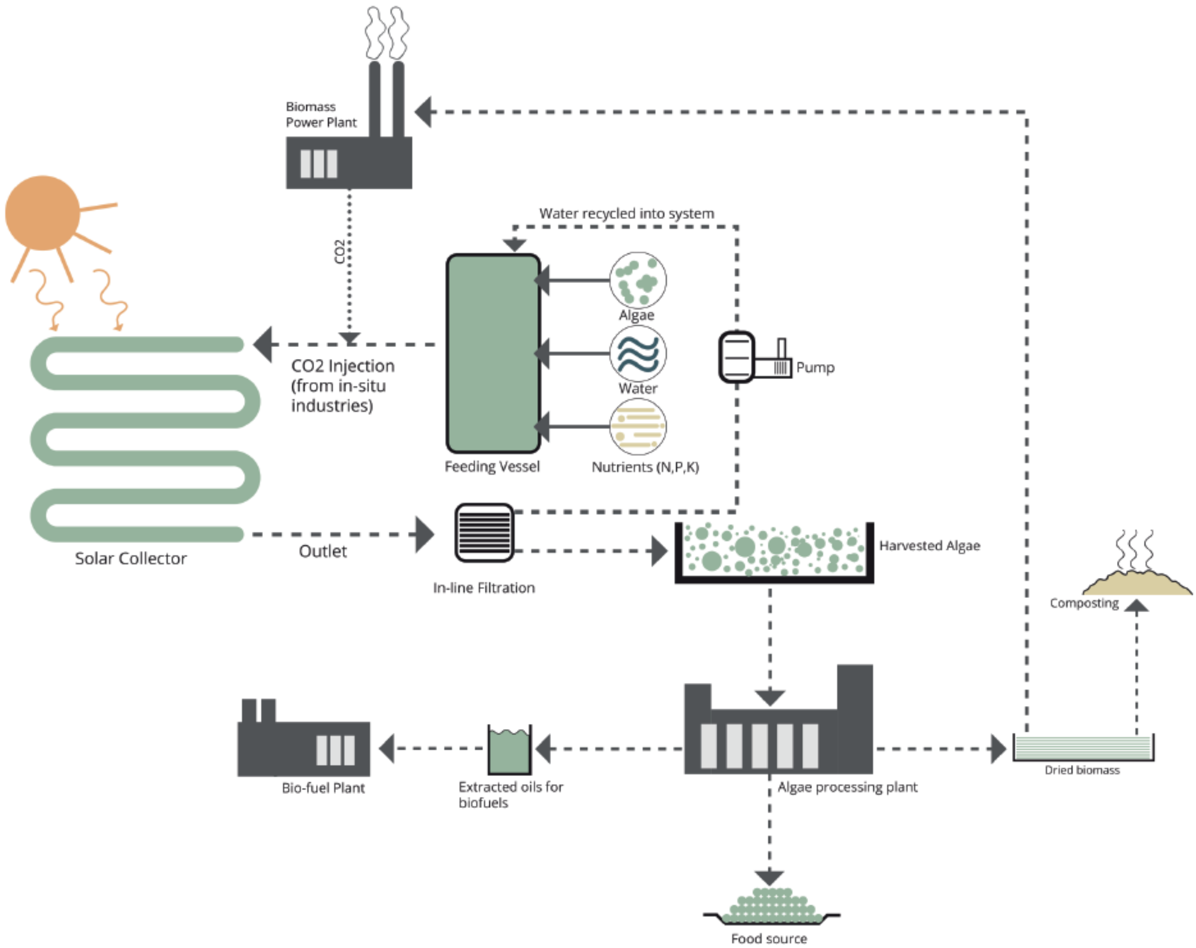


Figure-114: The algae harvesting process from growth of algae in the photobioreactor (above) to production of bio-fuel including the water recycling strategy.



The base flow of the river is adjusted to move through a constructed wetland (Figure: 115), this is done to ensure that, during a flood event, the water is not concentrated into one zone thus potentially damaging the constructed wetland system. This baseflow is then allowed to flow into the catchment channels (Figure: 116) and finally the open storage dams. This treated water is utilised to supplement the algae towers as well as the agroforestry and general landscape irrigation. The adjusted river baseflow then re-joins the original river flow at the third algae tower and then eventually ends up in the main dam. The original river is cleaned of all invasive species and debris and is allowed to flow naturally through wetland vegetation until it reaches the dam. The main dam, as it has historically been, will continue to be supplemented by the Daspoort Wastewater Treatment plant. Overflow from the main dam is allowed to exit the site on the north western corner below Charlotte Maxeke Road and into the river on the northern section of the site (Figure: 116).

Water Storage Dams and Tanks:
The constructed water storage dams have the sole purpose of providing primary water storage for landscape irrigation as well as the algae towers. Water from each dam is pumped into a water storage tank situated within the third algae tower (Figure: 117). The water is then gravity fed to the agroforestry plots and distributed to the general landscape areas. The height above ground level of the water storage tank allows it to generate upwards of 30 PSI. Overflow from the storage dams is allowed to flow into the main dam via a sub-surface piping system. These dams are also supplemented by the main dam should they run dry.

Constructed Wetlands:
The Carbon Farm incorporates two constructed wetlands the first is situated at the entrance of the river into the site on the southern border, the second is located at the point where the existing water channels enter the main dam. The first wetland is intended to filter the water received from the heavily urbanised catchment area of the river. The expected contaminants include hydrocarbons, debris and sediment. It is therefore necessary for the wetland to combine both sub surface and surface flow stages in order to ensure adequate treatment before entering the water storage dams. The purpose of the second wetland is to filter the uncon-

Figure-115: Image showing how the base flow of the original river is diverted into the constructed wetland and then eventually makes its way back into the dam.

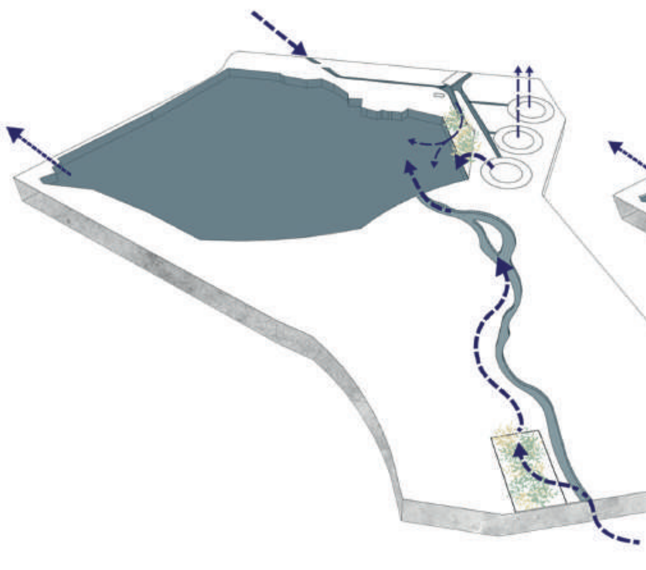
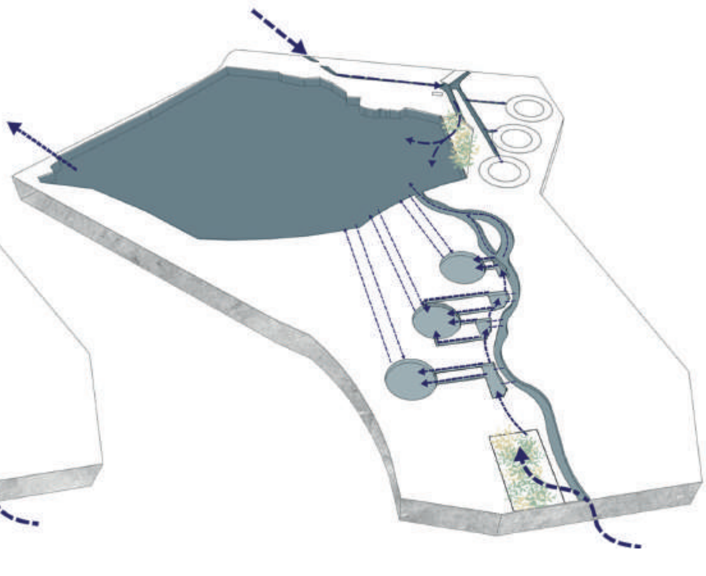


Figure-116: Image indicating the addition of water channels that direct water to the storage dams underneath the algae towers for use in the algae growth system.



taminated waste water from the algae treatment plant as well as general water from roofs and paving surfaces within the built fabric of the Carbon Farm. Although expected to be less contaminated than that of the water entering the site via the river, the wetland may also need to filter hydrocarbons, sediment and debris before entering the section of the dam which is demarcated for recreational use. The second wetland therefore incorporates sub-surface and surface flow stages to ensure adequate filtration.

Irrigating the Forestry:
Forestry, particularly with species such as *Pinus* can be very water intensive. The Carbon Farm however, utilises a trough and furrow irrigation technique and relies primarily on rain water to irrigate the forestry patches (Figure: 119). The troughs are strategically located where hard surfaces in the form of paving meet the edges of the forestry plots. The paving is then graded to fall towards these troughs. The troughs themselves are lined with a geosynthetic clay liner to avoid infiltration. The furrows are then joined at a ninety-degree angle to the troughs and when the trough is filled the water runs along the furrows thus irrigating the forestry patches.

Conclusion

When combined, all these systems create what is the backbone of a high functioning Carbon Farm. Each system is interconnected in some way to ensure that waste is minimised, emissions are decreased, water is used sustainably, and carbon sequestration and storage is maximised (Figure: 120). These systems ensure that the benefits in the form of biodiversity enhancement, climate change adaption and human well-being stem beyond the borders of the site.

Figure-117: Image showing the algae towers and their over-flow facilities which are connected to the main dam.

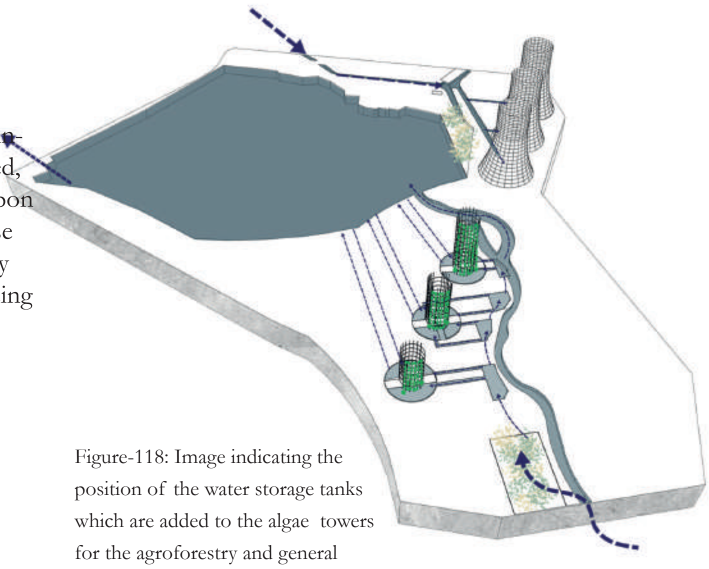
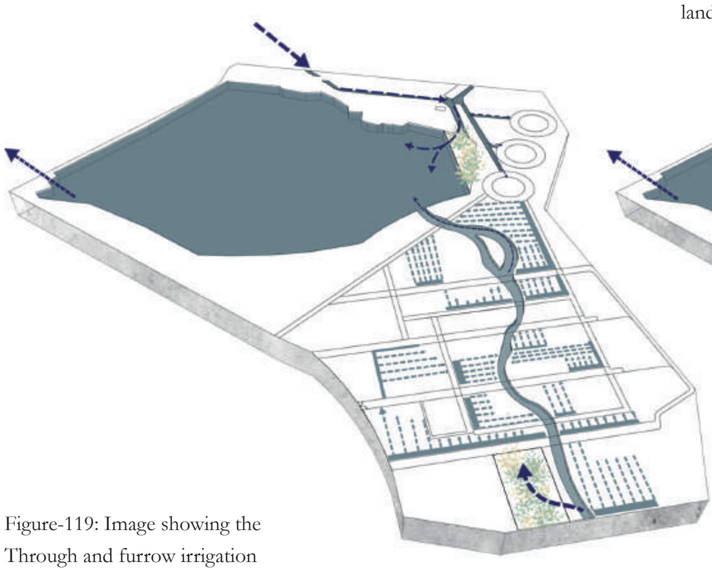


Figure-118: Image indicating the position of the water storage tanks which are added to the algae towers for the agroforestry and general landscape irrigation.



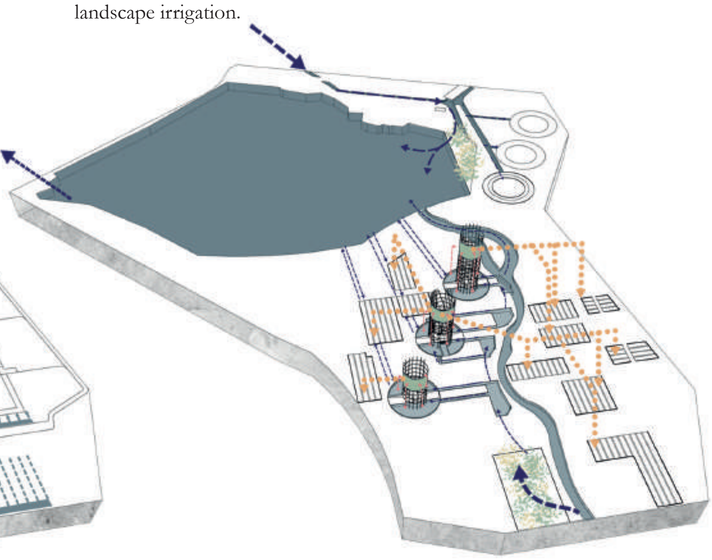


Figure-119: Image showing the Through and furrow irrigation system for irrigating the forestry patches.

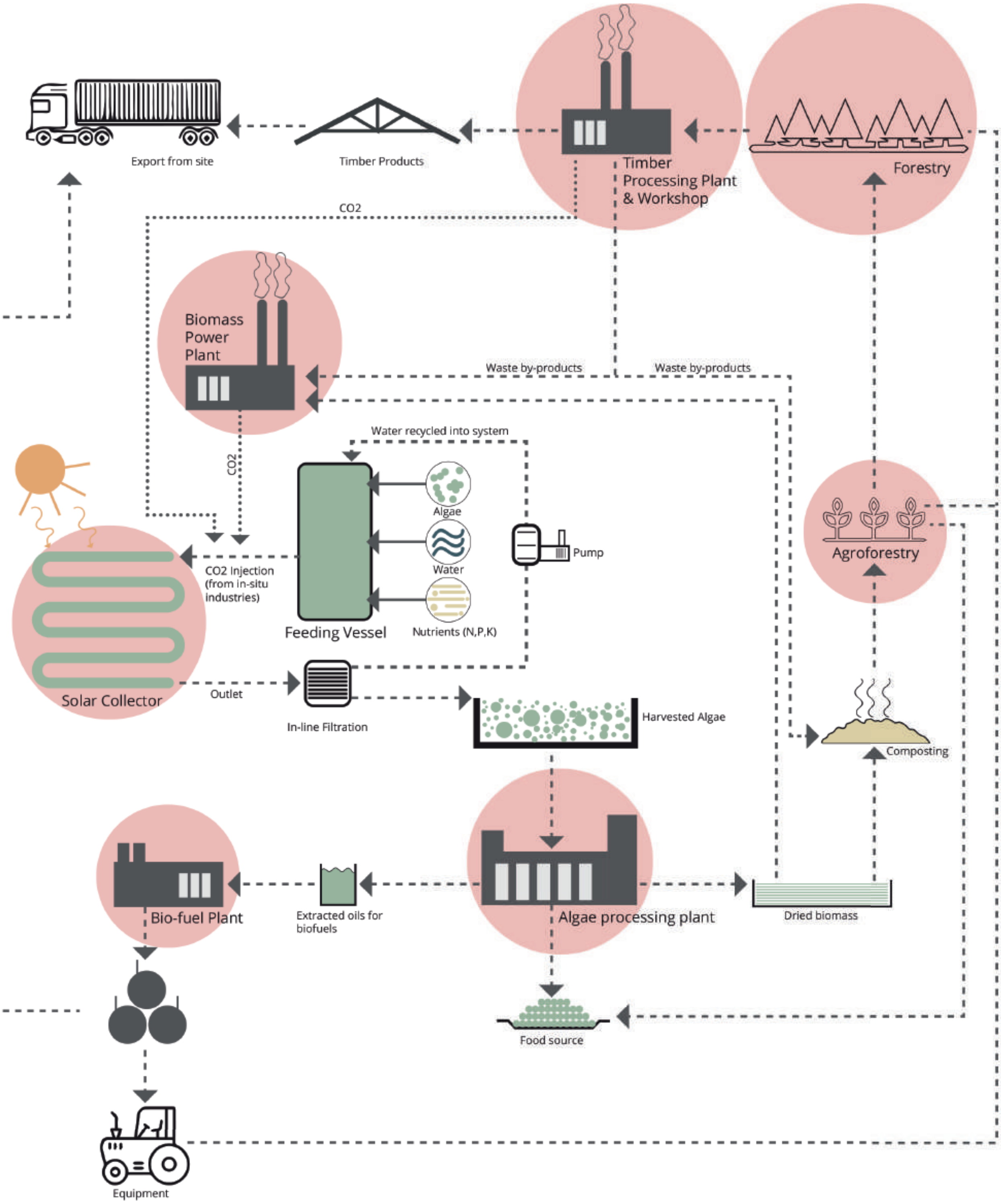


Figure-120: Diagram illustrating the four systems and how their processes are integrated in order to ensure that the Carbon Farm functions optimally.

7.5-MASTERPLAN PLANTING

The planting design for the masterplan is broken up into six zones namely (Figure:121): 1) The amenity forest zone- consists of plant and tree species indigenous to southern Africa which tolerate the conditions experienced on the site; 2) Wetland, riparian and water-edge zones- consist of plant and tree species indigenous to southern Africa which are able to tolerate high levels of water and perform functions such as water filtration. The species selected are also able to tolerate sustained periods of drought; 3) The indigenous ornamental and forest planting zones- these zones are located in the public open space areas. The plant and tree species selected for these zones are indigenous to southern Africa and are selected based on the aesthetic value as well as the parameters highlighted in chapter two; 4) Agroforestry zones- consist of plant species selected for their ability to produce an edible fruit or vegetable and are not necessarily indigenous to southern Africa; 5) Productive forest zones- consist of tree species selected for their fast growth rate as well as their value in timber. Their sole purpose is to maximise the sequestration of carbon; 6) Productive forest margin zones- these species are selected based on their ability to survive in deep shade as well as sun during the initial growth periods of the productive tree species.

The species selected are summarised in table 4.

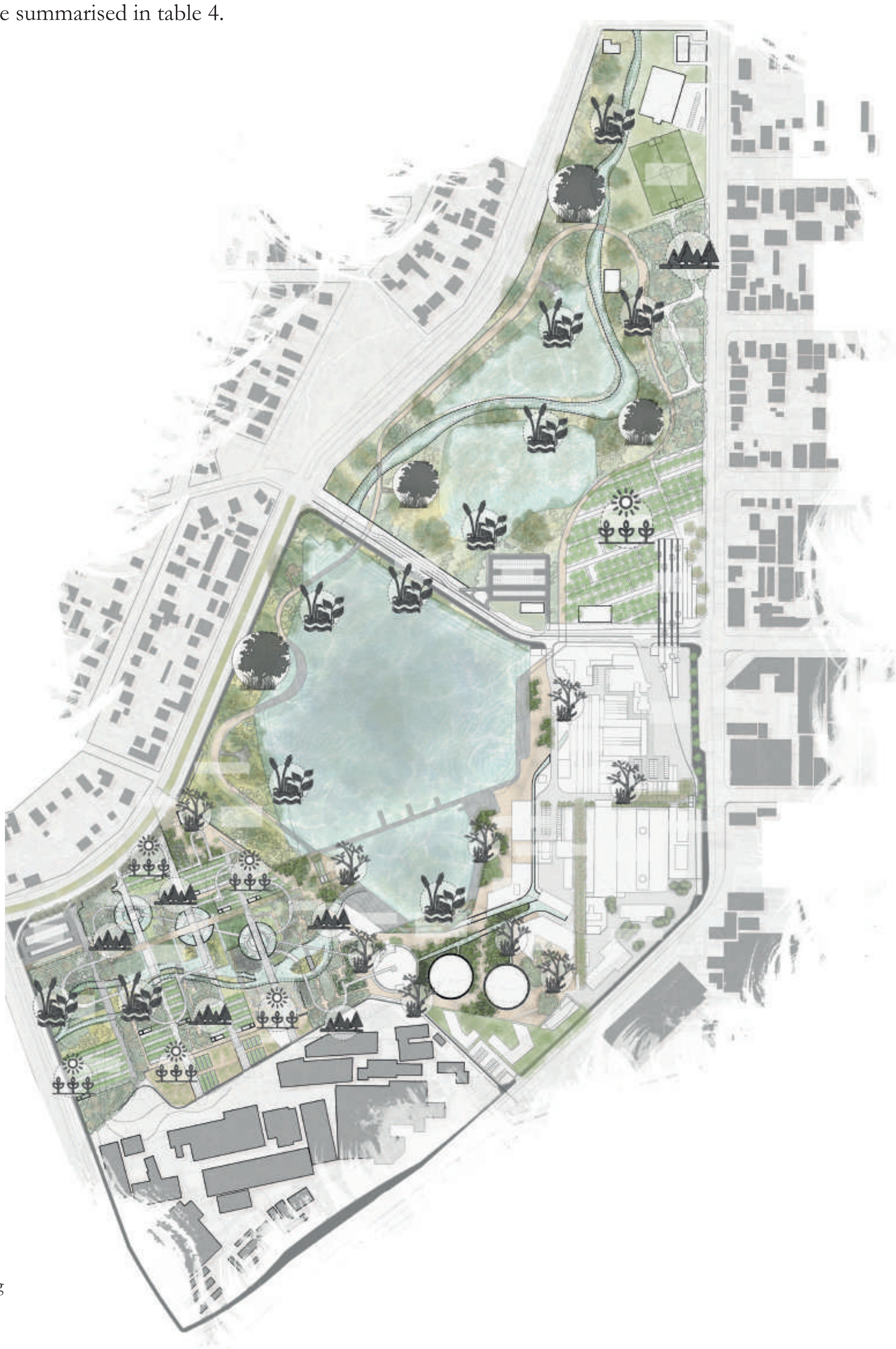
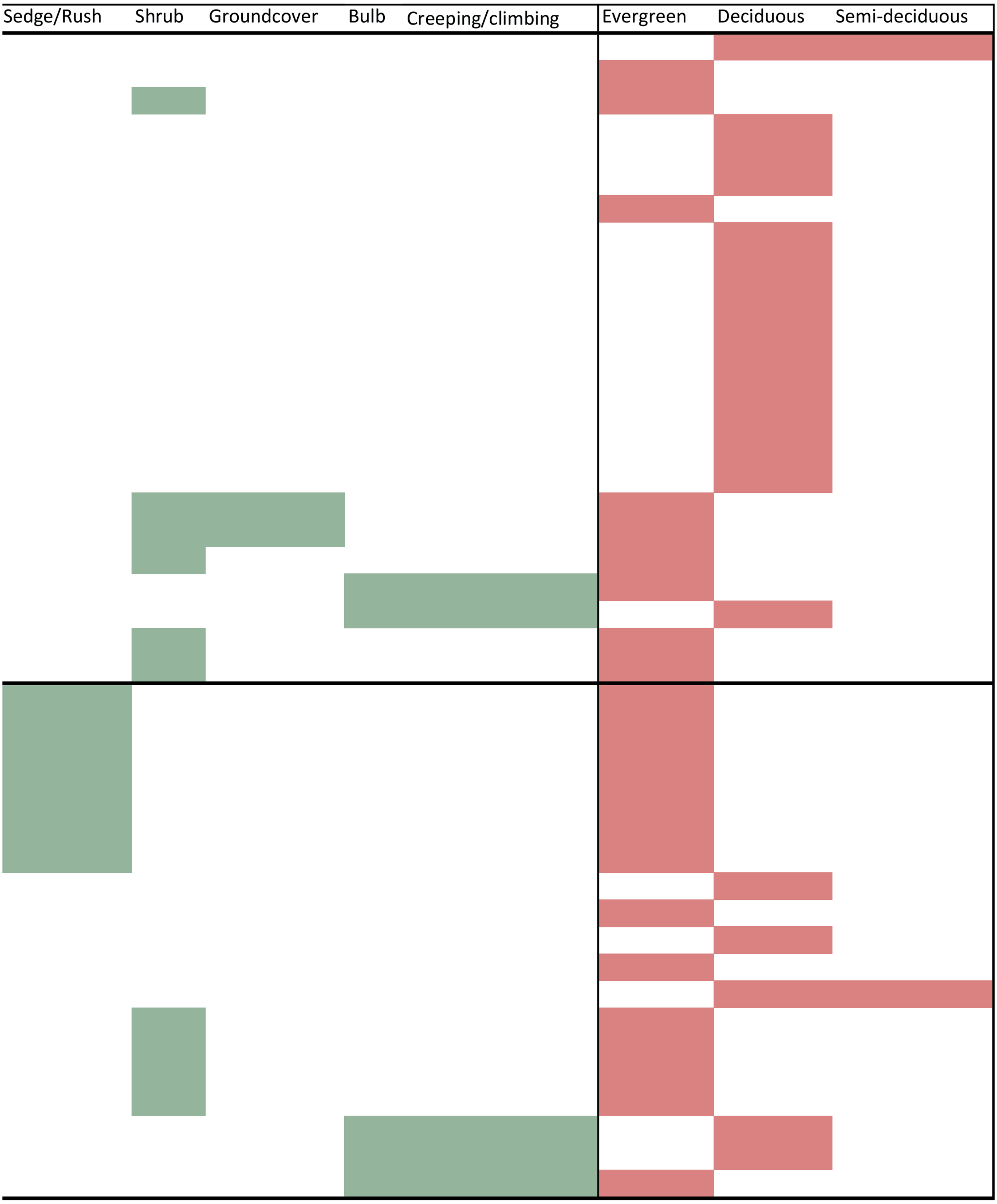


Figure-121:Drawing showing the masterplan planting zones. (NTS)

Plant Zone	Plant Name	Common Name	Tree	Grass
Amenity Forest 	Vachellia xanthophloea	Fever Tree	■	
	Olea europaea subsp. africana	Wild Olive	■	
	Buddleja saligna	False Olive	■	
	Celtis africana	White Stinkwood	■	
	Combretum erythrophyllum	River Bushwillow	■	
	Combretum molle	Velvet Bushwillow	■	
	Diospyros whyteana	Bladder Nut	■	
	Dombeya Rotundifolia	Wild Pear	■	
	Kiggelaria africana	Wild Peach	■	
	Aristida diffusa	Iron Grass		■
	Aristida junciformis	Bristle Grass		■
	Cenchrus ciliaris	Foxtail Buffalo Grass		■
	Digitaria eriantha	Finger Grass		■
	Chloris gayana	Rhodes Grass		■
	Eragrostis capensis	Heart-seed Love Grass		■
	Eragrostis curvula	Weeping Love Grass		■
	Eragrostis gummiflua	Gum Grass		■
	Asparagus laricinus	Bushveld Asparagus		
	Asparagus virgatus	Broom Asparagus		
	Barleria lancifolia	Barleria		
	Nerine krigei	Curly Leaved Nerine		
	Hypoxis hemerocallidea	Star Flower		
	Euclea crispa	Blue Guarri		
	Euclea undulata	Common Guarri		
Wetland, Riparian and Water Edge Zones 	Juncus krausii	Matting Rush		
	Cyperus prolifer	Dwarf Papyrus		
	Cyperus sexangularis	Bushveld Sedge		
	Schoenoxiphium lehmanii	River Grass		■
	Typha capensis	Bullrush		
	Andropogon appendiculatus	Vlei bluestem		■
	Stiburus alopecuroides	Purple Vlei Grass		■
	Chloris gayana	Rhodes Grass		■
	Salix mucronata	Safsaf Willow	■	
	Vachellia xanthophloea	Fever Tree	■	
	Gomphostigma virgatum	River Stars		
	Kniphofia uvaria	Torch Lily		
	Kniphofia galpinii	Dwarf Salmon kniphofia		
	Lippia javanica	Lemon Bush		
	Crinum bulbispermum	Orange River Lily		
	Eucomis pallidiflora	Giant Pineapple Lily		
	Zantedeschia aetheopica	White Arum		

Table 4: Indicating the Masterplan plant selection including: Plant type and whether it is evergreen, deciduous or semi-deciduous.


Sedge/Rush
Shrub
Groundcover
Bulb
Creeping/climbing
Evergreen
Deciduous
Semi-deciduous

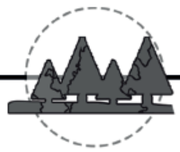
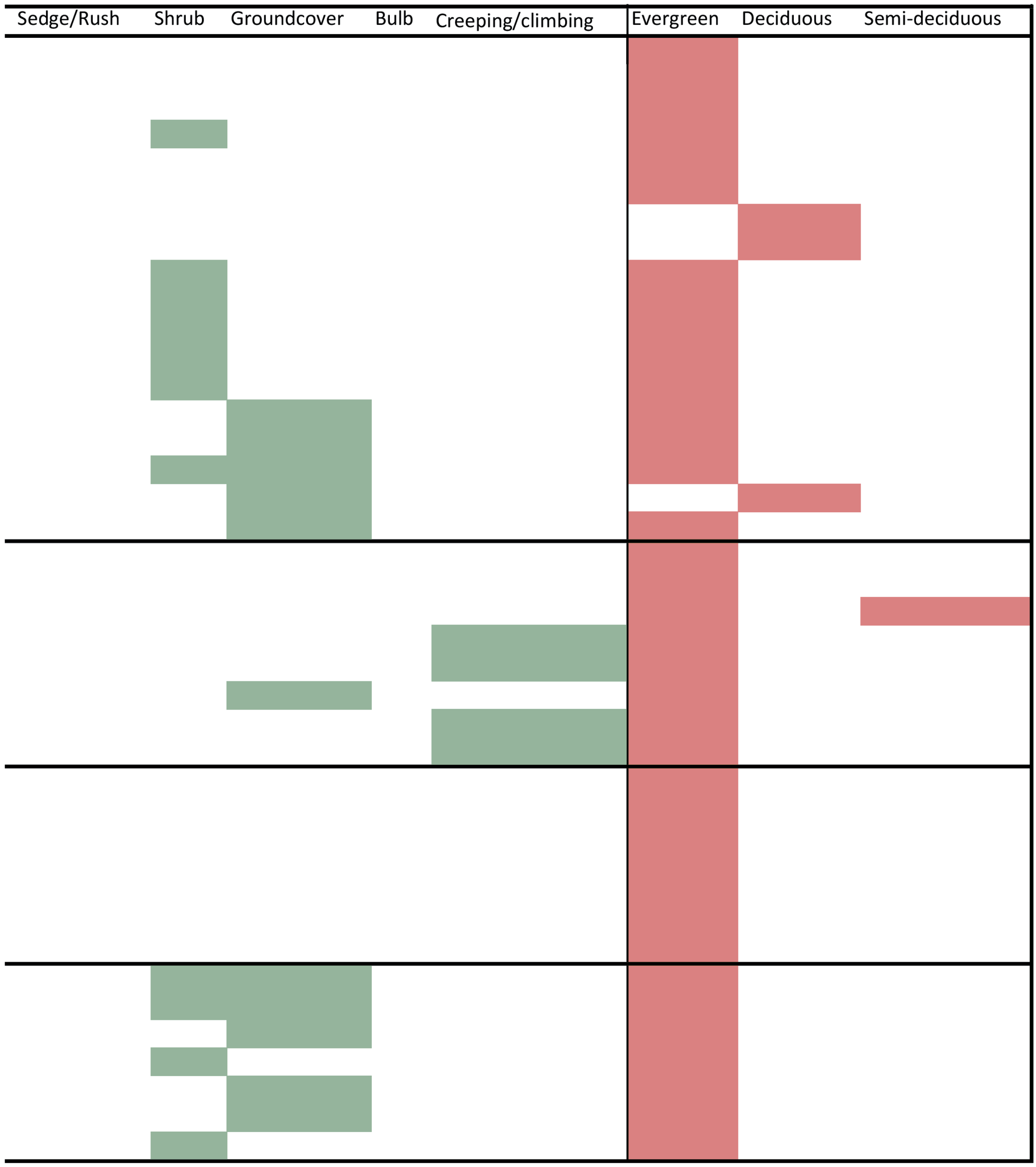
Plant Zone	Plant Name	Common Name	Tree	Grass
Indigenous Ornamental and Forest Zones 	Harpephyllum caffrum	Wild Plum		
	Poducarpus henkelii	Henkel's Yellow wood		
	Ptaeroxylon obliquum	Sneezewood		
	Diospyros lycioides	Blue Bush		
	Searsia leptodictya	Mountain Karee		
	Pittosporum viridiflorum	Cheesewood		
	Bollusanthus speciousus	Tree Wisteria		
	Celtis africana	White Stinkwood		
	Barleria elegans	White Bushveld Barleria		
	Euclea crispa	Blue Guarri		
	Hypoestes aristata	Ribbon Bush		
	Mackaya bella	Forest Bell Bush		
	Plectranthus ecklonii	Large Spur Flower		
	Asystasia gangetica	Creeping Fox Glove		
	Stachys aetheopica	African Stachys		
	Portulacaria afra	Porkbush		
	Ipomea crassipes	Leafy Flowered Ipomea		
	Plectranthus neochillus			
Agroforestry Zone 	Ceratonia siliqua	Carob Tree		
	Dovyalis caffra	Kei Apple		
	Schotia brachypetala	Weeping Boer-Bean		
	Ipomea batatas	Sweet-potato Vine		
	Tylosema esculentum	Marma Bean		
	Citrullus lanatus	Tsamma Melon		
	Ancylobotros capensis	Rock Milk Apricot		
	Passiflora edulis	Granadilla		
Productive Forest Zone 	Pinus platula	Platula Pine		
	Pinus pinaster	Cluster Pine		
	Pinus eliotii	Slash Pine		
	Pinus taeda	Loblolly Pine		
	Eucalyptus grandis	Rose Gum		
	Eucalyptus saligna	Saligna Gum		
	Eucalyptus globulus	Southern Blue Gum		
Productive Forest Margins	Asparagus laricinus	Bushveld Asparagus		
	Asparagus virgatus	Broom Asparagus		
	Asystasia gangetica	Creeping Fox Glove		
	Barelria obtusa	Bush Violet		
	Bulbine natalensis	Bulbine		
	Chlorophytum bowkeri	Giant Chlorophytum		
	Hypoestes aristata	Ribbon Bush		

Table 4(Continued): Indicating the Masterplan plant selection including: Plant type and whether it is evergreen, deciduous or semi-deciduous.


Sedge/Rush
Shrub
Groundcover
Bulb
Creeping/climbing
Evergreen
Deciduous
Semi-deciduous

7.6-FINAL SKETCH PLAN

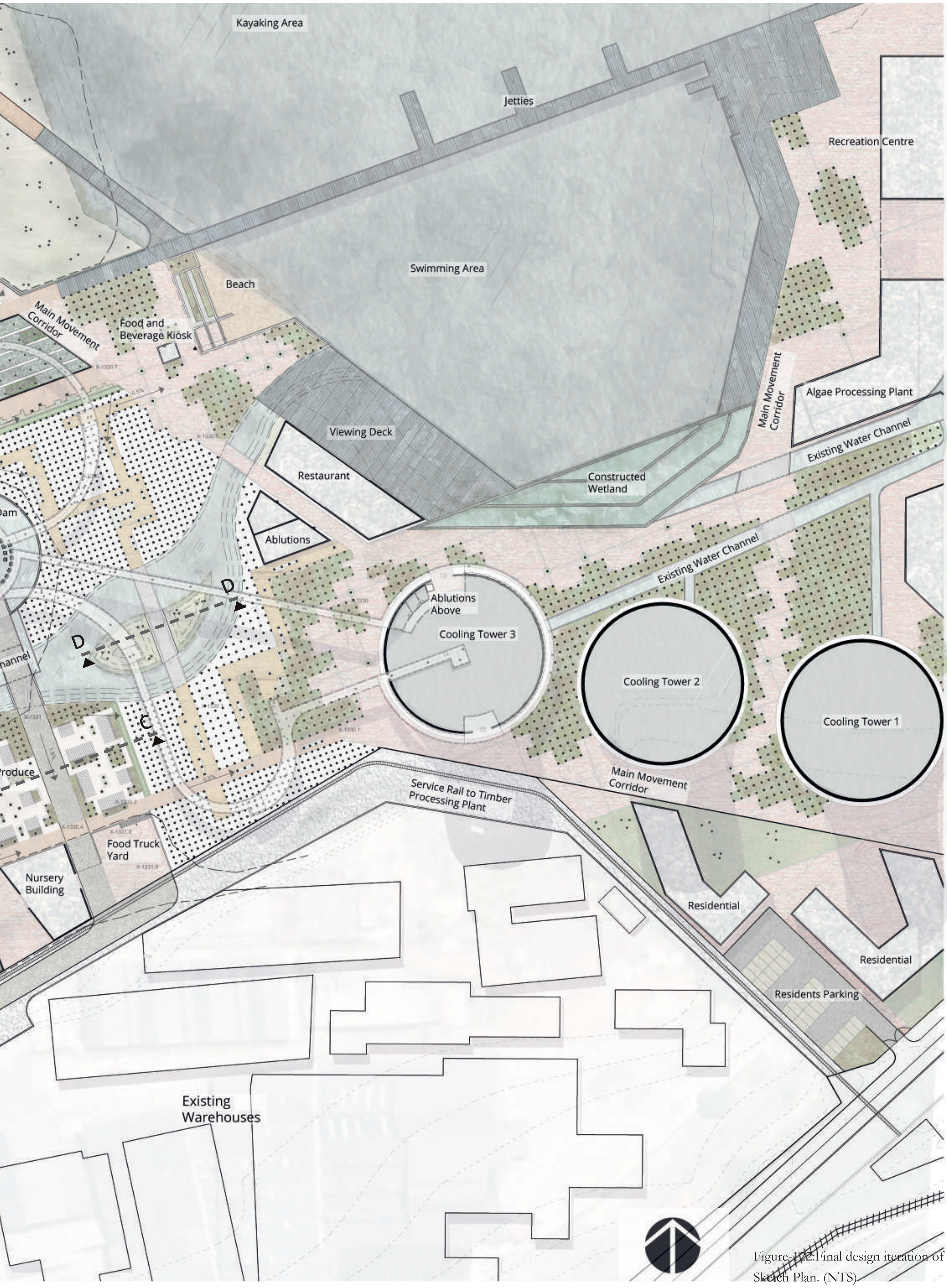
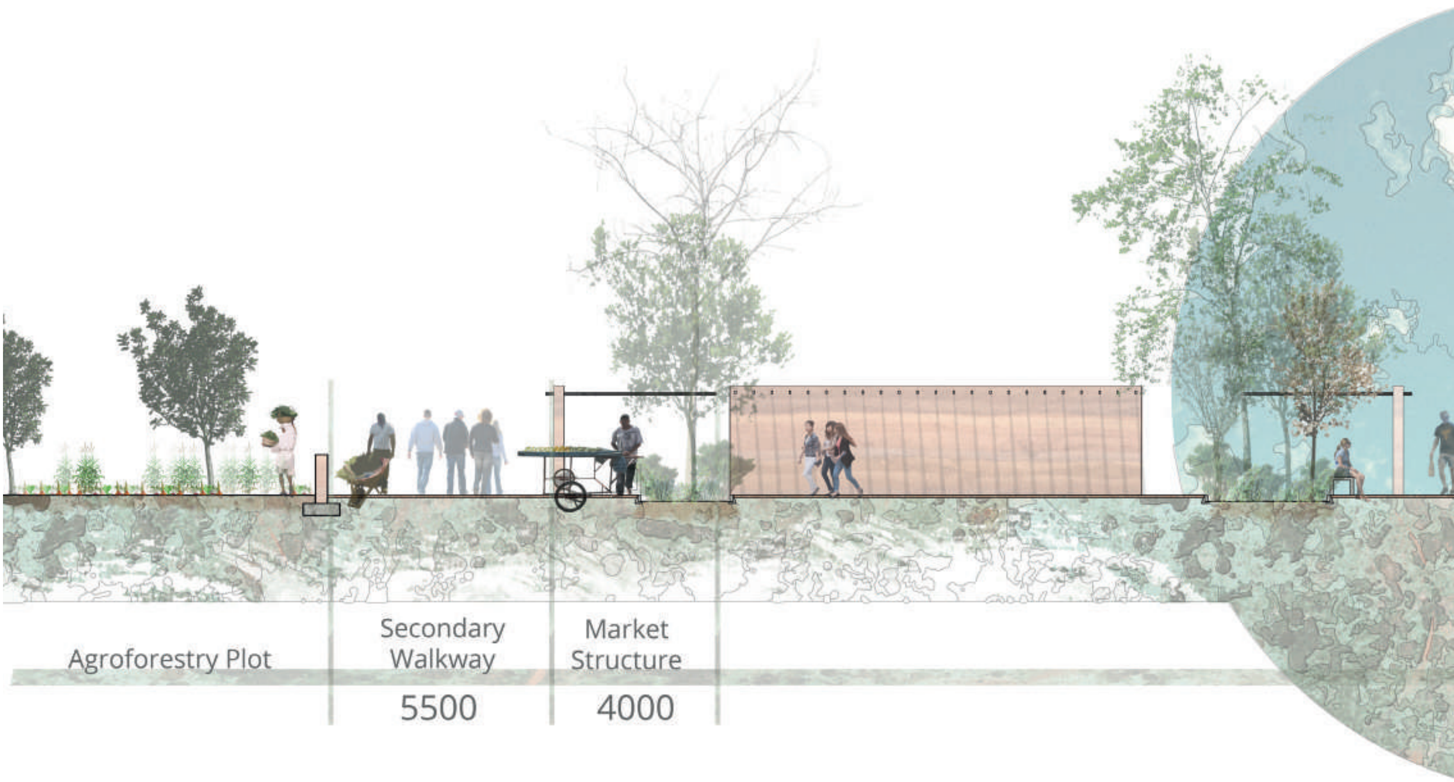
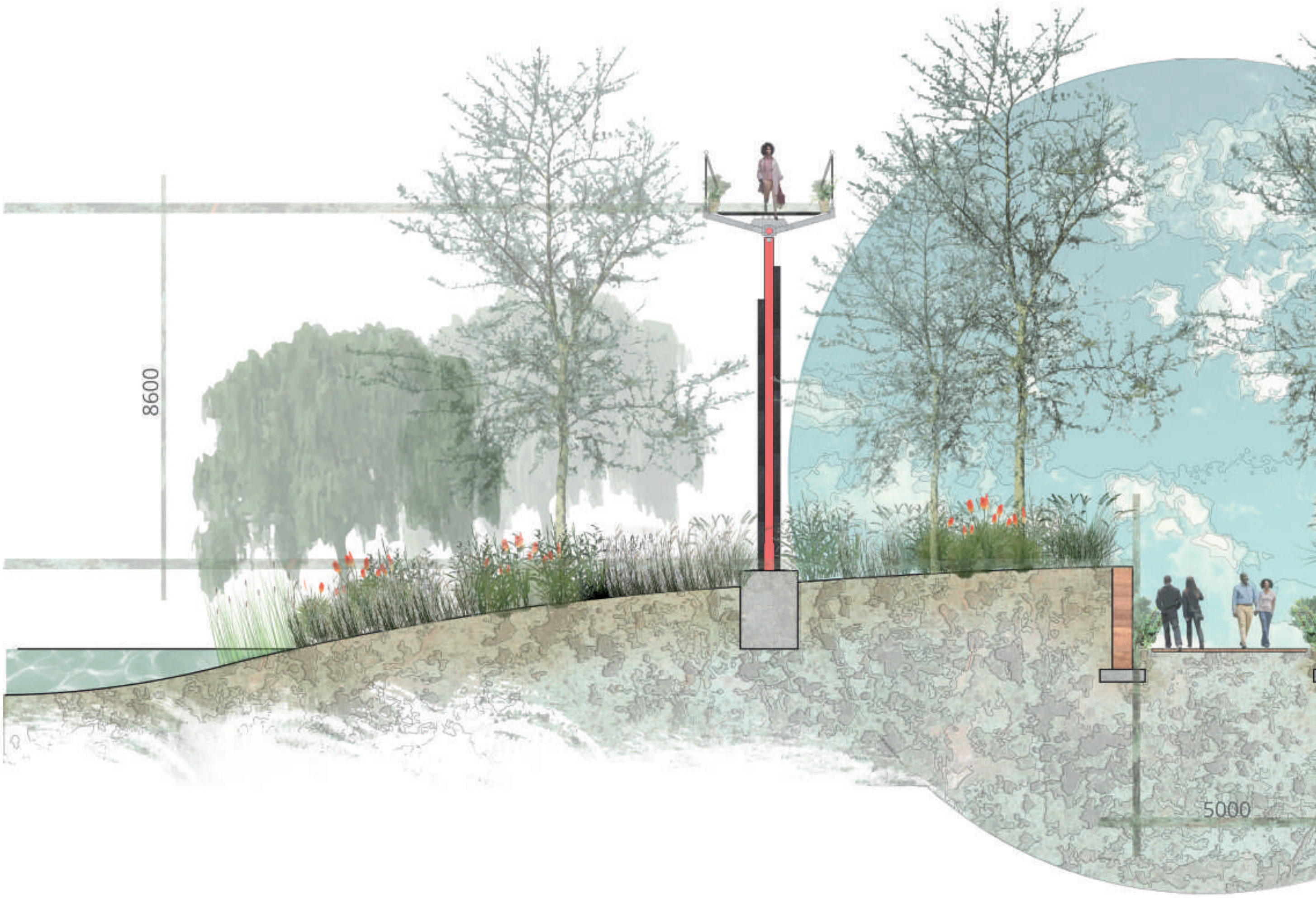


Figure-122:Final design iteration of Sketch Plan. (NTS)

7.7-SKETCH PLAN SECTIONS





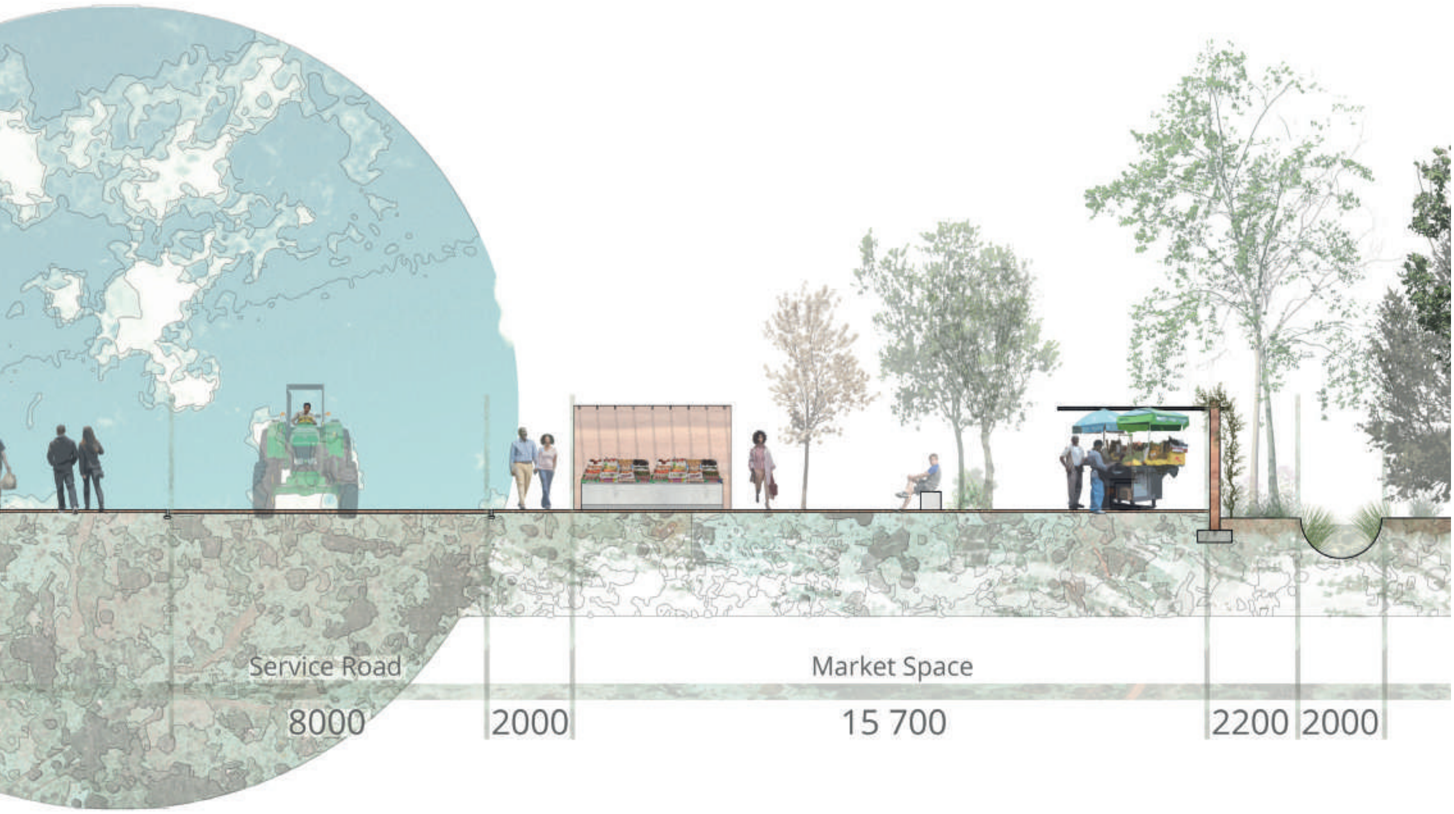
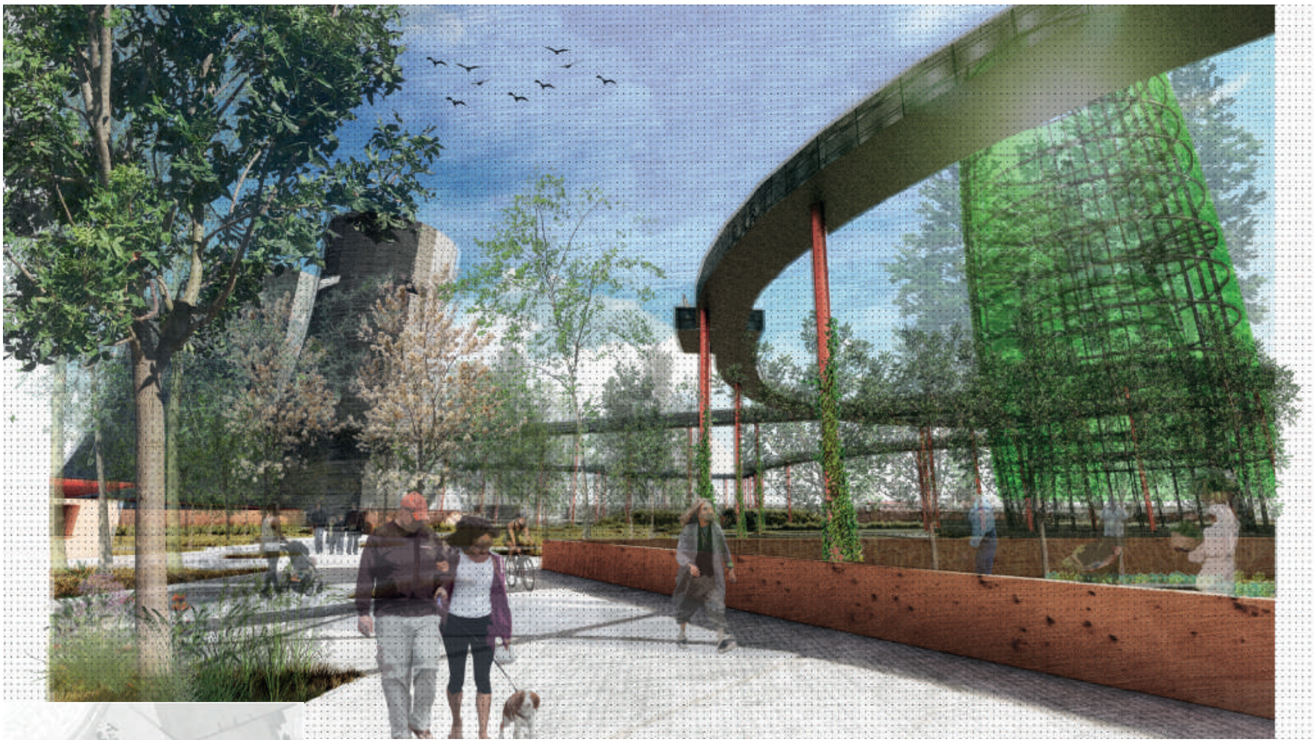


Figure-123:Section C-C through market space looking west. (NTS)

Figure-124:Section D-D through sunken walkway across the river. (NTS)

7.8-Ground Plane Perspectives



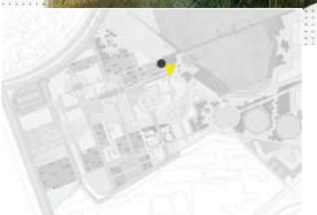


Figure-125:View of the Main Activity Corridor Looking Towards The Existing Cooling Towers with the Skywalk Moving Over an Agroforestry Plot.

Figure-126:Perspective View From the Tertiary Walkway Through the Amenity Forest Area Along the Dam.

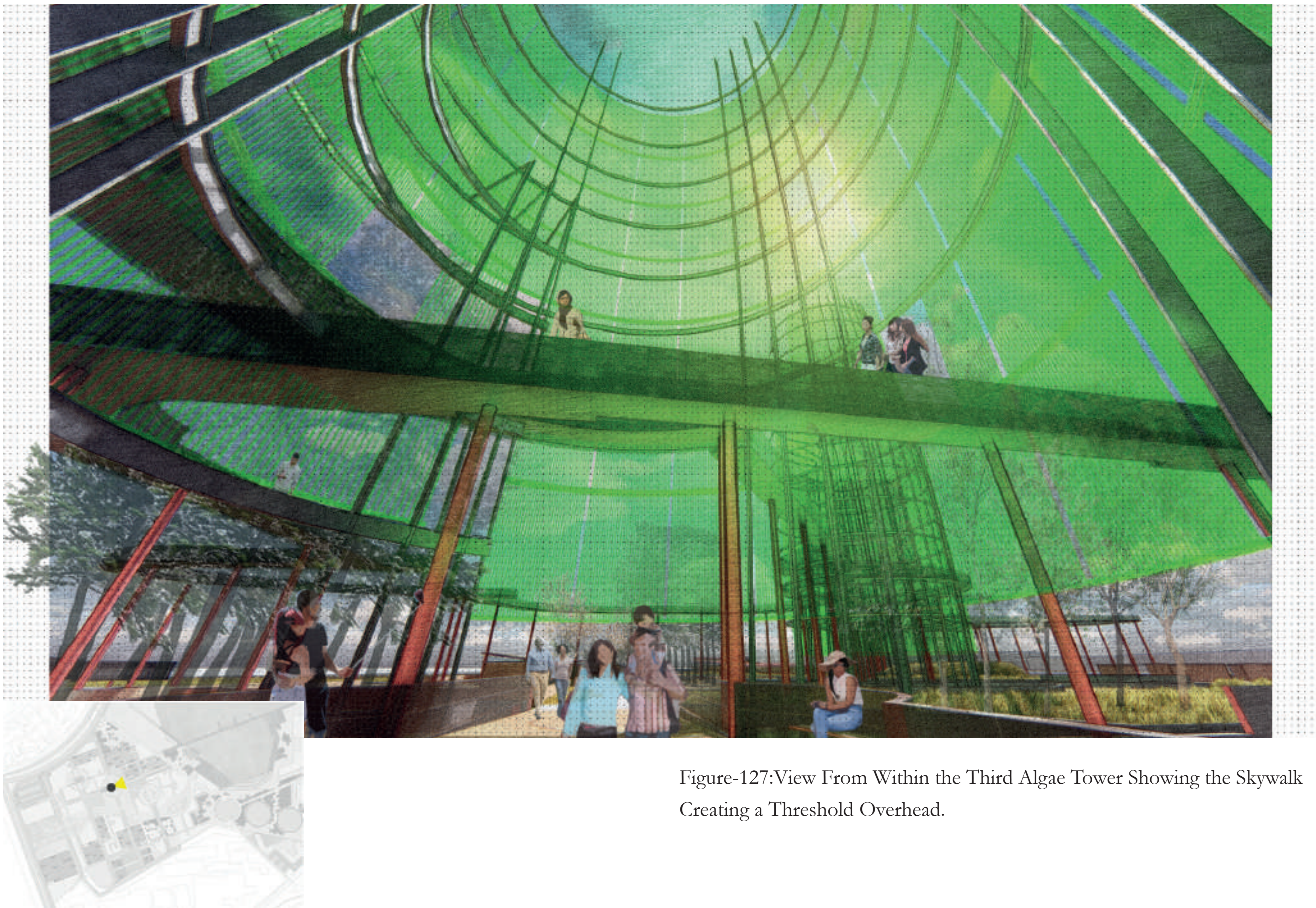


Figure-127:View From Within the Third Algae Tower Showing the Skywalk Creating a Threshold Overhead.

Figure-128:View of Market Space Along the River Cast in the Shadow of the First Algae Tower.

CHAPTER 8- THE CARBON SKYWALK

This chapter focuses on the narrative and experience of the Carbon Skywalk, through the design, material choice, expression of the planting strategies, technical resolutions and detailing.

Firstly, the development of the journey, from a simple meandering walkway to a defined route with specific vistas, is illustrated and discussed. The chapter then looks at how the planting strategy helps to enhance the user experience while respecting the planting parameters researched in chapter two. The spatial expression of the vistas and routes are discussed and illustrated.

Lastly the chapter explains the technical resolution of the skywalk, including the technical concept which drove the detailing and form of the skywalk's structure as well as the fixing and finishing of the chosen materials. Included in this investigation is the proposed method of construction. All of this culminates in a series of detail sections and three-dimensional exploded investigations, which communicate how the Carbon Skywalk will function and be experienced.

8.1-DEVLOPMENT OF THE SKYWALK

The skywalk was initially intended to take the user on a journey which was elevated above the productive nature of the ground plane, to allow them to experience the landscape from a different perspective. As seen in the previous chapter (See Figure: 104), the form was inspired by the overlaying of algae cells on top of the strong grid of the productive landscape below, to create a contrasting experience. However, with this approach, the skywalk became a walkway which meandered its way over the canopies of the forestry areas with little consideration for the potential vistas and varying experiences the design of the Carbon Farm offers. This meant that there was no narrative to the user experience.

The development of a narrative that informs the design of the skywalk, harnessed the potential of the varying user experiences that the Carbon Farm offers (Figure: 121). The narrative broadens the potential of the Carbon Farm and in particular the skywalk, as an experiential and educational journey through and over the landscape (Figure: 122).

8.2-THE JOURNEY

The narrative of the journey became an important element in the transition of the skywalk into what is now known as the Carbon Walk. The overarching narrative of the Carbon Walk takes the user on a journey of the development of the Pretoria West Power Station from what it was, an iconic landmark within Pretoria West– synonymous with carbon emissions, to what it is now: the Carbon Farm– a future landscape synonymous with the active sequestration of CO_2.

The journey begins at the western entrance. The user ascends a semi-enclosed ramp which is aligned with the underlying grid of the landscape. Along this route is an exhibition consisting of a time-line of the development of the Pretoria West Power Station, portrayed through historical photographs taken at the various stages of its construction. At key points along this initial route are large openings which allow the user to have views of the historic power station buildings, as well as smaller openings which give quick views of the forestry and agroforestry below. The first section of the route then culminates at the first algae tower.

The user is then taken on a tour through the various methods of carbon sequestration, which occur on the Carbon Farm. These methods include: forestry; agroforestry; the algae towers; wetlands and riparian zones as well as amenity forests. The user can pause and relax at these key points, the first of which are the constructed wetland and the riparian zones respectively (Figure:131).

The user then passes through a stage two forestry area (see Figure: 111) before entering resting zone three which sits above an agroforestry plot. The journey then extends towards the second algae tower where the user is taken through the middle of the tower (Figure:132). For the first time on the Carbon Skywalk the user is captivated by the scale and varying light conditions within the algae tower. The user is

Figure-129:Series of image indicating the development of the Carbon Skywalk from a simple meadering walkway to a developed journey.

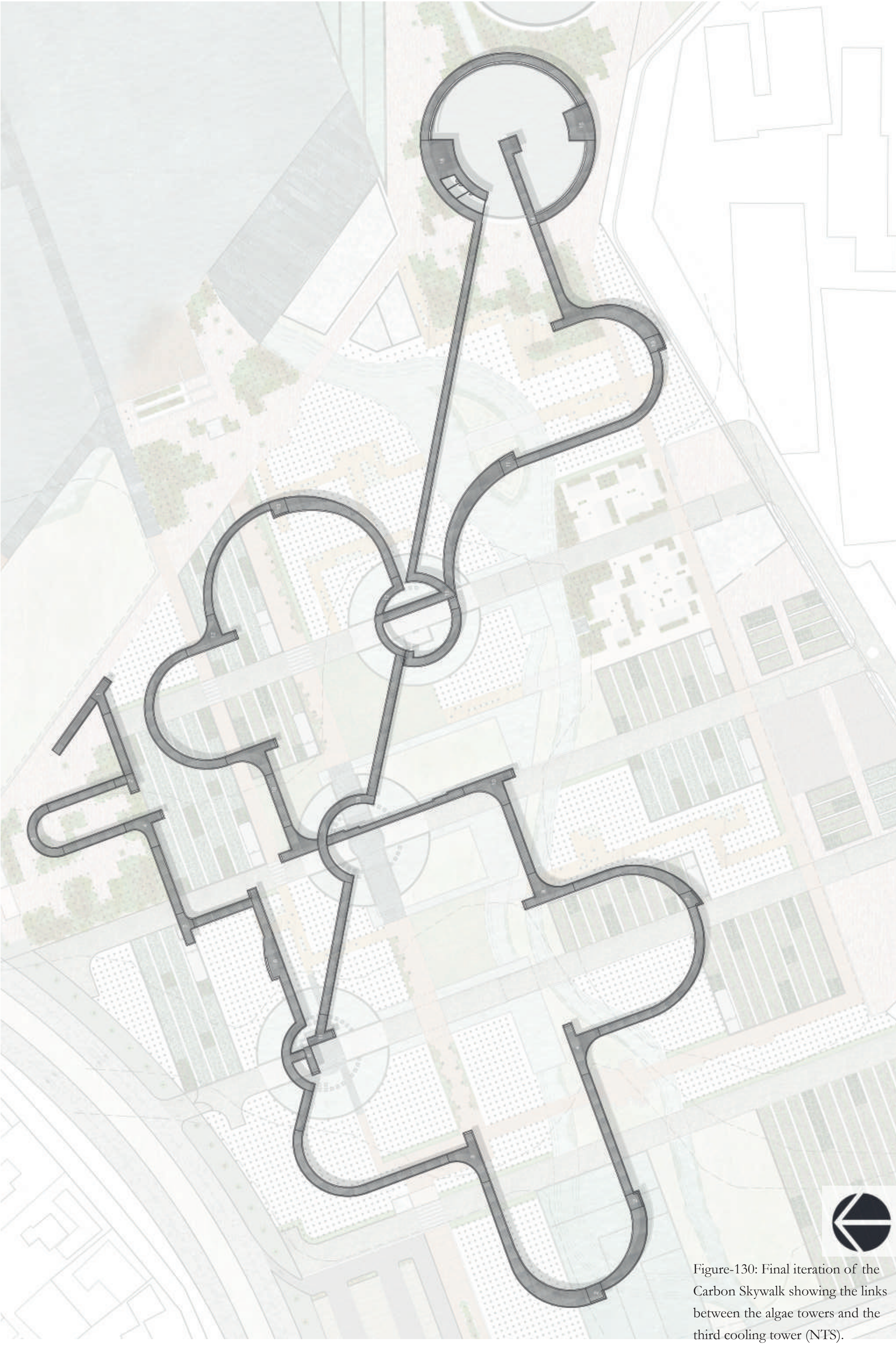
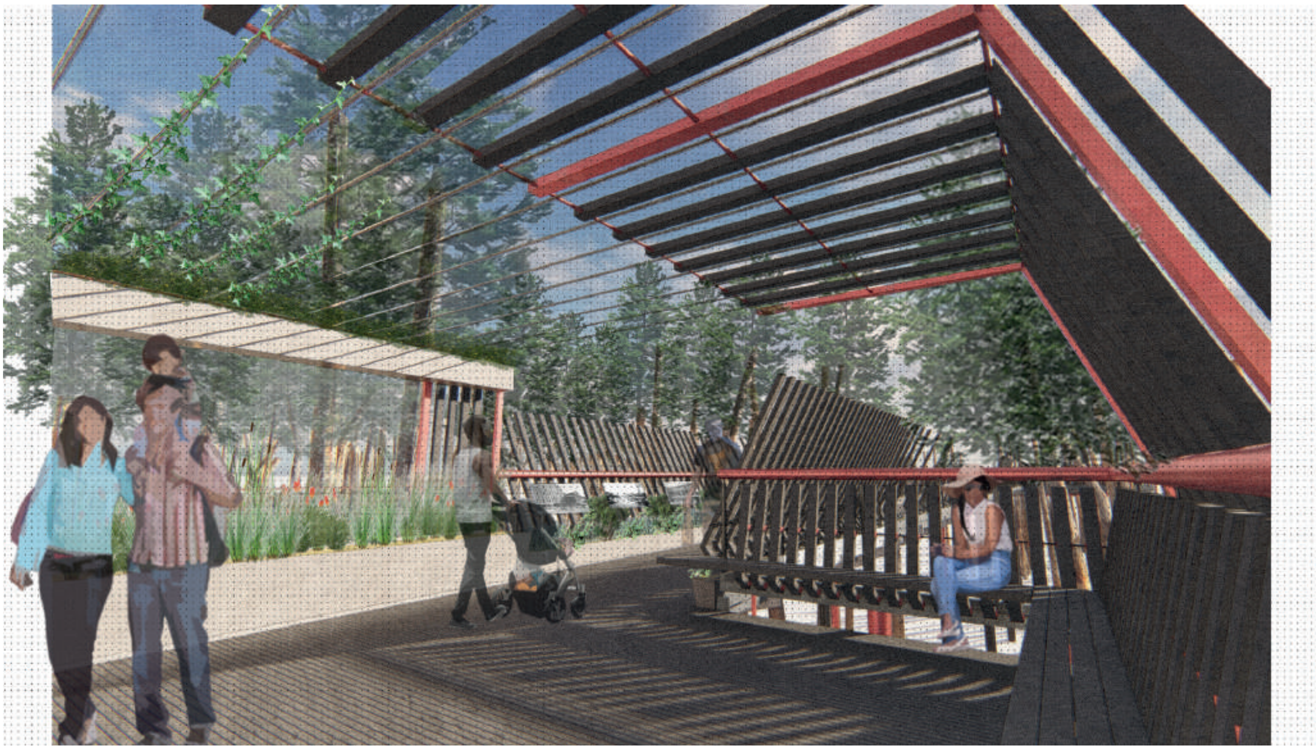


Figure-130: Final iteration of the Carbon Skywalk showing the links between the algae towers and the third cooling tower (NTS).



able to experience a futuristic inclined approach to carbon sequestration before once again moving onward along the journey.

The fourth stop on the Carbon Skywalk is within an indigenous amenity forested area where one is engrossed by a variety of tree canopies and species before continuing the journey. After this, the user is taken around the outside of the third and tallest algae tower where there is no separation -in the form of a balustrade- between the user and the algae tubes.

The fifth stop on the journey is above the river, particularly where it is separated by an island populated by diverse riparian forest vegetation.

Section six of the journey is located within a stage one forestry area, where one may experience the enormity in scale of the productive trees that sequester carbon (Figure:133).

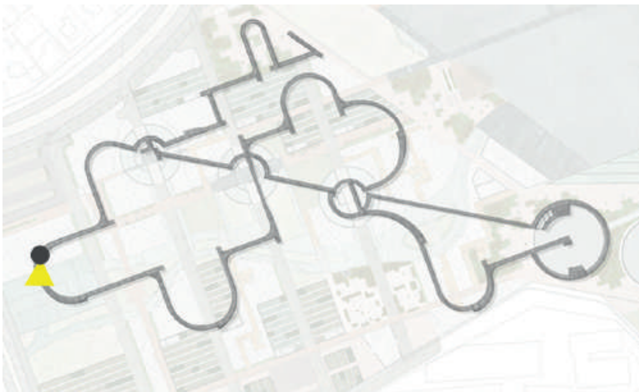
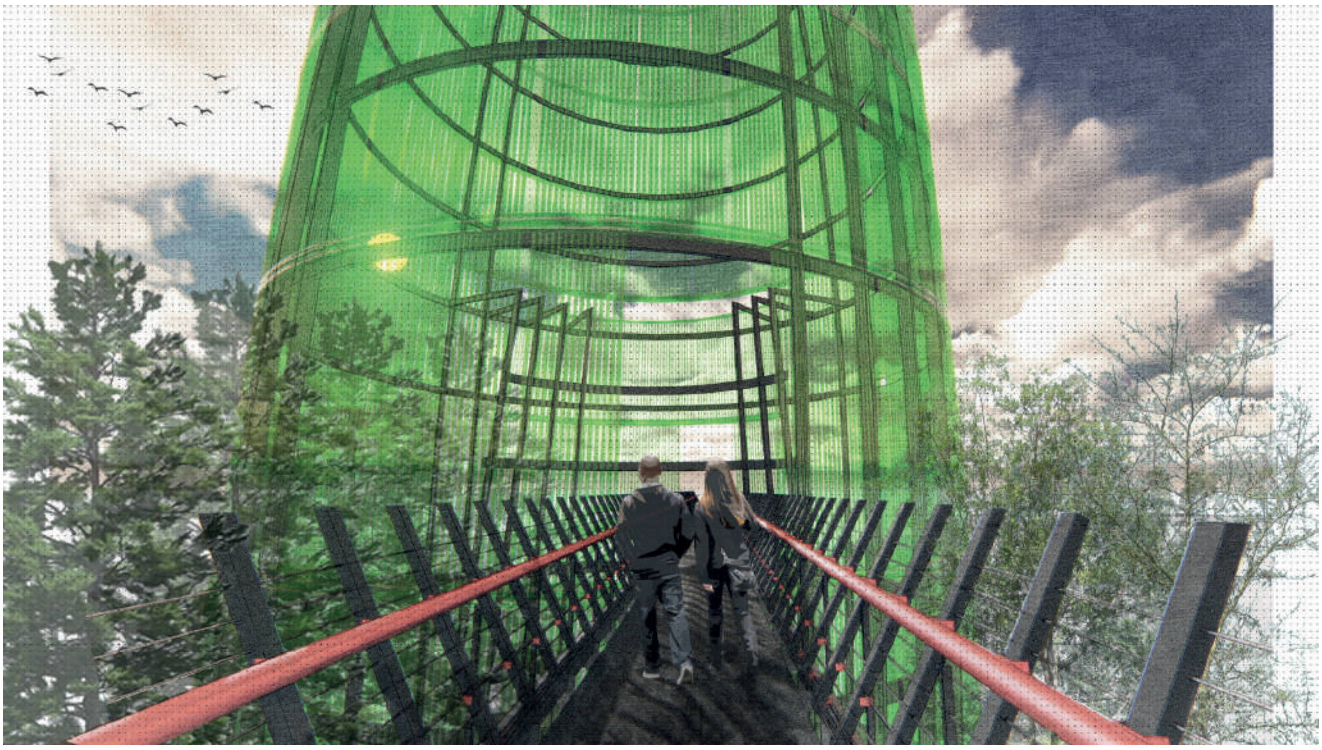


Figure-131:Images indicating the spatial experience of the Carbon Sequestration zones as well as the location of the first two stops on the Carbon Skywalk in the form of the wetland and riparian zones.



The sixth and final stop of the Carbon Skywalk takes you inside the third cooling tower. One is greeted by a narrow yet tall opening into the tower where one can experience the enormity in scale of the eighty-metre tall structure (Figure: 134). The cooling tower has strategically placed openings to allow varying light to stream through, at different times of the day, and strike the walkway in different angles. The end of this journey is symbolic of the paradigm shift prevalent on the Carbon Farm, breaking through the connotation of high carbon emissions towards a landscape which sets out to ensure that the future of productive and industrial urban landscapes is one which uses resources efficiently whilst actively absorbing atmospheric carbon dioxide.

The user is then given the option of ending the journey at the third cooling tower by taking the lift down or making their way back to the first algae tower around the outside of the cooling tower and along a straight walkway, which is at a higher level than the rest of the Carbon Walk.

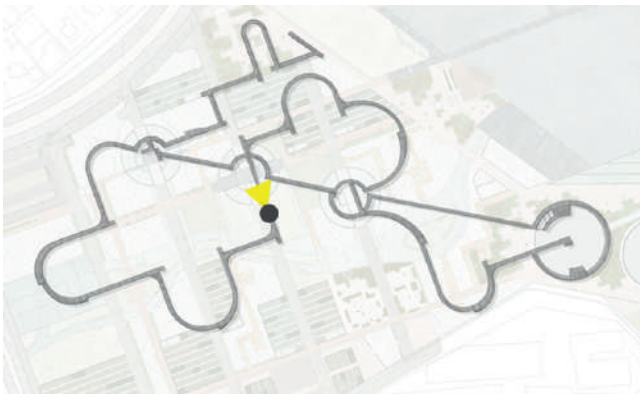


Figure-132:Images indicating the spatial experience of the threshold into the second algae tower as well as the location of the second tower.

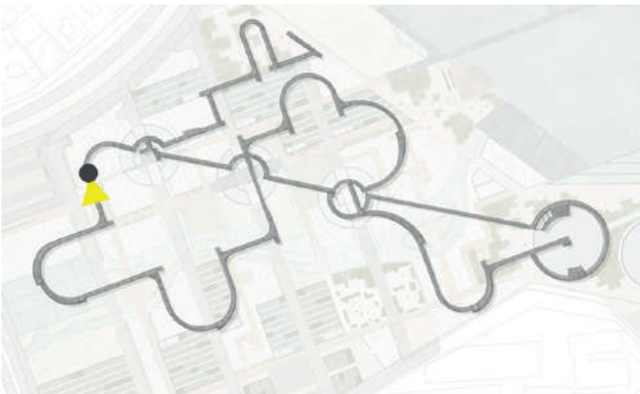


Figure-133:Images indicating the spatial experience within the canopies of the productive trees as well as the location of the stage 1 forestry zone

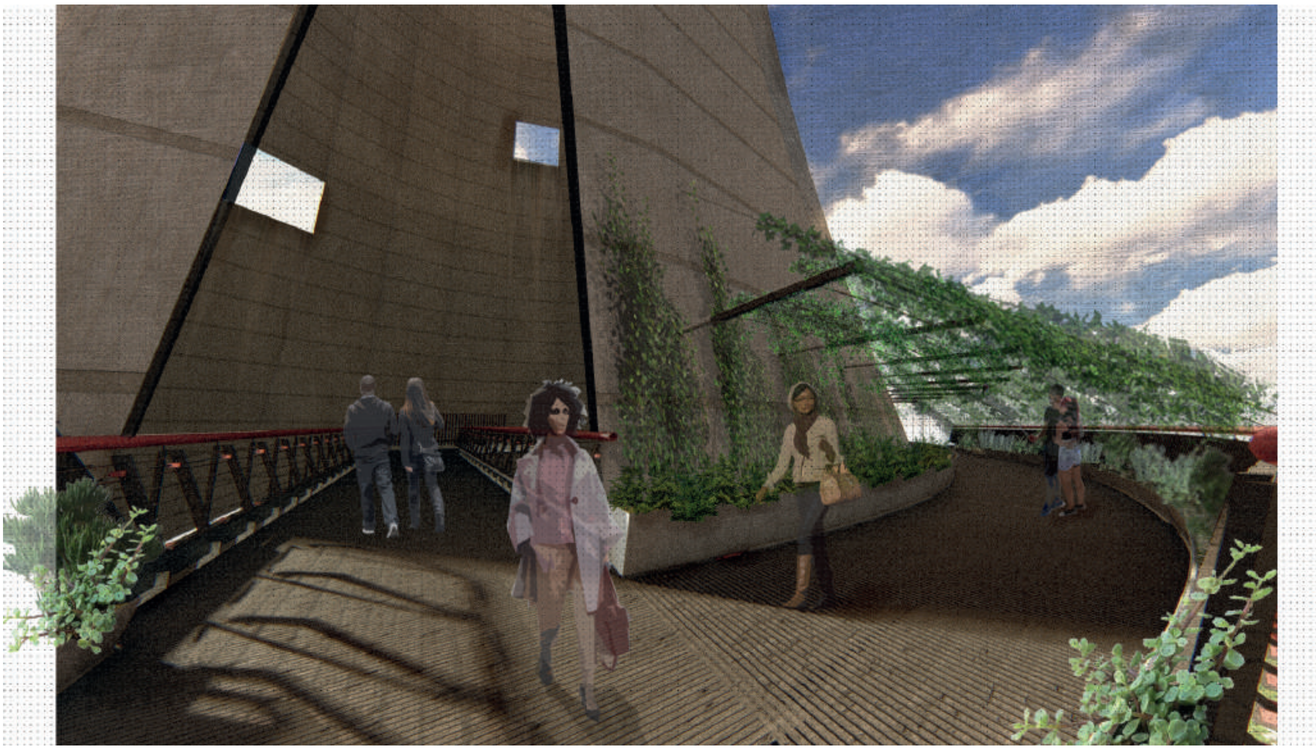


Figure-134:Image showing the threshold into the cooling tower as well as the openings which allow different light in at different times of the day.

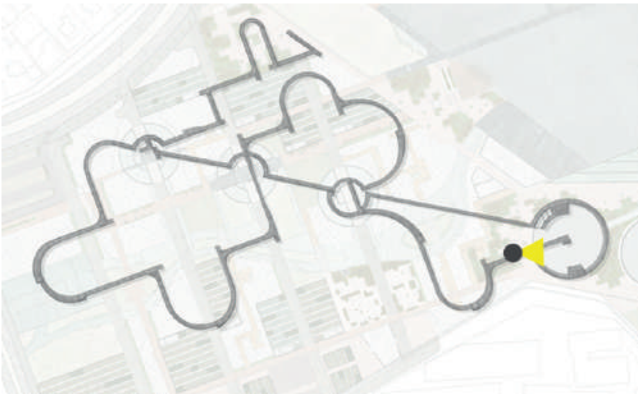
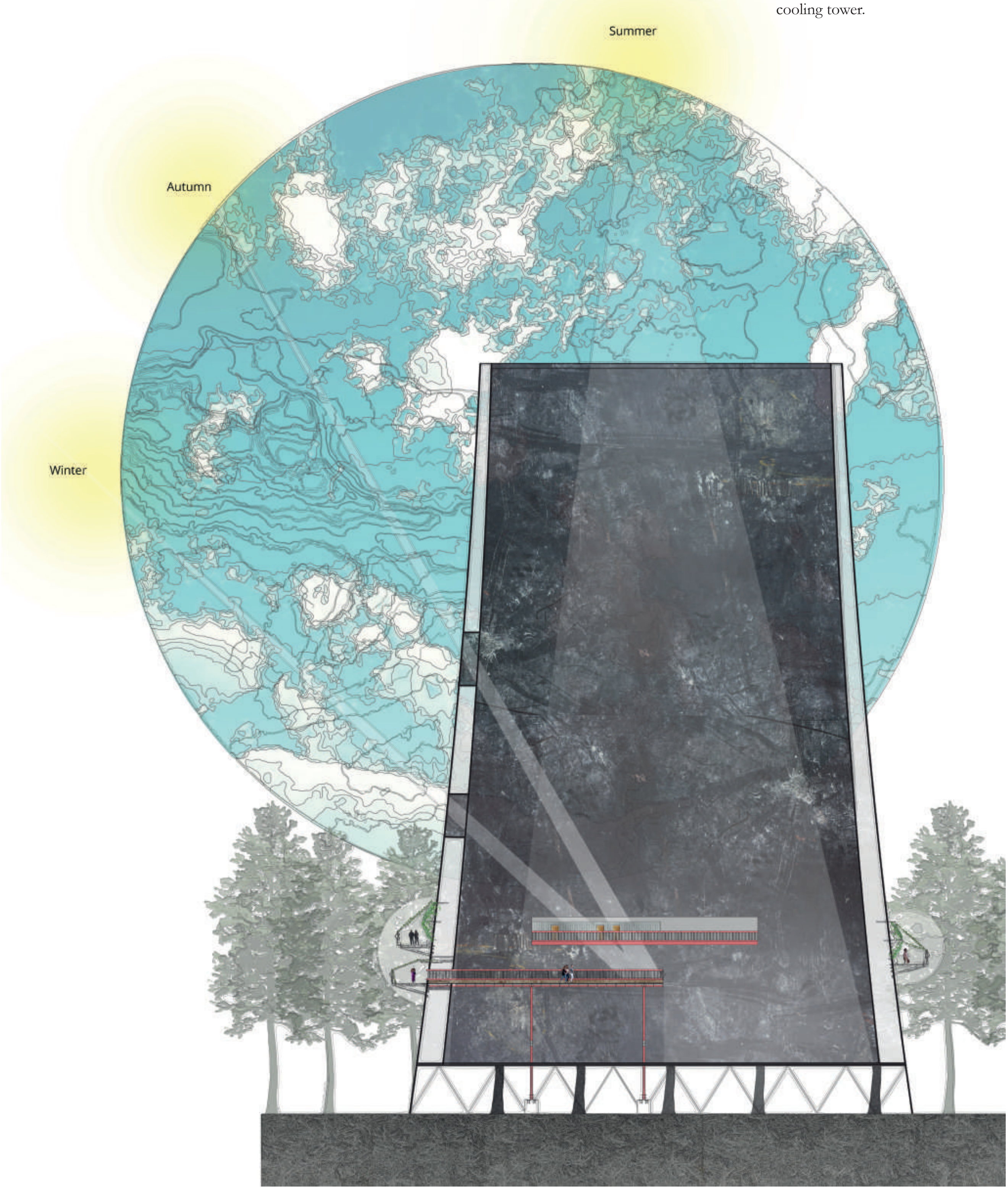


Figure-135: Section showing the a sun study for the summer, autumn and winter sun angles into the cooling tower.

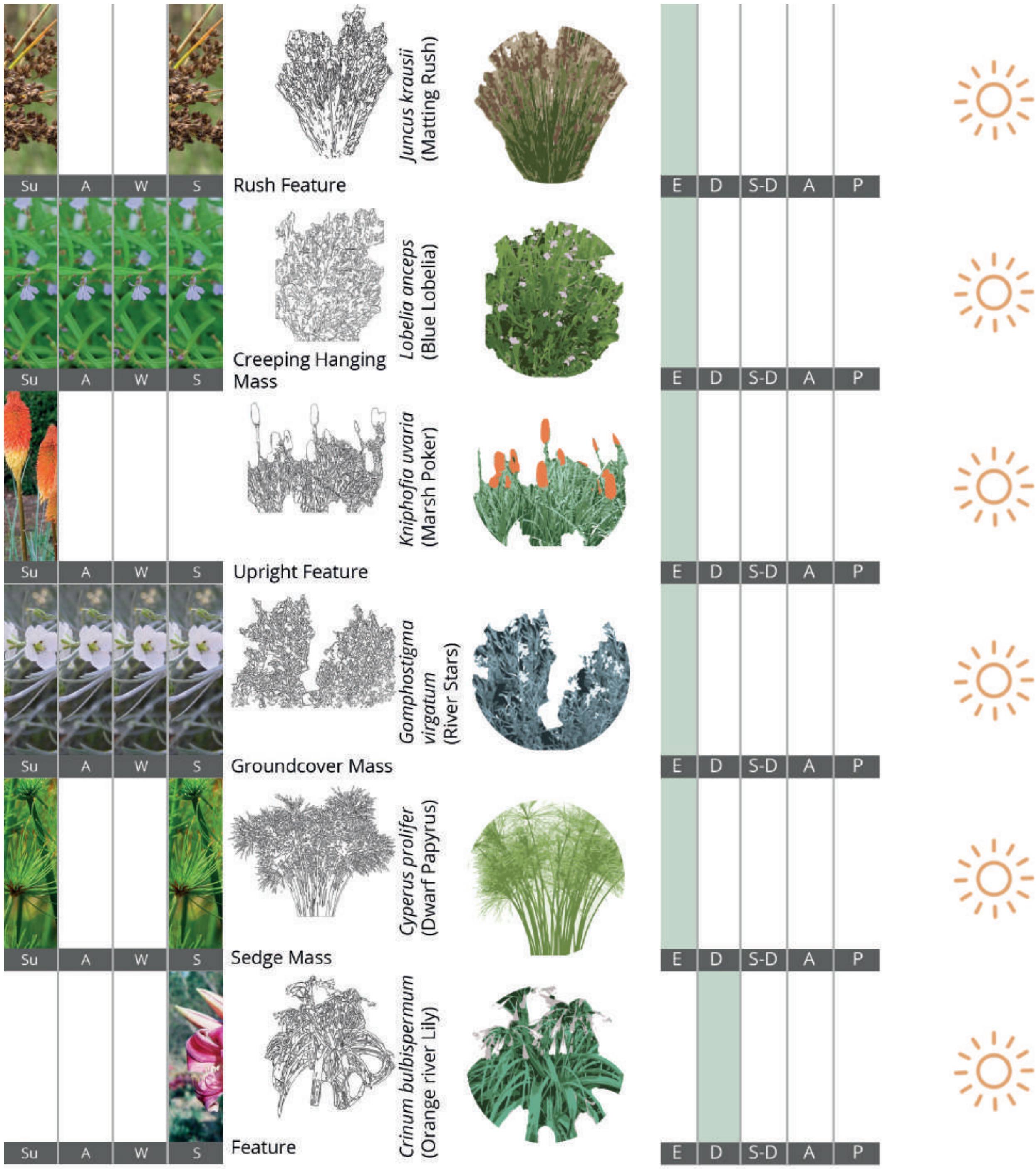


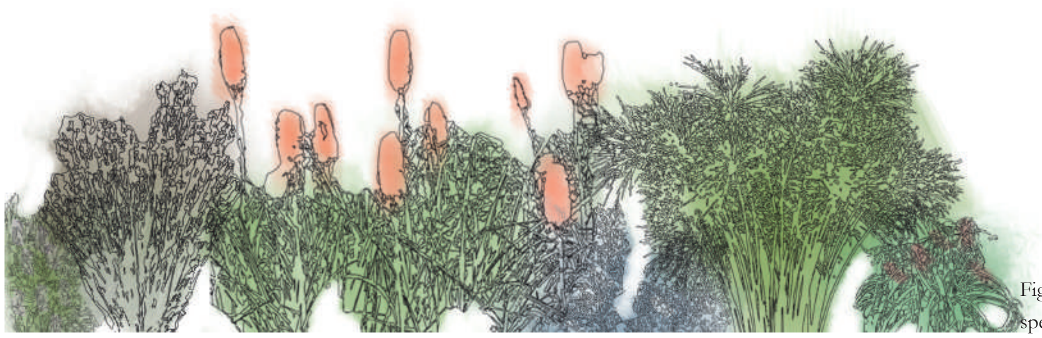
8.3-PLANTING STRATEGIES

Along with the requirements set out in chapter two (see figure 12 and table 3) the selection of plants is based on enhancing the user experience at the different resting points and routes along the Carbon Skywalk. As mentioned above there are various areas that emphasize the different methods of carbon sequestration prevalent within the Carbon Farm and the selection of plant species for these zones is based on the vegetation which are likely to be found within the respective habitat conditions, while considering the criteria for plant selection to meet various objectives researched in chapter 2. The planting selection for each of these zones will be illustrated and discussed below:

Zone 1: Wetland Zone (Figure: 136)
The wetland zone sits above the constructed wetland. The rationale behind the plant selection for this zone is therefore based around indigenous wetland species which can tolerate drought and have an aesthetic appeal. The species include: *Juncus krausii* (Matting Rush); *Cyperus prolifer* (Dwarf Papyrus); *Gomphostigma virgatum* (River Stars); *Kniphofia uvaria* (Marsh Poker); *Crinum bulbispermum* (Orange River Lily) and *Lobelia anceps* (Blue Lobelia). Within this indigenous mixture of plants there is structural diversity; variance in flowering time ensuring that at least one plant is flowering over each season and a variance in flowering colours thus creating seasonal change and food for various pollinators. The species are spatially mixed highly integrated and multi-storied.

Zone 2: Riparian Zone (Figure: 137)
Zone 2 is situated between the split river baseflows in a zone dominated by riparian vegetation. Although similar to the wetland zone, the riparian zone is dominated by indigenous grass species. The species selected are as follows: *Andropogon appendiculatus* (Vlei bluestem); *Stiburus alopecuroides* (Purple vlei grass); *Geranium incanum* (Carpet Geranium) and *Miscanthus junceus* (Broom Grass). The selected species are able to tolerate sustained periods of drought and have an aesthetic appeal. There is also a variance in flower colour and vegetation structure, which attracts a variety of biodiversity and feed pollinators.





Colour Code

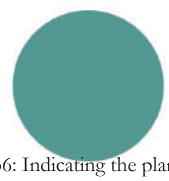
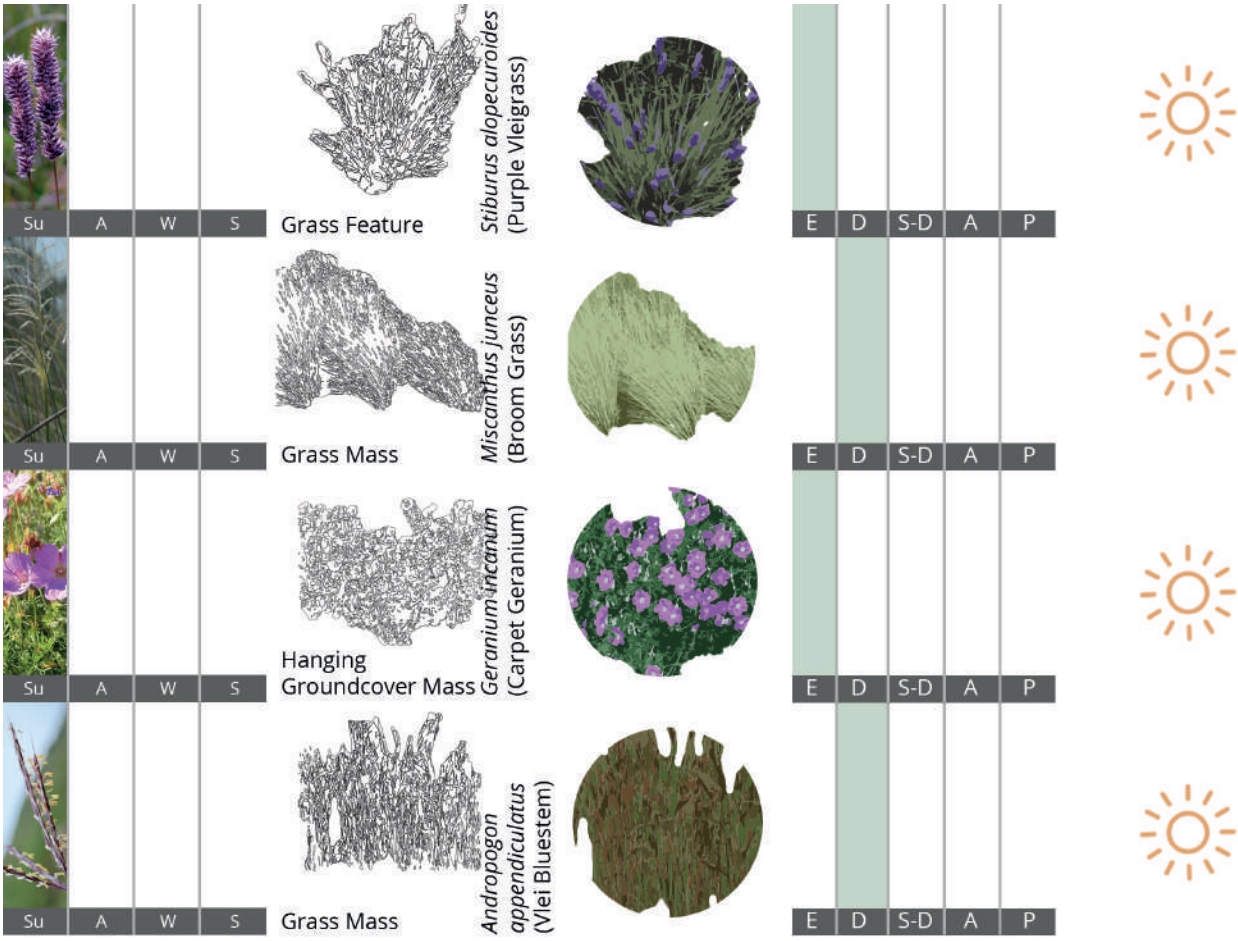


Figure-136: Indicating the plant species utilised in the wetland zone showing flowering time, plant structure and sun and shade requirements.

WETLAND ZONE PLANTING



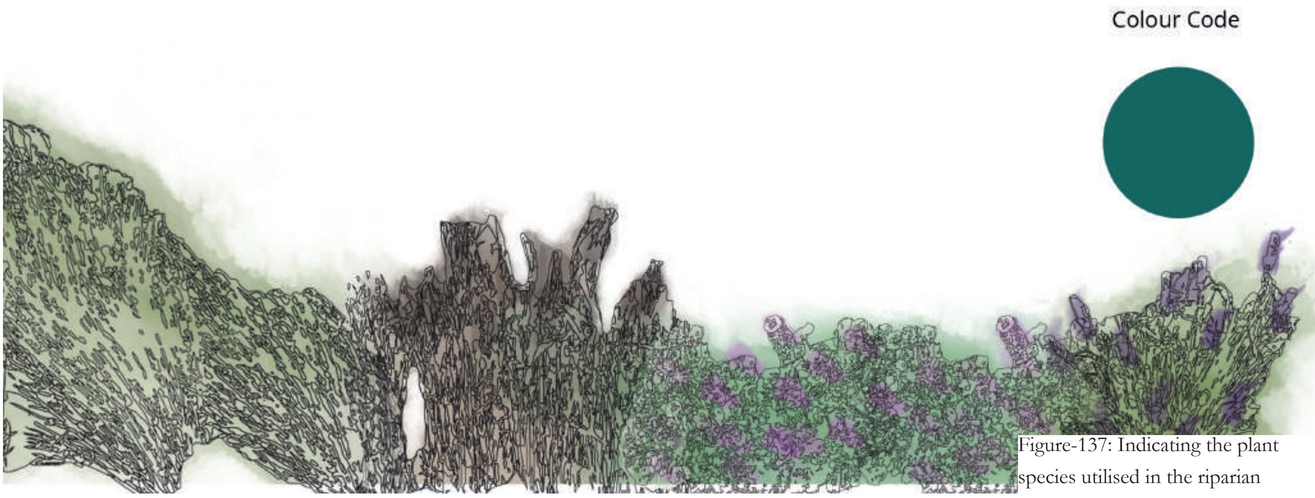


Figure-137: Indicating the plant species utilised in the riparian zone showing flowering time, plant structure and sun and shade requirements.

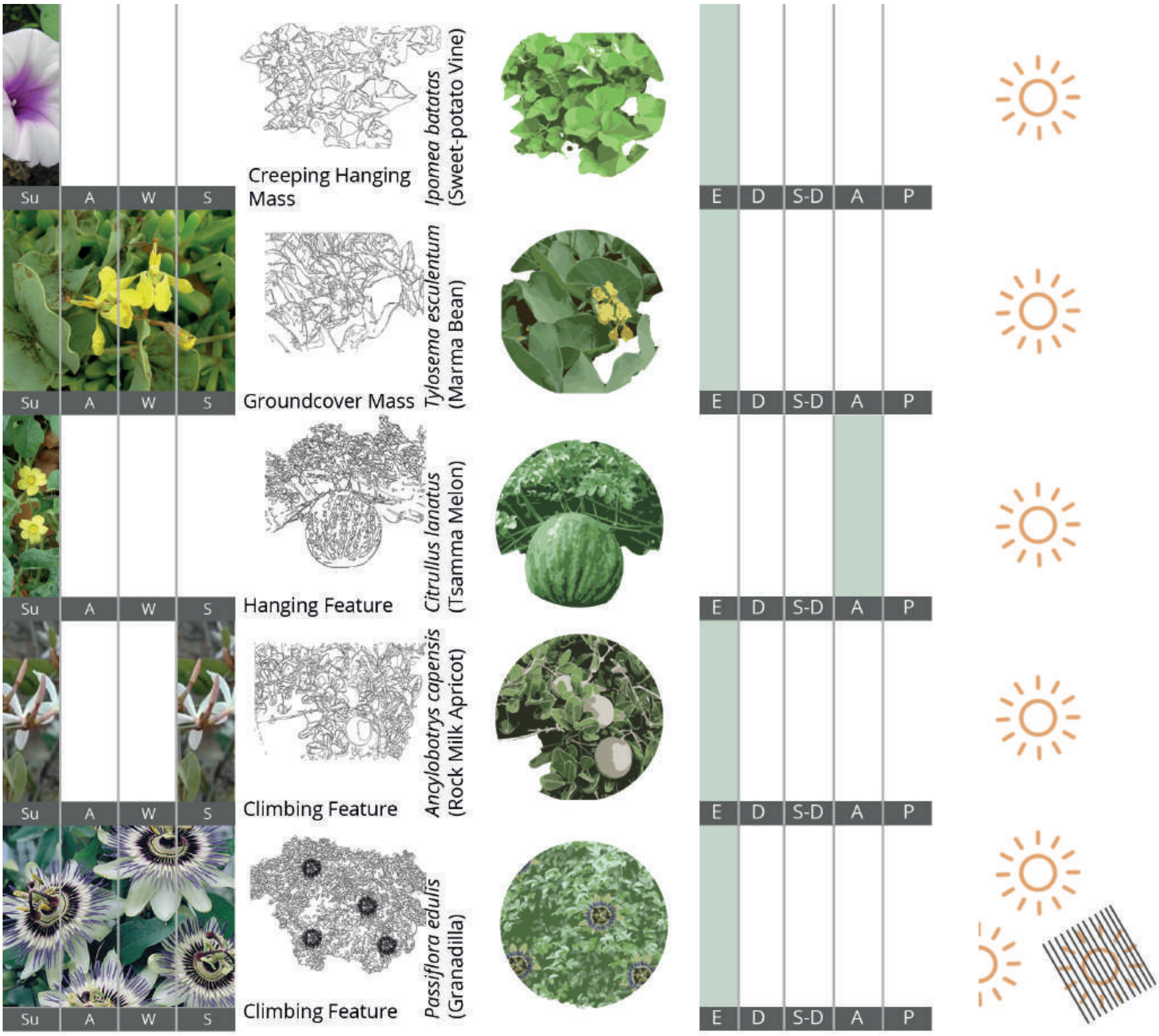
RIPARIAN ZONE PLANTING

Zone 3: Agroforestry Zone (Figure: 138)
The agroforestry zone plant selection is based around the aspect of human consumption. Therefore, the selected plants produce either a fruit or vegetable whilst still adhering to the requirements of carbon sequestration, climate change adaption and biodiversity enhancement. The selected species are therefore not necessarily selected based on their indigenousness. The species selected are: *Ipomoea batatas* (Sweet potato vine); *Citrullus lanatus* (Tsamma melon) *Tylosema esculentum* (Marma bean); *Passiflora edulis* (Granadilla) and *Ancylobotrys capensis* (Rock milk apricot). These species are edible and productive, structurally diverse; multi-storied; spatially mixed and flower over different periods of the year.

Zone 4: Amenity Forest Zone (Figure: 139)
The amenity forest zone is made up of plant species that occur naturally within indigenous forests and along forest margins. These species are shade loving and are for the most part evergreen. The selected species are as follows: *Rhoicissus tomentosa* (Common forest grape); *Asparagus virgatus* (Broom asparagus); *Hypoestes aristata* (Ribbon Bush); *Plectranthus verticillatus* (Gossip plant); *Asparagus asparagoides* (Cape smilax) *Chlorophytum bowkeri* (Giant chrolophytum); *Barleria lancifolia* (Barleria) and *Nerine krigei* (Curly-leaved Nerine). The selected species adhere to the need for structural diversity and integration. They are multi-storied and ensure to presence of flowers year-round.

Zone 5: Riparian Forest
The riparian forest zone consists of a combination of zone one and zone two's plant selection, highlighting the importance of both a wetland and a riparian zones' mutual benificiality when it comes to habitat creation and biodiversity enhancement. The selected species include: *Juncus krausii* (Matting Rush); *Kniphofia uvaria* (Marsh Poker); *Lobelia anceps* (Blue Lobelia); *Stiburus alopecuroides* (Purple vlei grass) and *Andropogon appendiculatus* (Vlei bluestem).

Zone 6 has a similar planting selection to zone 4 however, due to the fact that the forestry areas are harvested every twenty-five years the plants chosen will have to be able to tolerate both shade and sun. The selected species therefore consist of *Asparagus virgatus* (Broom asparagus); *Plectranthus verticulatus* (Gossip plant); *Asparagus asparagoides* (Cape smilax) and *Chlorophytum bowkeri* (Giant Chrolophytum).



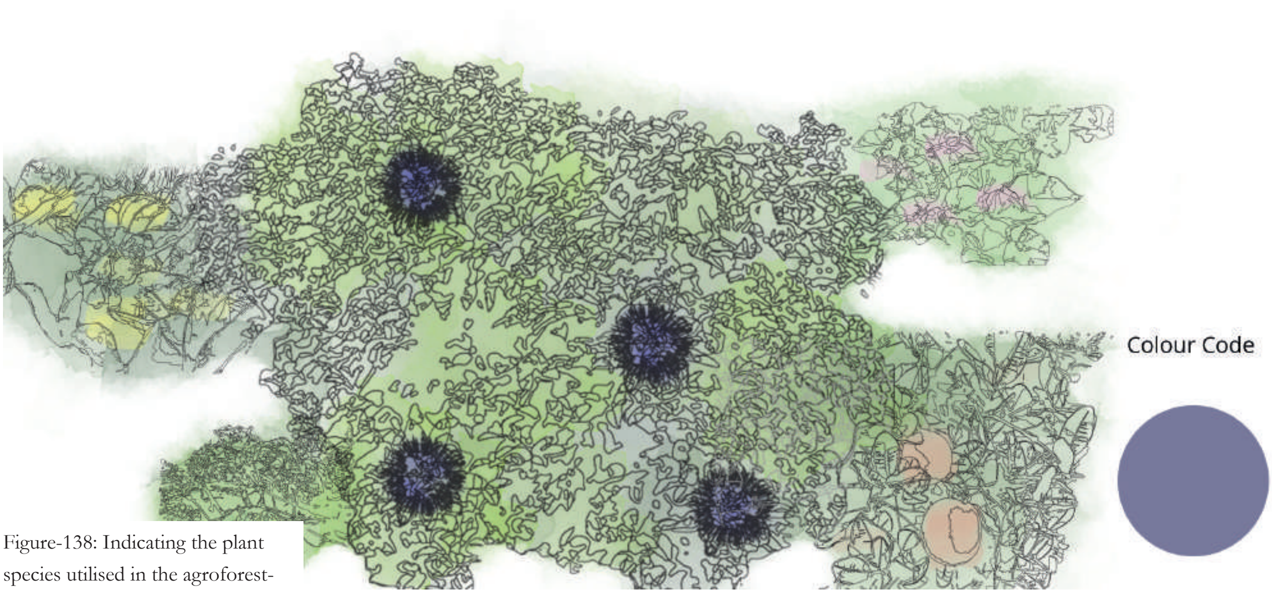


Figure-138: Indicating the plant species utilised in the agroforestry zone showing flowering time, plant structure and sun and shade requirements.

AGROFORESTRY ZONE PLANTING

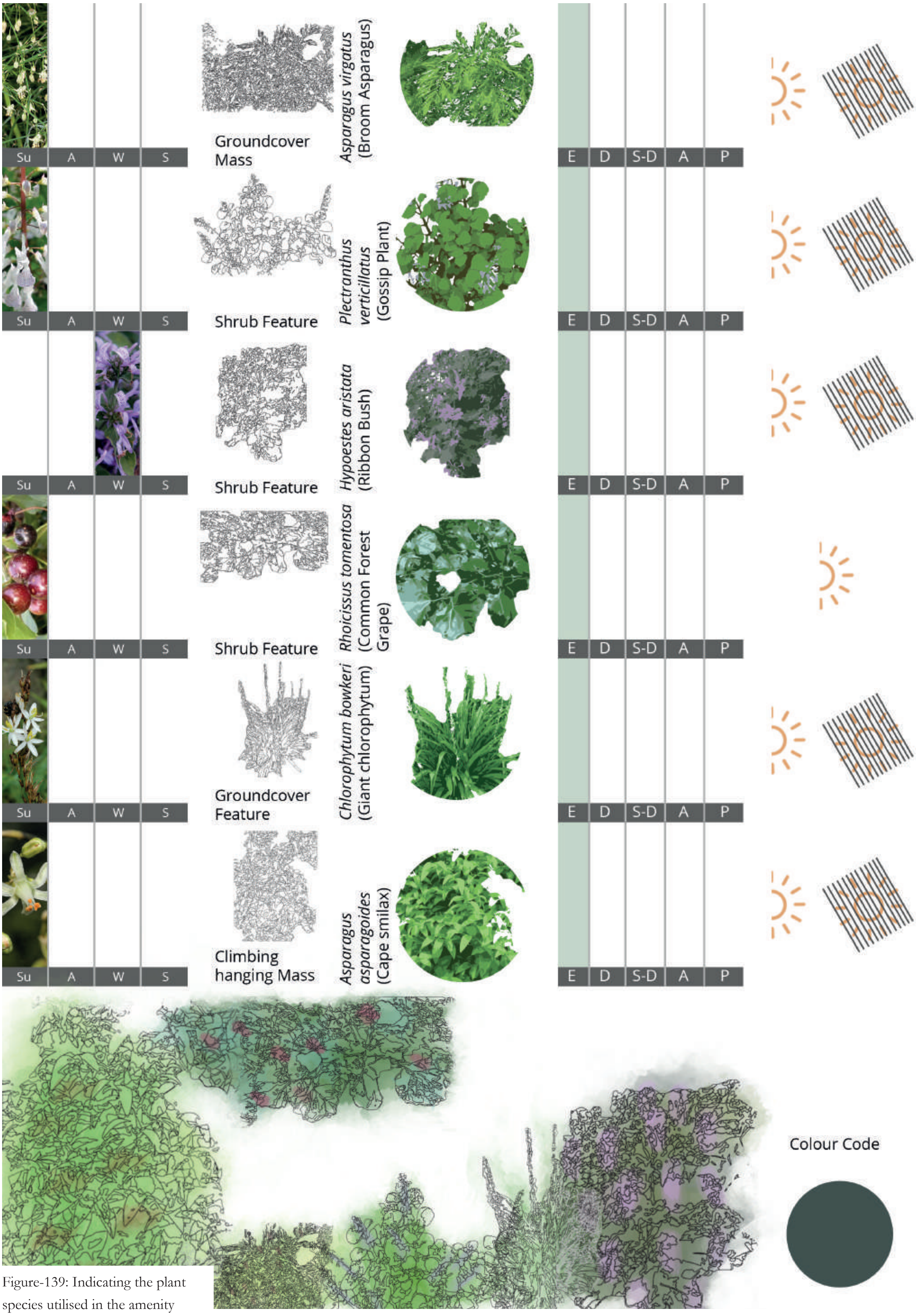


Figure-139: Indicating the plant species utilised in the amenity forest zone showing flowering time, plant structure and sun and shade requirements.

AMENITY FOREST ZONE PLANTING

The Straights (Figure: 140)
The carbon sequestration zones 1-5 highlighted above are connected by a series of straight routes which consist of a combination of harsh succulent type vegetation areas which transition, at specific moments, into softer less harsh, but just as hardy, succulent-type vegetation zones. The succulent vegetation ensures little maintenance and watering is required after the initial establishment period of twelve-months but is also symbolic of the type of vegetation that may be required should global temperatures increase due to climate change. The harsh succulents consist of *Portulacaria afra* (Porkbush); *Crassula ovata* (Jade plant); *Delosperma herbeum* (Highveld white vygie); *Senecio barbetonicus* (Bush senecio); *Kalanchoe sexangularis* (Bush kalanchoe) and *Chasmatophyllum masculinum* (Tiger's jaw). These zones are located along the majority of the Carbon Skywalk on the expanses between the carbon sequestration zones and transition to the softer succulent-type species just before the carbon sequestration zones are situated.

The softer succulent-type species consist of *Crassula multicava* (Fairy crassula); *Kleinia fulgens* (Coral senecio); I*pomoea oenotheroides* (Christmas flower); *Kalanchoe thyrsiflora* (White lady) and *Bulbine abyssinica* (Bushy Bulbine). (Figure: 134)

The Crossings (Figure: 142 and 143)
Wherever the Carbon Skywalk crosses over a piazza, lawn commons or main walkway on the ground plane the planting selection changes to ensure maximum growth over its edges and along its balustrades. This is done to maximise the coverage of the walkways structure to create the experience of a Carbon Skywalk overgrown with CO2 absorbing plants. Due to where these crossings happen it was necessary to select plant species for both full sun conditions as well as semi-shade conditions. The full-sun species selected include: *Rhoicissus tridentata* (Bushman's grape); *Plectranthus neochilus* (Smelly spur-flower); *Senecio tamoides* (Canary creeper); *Cyrtanthus mackenii* (Ifafa lily) and *Thunbergia alata* (Black-eyed Susan). The semi-shade species include: *Bowiea volubilis* (Climbing lily); *Jasminum breviflorum* (Wild jasmine); *Asparagus plumosus* (Asparagus fern); *Asparagus transvaalensis* (Bushveld asparagus) and *Pallaea calomelanos* (Hard fern).

The Entrances (Figure: 144)
The stretches around the algae towers as well as the entrance to the cooling tower called for plants which are able to draw the viewer's eyes upwards in order to absorb the verticality and scale of the structures which stand before them. The plant species selected therefore, are upright growing in form and evergreen. These species consist of: *Strelitzia juncea* (Rush-leaved Strelitzia); *Sansevieria pearsonii* (Spikey mother-in-law's tongue); *Aristea abyssinica* (Blue-eyed grass); *Kniphofia galpinii* (Orange flame poker) and *Freylinia tropica* (Honey-bell bush).

The Junctions (Figure: 145)
The junctions are located at major changes in the direction at the end of the straight sections. These areas are designed to frame certain views back on the journey and the views that are to come. The areas also serve as resting points along the Carbon Skywalk. The plants selected for these zones therefore need to be of a soft and relaxing nature to directly contrast the harshness of the straight sections mentioned above. The plants selected for these zones include: *Aristida junciformis* (Bristle grass); *Asparagus densiflorus* (Emerald fern); *Plectranthus ecklonii* (Tall spur-flower); *Agapanthus africanus* (Miniature agapanthus) and *Asystasia gangetica* (Creeping fox glove).

The Cooling tower and Columns. (Figure: 146)
The rationale behind the selection of plants for the cooling tower as well as the columns of the Carbon Skywalk is to ensure maximum growth and coverage of vegetation. Therefore, a combination of aggressive creepers and climbers was selected to maximise the coverage and associated experience. The selected species include: *Ancylobotrys capensis* (Rock milk apricot); *Combretum microphyllum* (Flame Creeper); *Ficus pumila* (Tickey creeper) and *Mondia whitei* (White's ginger).

Conclusion (Figure :147)
Overall there are fifty-five different plant species with varying structures, flowering times, water and aspect requirements as well as growth rates, on the Carbon Skywalk alone. The selection of all the species is based on the requirements, relevant to plant selection meeting the various objectives as set out in chapter two. The high biodiversity increases the plant palettes' abilities to withstand changing climate whilst maximizing the absorption of carbon via the creation of biomass. The selected plants do not only serve on a pragmatic level but also aid in the spatial experience and didactic experience of the Carbon Skywalk.

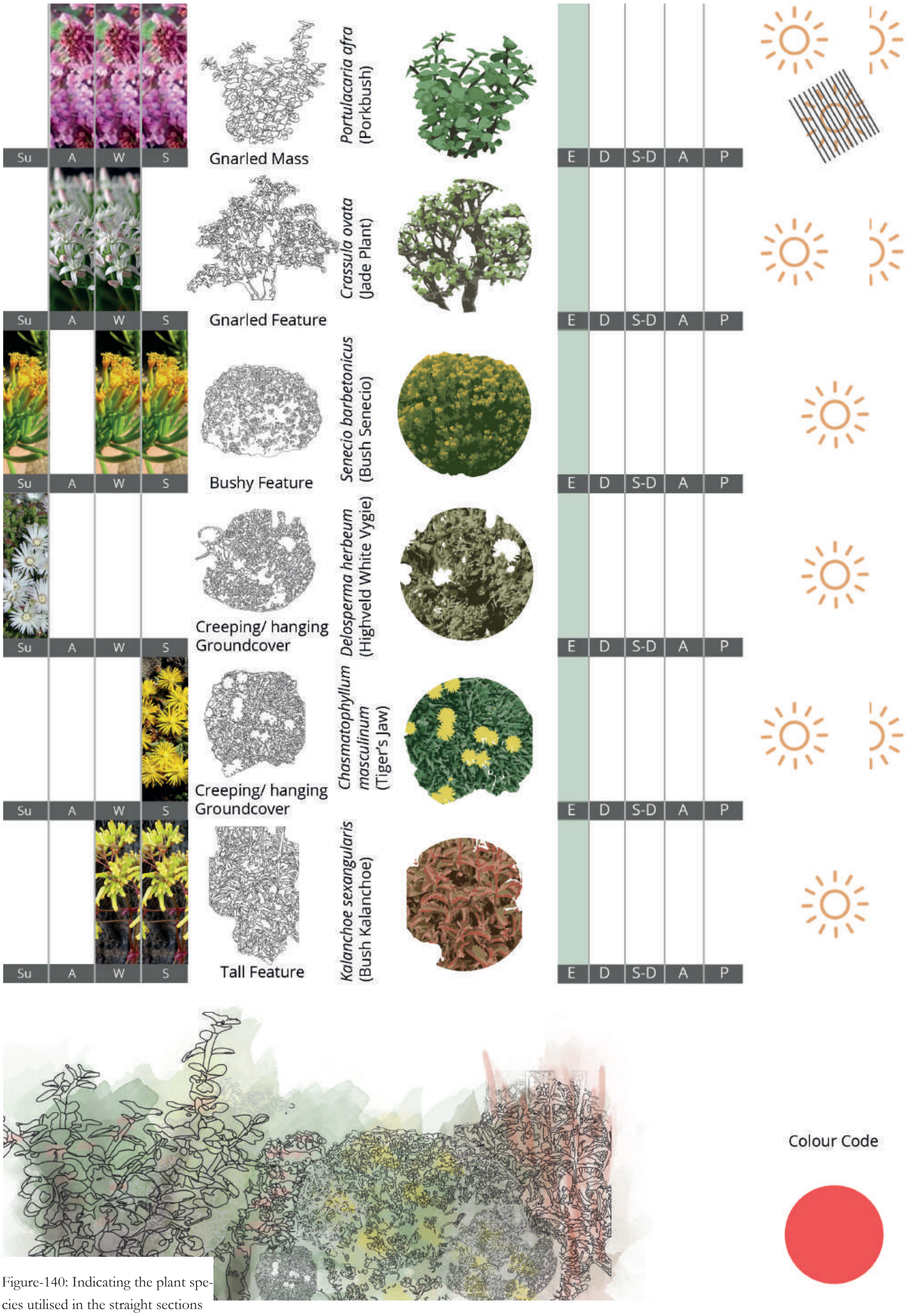
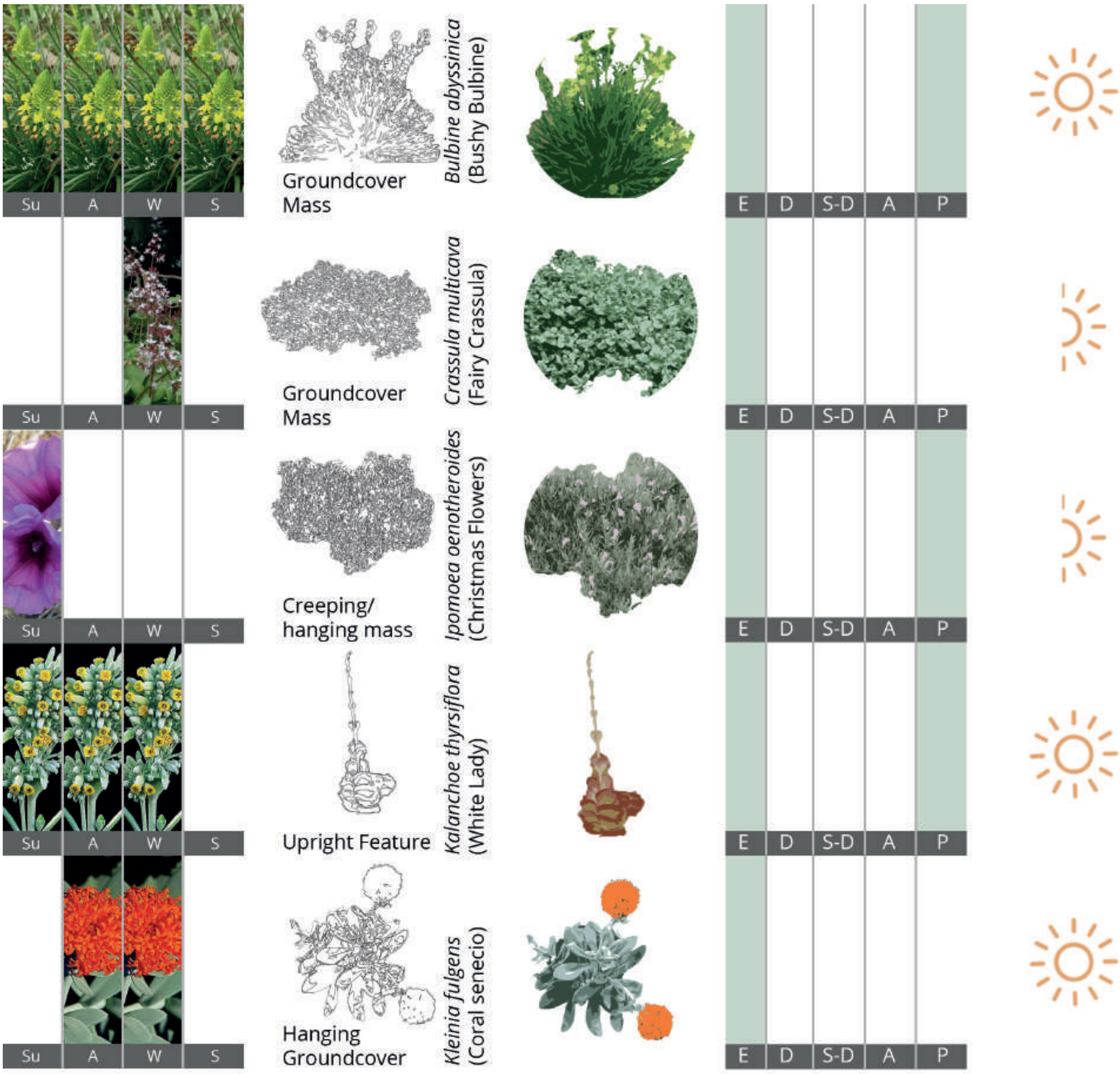
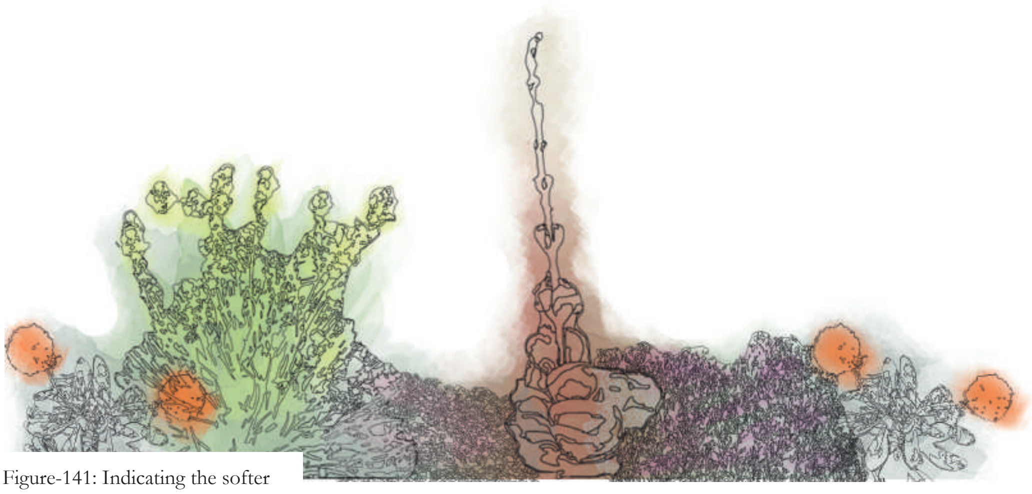


Figure-140: Indicating the plant species utilised in the straight sections of the Carbon Skywalk showing flowering time, plant structure and sun and shade requirements.

THE STRAIGHT ZONES PLANTING





Colour Code

Figure-141: Indicating the softer succulent species showing flowering time, plant structure and sun and shade requirements.

THE SOFT SUCCULENT ZONES PLANTING

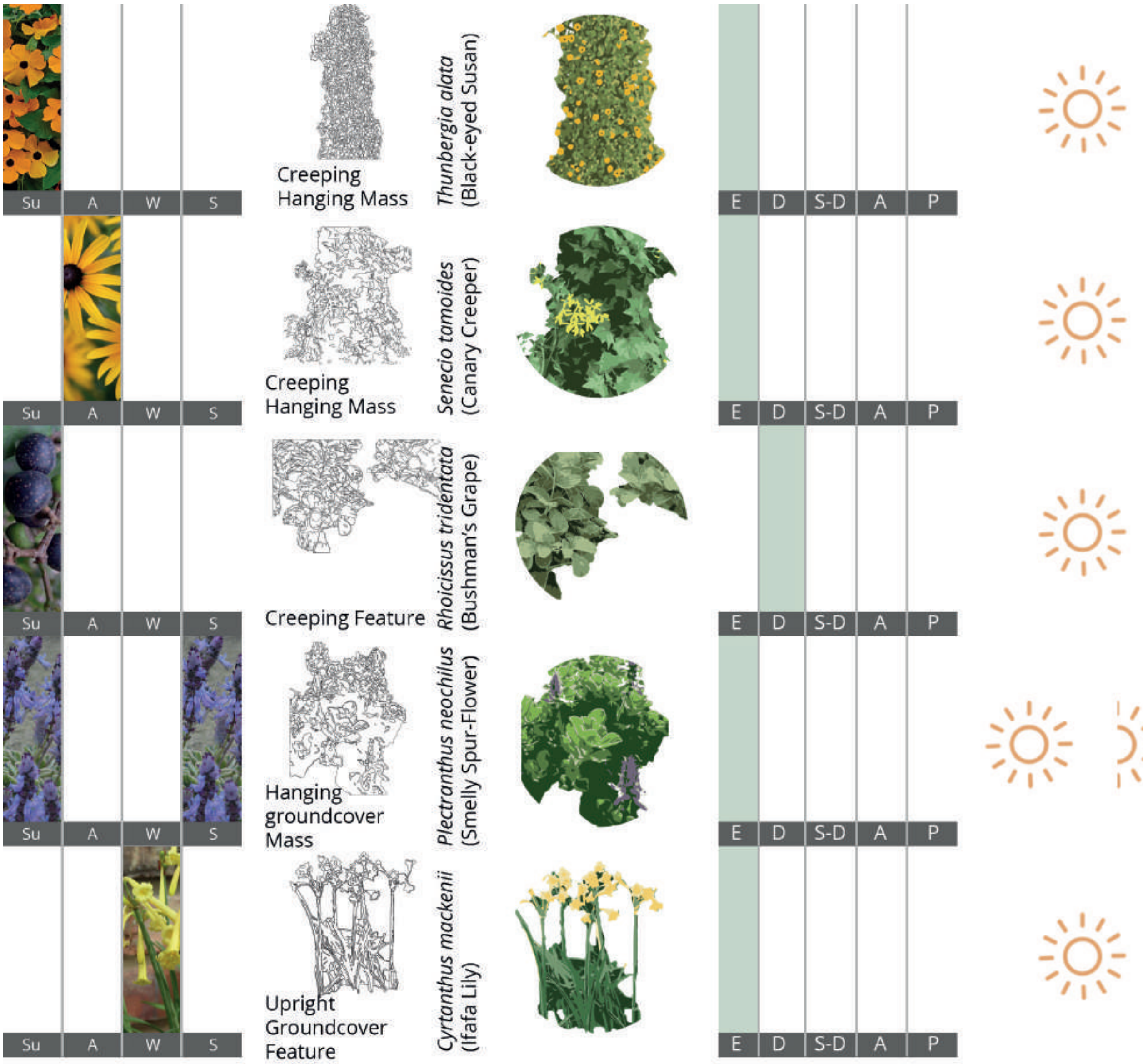


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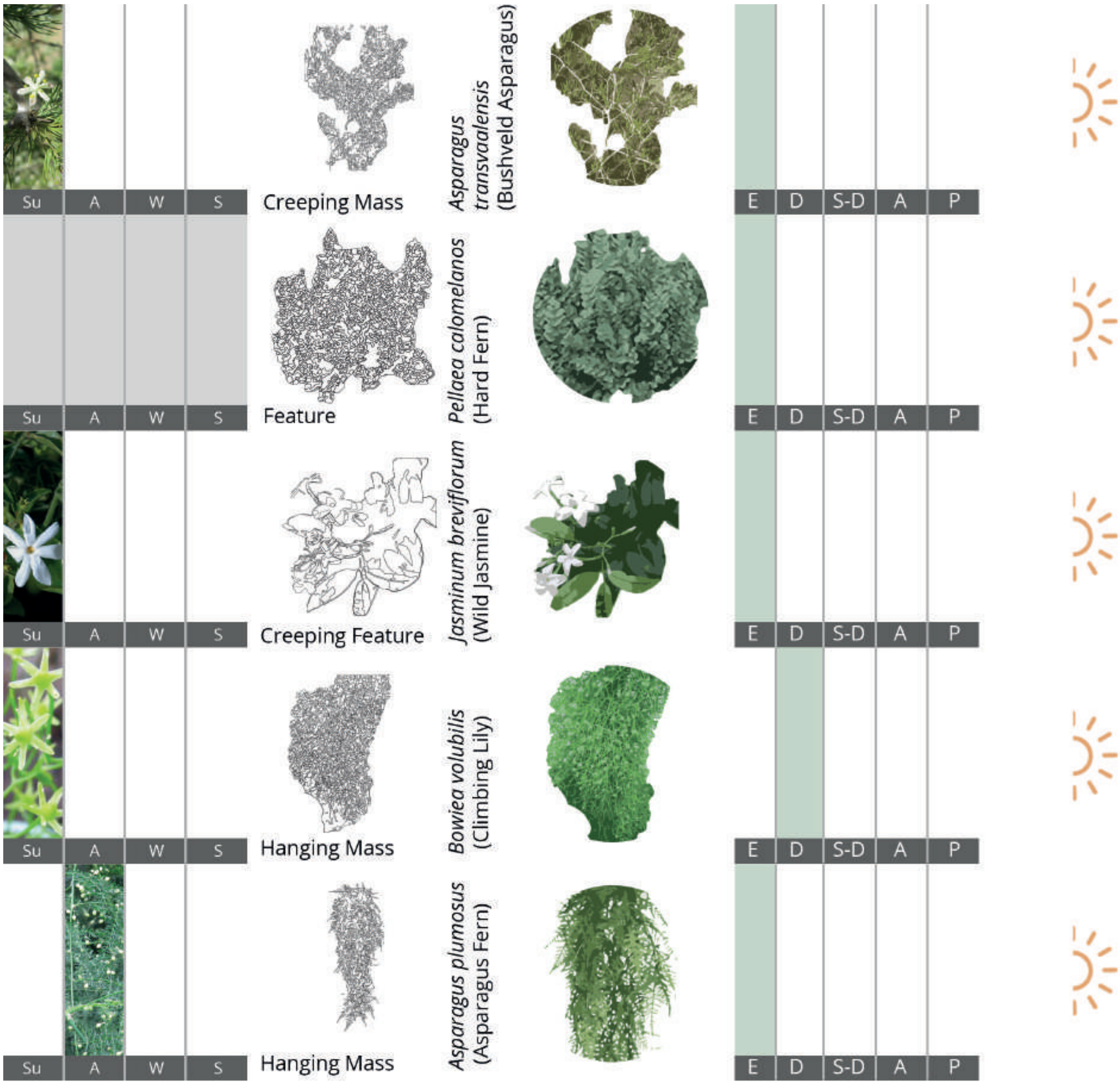
Figure-142: Indicating the overhanging full sun plant species showing flowering time, plant structure and sun and shade requirements.

THE OVERHANGING FULL-SUN ZONES PLANTING



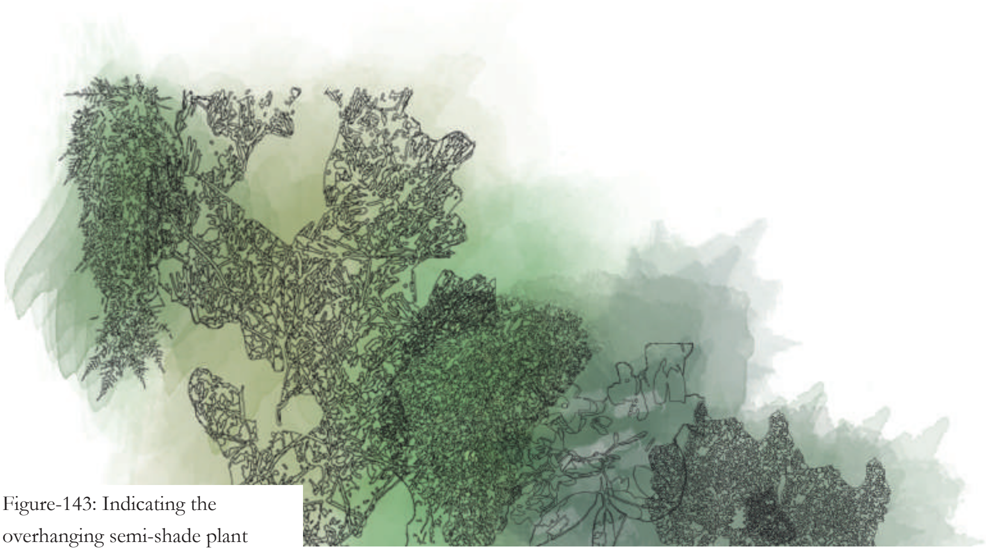
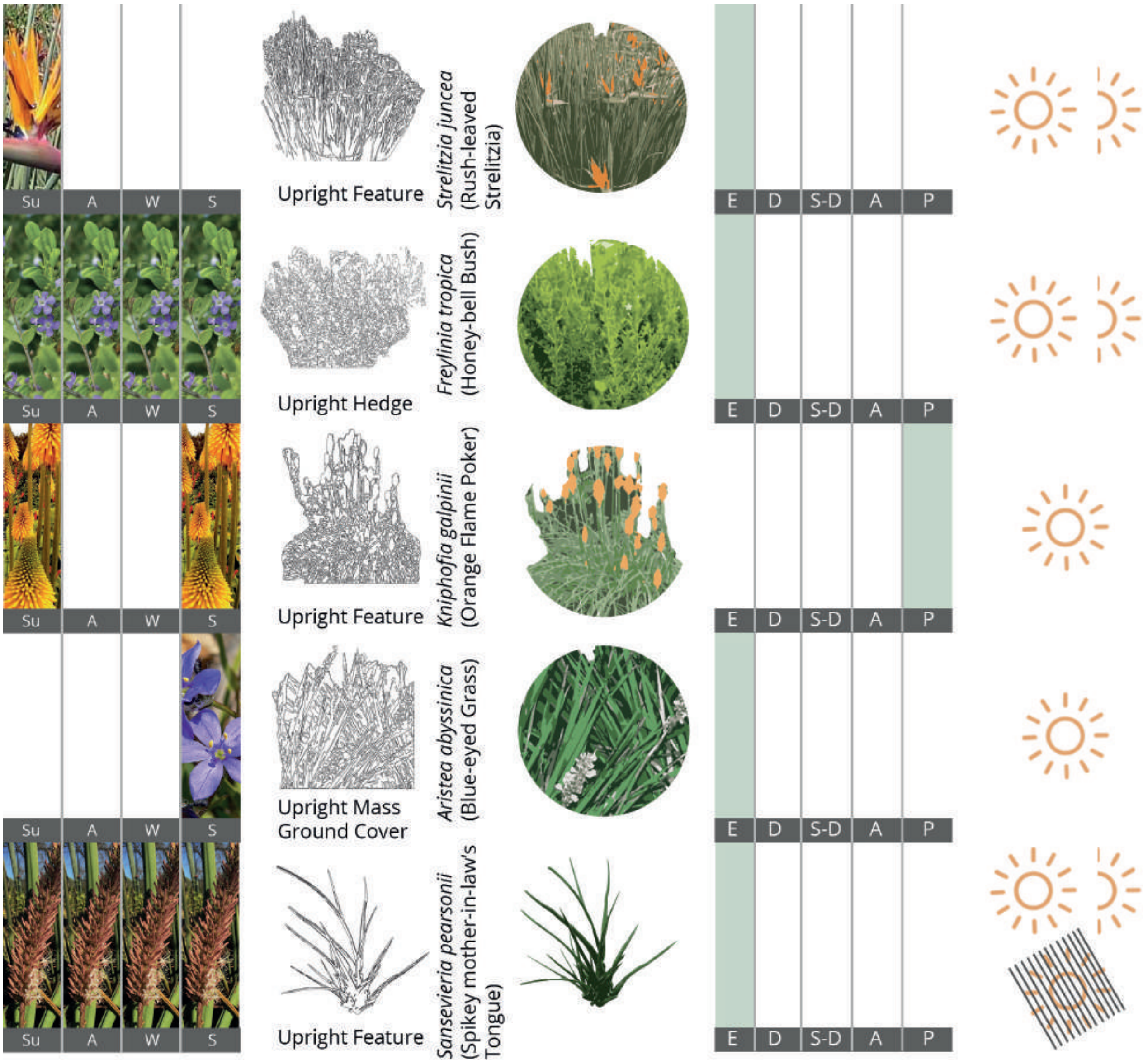


Figure-143: Indicating the overhanging semi-shade plant species showing flowering time, plant structure and sun and shade requirements.

Colour Code

THE OVERHANGING SEMI-SHADE ZONES PLANTING



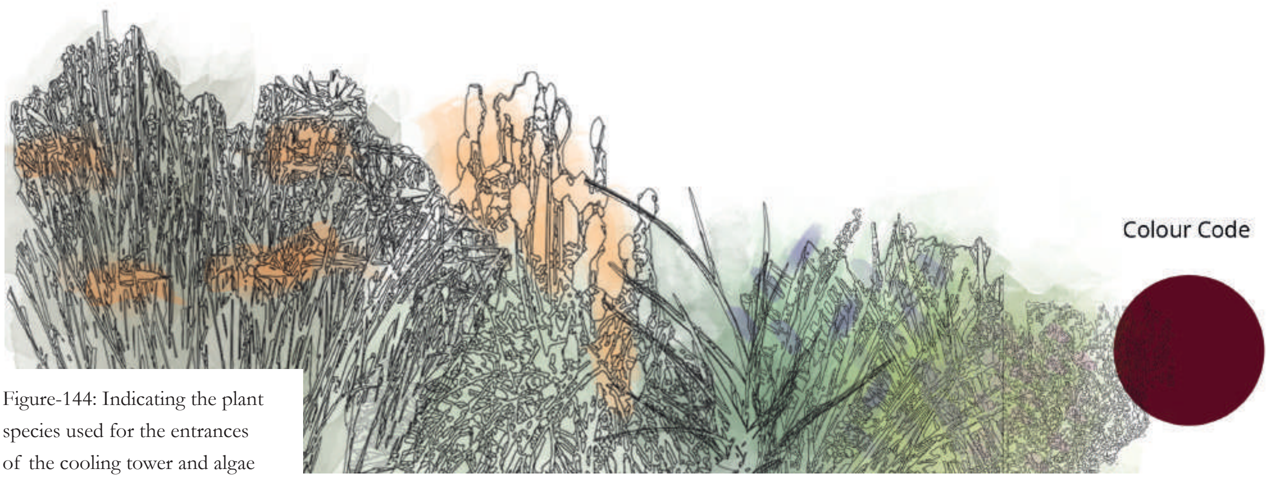
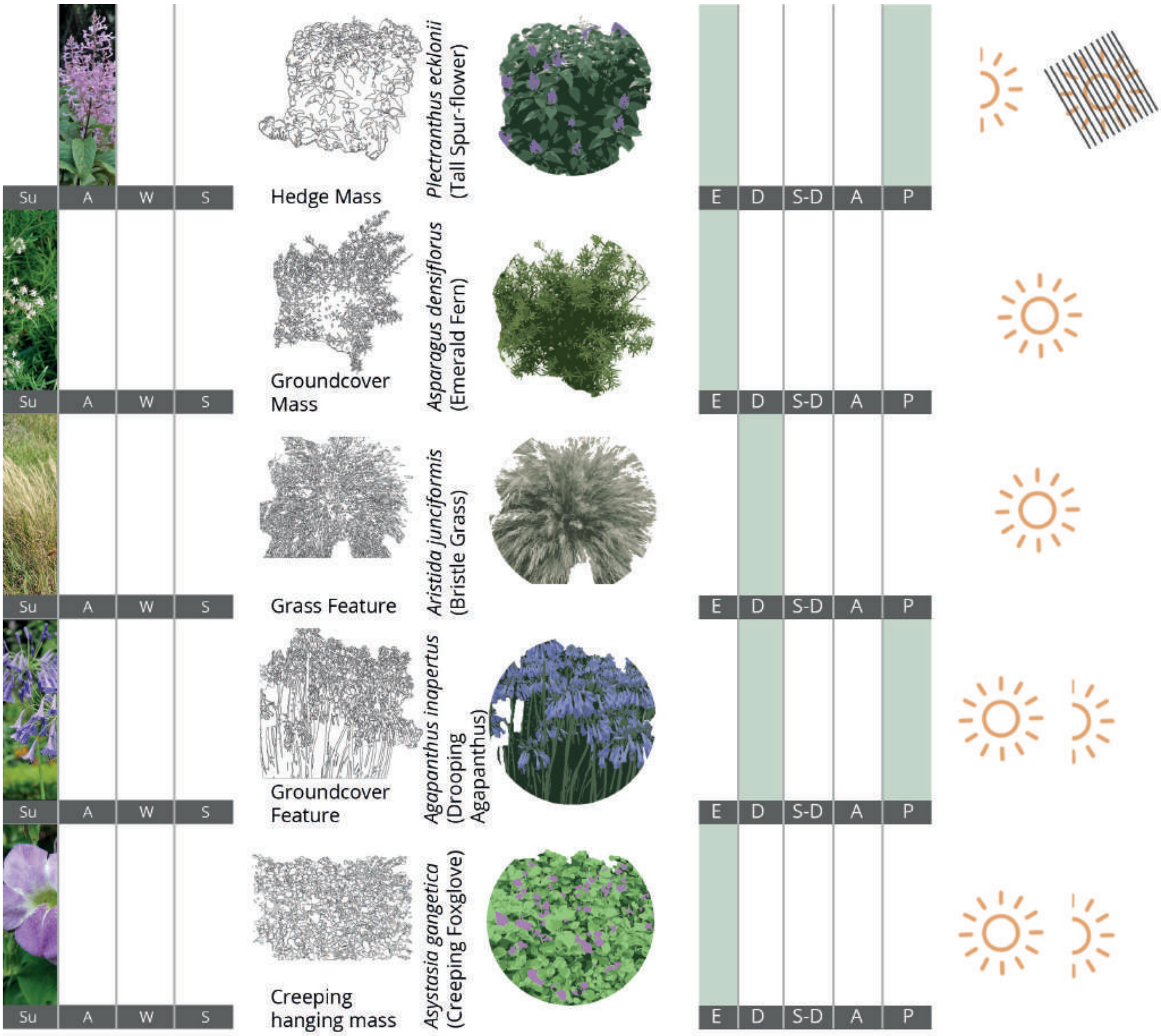


Figure-144: Indicating the plant species used for the entrances of the cooling tower and algae towers showing flowering time, plant structure and sun and shade requirements.

THE ENTRANCES TO THE COOLING TOWER AND ALGAE TOWERS PLANTING



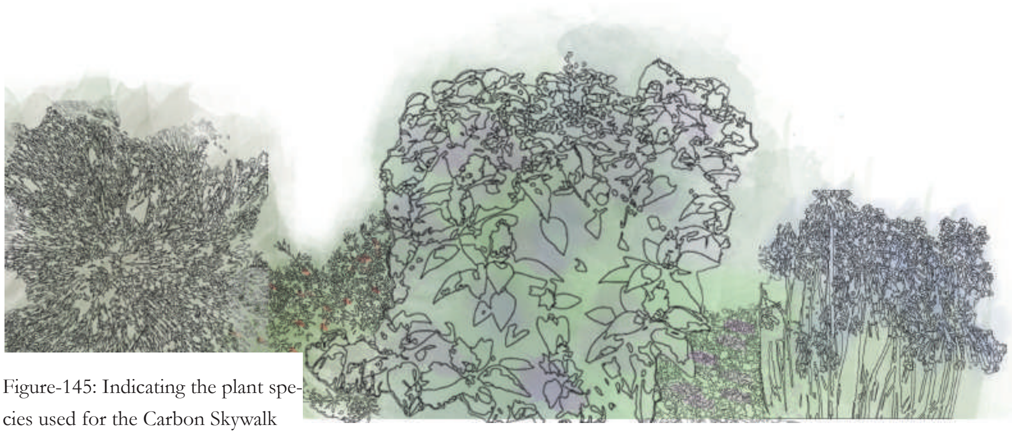
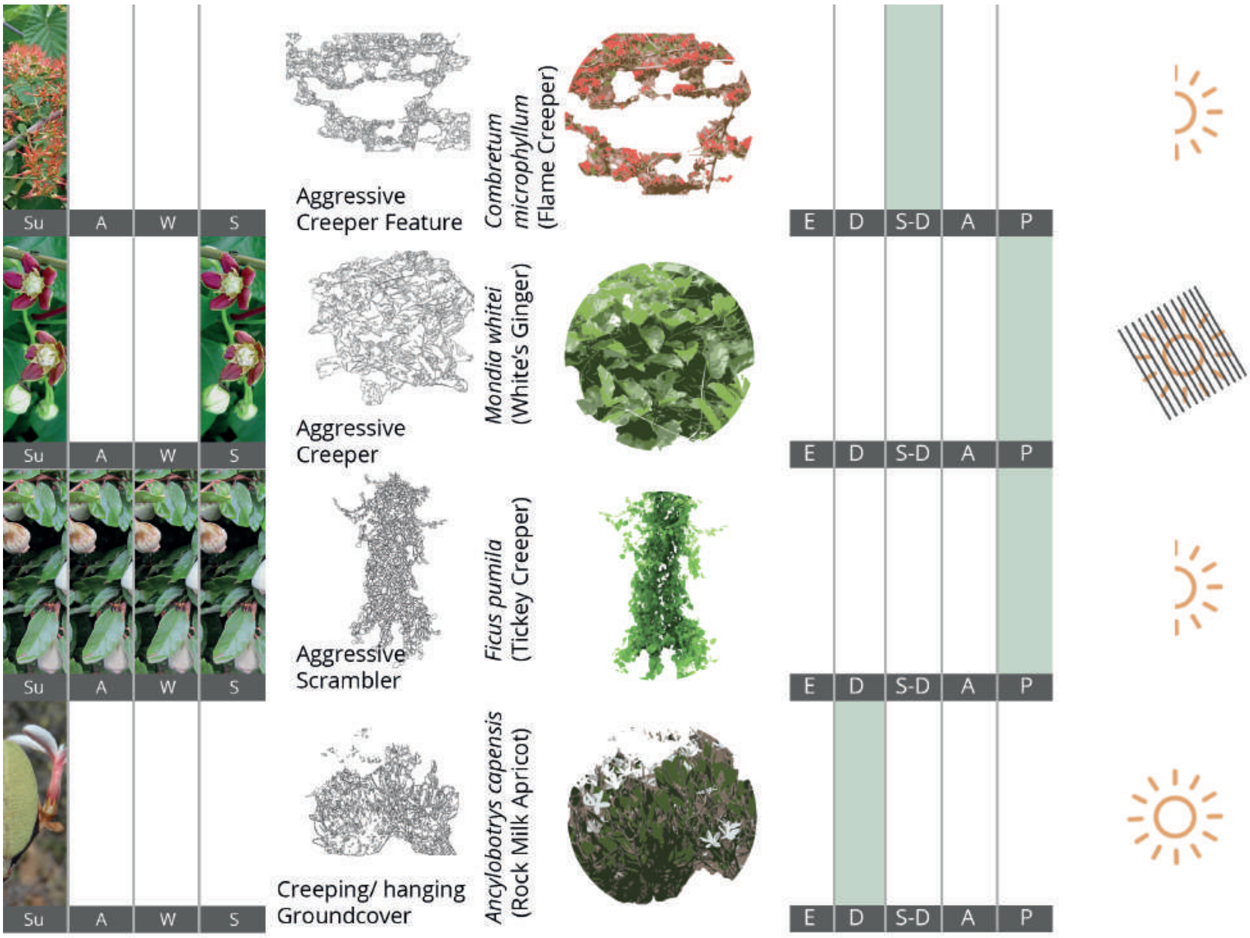


Figure-145: Indicating the plant species used for the Carbon Skywalk junctions showing flowering time, plant structure and sun and shade requirements.

THE JUNCTIONS OF THE CARBON SKYWALK PLANTING



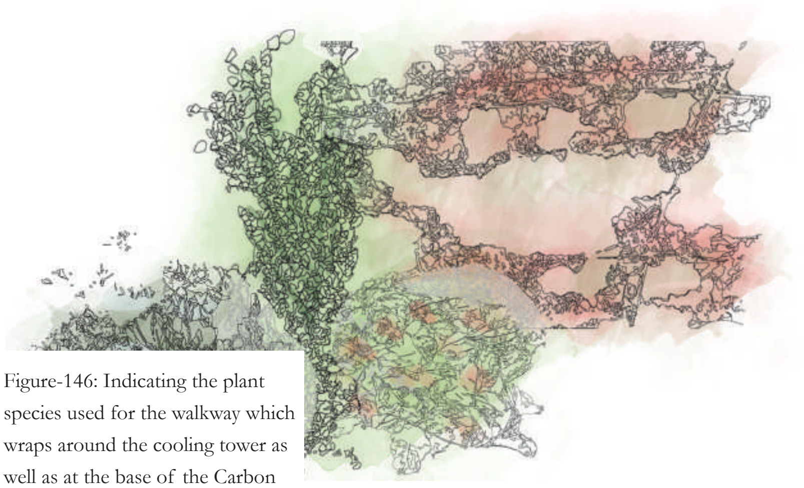


Figure-146: Indicating the plant species used for the walkway which wraps around the cooling tower as well as at the base of the Carbon Skywalk's support columns showing flowering time, plant structure and sun and shade requirements.

Colour Code

THE COOLING TOWER AND COLUMN BASE PLANTING

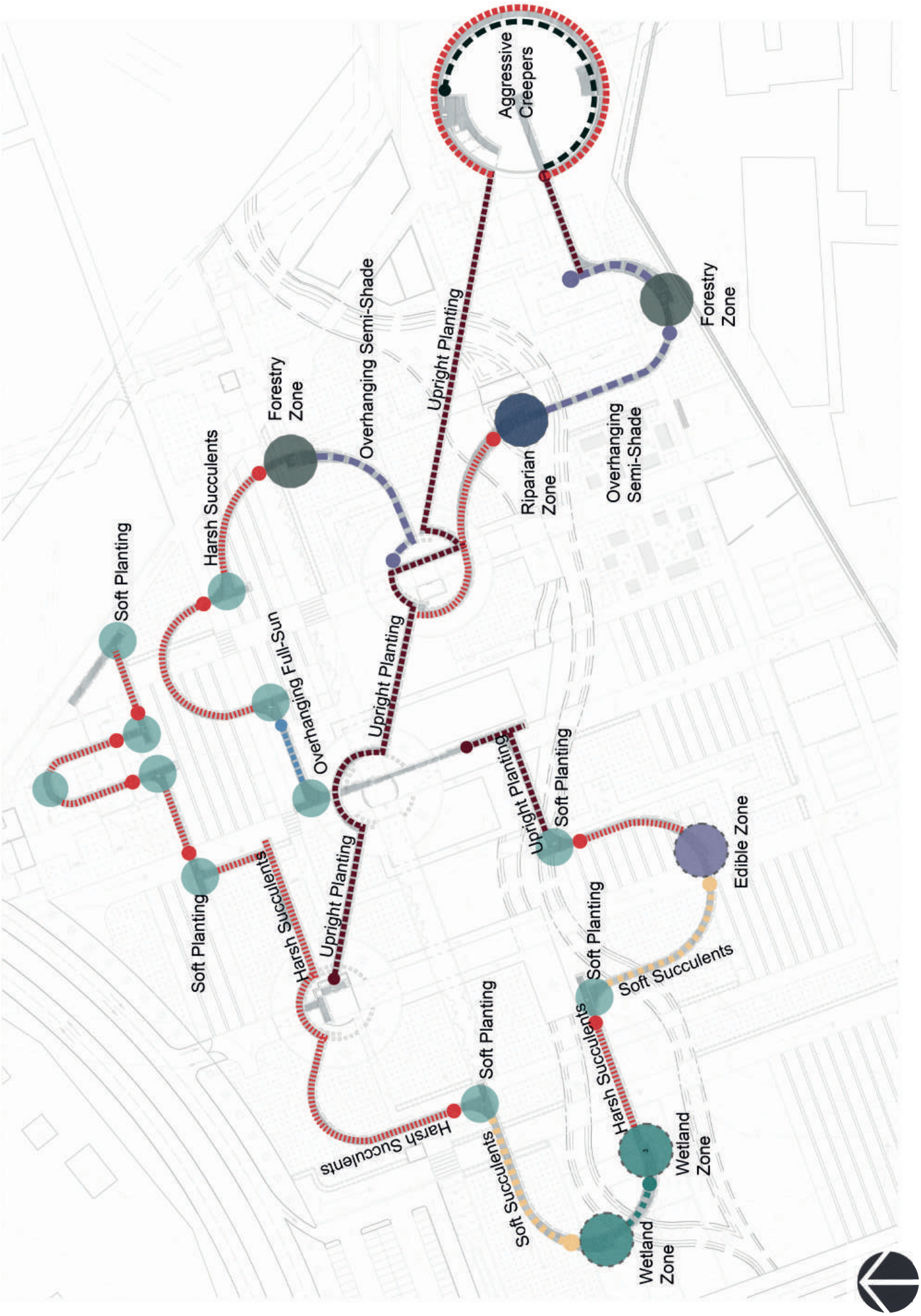


Figure-147: Image of the overall planting strategies prevalent on the Carbon Skywalk.

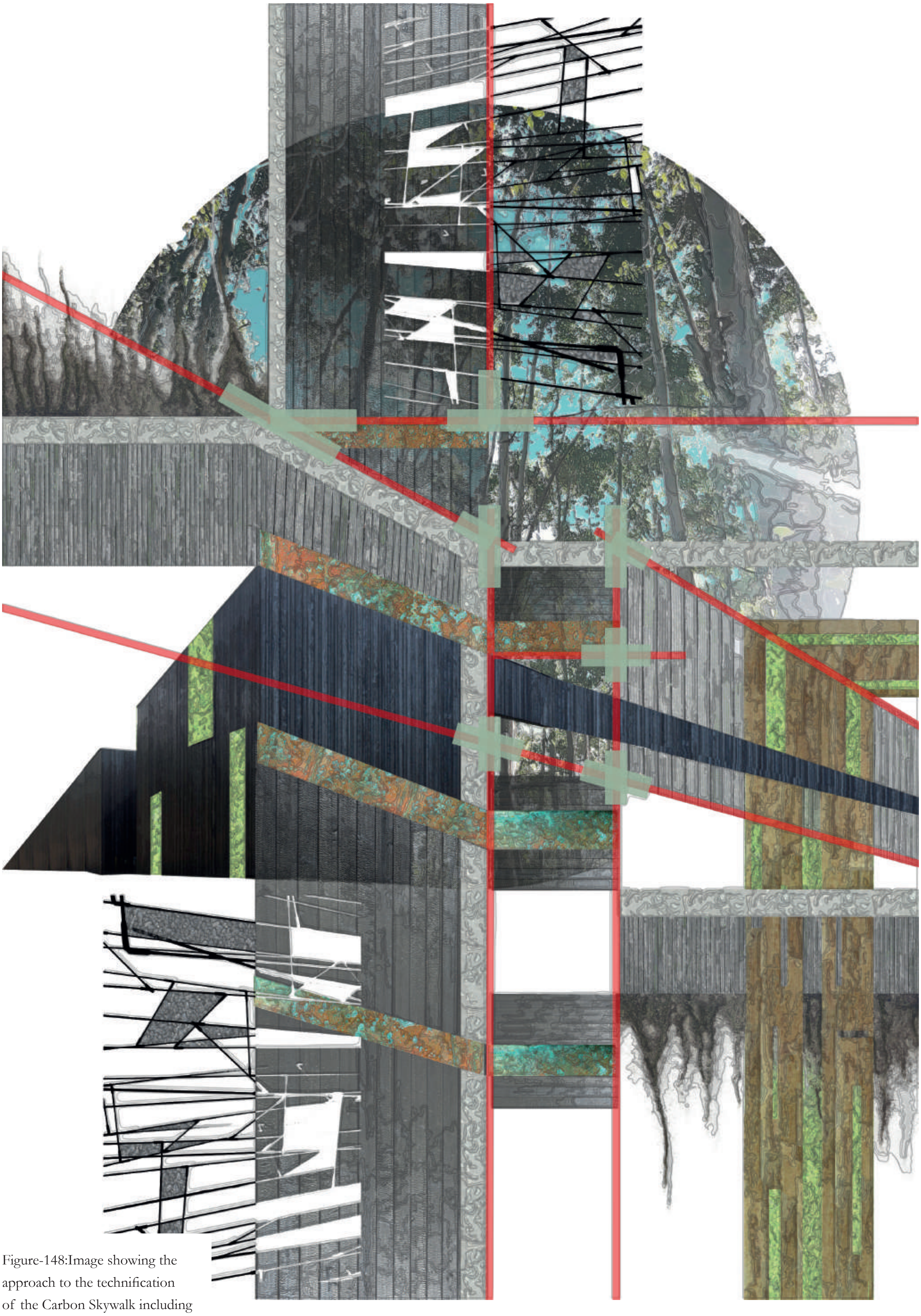


Figure-148:Image showing the approach to the technification of the Carbon Skywalk including materiality and form.

8.4-TECHNICAL INVESTIGATION

The Concept:
How does one feel and experience carbon sequestration? This is a question which guided the narrative of the Carbon Skywalk and this directed the approach to the technification of the Carbon Walk as well. It became necessary in this case to create a boardwalk which is not only structurally sound but also appropriate to the industrial nature of its context through form and material use. (Figure: 148)

The Structure and Form:
The structure of the Carbon Skywalk evolved from a local precedent in the form of the Boomslang canopy walkway, designed by architect Mark Thomas and structural engineer Henry Fagan, located in the Kirstenbosch Botanical Gardens (Figure: 149 & 150). The Boomslang's structure essentially consists of three components, a spine (hot rolled structural round tubing) and two rib cages pre-cut galvanised mild steel plates which are fixed to the spine. The approach to the Carbon Skywalk's structure is similar to this however, the form of these components is altered to be more appropriate to the industrial nature of Pretoria West. The angularity of the structure and balustrade posts is inspired by the nature of the industrial buildings within the context of Pretoria West (Figure: 151).

The Materiality:
Material choice for the Carbon Skywalk was driven by two factors namely: the pragmatics of the structure and the conceptual approach. The materials chosen are as follows: mild steel for the structural elements, chosen for its structural properties; pine for the walkway surface and balustrades, chosen for its inherent carbon storage and availability; and lightweight concrete for the walkway planters and screen walls, chosen for its robust nature and weight properties. On top of the pragmatic selection of the material choice, it is

Figure-149: Section perspective showing the rationale of the Boomslang in Kirstenbosch Botanical Gardens.

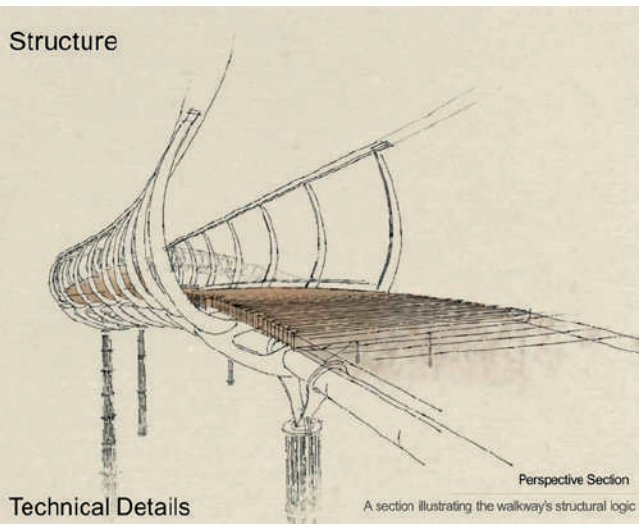
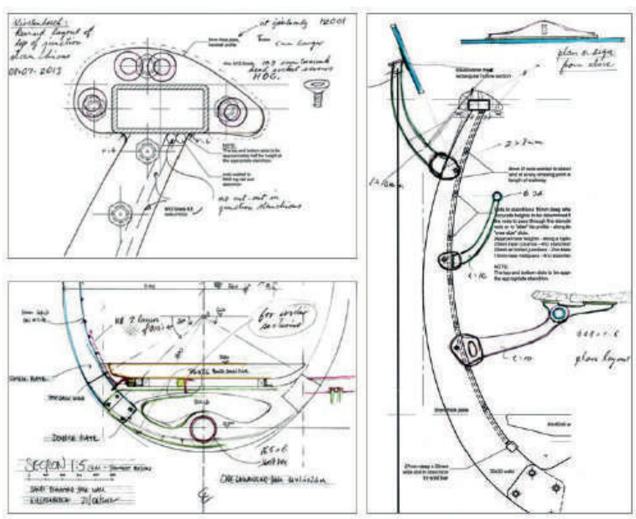


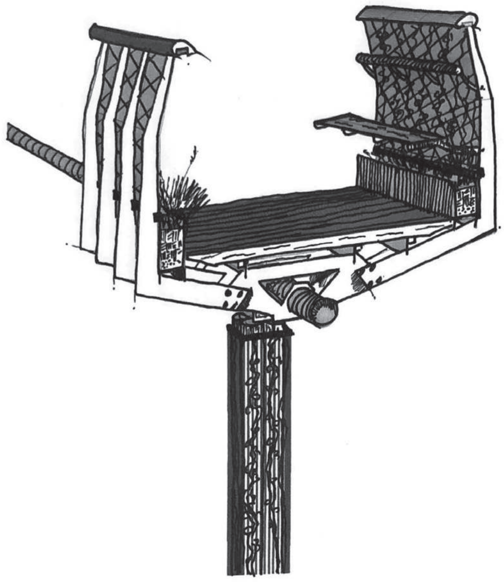
Figure-150: Technical details of the Boomslang in Kirstenbosch Botanical Gardens.

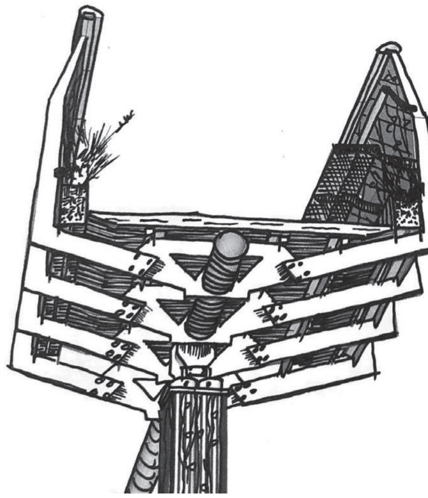


also conceptually driven. The steel and concrete speak to the nature of the industrial context as well as the original materials used for the power stations buildings. The pine speaks to the programme of the Carbon Farm, a productive landscape dominated by plantations. The material narrative is therefore a gradual transition from the past to the future. All these materials are sourced locally from within Pretoria West.

Finishing:
To further highlight the conceptual approach of the Carbon Walk, the finishing of the steel, timber and concrete became an important factor. The steel is initially hot dipped galvanised and then powder coated in red to emphasize the design form and to make it clearly distinguishable from the timber. The red colour is similar in nature to the red of the face bricks used for the construction of the power station buildings. The finish of the timber is what is known as Shou Sugi Ban or carbonised timber. This involves the charring of the surface of the timber by burning it with fire then sealing it with a boiled linseed oil. The charring of the surface brings out the grain of the timber but also waterproofs it ensuring longevity in outdoor conditions. This approach also embodies and communicates the idea of carbon sequestration in timber which is an important factor in the narrative of the Carbon Skywalk. The finish on the concrete is board-formed using pine planks in the formwork to give a timber texture to the concrete.

Joints and Fixings
The rationale behind the joints between the steel, timber and concrete is once again to ensure that there is clear distinguishability between each of the materials. The joints are therefore purposefully blatant in nature and allow the observer to able to notice them whether from below or atop the Carbon Skywalk.





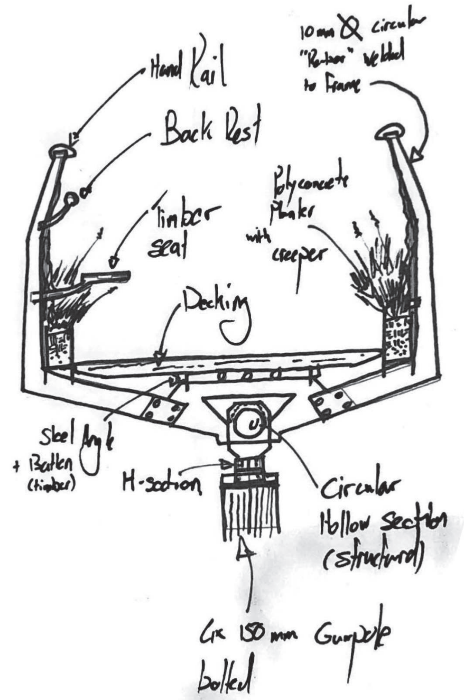


Figure-151: Initial explorations at adapting the Boomslang's structure to be more context specific in terms of form. Planters added to reinforce the concept of growth.

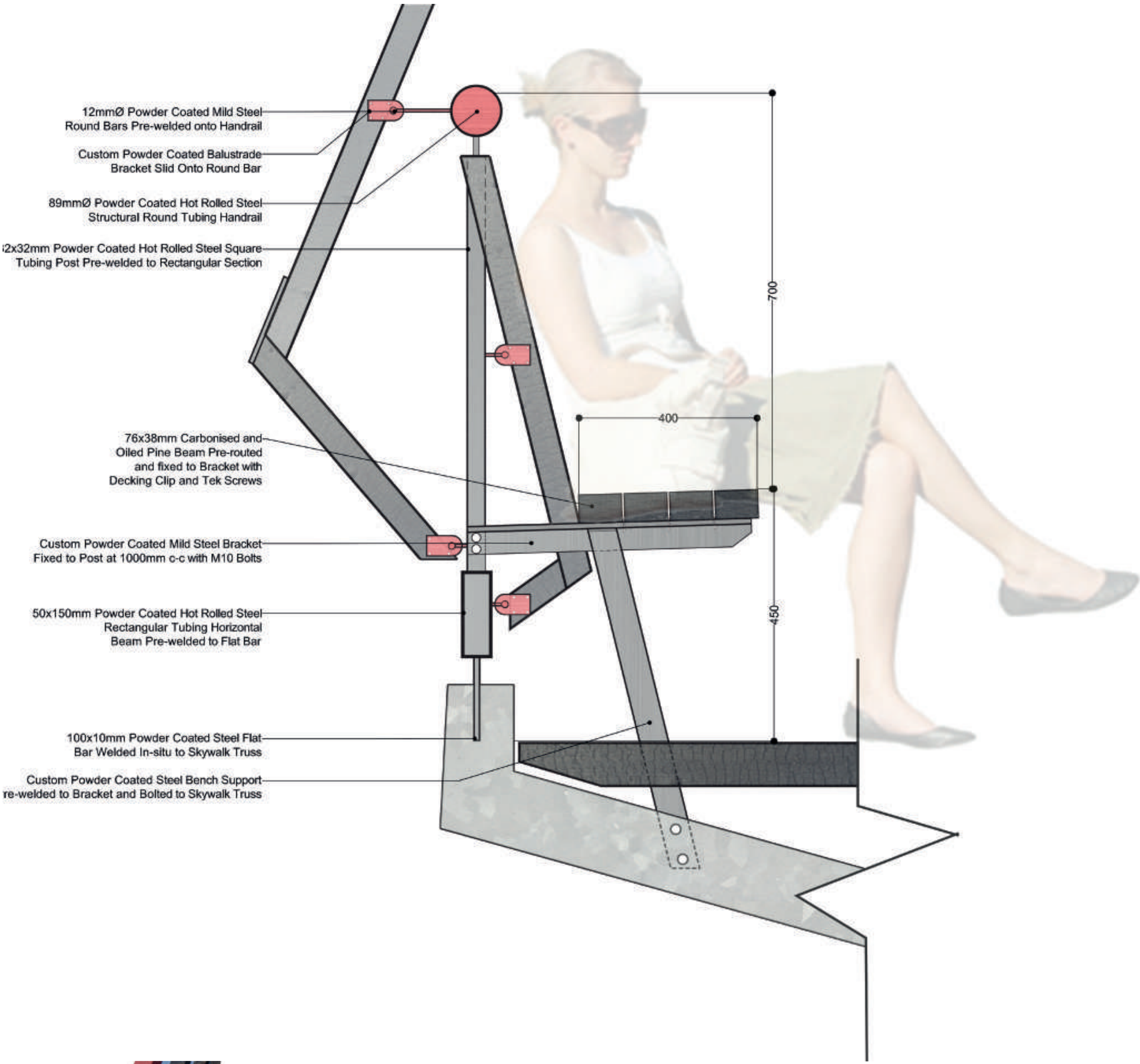


Figure-152: Typical detail section and perspective view through carbon sequestration zone seating area. (NTS)

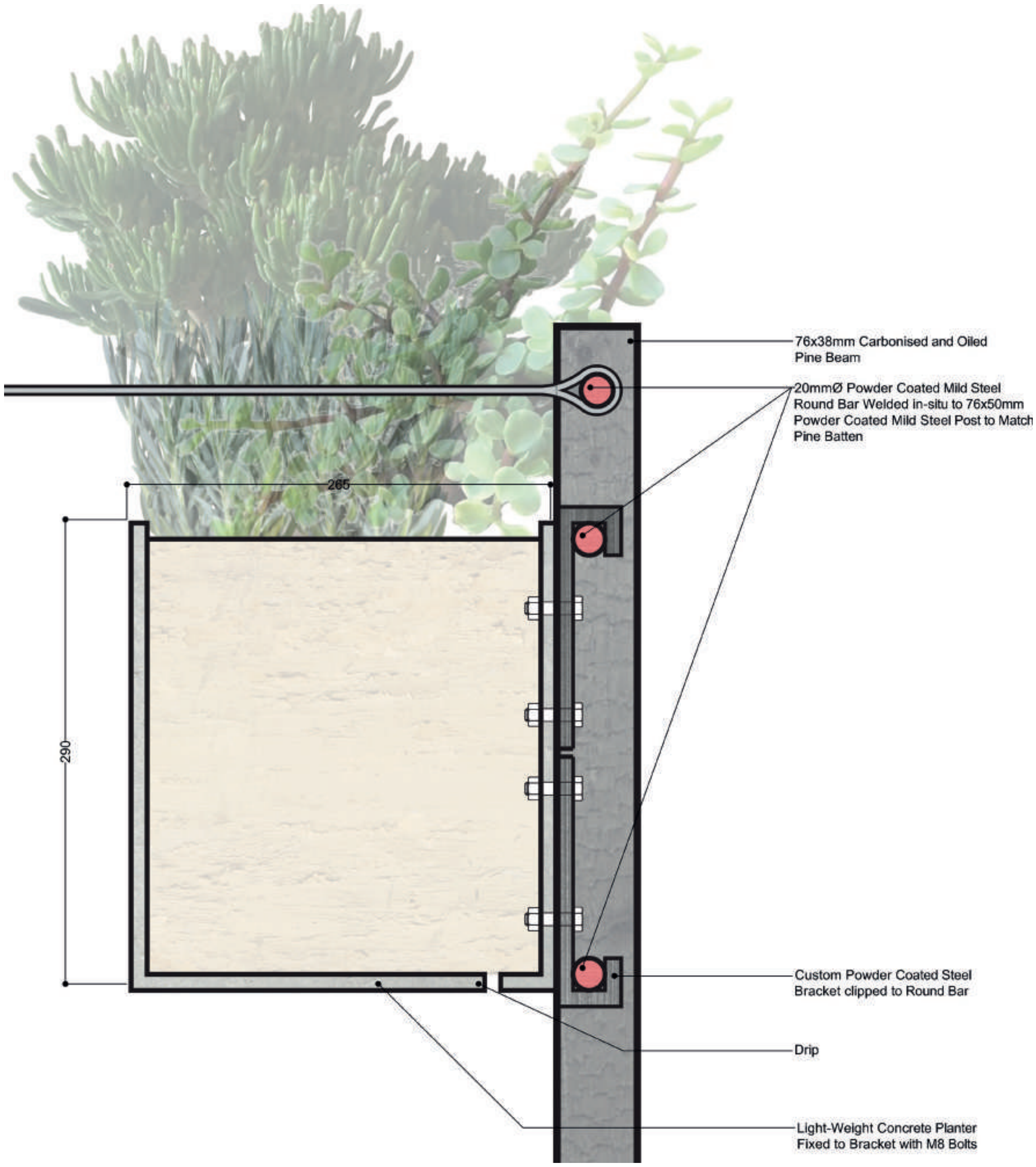


Figure-153: Typical detail section and perspective view through carbon sequestration zone suspended planter. (NTS)

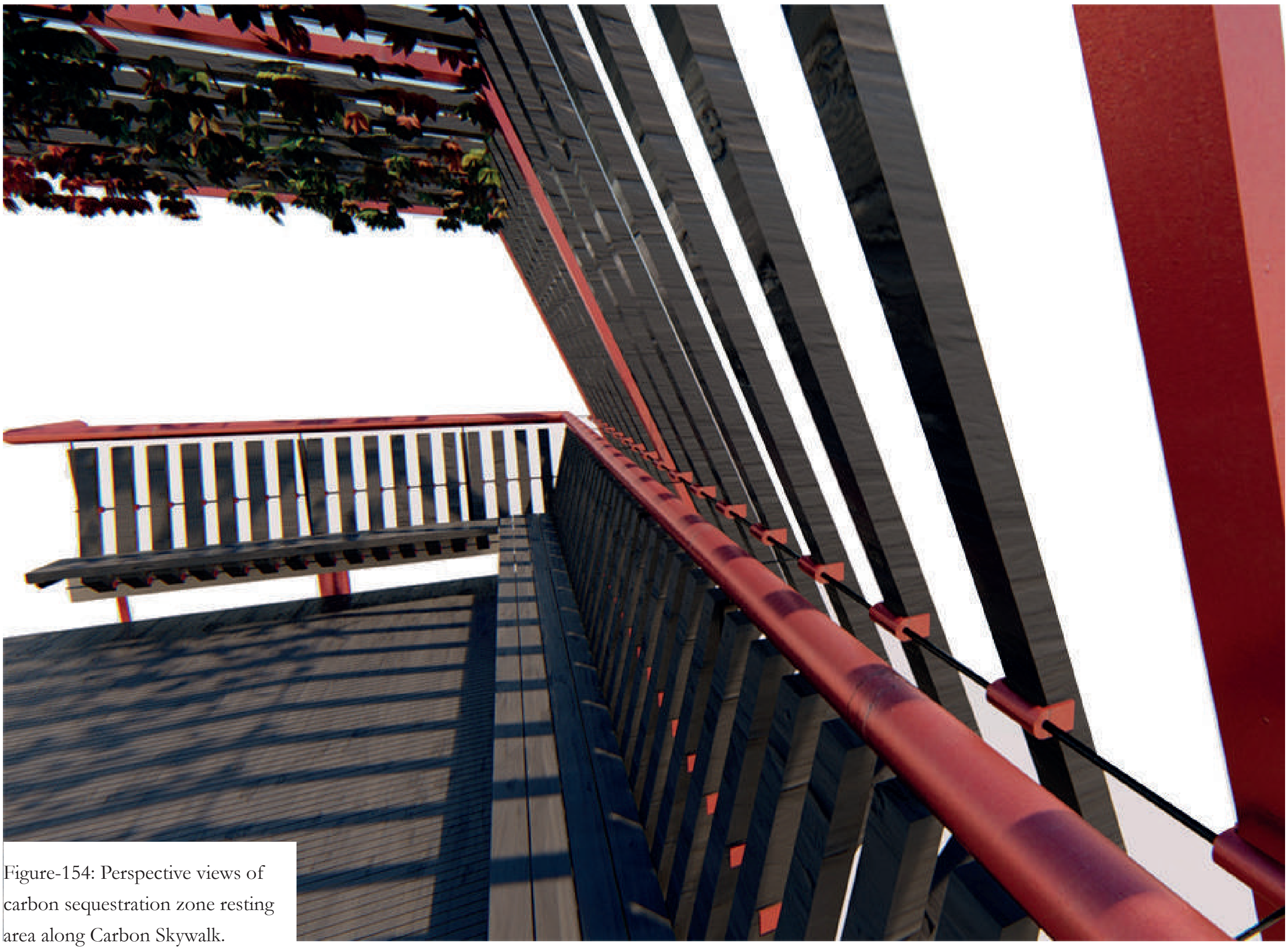


Figure-154: Perspective views of carbon sequestration zone resting area along Carbon Skywalk.

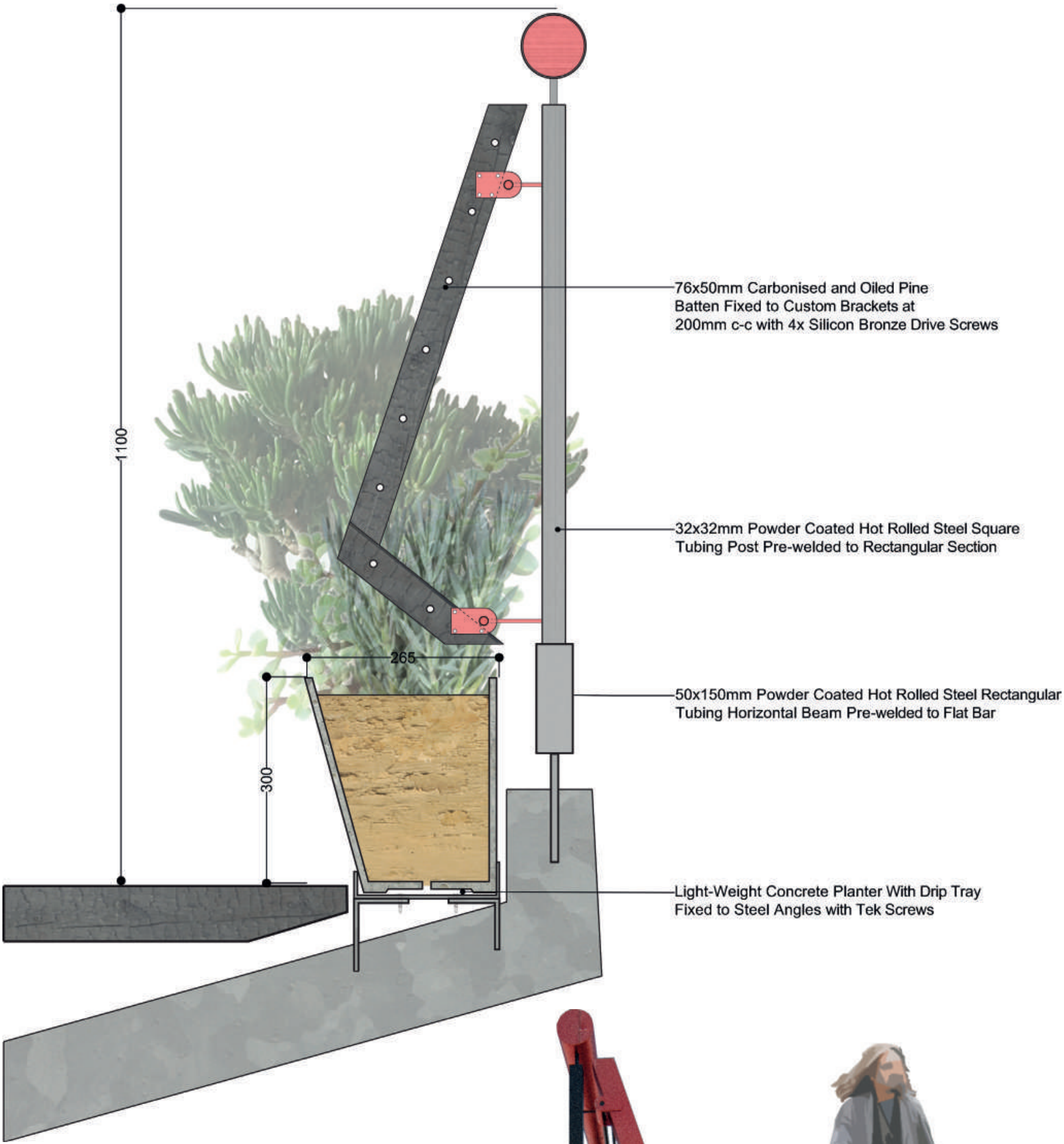


Figure-155: Typical section (NTS) and perspective view of standard balustrade on the Carbon Skywalk.

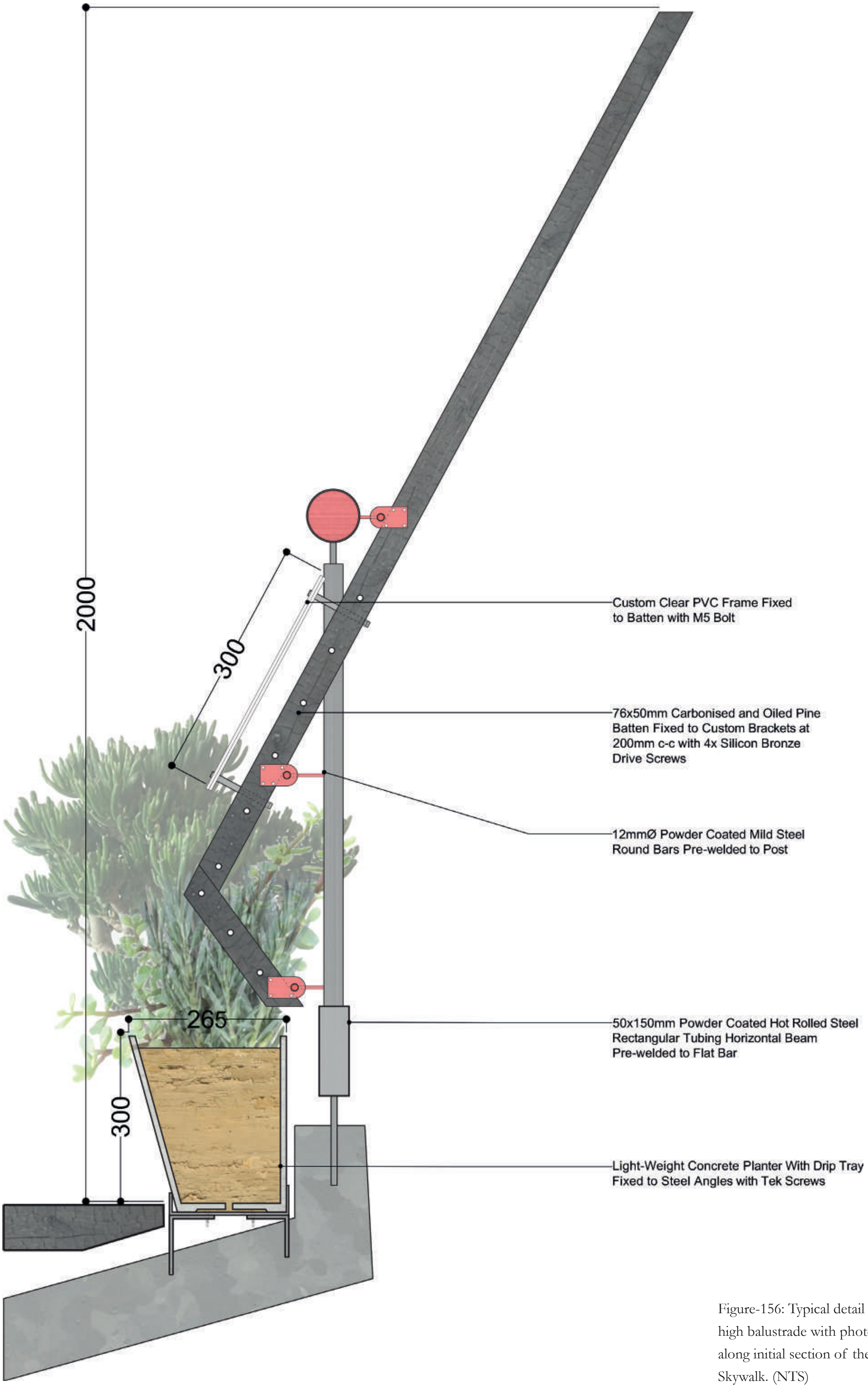


Figure-156: Typical detail section of high balustrade with photo frame along initial section of the Carbon Skywalk. (NTS)

Figure-157: Perspective views of the high balustrades and photo frame details along initial section of the Carbon Skywalk.

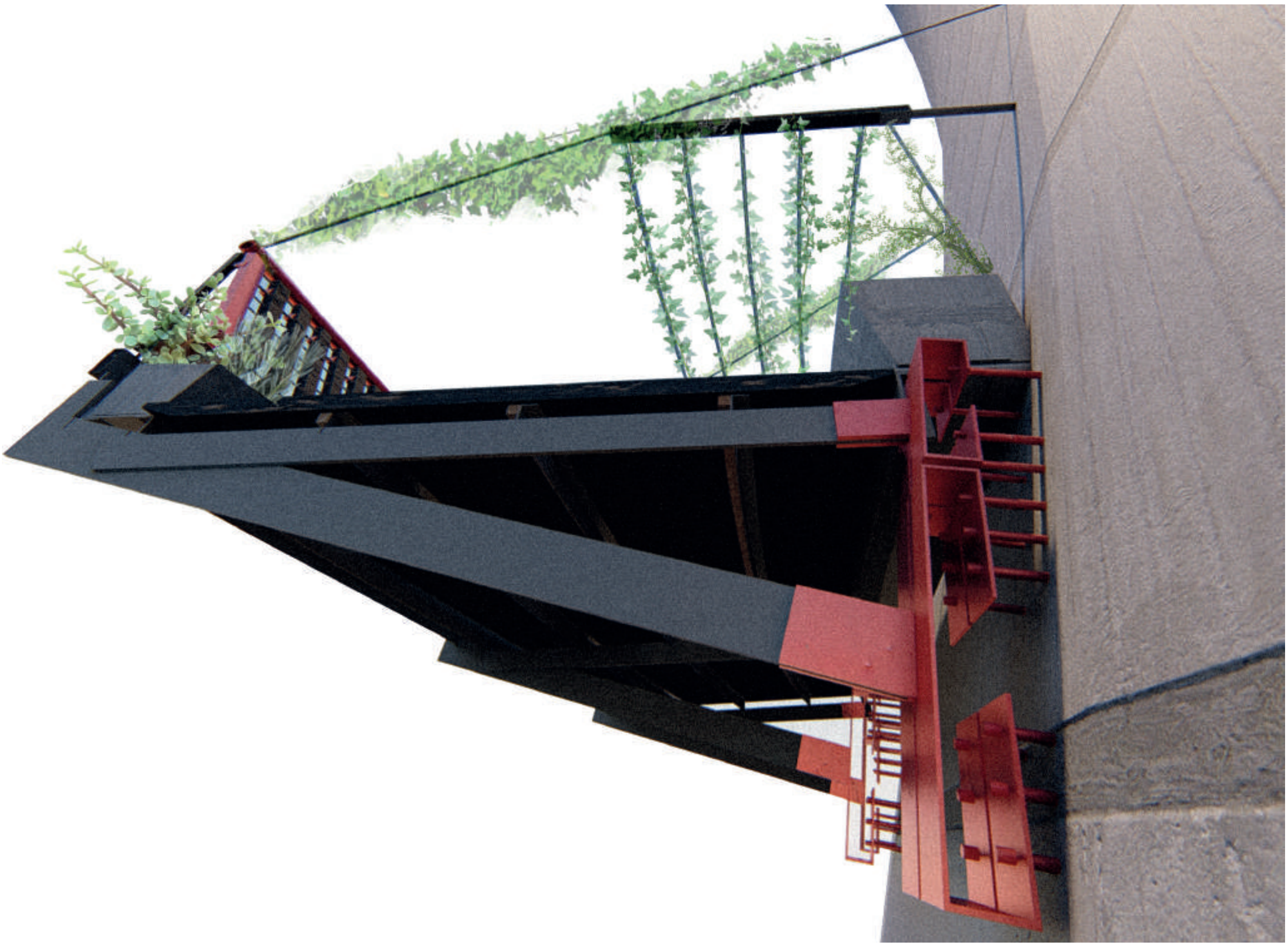


Figure-158: Perspective detail views of the Carbon Skywalk's connections to the cooling tower.

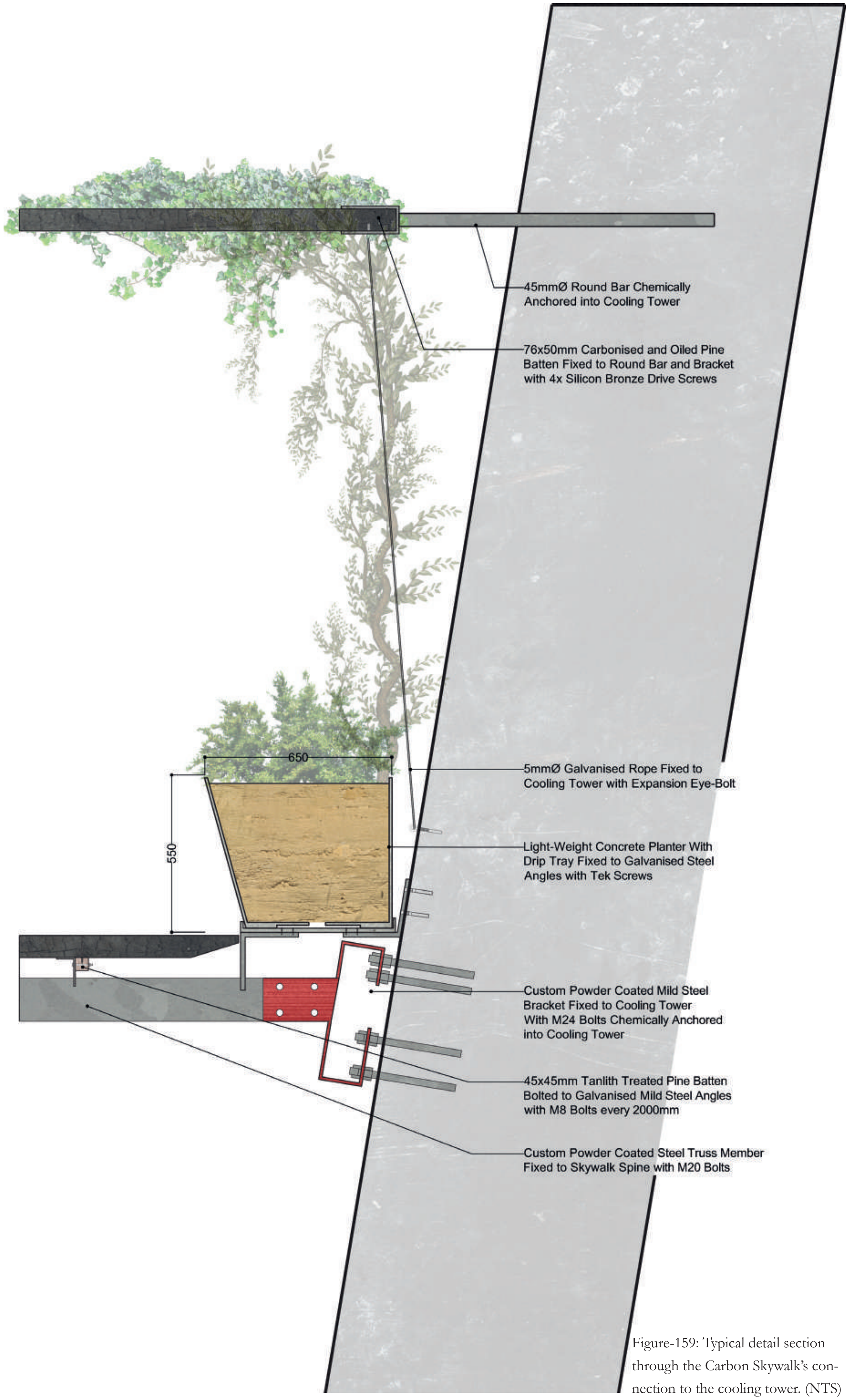


Figure-159: Typical detail section through the Carbon Skywalk's connection to the cooling tower. (NTS)

Figure-160: Perspective views of the seating details along the Carbon Skywalk.

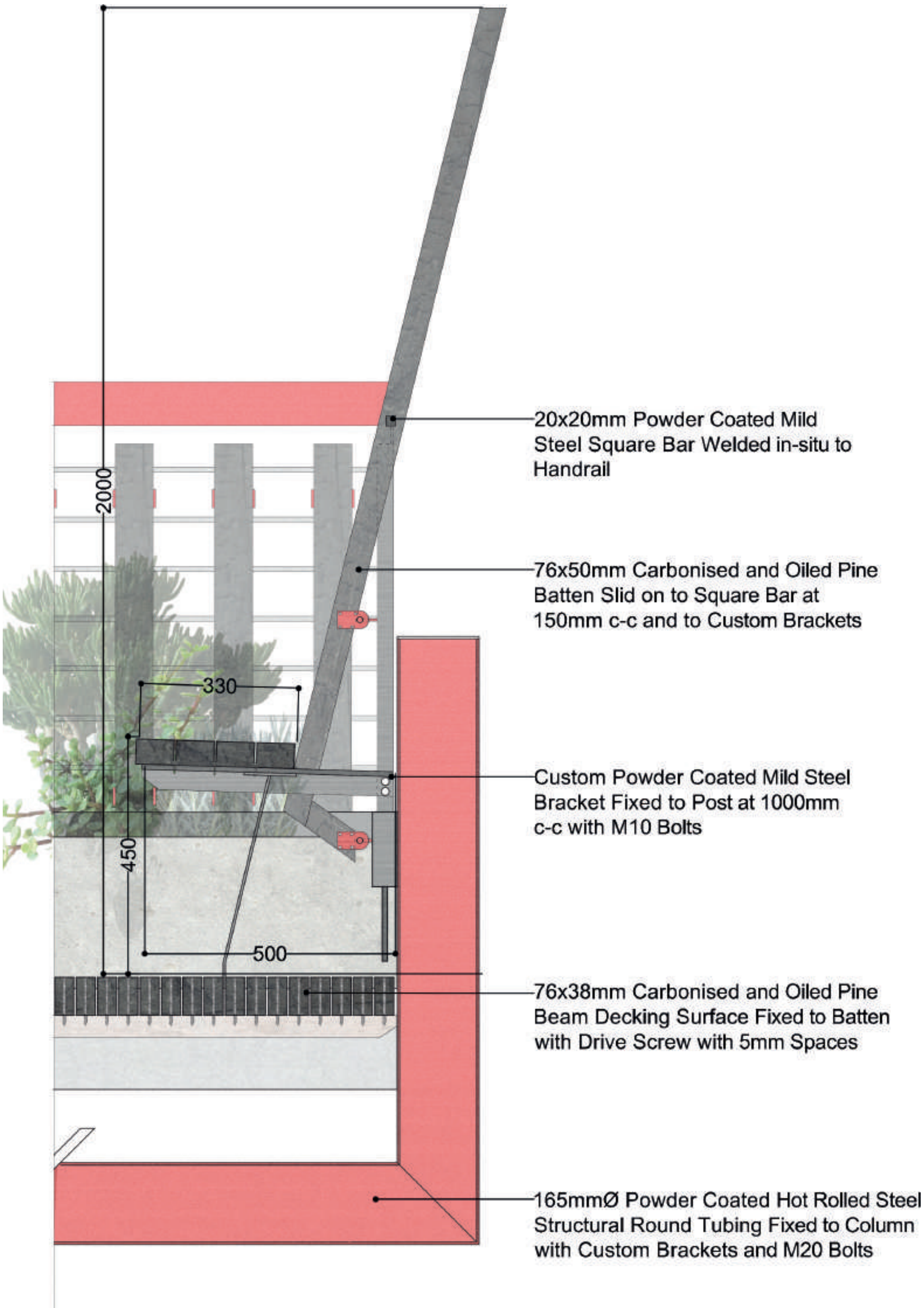


Figure-161: Typical detail section through a bench in a junction zone of the Carbon Walk. (NTS)

Basic Method of Assembly

Step 1: The columns are fixed to submerged in-situ concrete footings, at roughly 12 metre centre-to-centre, with HILTI HIT-Z-R M20 stainless metric anchor rod drilled into concrete footing (Figure: 162)

Step 2: The initial pre-bent spine sections are then lifted by a small crane and fixed to columns via the support bracket with 8x M16 galvanised hex bolt and nut. Spine sections are to have a 2.5 metre cantilever on either side of column (Figure: 163)

Step 3: The in-between spine sections at 5 metre lengths are raised and connected to initial spine sections via custom joint brackets bolted together with M10 galvanised hex bolt and nuts (Figure: 164)

Step 4: The trusses are raised and fixed to spine with M16 galvanised hex bolts and nuts (Figures: 165 and 166)

Step 5: Pre-bent mild steel angles are placed into pre-cut slots in the spine and truss structures (Figure: 167)

Step 6: 44x44mm tanalith treated curved timber battens are then fixed to central mild steel angles with galvanised tek screw hex bot and nut at 1000mm c-c (Figure: 167)

Step 7: 38x76mm carbonised structural pine beams are twice fixed to the 44x44mm timber battens beneath at c-c distance varies according to curve of walkway with number 10 galvanised wood screws counter sunk and filled (Figure: 168)

Step 8: The pre-assembled and finished steel balustrade support structure is raised and placed into the pre-cut slots in trusses. The balustrade supports are assembled in 2 metre lengths (Figure: 169).

Step 9: The pre-manufactured concrete planters and drip-trays are placed on top of the mild steel angles (Figure: 170).

Step 10: Carbonised pine balustrade posts are fixed to the steel balustrade support structure with custom galvanised mild steel brackets. The posts are fixed to the bracket with galvanised wood screws (Figure: 171)

Step 11: 5mm diameter galvanised steel cable is threaded through pre-drilled holes in balustrade posts and connected to steel balustrade support structure every 10 metres (Figure: 172).

Step 12: The planters are filled with appropriate soils, mulch and irrigation system connected from cable trays below decking structure (Figure: 173).

Step 13: The planters are then filled with the selected plant species (Figure: 173).

Step 14: The balustrade and decking beams are finally finished with 3 coats of boiled linseed oil.

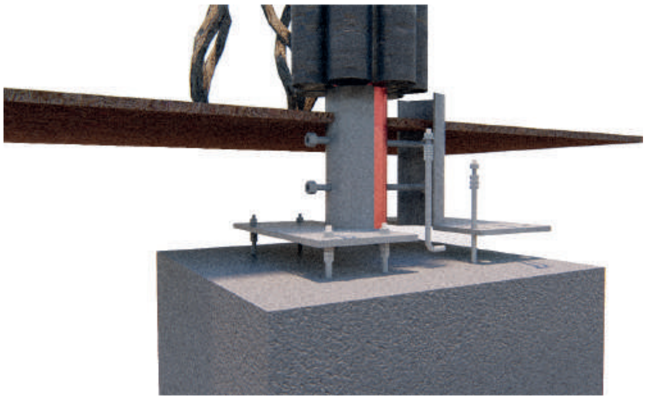


Figure-162: Step 1- The columns being fixed to the concrete footing.

Figure-163: Step 2- Fixing the structural round tubing spine to columns with the custom brackets.

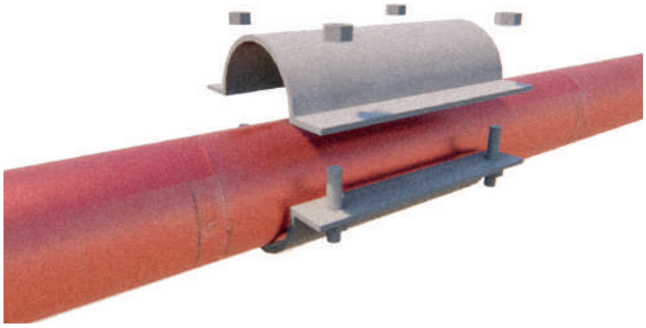


Figure-164: Step 3- Connecting the 5m lengths of structural round tubing with custom brackets

Figure-165: Step 4- Attaching the initial truss elements to the structural round tubing.

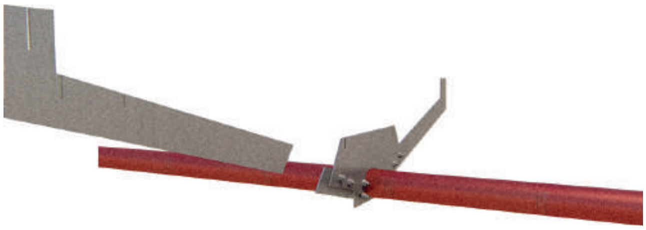


Figure-166: Step 4 continued- Attaching the truss arms to the initial truss structure.

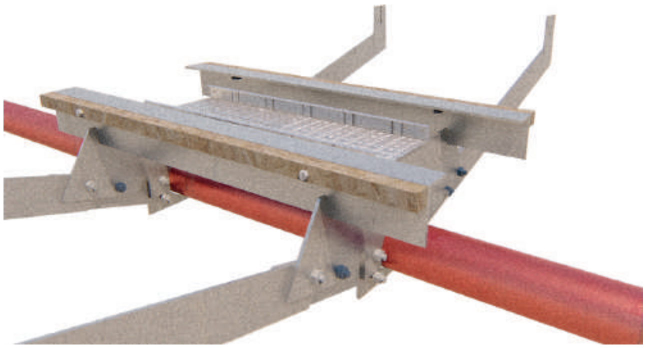


Figure-167: Steps 5 & 6- Placing of pre-bent steel angles and 44x44mm curved timber battens as decking support.

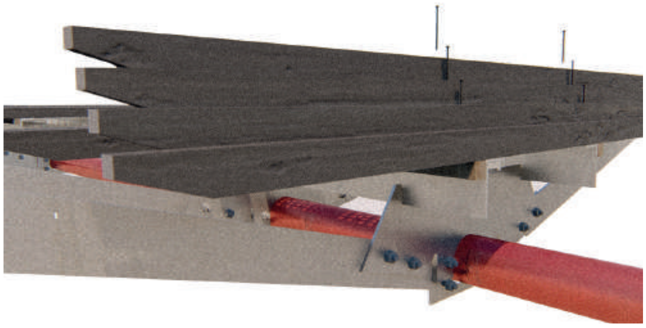


Figure-168: Step 7- Attaching the 38x76mm structural pine decking planks to the timber battens with wood screws.

Figure-169: Step 8- Placement of pre-assembled balustrade support structures.

Figure-170: Step 9- Placement of pre-manufactured lightweight concrete planters and drip trays.

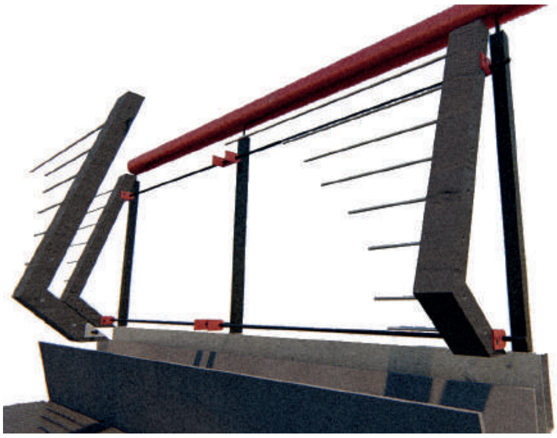


Figure-171: Step 10- Attachment of the pine balustrade to the balustrade support structure via custom steel brackets.

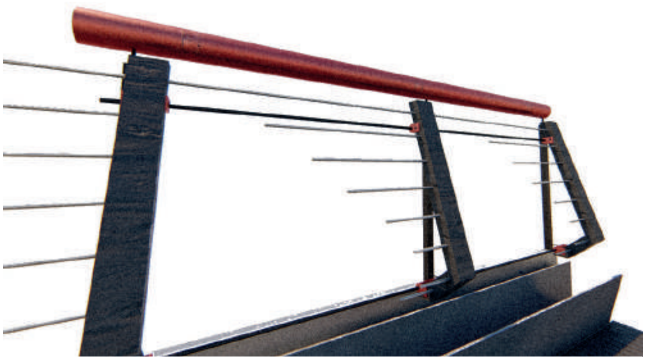


Figure-172: Step 11- Threading of galvanised steel rope through pre-drilled holes in the balustrade posts.

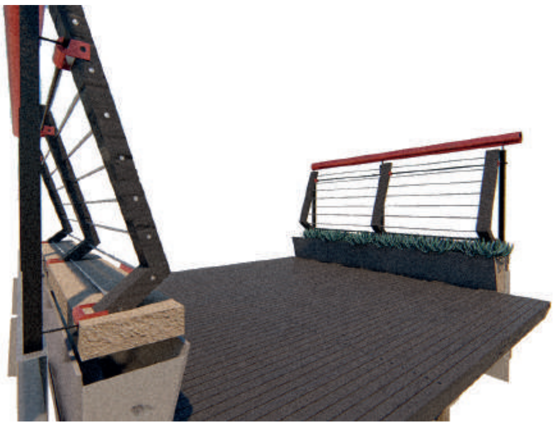


Figure-173: Steps 12 & 13- Filling of concrete planters with the appropriate soils as well as the selected plant species.

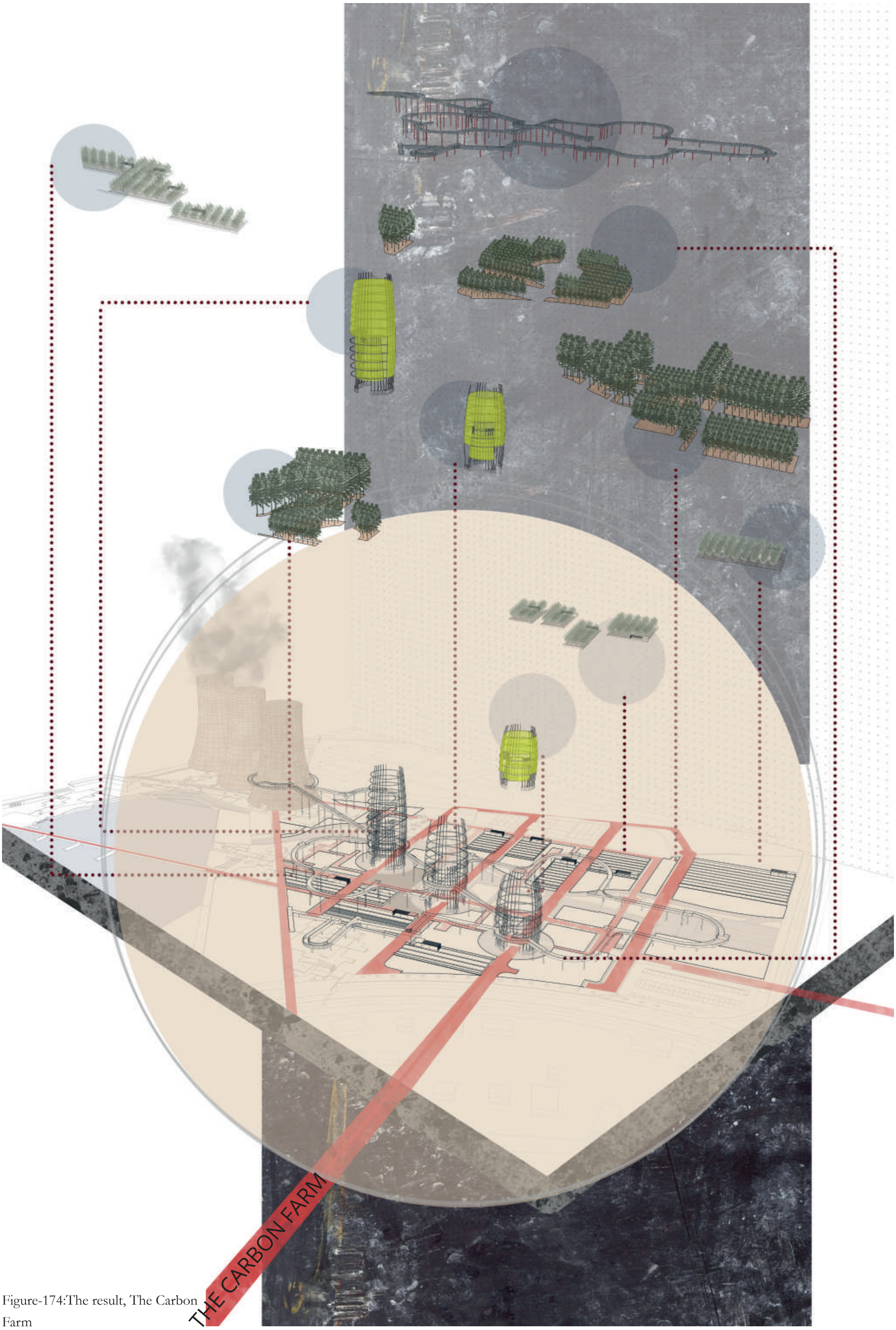
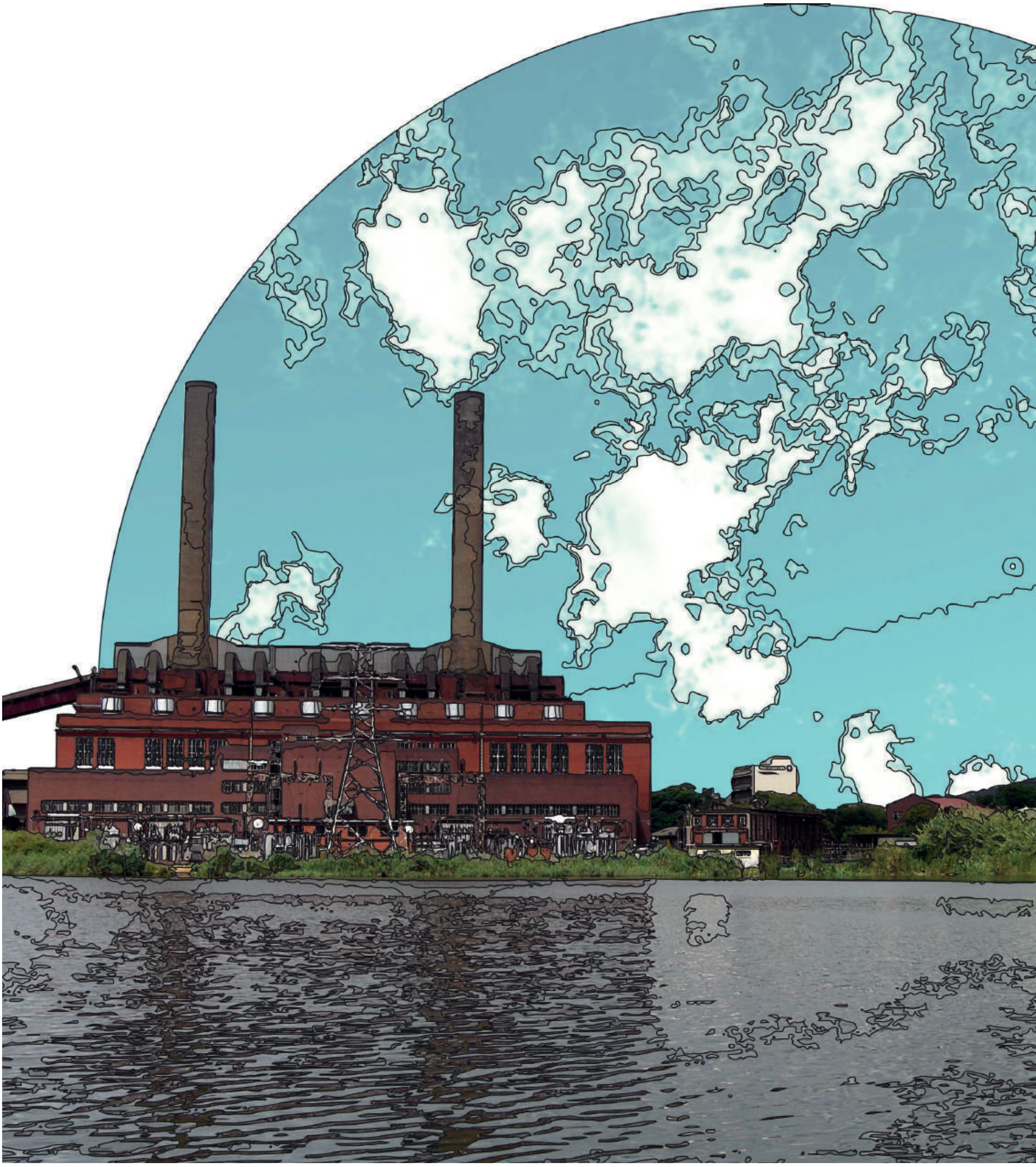


Figure-174:The result, The Carbon Farm



CHAPTER 9- CONCLUSION

This chapter concludes the dissertation by summarising the outcomes of the study as well as the resultant design intervention.

This dissertation sought to define a new approach to the urban productive landscape, one which is intensely focused on carbon sequestration, on an industrial site that is synonymous with carbon emissions.

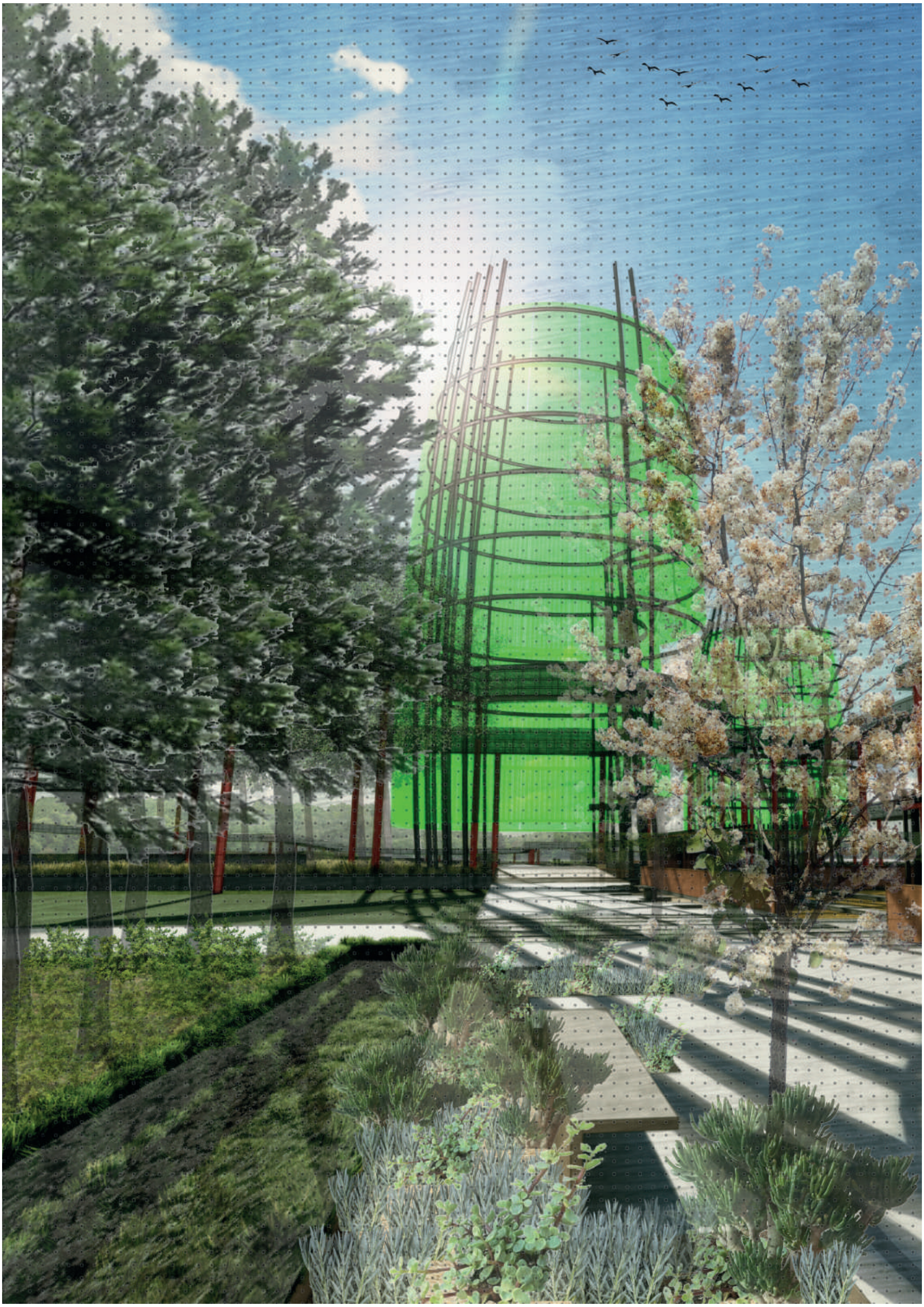
The dissertation identified the need for active carbon sequestration within the industry-focused Pretoria West region, by recognizing the carbon emissions of the more prominent emitters within its borders. Notably, there are currently an insufficient number of trees within the greater Pretoria West region in order to effectively sequester the amount of carbon currently being produced.

The research highlighted the effectiveness of urban forestry in the reduction of atmospheric carbon and discovered a set of guidelines to optimise the process of carbon sequestration. The research, however, looked beyond carbon sequestration, and discovered guidelines to enhance biodiversity as well as climate change adaption to address aspects of human well-being as well as site health and rehabilitation through the enhancement of ecosystem services and functions.

The Carbon Farm is inspired by the UN-REDD+ mechanism and seeks to address the social issue of urban food security in Tshwane by applying principles of agroforestry in order to enhance food production. This gives opportunity for self-sufficiency and income generation for the surrounding populace. Coupled with the application of productive forestry and algae farming, the Carbon Farm will insure that carbon sequestration is maximised. The social focus of the UN-REDD+ mechanism emphasizes the need for the landscape to be a place for social interaction, hence the Carbon Farm includes public open spaces such as piazza spaces, lawn commons, an area for swimming and kayaking as well as a jogging, walking and a cycling route. The design proposals that includes algae towers and a Carbon skywalk enhances the appeal of the farm to attract a wider range of users. This provides the opportunity of educating the user on the importance of carbon sequestration and reduction of emissions. Visitors can purchase some of the carefully selected plant species found in the landscape from the nursery, thus contributing to the enhancement of carbon sequestration and biodiversity beyond the borders of the Carbon Farm.

The on-site processing of the harvested timber as well as the bio-fuel and algae processing plants ensured that the Carbon Farm can function as an efficient system minimising transport costs and emissions generally associated with raw material processing.

In closing, the Pretoria West Power Station is a historical landmark within Pretoria. Its vastly underutilised landscape has the potential to become something which both literally and metaphorically offsets its past transgressions in terms of its impact on the atmosphere. The Carbon Farm challenges the way industrial landscapes are viewed, from a highly polluted landscape which should be situated on the outskirts of cities, to a landscape which is greatly efficient, clean and attractive to a general populace whilst ensuring that emissions created are absorbed in-situ. It is the hope of the author that the Carbon Farm and the principles applied in terms of carbon sequestration, biodiversity enhancement and climate change adaption can be seen as a prototypical urban productive landscape, which can be considered as part of the UN-REDD+ mechanism.



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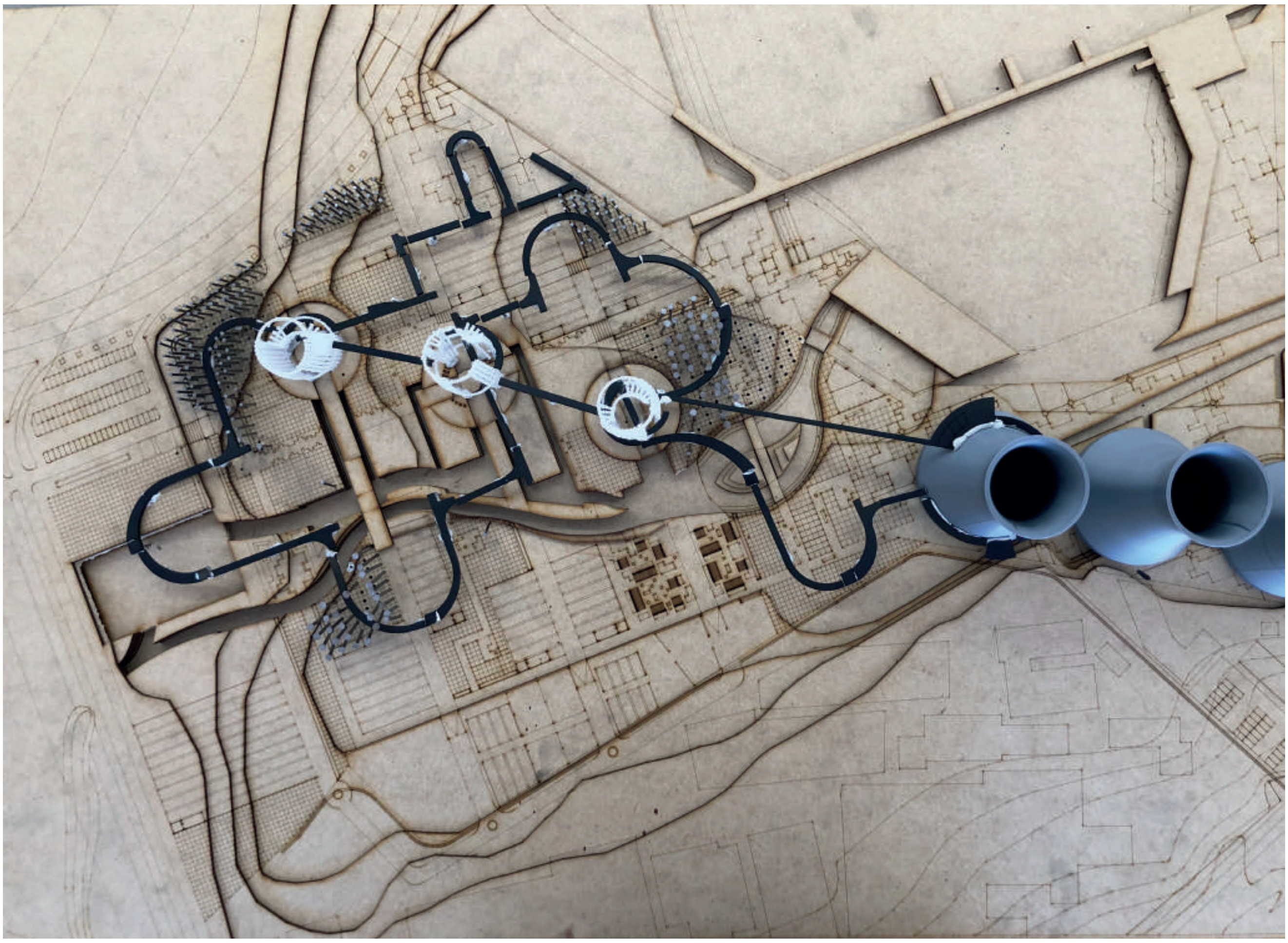

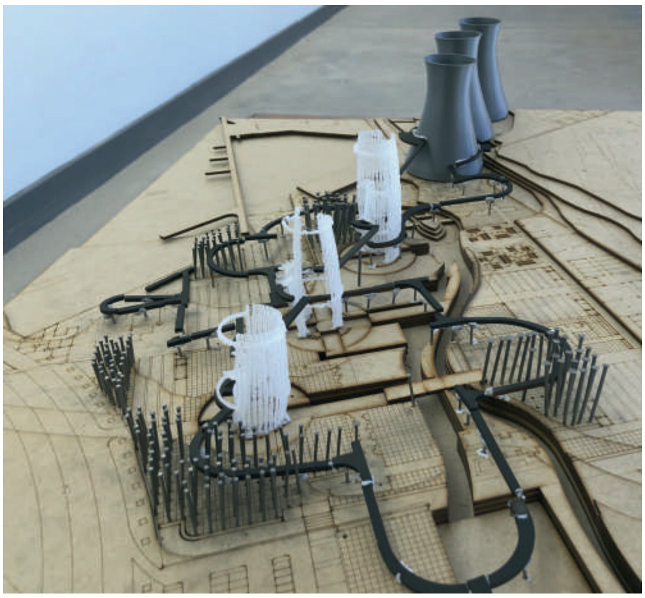

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