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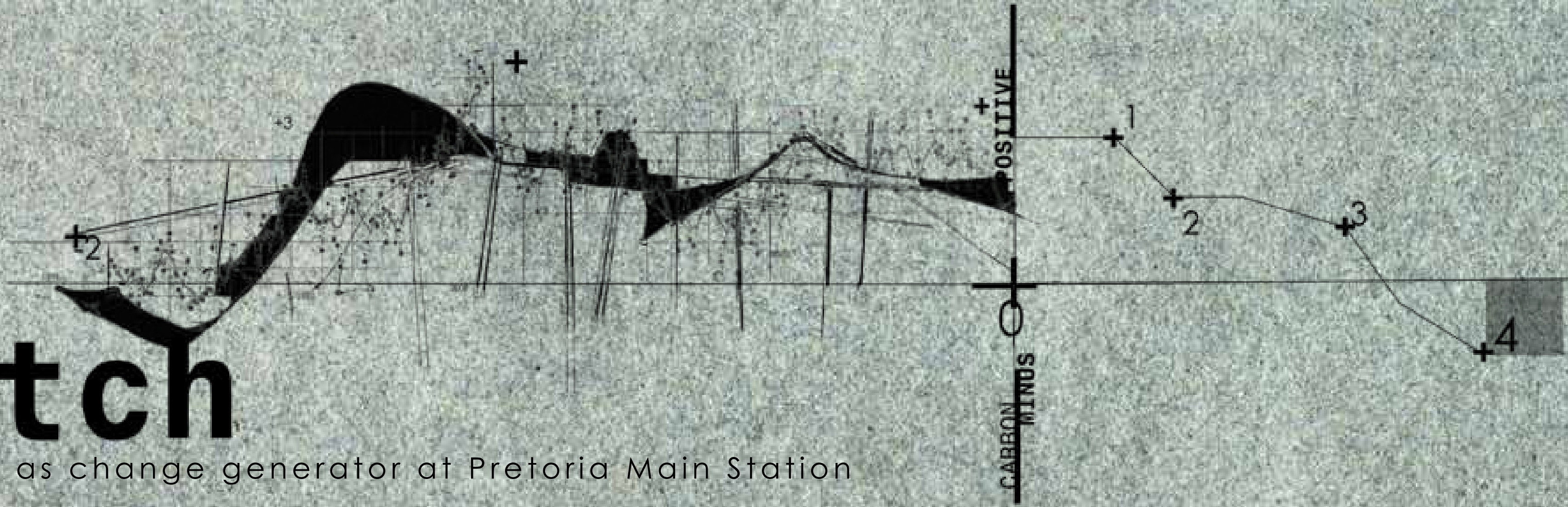

switch

a BRT terminal as change generator at Pretoria Main Station

jm hugo 2010

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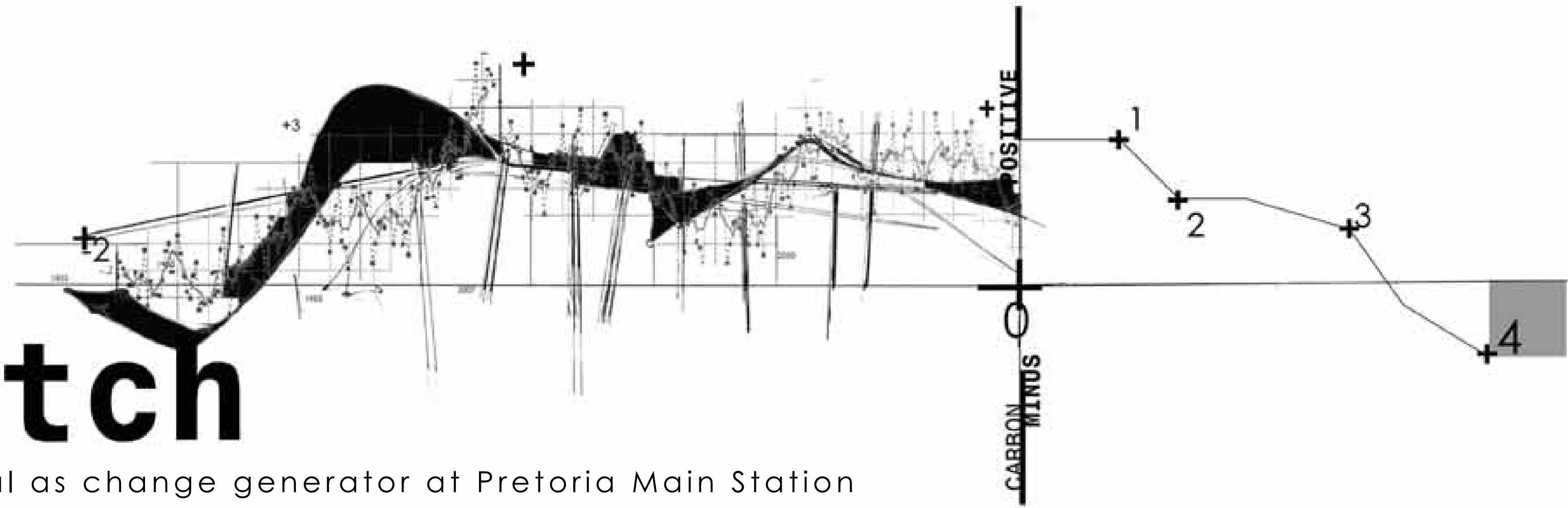

switch

a BRT terminal as change generator at Pretoria Main Station

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STUDENT	Jan Marais Hugo
STUDY LEADERS:	DR H STOFFBERG A BARKER
STUDY FIELD:	Environmental Potential

University of Pretoria
2010

Submitted in partial fulfillment of the requirements for the degree of Magister in Architecture (Professional) in the Faculty of Engineering, Built Environment and Information Technology
University of Pretoria
November 2010

A I

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Keywords
Transport, Bus Rapid Transport System, linking structure, low carbon, embodied energy, climate change.

The study responds to the increasing effect that climate change has on earth and society. In a global context of rapid urbanization and population growth the project aims to establish the role that architecture can play in the mitigation of climate change. **It addresses the embodied energy and carbon footprint of architecture in an urban context.**

The architectural building type that will be investigated is a transport interchange, specifically the BRT terminal at Pretoria Main Station and associated prototypical BRT stations. An architectural response that promotes public transport use will be investigated.

The proposed transport interchange will act as a seam to linking Salvokop with the city, while linking the whole of Tshwane.

The architectural intervention will use strategies to respond to predicted climate changes for Tshwane, and adopt strategies to mitigate it. Architectural technologies will be investigated to ensure that the structure has a low carbon footprint and low embodied energy.

Through energy conscious design strategies the energy use of the structure will be kept to a minimum.

The design will also address the social and historical context of the Pretoria Main Station, to ensure a coherent transport interchange that integrates all modes of transport.

The design will contribute to the historical character of the site with an ecosystemic layered approach, adding new functions and layers to the existing, to ensure its adaptability and sustainability.

This study forms the part of a departmental research study through the department of Architecture at Pretoria University - “Environmental potential” and the United Nations Development Programme [UNDP] and Global Environment Facility [GEF]. It aims to comply with the prerequisites for an M[Prof]Arch degree while achieving the goals and objectives set by the research study.

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This study is undertaken in partnership with the UNDP-GEF and the Environmental Potential Study Unit of the Department of Architecture, University of Pretoria.

Note: Refer to Appendix Page 288 for full proposal as submitted to UNDP-GEF

P I

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Low carbon Bus Rapid Transit Stations
UNDP/GEF Student Grant Project Proposal

The Research Objectives

The first objective of this study is to design, with recognition of the GEF BRT Climate change requirements, a low carbon Bus Rapid Transit Station and auxiliary building/s. The chosen site is that of the existing Pretoria Main Station. This Station serves as an interchange for the BRT systems and act as an integral transportation hub for other modes of transport.

The second objective of the study is to design the low carbon BRT Station and auxiliary building/s in such a way that some of the modules can be used as a prototype and/or model for other such nodal and modal interchanges.

The third objective is to respect the cultural and historical setting of the Pretoria Main Station and hence be sensitive in responding to its context.

The fourth objective is that the study should incorporate aspects of LEED [or other green building rating systems]. It should include a design approach and normative position regarding the cradle-to-grave definition of materials and their production and a low carbon footprint study. It must also address the embodied energy and life-cycle performance and management of these aspects within the architectural research and design resolution.

The fifth aim is that the student and the two study promoters attend a South African Green Building Council GreenStar course.

The anticipated approach to the research and methodology to be applied

The study will commence with a literature study and the gathering of data relevant to the design of a Climate Change sensitive low carbon BRT station and Auxiliary building/s.

After the literature study a design will commence. The design will be refined through an iterative process. The final design of the structures will be measured with a green building rating system. A set of developed detail technical drawings will be provided to support the design. The designed structures are academic investigations and will culminate in a mini dissertation and two publications to be submitted for peer reviewed publication in Architecture SA.

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Met dank aan my Skepper.
Dankie Ilse, Arthur, Hennie, Talita, Danica en my ouers.

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30-50% loss of global biodiversity [2100][1]

39% of world population exposed to rising sea levels[2]

50% less rain fed agriculture in Africa [2020][3]

250 million exposed to water shortages in Eastern Africa [2020][4]

150 million Environmental refugees [2050][5]

60% increase in CO2eq to 430 ppm [<1900 to 2006][6]

Hottest years ever recorded **[1998, 2002, 2003, 2004, 2005]**[7]

1.[Walker & King 2008:41 2]. [Roaf et al 2009:119] 3+4. [Ramos & Kahla 2009:262] 5. [Roaf et al 2009:135] 6.[Walker & King 2008:22] 7. [Roaf et al 2009:51]

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D E S I G N O F A

Intention: **LINKING STRUCTURE**
CONNECTING [place/movement/people]
CLIMATE CHANGE SENSITIVE
LOW CARBON INTERVENTION

B R T T E R M I N A L B U I L D I N G

Client: **CITY OF TSHWANE**
UNDP/GEF [UP RESEARCH PROPOSAL]
Site: **PRETORIA MAIN STATION**
Research field: **Environmental Potential**

C O N T E N T S

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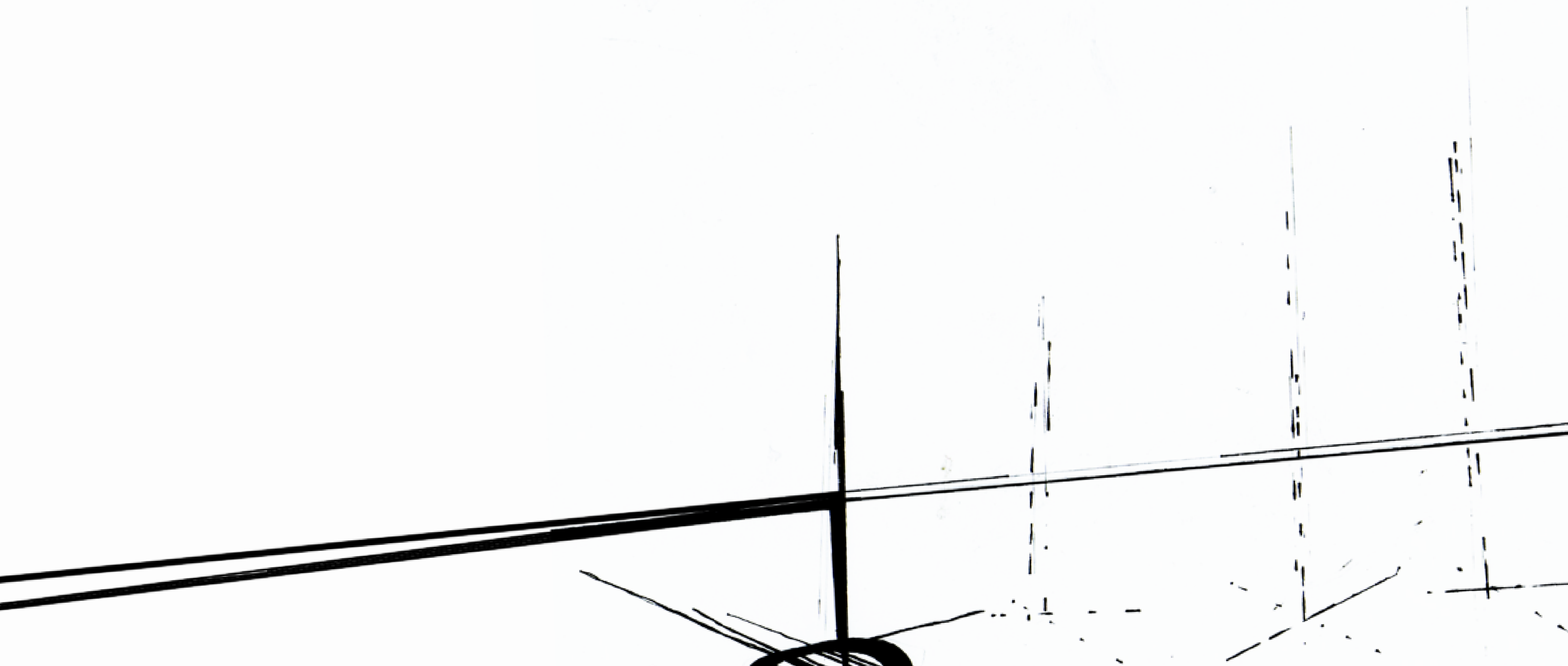
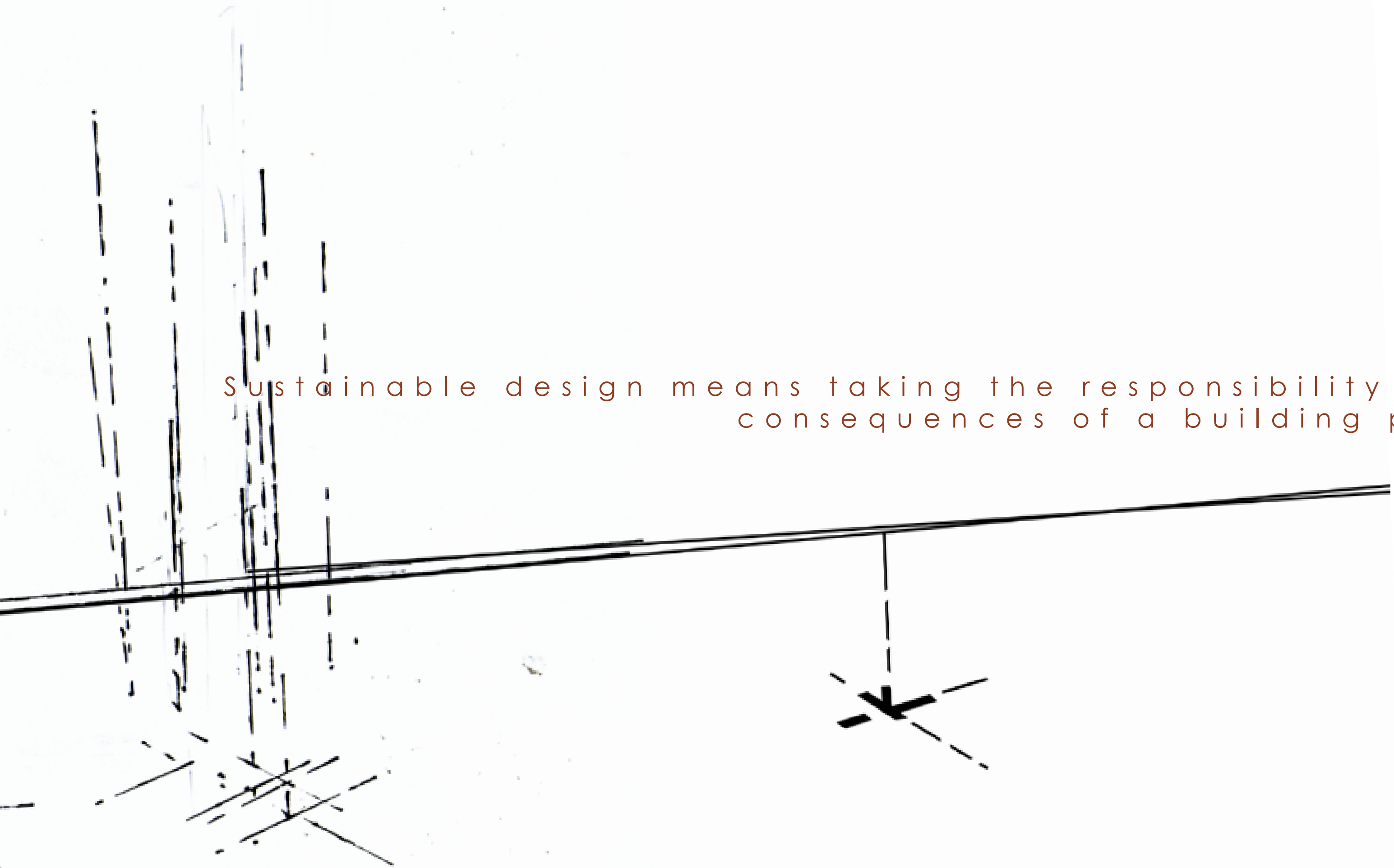


_ 1 CHANGING PARADIGMS



Sustainable design means taking the responsibility to anticipate the wide consequences of a building proposal...

[Bennet 2003:126]

1.1 INTRODUCTION

Changes occur daily.
Fast!
Other times very slowly.

Out of changes revolutions are born.

The human race is at a point in history where paradigms are going to be shifted, societies will change, and lifestyles are going to be turned around.

And the unimaginable will become a daily ritual.

Climate change will alter the face of the planet and so will the humans' understanding of the future and their interaction with the planet. **If we don't adapt, the planet will adapt without us.**

As reported by AM Omar [2007:2354] an average temperature increase of between 1.5 - 4.5 ° C will cause a series of environmental impacts. The impacts will range from rising sea levels, extreme weather conditions, floods, draughts, loss in biodiversity and mass migration of environmental refugees

To develop or not

In many developing countries climate change is still not recognised as an immediate problem. These countries rather focus on their social and economic development [Roaf et al 2009:127]. In an utilitarian paradigm this becomes a difficult ethical choice:

_ choosing not to develop, which would essentially lead to no future for anyone
_ or overdeveloping and as consequence having no future either.

Even with improved technologies that reduce greenhouse gasses, globally, there have been very little reduction in greenhouse gas emissions. This can be accounted to global development occurring at a very fast rate [Bennetts, Radford & Williamson 2003:120].

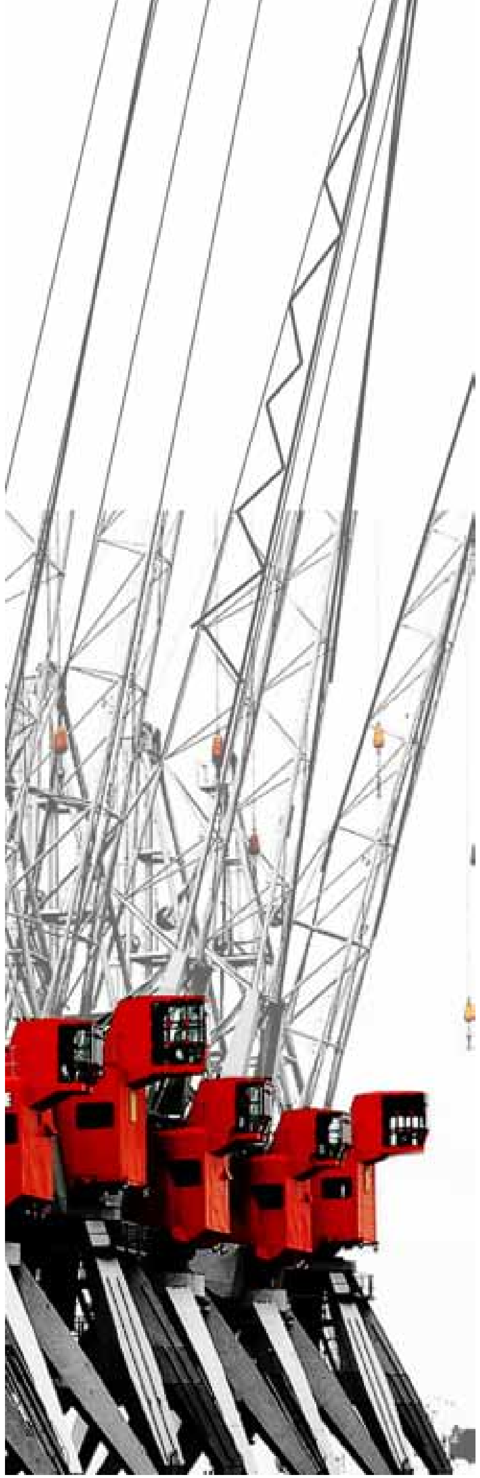


Figure 1-01: Develop! How much is too much?
[Source: B Mickewaith [www.brianmicklethwait.com]

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Sustaining all

Sustainability can be defined as a response to economical, sociocultural and environmental factors [Bennetts et al 2003:xi]. In developing countries institutional sustainability becomes ever more important in order to meet and implement sustainable practices. As clearly stated in the Bruntland report, sustainability and development are integrally connected [Bennetts et al 2003:xi]. One cannot succeed without the other.

Yet climate change and the depletion of non-renewable energy resources, as well as the scarcity of materials and water, are disastrous to development [P Jones 2009:380]. This means that the Bruntland report has serious implications. **Unless these issues regarding climate change and resource depletion are addressed, development will be limited if possible at all.**

Tshwane dislocated

Within this context of climate change and the possible effects that are predicted for South Africa, quick and efficient adaptations must be made at a national and detail level. Many cities in South Africa, Tshwane being a typical example, are still promoting the Apartheid city layout. It was aimed at segregating people into racial zones seperated by buffer zones [Du Plessis et al 2003:243]. This **created large displaced districts where the population with the lowest income lives the furthest from the city centre.** This spatial layout has led to heavily subsidised public bus and rail transport systems which, because of the decentralised low-density nature of these cities, are inefficient and unsustainable [Du Plessis et al 2003:243].

Figure 1-02: Dividing the population [Source: Collage by Author]

Vision and intervention

In South Africa[1] 20% of all energy used is spent on transport [Winkler et al 2006:24]. In the light of this the vision of the Bus Rapid Transit [BRT] system for Tshwane is to develop a more sustainable, efficient and accessible public transport system. As the vehicles use cleaner fuels and transport higher numbers of commuters than conventional bus systems [Wright & Hook 2007:702-705]. This will contribute to the mitigation of climate change in South Africa.

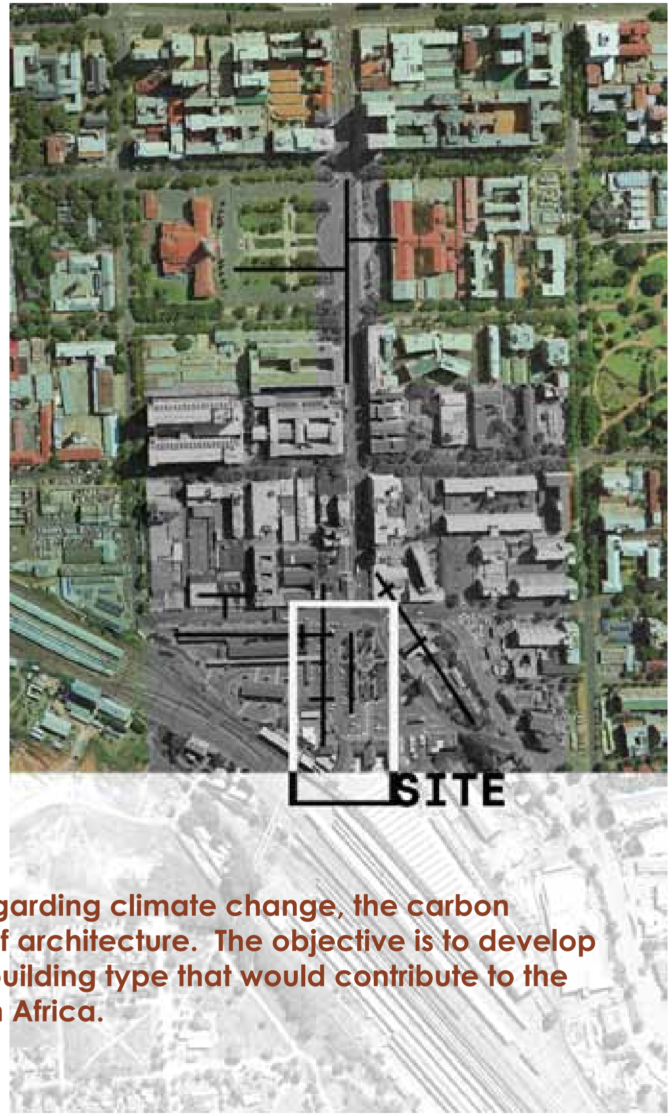
Architects have a specific role to play in the mitigation of climate change, as buildings are directly responsible for the depletion of natural non-renewable resources and the production of greenhouse gas emissions [Bennett et al 2003:03]. According to the International Energy Agency [2009:49] in South Africa buildings contribute up to 10% of the national CO_2 emissions due to energy consumption. Taking the construction of these structures in account this figure can rise up to 30% globally [UNEP SBCI 2009:03].

This thesis project focuses on the design of a low-carbon BRT station and terminal building.

The BRT station is proposed to be prototypical and will theoretically be constructed throughout Tshwane. A low-carbon prototype is aimed at having a low embodied energy and to be energy efficient, to limit the overall environmental impact of the transport system.

The site for the intervention is the Pretoria Main Station. It is a very busy modal interchange that has rich architectural and historical value. It is the termination point of the cardus maximus that links the site with the heart of the city [Holm 1998:61]. With the increase in transport systems and connectivity the precinct will develop substantially over the next 30 years. At the moment it is an illegible, over congested and defragmented site that needs to be addressed [Seabrook 2009:38].

This project aims to address issues regarding climate change, the carbon footprint and the embodied energy of architecture. The objective is to develop a low carbon prototypical transport building type that would contribute to the mitigation of climate change in South Africa.



1: South Africa's Energy consumption in 2000. [Winkler et al 2006:24]

Figure 1-03: Site choice [Source: Author]

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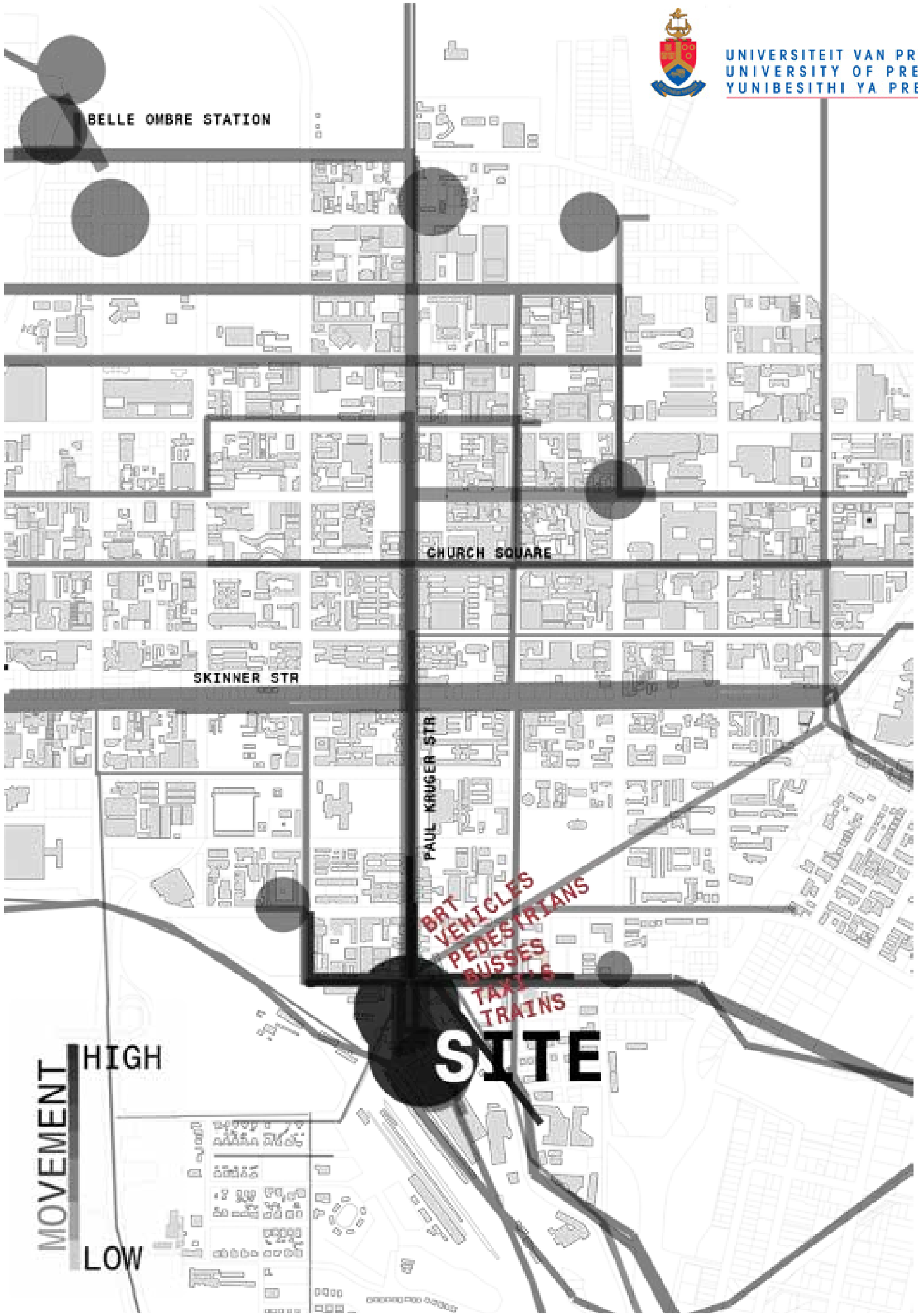

Figure 1-04: Movement patterns in the city centre [Source: Author]

This study is undertaken in partnership with the UNDP-GEF and the Environmental Potential Study Unit of the Department of Architecture, UP. The goals for this study as proposed by the UNDP-GEF is to promote public transport systems in South Africa that reduce greenhouse gas emissions, while promoting a long term change towards more efficiency and less pollution. Through this project the UNDP-GEF aims to increase the knowledge and understanding of the designing, management and constructing sustainable transport systems.

Client [for the project]:

City of Tshwane
Public works and Infrastructure Development Department - Transport Division

Site owners/clients:

Transnet

Client [for the research project]:

UNDP-GEF

1.2 AIMS & OBJECTIVES

The objective is the design of BRT terminal building that responds to the historical and current context while adapting over time.

The structure aims to become a seam that links Salvokop with the rest of the city. Functions will be placed on the linking structure to ensure that the seam becomes permeable a border that will ensure the future growth and sustainability of Salvokop.

This project aims to address the urban context, historically and culturally, with development guidelines that will lead to lower greenhouse gas emissions, as proposed as a specific target area by Jones [2009:381]. These guidelines will be informed by New Urbanism approaches as well as the Green Star SA guide in order to achieve a transport interchange that will function efficiently within its context.

As the site is of cultural and historic value, the design will be sensitive and must enhance the heritage resources and the setting. **The design will add new functions to the existing and historical in order to ensure the sustainability and adaptability of the station.**

The design will incorporate "bioclimatic" design approaches as proposed by Omar [2007:2334] that include energy conservation during construction and the use of renewable energy sources. This will contribute to a **lower embodied energy and lower carbon footprint for the structure.**

The life cycle performance of the materials will be analysed, informing the use of materials and the design of the structure. This inturn will inform techniques of reusing and recycling materials. Components of the design will be designed to be prototypical and possibly adaptable, as suggested by theories of ecological construction approaches.

A new low-carbon BRT station/terminal prototype can be developed from this project to assist in informing the future development of sustainable transport systems.

1.3 METHODOLOGY

The project will be approached by using theories of. Yet as Bennetts et al [2003:13] state that these theories, like Hanover principles, are very conceptual and vague.

To inform and guide the design the principles of New Urbanism, ecological design theories and the Green Star SA Office Design and Office Manual/ rating system will be implemented to ensure a low-carbon design will be achieved.

These three theories or approaches will be combined with a grounded theory approach. This means analysing the context, the effects of climate change in Tshwane, the users' needs, material properties and low-carbon construction technologies. Even though the first and second theories does not address climate change and low carbon technologies, the research process would make use of their ideas and approaches.

1.3.1 Theoretical premise

Theory 1: New Urbanism

New Urbanism is a response to functionalist city planning that disregards the communities and users within cities. It is aimed at promoting more liveable, sustainable societies [Gehl 2006:7].

New urbanism focuses on the notion that societies or buildings are never isolated but are made up from a series of patterns that are interdependent and supportive of each other [Alexander 1977:xii]. At the same time it addresses the need for urban regeneration in a fair and community centred manner as advocated in *Death and Life of great American cities* [Jacobs 1961].

The work of these theorists will be used to inform the urban framework and the urban response of the proposed intervention.

Even though New Urbanism theories do not address carbon and climate change issues in particular, the suggested urban typologies do advocate lifestyles and environments that will mitigate climate change.

Theory 2: Ecological design and construction

Construction ecology is defined by Kilbert, Sendzimir and Guy [2003:19] as a process of "biomimicry" where by human industries or designs use nature or concepts of nature as a new paradigm to work within as well as inform their designs. They propose studying processes and problems at different scales, aiming to achieve a diversity of systems to attain sustainable cyclical process or design [Kilbert et al 2003:18]. Kilbert et al [2003:16, 21+24] promote a cradle to cradle concept for the use of material while also looking into the possibilities of adaptable architecture.

Only certain aspects and approaches regarding materials use and tectonics can be used to inform the project.

1.3.2. Responding to the design problem

Theory 3: Green star SA
– Office Design and Office – As Built v1 2008.

The Green Star SA handbook [2008:xiii] aims to encourage new and innovative design approaches and uses of technology. The handbook promotes and discusses more sustainable approaches that aim to reduce the built environment's environmental impacts.

It is a rating system that creates a benchmark from which projects can be judged, it also aims to create co-operation between the different professionals in the building industry. The rating system assigns responsibilities to the various parties involved.

The manual and rating system will be used to guide the design. The BRT prototypical station [assessed in its a-contextual setting]will also be assessed using the rating system.

Problem – Understanding and contextualising
Climate change and its effects within the urban environment will be researched and contextualised to Tshwane and the local climatic changes that can be expected. From this an architectural response can be developed, to inform design decisions.

Response – Mitigation strategies
Mitigation strategies to lower the carbon footprint of Tshwane will be analysed. The first strategy that will be researched is changing the public transport system. The proposed Bus Rapid Transit system for Tshwane will be analysed. The building program will be derived from this research as well as limitation and specifications for the BRT prototypical station.

Strategies to achieve a low carbon intervention will be researched making use of New Urbanism, Ecological construction, Sustainable architecture, low carbon theories and the Green Star rating handbook.

Frameworks
From the literature study and site analysis a series of frameworks will be developed:

a) Precinct framework.
Integrating New Urbanism theories with a context analysis. It will also asses previous frameworks for the area to inform the new framework.

b) Historical response framework
An architectural response to the historical resources on site will be developed by researching the history and development of the site and Tshwane in general. From this the value of the different components will be ascertained to inform the type and impact of the intervention.

The framework will incorporate the Burra Charter as a guide to developing heritage resources.

c) Material use framework
Using embodied energy calculators, the embodied energy of the possible materials for the BRT prototype will be analysed and calculated.

The embodied energy and carbon footprint of the Rea Vaya BRT prototype station in Johannesburg will be calculated. From this a material use framework and a benchmark for the proposed BRT prototype will be developed.

1.3.3. Precedents

Precedent studies will be done for the following aspects:

a) BRT prototype designs
- _ planning and integration in urban context
- _ legibility
- _ material use

b) Station designs and transport system integration
- _ urban integration
- _ movement layering and layout
- _ material use

c) Planning and form generation
- _ planning
- _ movement through spaces
- _ thresholds
- _ manipulating movement & integrating movement patterns

d) Sustainable interventions
- _ design & planning strategies
- _ energy use and generation
- _ material use

e) Resource efficient designs
- _ sectional layout
- _ facade detailing
- _ ventilation systems
- _ energy generation

1.3.4. Delimitations

The existing site conditions as on February 2010 will be accepted as the basis for the new intervention. Any further developments will be disregarded.
The embodied energy of materials is ascertained by using UK and Australian quantities, as no recent South African energy quantities are currently available or easily accessible. One South African study by Daniel Urirah has been done but it is outdated.

1.3.5. Assumptions

- There are permanent markets towards to west of the Station.
- Pedestrian and vehicular bridges connects Salvokop to the city.
- There is a taxi rank and southern BRT lines within Salvokop .
- The following transport systems are in opertation: Gautrain, Metrorail, taxi's, long distance busses and BRT systems
- All 6 proposed BRT transport routes are in opertation.
- The Gautrain will use the BRT as feeder system
- A new parking structure towards the east of the Gautrain structure will be built.

1.4 PROJECT & DOCUMENT LAYOUT

Laying out the process used in the research project.

1 INTRODUCTION

FINDING FOCUS

- Establishing the focus of the study
- Starting from the basic premise of sustainable design
- Justifying the project and chosen site

2 PRE PLANNING

Research and definition of theory /approaches/technologies for the project:

_ Establish the effect climate change.
_ Its effect in urban context - specifically Tswhane
_ Specify climate change mitigation strategies
_ Establish the need for transport and why BRT system is good solution
_ Developing a series of low carbon strategies and technologies
_from the urban scale to the detail
- Choosing an appropriate rating system

3 FRAMING PROJECT

precedents
frameworks

Analyse the context

- Research precedents to inform the direction of the project
- Developing frameworks
  _Establising guidelines for the urban intervention
  _the historical response
  _Research\ material use and systems/approaches to guide the intervention.

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PROJECT DESIGN

4 architectural intension

concept+approach

Researche existing precedents to inform the design and process

_Develop a concept
_Develop a design and through to a technical level
_design through an iterative process
- Evaluating design using methods of assessing spatial performance, material use, carbon footprint and environmental performance

design development

5 technical documentation

6 CONCLUSION

_ 2

PRE_PLANNING

"... the environmental crisis is a design crisis. It is a consequence of how things are made, buildings are constructed and landscapes are used..."

[Guy 2002:228]

2.1 CARBON AND A CHANGING CLIMATE

Climate change is a complex problem that has a series of consequences on the living and built environment. In the last few years the relationship between climate change and carbon has become more important. As indicated in the Graph 2-01 the rate at which the global average temperature has risen has increased at the same rate the greenhouse gases in our atmosphere.

With the increase in greenhouse gasses in the earth's troposphere, more heat is trapped within the earth's atmosphere.
This leads to an increase in energy content in the atmosphere causing long term weather pattern changes and extreme weather events [Walker & King 2008:49]. This inturn leads to rising sea levels, food and water shortages, effects the human health and a loss in global biodiversity [Discussed in detail in section 2.1.5].

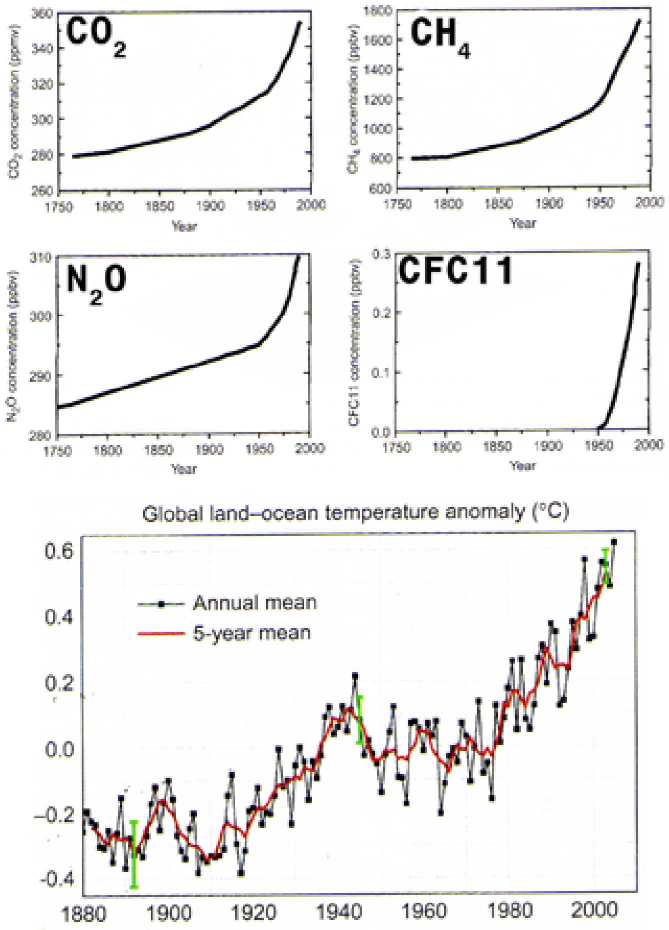
One of the sectors that plays a big part in this is the built environment.
When designing buildings in the urban context in a climate that is changing the designer needs to address the following two issues:

a) How does one adapt the existing structures or new structures to accommodate the change in climate patterns in the next 30 years?
b) How does one mitigate climate change through architecture?

Understanding climate change and its consequences for Tshwane equips the designer to design robust buildings with a longer life cycle in a climate that is changing

2.1.1 Changing into a global problem

For many years the existence and impact of climate change was debated by many scientists around the world. The possible impact of global climate change was first discussed in the 1968 at the first meeting of the Club of Rome [Roaf et al 2009:7]. Yet only in the mid 1980's did scientific simulations shown clear evidence of what is happening, after which the Intergovernmental Panel on Climate Change [IPPC] was founded in 1988 [Freed 2008:220].



Graph 2-01: The increase in greenhouse gasses from 1880-2000
[Source: Roaf et al, p 4 &52]

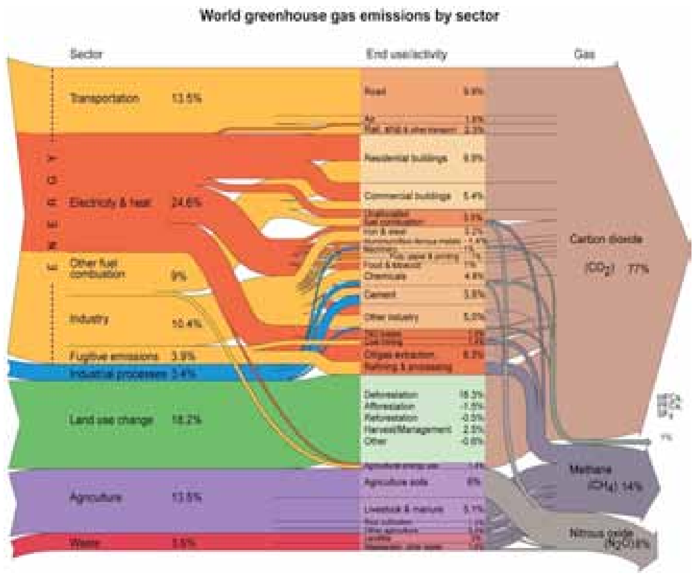


Figure 2-05: Diagram indicating the sources of greenhouse gasses [Source: IPPC website accessed 26 Feb 2010]

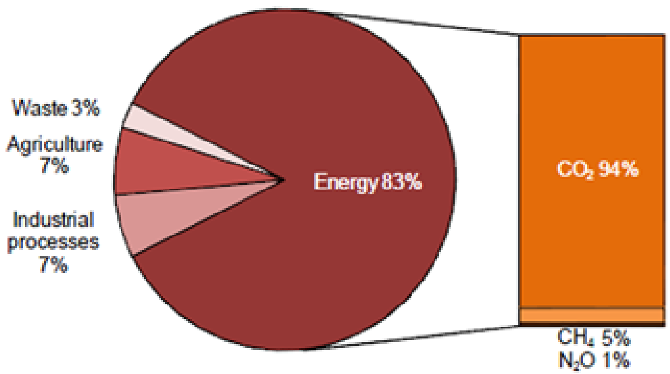


Figure 2-06: The sectors causing in GHG emissions [Source: IEC 2009 p 8]

For a long period the true cause and impact of climate change wasn't clear and **only in 2007 did the IPCC state that it is 90% sure that climate change is indeed manmade and will "...continue for centuries"** [Freed 2008:221; King& Walker 2008:13].

In 1997 the Kyoto Protocol was adopted, requiring developed countries to cut down their greenhouse gas emissions to 5% below 1990 figure by 2012. In 2005 the protocol came into force and was ratified by 184 nations [UNFCCC homepage 2010]. It was not aimed at solving the problem but at starting the mitigation process [Bennet 2003:116 & Miller 2004:295].

In December 2009 the COP 15 was held in Copenhagen, yet little progress has been made regarding the acceptance of legislation or taking definitive action to mitigate the effects of climate change [Walsh 2009:01]. Hopes that countries will recommit themselves to the Kyoto protocol were dashed, leaving the global community yet again without a focussed direction to reducing global greenhouse gasses.

2.1.2 Greenhouse gasses

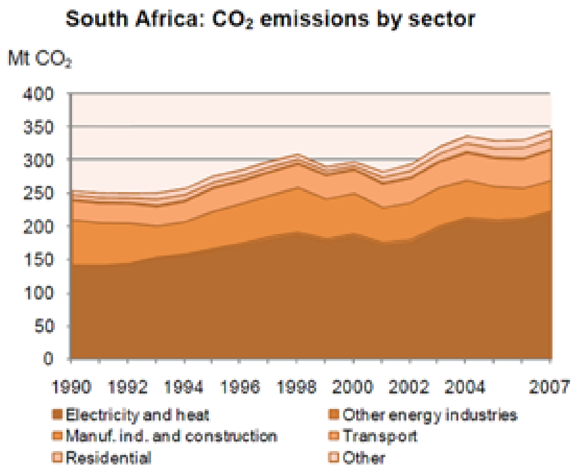
Even though greenhouse gasses make up only a fraction of the earth's atmosphere, the "...heat trapping ability..." of these gasses keeps the earth's temperature in check [Bennet et al 2003:111]. Greenhouse gasses are transparent to short waves but opaque to long waves which allow the heat rays of the sun to penetrate the earth's atmosphere but not to reflect heat back into space.

The problem arises when the quantities of greenhouse gasses increases beyond the natural balance that promotes life on earth.

Greenhouse gasses are a collective name for the following gasses: carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Water vapour (H_20) and Halocarbons (CFC-11 and CFC-12) [Bennet et al 2003:112]. To this list one could add hydroflurocarbons as well as carbon tetrachloride [Miller 2004:282].
These different gasses are all produced by human practices such as energy production, consumption, industrial and agricultural as well as ecological processes [Awuor et al 2008:231].

The Kyoto Protocol employs a system of equating the different greenhouse gasses and their effects. This is called the GWP 100 values. As shown in Table 01 the warming effect [up to 100 years after its emission] of a gas is equated to a single CO_2 equivalent [Sekiyo & Okamoto 2010:364]. These CO_2 eq are used to assess life cycle assessment [LCA] and life cycle climate performance [LCCP].

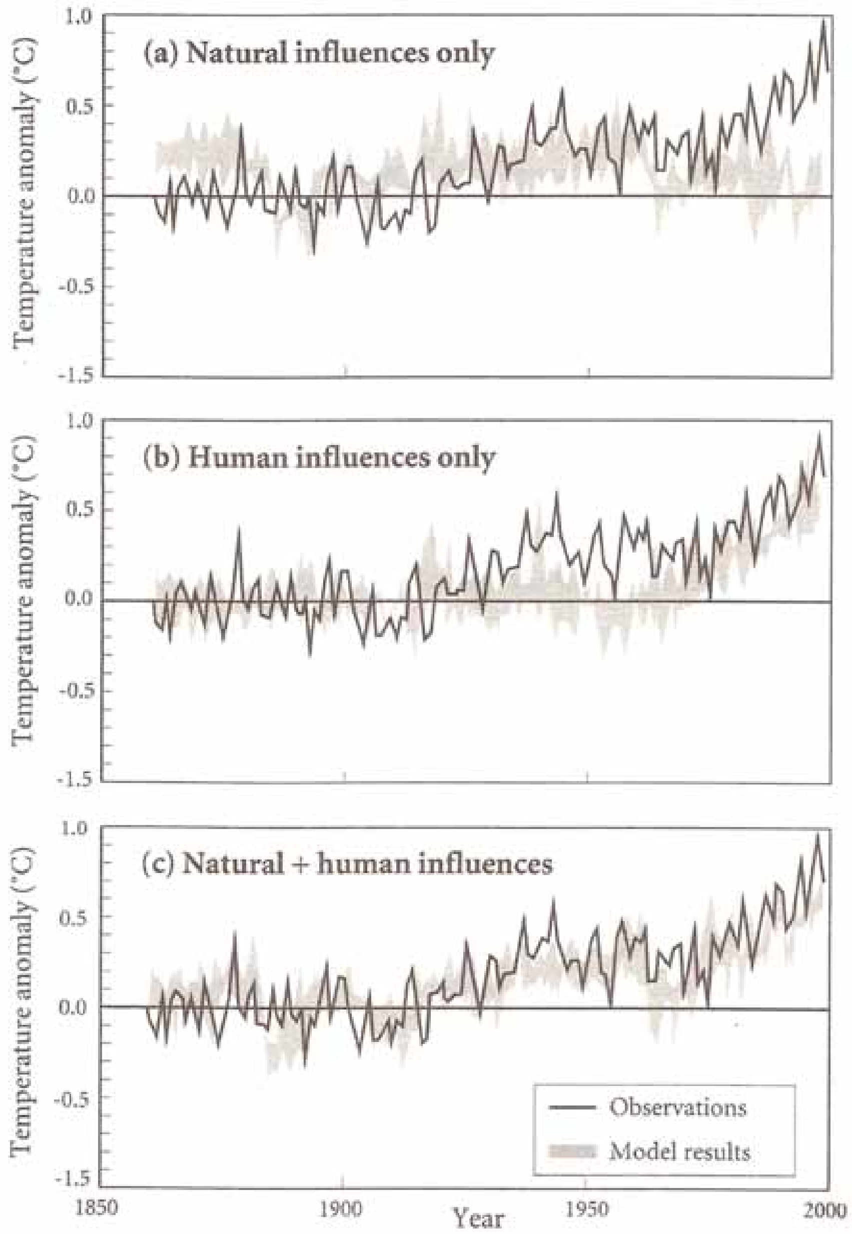
In South Africa the main contributor to greenhouse gasses is the burning of fossil fuels for energy generation as well as other forms of combustible energy sources [Du Plessis et al 2003:244]. South Africa is among the top 20 green house gas emitting countries and contributes 2% of the global CO_2 eq emissions. This amounts to 41% of Africa's total greenhouse gas emissions [Du Plessis et al 2003:244].



COMMON NAME	CHEMICAL FORMULA	LIFETIME [time in toposphere]	Human Sources	Relative warming potential [compared to CO_2]
Carbon dioxide	CO_2	-	Burning of fossil fuels, deforestations	1
Methane	CH_4	12 years	Agriculture, cattle herd, landfill sites , natural gasses	23
Nitrous Oxide	N_2O	114-120	Burning of fossil fuels, fertilizers, life stock waste	296
Chlorofluorocarbons	CFC's	11 - 20	Air conditioners, refrigerators, plastic foams	900-8300
Hydrofluorocarbons	HCFC's	9-390	Air conditioners, refrigerators, plastic foams	470-2 000
Hydroflurocarbons	HFC's	15-390	Air conditioners, refrigerators, plastic foams	130-12 700
Halons		65	Fire extinguishers	5 500
Carbon Tetraclhoride		42	Cleaning agent	1400

Table 2-01: Carbon equivalent values [Source: Miller, p 282]

Graph 2-02: Graph indicating the sectoral contribution to GHG emissions [Source: IEC 2009:21]



Graph 2-03: Graphs indicating the increase temperature and the influences [Source: Walker & King, p 22].

The quantities of greenhouse gasses in the atmosphere has fluctuated over millions of years. It is measured in parts per million [PPM] and is related to a CO_2 eq number. During the ice age the CO_2 eq in the atmosphere was 180-190 PPM CO_2 eq. During the warmer periods during the preindustrial age it ranged around 290 PPM CO_2.

At the turn of the 20th century the CO_2 levels ranged between 260-290 ppm. The change in the atmosphere can be attributed to the development of the Industrial Revolution [Walker & King 2008:22] though no significant increase was measured.

In 2007 the measured value of CO_2 levels ranged at 383 ppm CO_2 eq which is 40% higher than at the start of the 20th century, yet Walker & King [2008:22] states that because of the presence of methane and the rate at which CFC's destroy the ozone, it would be more accurate to state that the levels are closer to 430 ppm CO_2 eq.

In Graph 2-03 the increase in greenhouse gasses in the earth's atmosphere and the temperature increase are clearly shown. It was found that globally there has been an average increase of 0.6 °C [Engelbrecht 2010].

2.1.3 PREDICTED CLIMATE CHANGE IN AFRICA AND SOUTHERN AFRICA

According to the fourth IPCC assessment on climate change [2007] the following can be expected in South Africa and Southern Africa:

If the emission rates are kept at a level of high to medium **the average air temperature increase for Africa could be expected to be between 3-4 °C [period 2080-2099].** Yet the average temperature rise in Southern Africa could be expected to be 3.7 °C in summer. What is alarming though is that for the period 2070-2099 between September to November an average temperature increase of 7 °C can be expected [IPCC 2007].

The increase of vegetation in these warmer conditions will help to cool the average temperature, by up to 0.8 °C [IPPC 2007]. Yet in an urban environment this lowering in temperature cannot be expected as the heat island effect will increase the average temperature.

The IPCC assessment on climate change [2007] states that the whole of Africa will experience a decline in rainfall, with a likely decrease in the Mediterranean, North Sahara, West coast and Southern Africa. In the western parts of Southern Africa a 40% decrease in precipitation is predicted.

In contrast, significant regional climate changes will occur, with the central and eastern plateau and Drakensberg regions possibly experiencing higher summer rainfalls [IPCC 2007]. Yet according to Meadow & Hoffmann [2003:177] the increase in rainfall will not necessarily mean a higher moisture content in the soil, as a lot of the moisture would be lost to evo-transpiration due to higher average air temperatures.

An increase in humidity can be expected in the central plateau of South Africa [Mason et al 2003:254] but this will not mean an increase in groundwater. One issue of concern though is the fact that the number of rainfall days during the summer will decrease, yet increase in its intensity [IPPC 2007 & Mason et al 2003:254].

Water resources will decline significantly and become increasingly vulnerable.

NOTE: The following information regarding the figures predictions for Southern Africa and South Africa might change as the IPCC [2007] states that there is a lack of computational facilities as well as a lack in human resources to process information and collect data in Africa.

2.1.4 The impact of climate change

Climate change has a series of effects each with dangerous global consequences:

Loss of biodiversity

Global biodiversity is at serious risk with 30-50% of all biodiversity on earth bound to be lost by the end of the century [Walker & King 2008:41]. This can be attributed to changing weather patterns occurring , too fast for species to migrate or adapt, as noted by Rutherford et al [1999:11]. Fire frequencies will also increase, causing the degradation of the leftover green environment. With the expected hot and humid climates the reproduction of diseases will increase significantly, causing an increase in their transmittance [Rutherford et al 1999:7 & Walker & King 2008: 41].

Droughts

Africa, especially east Africa, will experience severe droughts, because of the cooling of the Northern Atlantic [Walker & King 2008:47]. **This will lead to increasing pressure on water resources, by 2020 up to 250 million people could be exposed to water shortages.** Much shorter planting periods would cause a shortage of food with rain fed agriculture dropping by up to 50% [Ramos & Kahla 2009:262].

Extreme weather patterns

The Research Centre on the Epidemiology of Disasters has noted that there has been **a major increase in climate related natural disasters** [Sherbinin et al 2001:40]. This can be related to the increase in heat and energy in the earth atmosphere, especially the surface temperature of the ocean [Walker & King 2008:49]. Though this will not necessarily increase the frequency of extreme weather events; the intensity and duration of these events are noted to have increased [Sherbinin et al 2007:40].

Heat waves.

The increase in the frequency and intensity of heat waves [Kovats &Akhtar 2008:170]can be linked to the fact that the earth's ambient temperature has increased, making the odd spike in temperature all the more dangerous. **The warmer, dryer summers in many cities will contribute significantly to the occurrence of heat waves** [Walker & King 2008:50&55].

Rising sea levels and flooding

As noted by Sherbinin et al [2007:39] by 2015 5% of the world's population [more than 400 million] will be living in megacities ,two thirds of which are coastal cities.

With rising sea levels many coastal cities are at risk. It is estimated that three billion humans live in coastal cities. **The rising sea levels will lead to excessive erosion and loss of top soil and place severe stress on the living (available) space with in these cities** [Walker & King 2008:56].

Food supply and sources

While food production is predicted to be on the increase on the middle to higher latitudes, it is Africa that is going to suffer the most severely in terms of food shortages [Walker & King 2008:56]. In the central latitudes the average temperature will increase significantly, making it too warm for most existing plant types to be grown [ibid]. Ramos and Kalha [2009:262] also reports that **food production will drop significantly with rain-fed agriculture dropping by 50%.**

In Africa the following changes can be expected:

a)75-250 million people in Africa will face water shortages
b)A drop of up to a 50% in agriculture production will occur
c)Malaria range to decrease in Southern Africa, but will extend into the Eastern Highlands
d)Large coastal cities such as Lagos and Alexandria will be at risk
e)The occurrence of heat waves will increase

[Walker & King 2008:60-61]

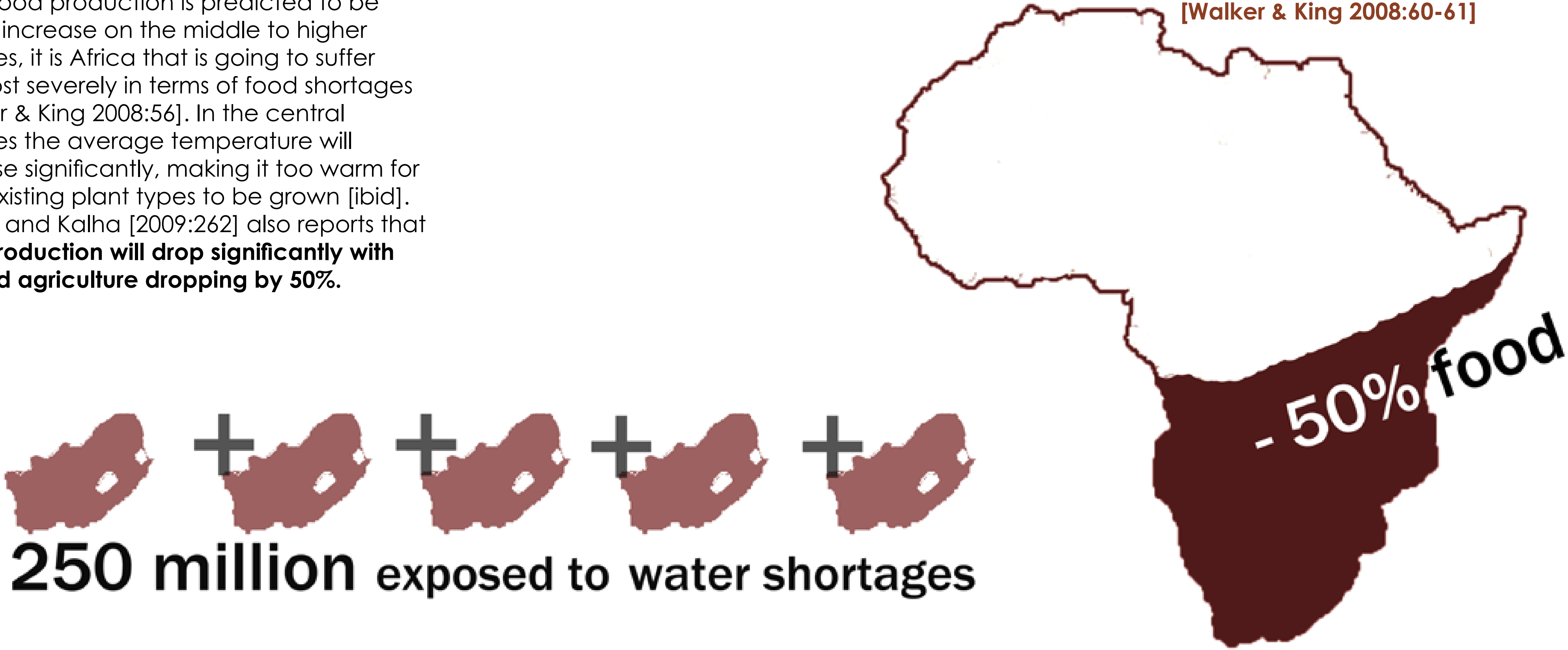


Figure 2-07: Predicted food and water shortages caused by climate change [Source: Author]

2.1.5 Climate change and the urban environment

The effect of climate change on the urban environment will be even more severe due to an increase in emissive sources and density of inhabitants. As stated by Awuor et al [2008:232] one can expect an increase in energy, food and water consumption, all of which will exacerbate the other impacts of climate change.

The current global trend indicates that urbanization is occurring at an increased rate. In 2007, 50% of the world's population was urbanised, which will increase to 75% by 2050 [Burdett & Rode 2007:9]. Large parts of the population will be at risk; the majority of the affected population will be poor and unable to prepare for or adapt to the shocks of extreme weather conditions [Sherbinin et al 2007:40].

There is a series of health risks that will affect urban populations, ranging from illnesses caused by the increased distribution of infectious diseases, to deaths caused by heat waves, floods, storms, fires and droughts [Awuor 2008:232]. Water-/ food-borne diseases will escalate along with the increase in severity of storms and drought conditions leading to low levels of flowing water and bad water quality [Kovats & Akhtar 2008:16].

Most structures will not be comfortable or liveable within 30 years from now, as climate change will increase the ambient heat significantly [Chow et al 2002:233]. Bennet et al [2003:113] state that **the heat island effect in urban areas can contribute to climate change temperature increases of up to 10 °C more than in nearby rural areas .**
The problem of heat island effects within the urban environment will have to be mitigated in order to achieve thermally comfortable buildings.

With solar irradiance increasing, building materials must be used that will withstand the heat as well as insulate more efficiently [Chow et al 2002:231].

Walker and King [2008:55] warn that the dryer, warmer summers will lead to more severe heat waves. With the increase in temperature comes an increase in fires in urban environments, as was experienced on Greece's mainland in 2007 with widespread fires during the high summer period. Buildings and urban open spaces will have to be adapted to deal with higher temperatures and the possibility of fire exposure.

The heat island effect will cause extreme climatic conditions which will result in increased rainfall over shorter time periods, intensified thunderstorms [electrical storms] and an the increase in hail storms and their intensity [Kovats & Akhtar 2008:161].

Even though there will be an increase in the severity of precipitation, Kovats & Akhtar [2008:166] state that the IPCC has predicted that water sources will become more vulnerable. Most water will be lost to storm water runoff as the intensity of rain storms increases. The access to and quantity of fresh water resources will decrease severely [Awuor 2008:235], prompting city dwellers to start recycling water and harvest rainwater.

Awuor [2008:242] calls for early warning systems ranging from highly technical meteorological sensors to low-tech human reaction groups. In Bangladesh groups of cyclists with whistles convey information regarding impending storms to the public in the street [Walker & King 2008:67]. The use of soft and hard engineering to adapt cities to possible threats, as well as the protection and reuse of resources such as water, is also important to ensure survival [Awuor 2008:239 -240].

2.1.6 Climate change conclusions

Climate change leads to a series of adverse effects, causing changes to global weather patterns as well as micro climates in the urban environment. It is clear that the safety of city dwellers will become increasingly important to address.

At the same time natural resources will become even more vulnerable and scarce, demanding that society will have to become more responsible with how these resources are used and preserved.

In order to respond to these changes one must first understand the local urban context and the local effects of climate change, so that the necessary precautions can be taken.

Figure 2-08: Heatwaves and increasing affect of fire ["The great Chicago Fire" - [http://contentloco.com/travel/top-things-you-should-know-about-chicago.aspx]

2.2 CLIMATE CHANGE AND CARBON IN TSHWANE

"Cities are the defining ecological phenomenon of the twenty-first century."

[Newman & Jennings 2008:02]

Cities are areas where massive changes can be made that would either cause or mitigate climate change. Globally cities have recognised the importance of sustainable development. Since 1994 Seattle has implemented a comprehensive sustainability plan with emphasis on the following:

1. Linking and integration of sectors and areas
2. Inclusion of all stakeholders
3. Long-term visions and goals [thinking past annual budgets]
4. Quality and diversity of interventions

[Ruano1999:152]

Tshwane should plan its sustainable interventions and mitigation strategies with the same intension. **Large interventions with long term visions are needed in this city.** These must aim to empower and integrate all sectors of the local population. The aim must be on developing high quality systems within the city that addresses the very quality of life.

In Bogotá, Columbia, the BRT transport system was integrated with green belts, cycle lanes, car-free days and road restrictions [Newman & Jenning 2008:142]. All these strategies and interventions were implemented to promote a more pedestrian friendly and humane city.

2.2.1 Tshwane, seperation and transport system

Tshwane is a typical South African city that was changed significantly during the Apartheid era [Du Plessis et al 2003:243]. It developed as a centralised, dense city contained within its natural boundaries [Holm 1998:60].

In 1923, under the Group Areas Act of the Apartheid era,**the city was fragmented into segregated racial zones** [Chipkin 1998:160], resulting in a city with isolated and dislocated suburbs where the poorest of the population were forced to stay the furthest from the city centre [Du Plessis et al 2003:243].

In 2000, six years after the establishment of a free democracy, these segregated urban areas were integrated into one city. The municipal area of Pretoria changed its name to the City of Tshwane, effectively doubling the urban area but remaining as a fragmented low-density metropolis [Berstein & Mcharthy s.a:1].

The low-density nature of this metropolis has led to an unsustainable and energy inefficient public transport system
[Du Plessis et al 2003:252].

The first phase of the BRT system aims to connect the northern suburbs of Tshwane with the city centre [Advanced Logistics Group 2008:4]. This will encourage corridor development as well as improve the lives of the population staying in area
[Pienaar et al 2007:426].

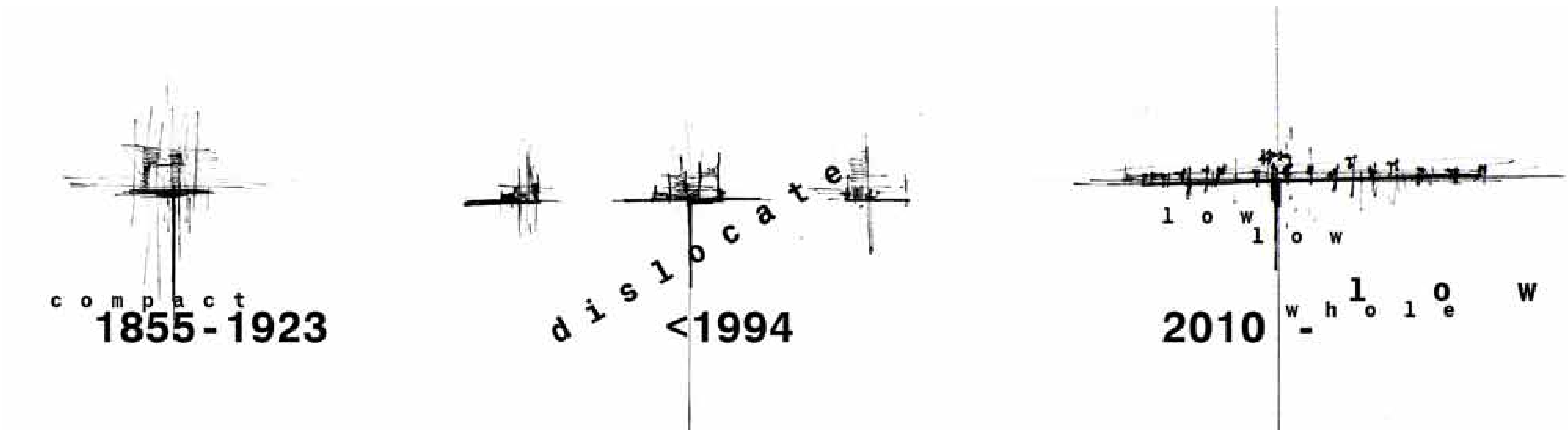


Figure 2-09: From Pretoria to Tshwane – compact to low density [Source: Author]

2.2.2 Tshwane and climate change today

Climate change has global effects that can be measured and predicted, yet regionally these changes can be very different from each other and very difficult to predict. These predictions are, according to F Engelbrecht [Principal Researcher Atmospheric Modelling at the CSIR], only broad indication and not necessarily accurate.

In research done to assess the global temperature increase and compare it to Southern Africa's climate, it was found that globally there has been an average increase of 0.6 °C, while during the same period in the central area of South Africa there has been a temperature increase of 1.4-1.6 °C. This can be attributed to the high pressure system that forms over this area and drives moisture and clouds away, making this area extremely susceptible to temperature increases [Engelbrecht 2010].

This means that in the event of a CO_2 eq increase to 560ppm by 2060, **an average temperature increase of 4°C in summer and 6°C in winter can be expected for Tshwane.** This is double the global average temperature increase in winter [Engelbrecht 2010]. It could lead to a need for less in winter yet cooling of indoor environments in summer will become vital.

In winter the subtropical belt will be enhanced, leading to a generally dryer Southern Africa, with especially dry areas in the Western Cape. On the whole South Africa will be dryer, yet the central regions will experience a small increase in rainfall [Engelbrecht 2009:1032]. **The rainfall in Tshwane might be a little more in the next 60 years. Unfortunately the intensity of the rainfall will increase while fewer rainy days are to be expected [section 2.1.4]. Great volumes of valuable water will be lost in the process due to unmanaged stormwater runoff [Engelbrech 2010].**

Very little research has been done with respect to climate change in Africa [Engelbrecht 2009:1013], thus information regarding relative humidity and wind patterns has not been analysed or researched. According to Engelbrech [2010] one can expect a lower humidity during the winter period in spite of an increase in air temperature

2.2.3 Responding to climate change in the urban environment

"[E]xposed, vulnerable, energy-profligate buildings" [Roaf et al 2008:344] are still being designed, even though the problems and effects of sustainability and climate change are well known to our 21st century society. To ensure the sustainability of buildings designers must design new structures to adapt to the climate changes that can be expected in the future.

By adapting to these forecasts the energy efficiency of structures will increase, in the process mitigating climate change.

Within the urban context, buildings and street materials must be designed to reflect as much heat as possible. This can be achieved by **adding vegetation to streetscapes as well as using lighter, reflective building materials** [Haselbach 2008:68].

Adequate shading and drinking fountains must be provided in public spaces [Roaf et al 2009:60]. This will **protect vulnerable inhabitants from excessive shocks to their health during heatwaves.**

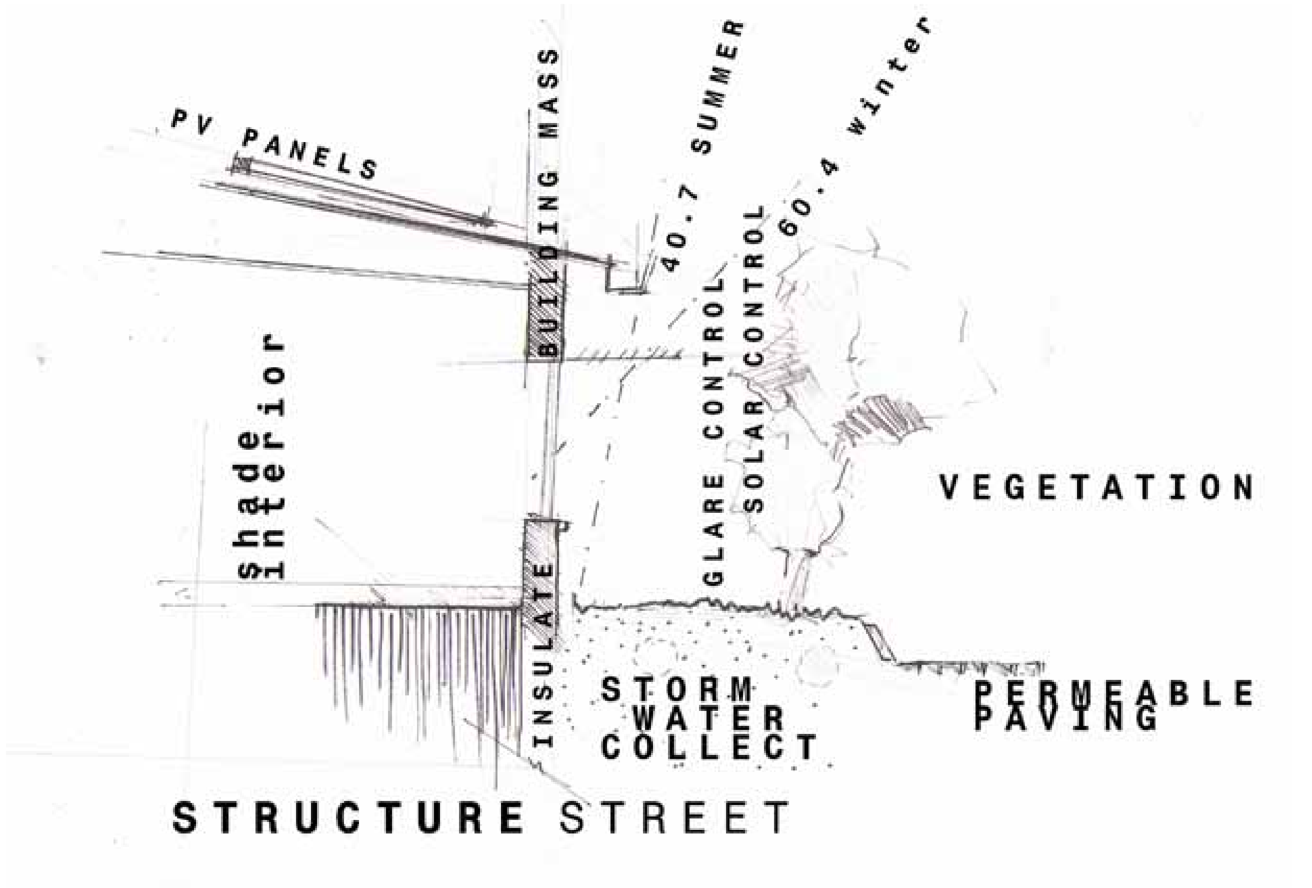


Figure 2-10: Adapting buildings for climate change [Source: Author]

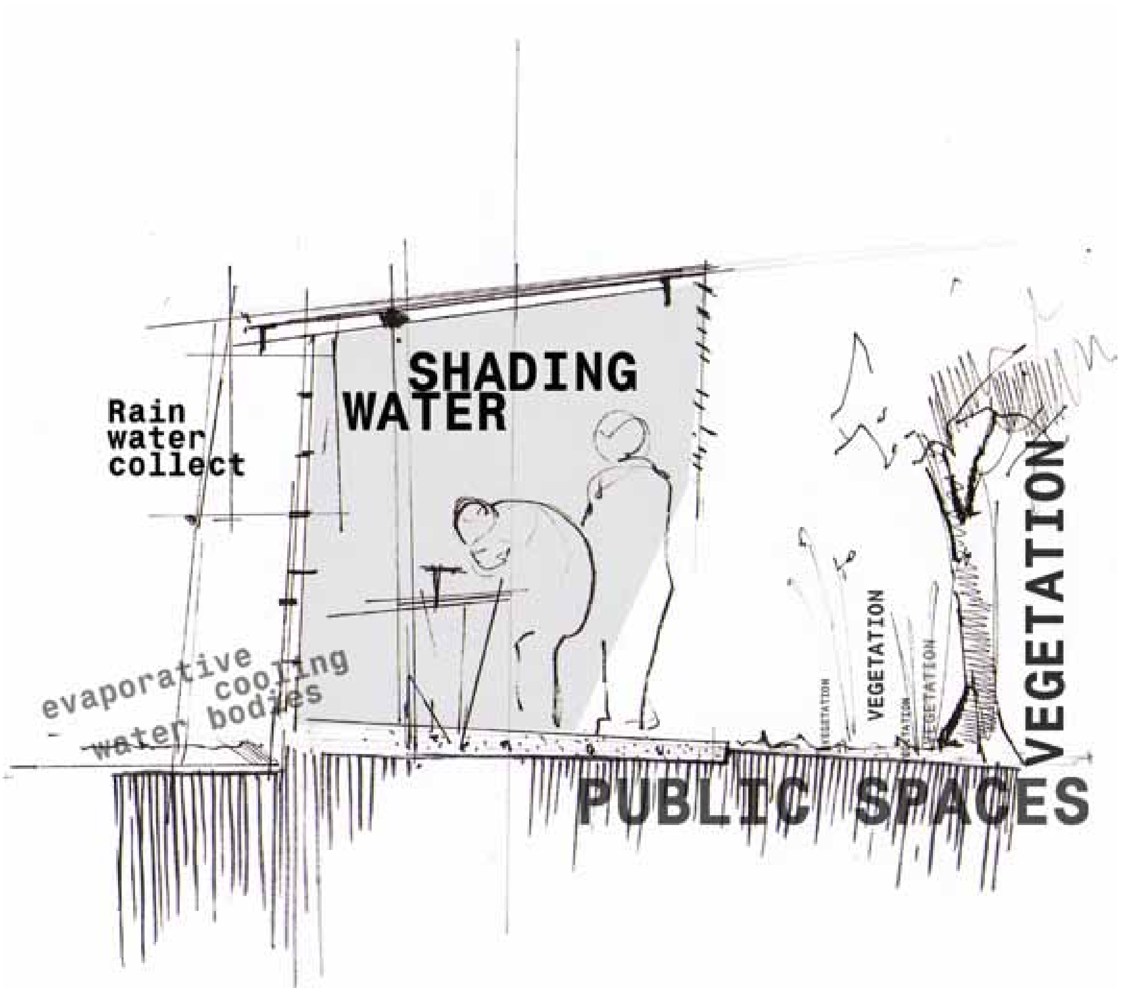


Table 2-02: Shading in public spaces [Source: Author]

With the increase in solar irradiance the thresholds between interior spaces and outdoor spaces must be considered. By making use of a series of screens the glare and discomfort experienced upon exiting buildings can be lessened.

Less cloud cover is to be expected in the winter. **The solar shading must protect the occupant from unnecessary glare,** especially on work surfaces.

As the temperature in Tshwane is expected to increase it will be important to ensure that the heat capacity of building materials is addressed. Buildings must be designed to insulate against increased air temperature, while shading of the building facade in the summer is important. It will become very important to **shade western facades to ensure cool evening temperature in buildings** [Roaf et al 2009:55].

Ventilation during the summer period will become very important. **As Tshwane is going to become less humid evaporative cooling will become a very effective and efficient ventilation method.**

Fortunately warmer winters will lead to warmer indoor temperatures, leading to less heating being required. The designer must take advantage of this by using passive solar heating methods to heat structures in the colder months.

During storms, or in the rainy season, the management and reuse of storm water must be an important priority for all sites and buildings. **The gutter systems and rain water harvesting systems should also be adapted to accommodate higher quantities of water.** The harvesting of rain water will be of increasing importance -as discussed in section 2.1.5.

The generation of photovoltaic solar energy will become more efficient, especially during the dry winter months when little cloud cover is expected.

With the increase in heat waves in Tshwane, the designer must ensure that the structure is adequately protected in the event of a fire. This means adhering to fire regulations and, most importantly, ensuring safe escape route and safety measures for the users of the building

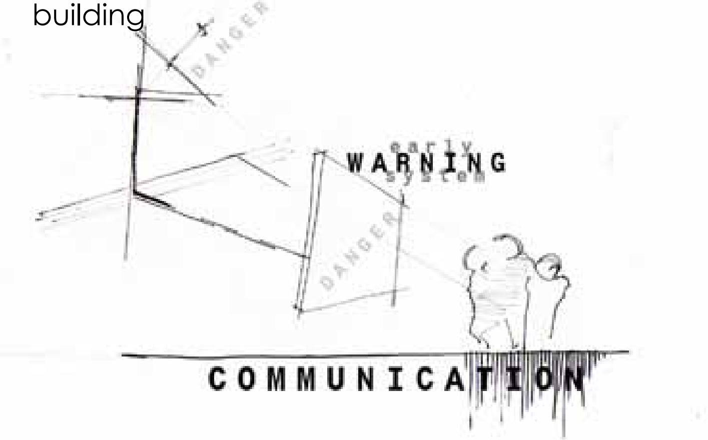


Figure 2-11: Warning systems in buildings [Source: Author]

Buildings can also start to incorporate warning systems to warn the public about possible extreme weather events and as well as in the event of a disaster. This can be include public awareness programs to mitigate climate change.

Responsive and robust structures will be needed to ensure comfortable buildings in the near future.

2.2.5 Mitigation options and focus

Adapting and designing buildings to respond to the changes in climate are important to ensure sustainable cities and societies. Yet adopting methods of mitigating climate change are even more important.

The Stern report states according to Roaf et al [2009:18] that **it will cost 20% of the GDP to continue with the "business as usual" approach and a general denial from the public if temperatures rise by 5.8 ° C globally, though it will only cost 1 % GDP to reduce greenhouse gasses and stabilising it at a maximum level of 350 CO_2 ppm.**

In this study the focus is on more sustainable modes of public transport and low carbon architecture.

2.3 TRANSPORT- A BUS RAPID TRANSIT SYSTEM IN TSHWANE

Figure 2-12: Energy consumed by transport increase with 40% [1990 - 2007] [Source: Author]

The energy & heating and the transport sectors generate up to two thirds of the global greenhouse gas emissions worldwide. These are also the fastest growing sectors in terms of greenhouse gas emissions and have increased with 60% and 45% respectively between 1990 -2007 [IEC 2009:13]. In 2007 the global CO_2 emission for transport was 6 632.5 million tons.

In developing countries the greenhouse gas emissions linked to transport are predicted to increase with 60% by the year 2020 [IEC 2002:20]. To ensure a sustainable future, developing countries will have to adapt and develop public transport systems.

Public transport systems have positive environmental impacts, by displacing single occupant vehicle usage [Wright & Hook 2007:85]. In a scenario analysis for a "large developing-nation city" [according to the author the size of Curitiba, Bogota], **a 1% reduction in private vehicle use and shift to public transport use has a 1 million tonnes CO_2 reduction over a 20 year period**[Wright & Fulton 2005:710]. Integrating this with pedestrian and cycling routes to promote sustainable movement patterns increases the reduction in CO_2 substantially [*ibid* 2005:711].

In South Africa the vision of developing a Bus Rapid Transit [BRT] system for Tshwane is to develop a more sustainable, efficient and accessible system. This will contribute to the mitigation of climate change in South Africa, as 20% of all energy used in the country is spent on transport [Winkler et al 2006:24]. In the year 2007 it was found that South Africa produced 345.8 million tonnes of CO_2 [IEC 2009:45]. According to the Graph 2-02 [p.19] and the statement that 24% of global greenhouse gas emissions is produced by the transport sector [IEC 2009:21 ; Wright & Hook 2007:701]. South Africa's transport sector would have produced roughly 82.995 million tons of CO_2 in 2007.

Research done in Bogota found that the air quality improved significantly after the implementation of a BRT system. There has been a reduction of 44% in sulphur dioxide, 7% nitrogen dioxide and 24% particle matter [Wright & Hook 2007:699]. This can be credited to the BRT busses that use of cleaner fuels and has more efficient engine technologies, [Wright & Hook 2007:702-705].

Implementing a BRT system in Tshwane will contribute as a climate change mitigation strategy while at the same time improving the living standards of the inhabitant of the city.

2.3.1 The Bus Rapid Transit system

The Bus Rapid Transit system is a "road based public transport system" [Advanced Logistics Group 2008:2] which can easily provide highly efficient transport for high numbers of commuters over a short time period. **The BRT is a very flexible and adaptable system** [Levinson et al 2003:4], that can adapt to future changes and fluctuation without compromising the initial phases [Advanced Logistics Group 2008:8].

It is a safe affordable transport system that creates an environment for social interaction and the interaction of people of different income groups [Wright & Hooker 2007:86].

2.3.2 The BRT system in Tshwane

In the 1970's urbanisation occurred at a very fast rate in South America. In order to address the shortage and increasing strain on the existing public transport systems the BRT system was developed [Wright 2001:1]. The system is a series of right-of-way bus lanes that are integrated into the existing road networks. It is a very fast, efficient and cost-effective method to provide transport [Wright 2001:1].

The BRT system aims to link the isolated suburbs of Pretoria with the city centre, while at the same time increasing the western and eastern movement of commuters [Advanced Logistics Group 2008:4]. The different routes are planned to provide the most coverage in Paul Kruger Street and the heart of the city as recommended by Advanced Logistics Group [2008:05].

As stated by Pienaar et al [2007:426] the BRT system will promote the current corridor development, as experienced in Curitiba [Wright & Hook 2007:87],while improving the daily lives of the inhabitants living on the periphery of Tshwane through densification and providing an easier, safer and quicker means of travelling. It is proposed to be a legible and user friendly system, accommodating the tourists and locals alike [Advanced Logistics Group 2008:15].

2.3.3 The whole BRT system

According to a BRT presentation [Olivier 2009:04] 6 priority corridors were identified within Tshwane which will be developed as BRT routes or enhanced bus routes. These routes together with their feeder zones will provide much needed coverage across Tshwane to improve public transport.

Stage 1 includes two trunk lines and two enhanced bus routes. The aim is to accommodate movement from the northern suburbs as well as east-west movement though the city
[Advance Logistics Group 2008:5].

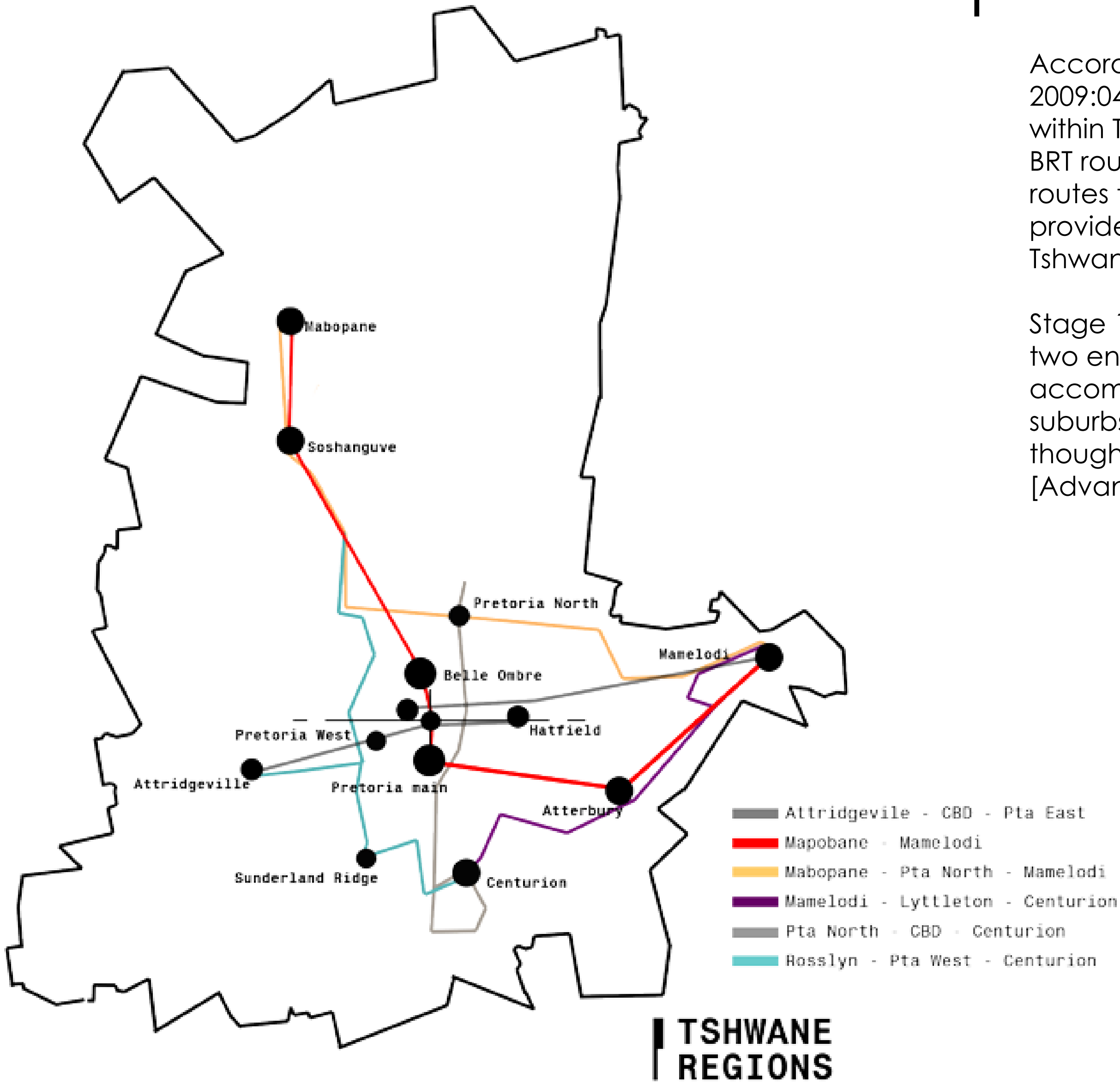


Figure 2-13: Six priority corridors in Tshwane [Source: Author]

2.3.4 Routes and BRT in Tshwane [STAGE 1]

Two BRT lines are proposed for Stage 1 of the BRT development, as indicated in Figure 12:
Line 1 _ Mabopane - Pretoria Main Station
Line 2_ Mamelodi - Belle Ombre Station
[Advanced Logisitics Group 2008:69]

These two lines aim to facilitate and improve the connection between the northern and north eastern suburbs and the city centre. Line 1 and 2 will be trunk lines with dedicated bus lanes [Advange Logistics Group 2008:06].

Each will have two services, being a normal line stopping at each station and an express line stopping only at selected stations and at the terminals [Olivier 2009:21].

The terminals for these two lines will be at

1. **Mabopane Station**
2. **Belle Ombre Station**
3. **Pretoria Main Station**
4. **Mamelodi ***

The BRT lines 1 & 2 are focussed on giving as much public transportation coverage as possible in Paul Kruger Street [Advanced Logistics Group 2008:5]. This will lead to an increased frequency of public transport along this street, reducing private vehicle use. In the process a more pedestrian orientated route will be created with lower speeds and narrower lane widths for vehicles [Advanced Logistics Group 2008:47].

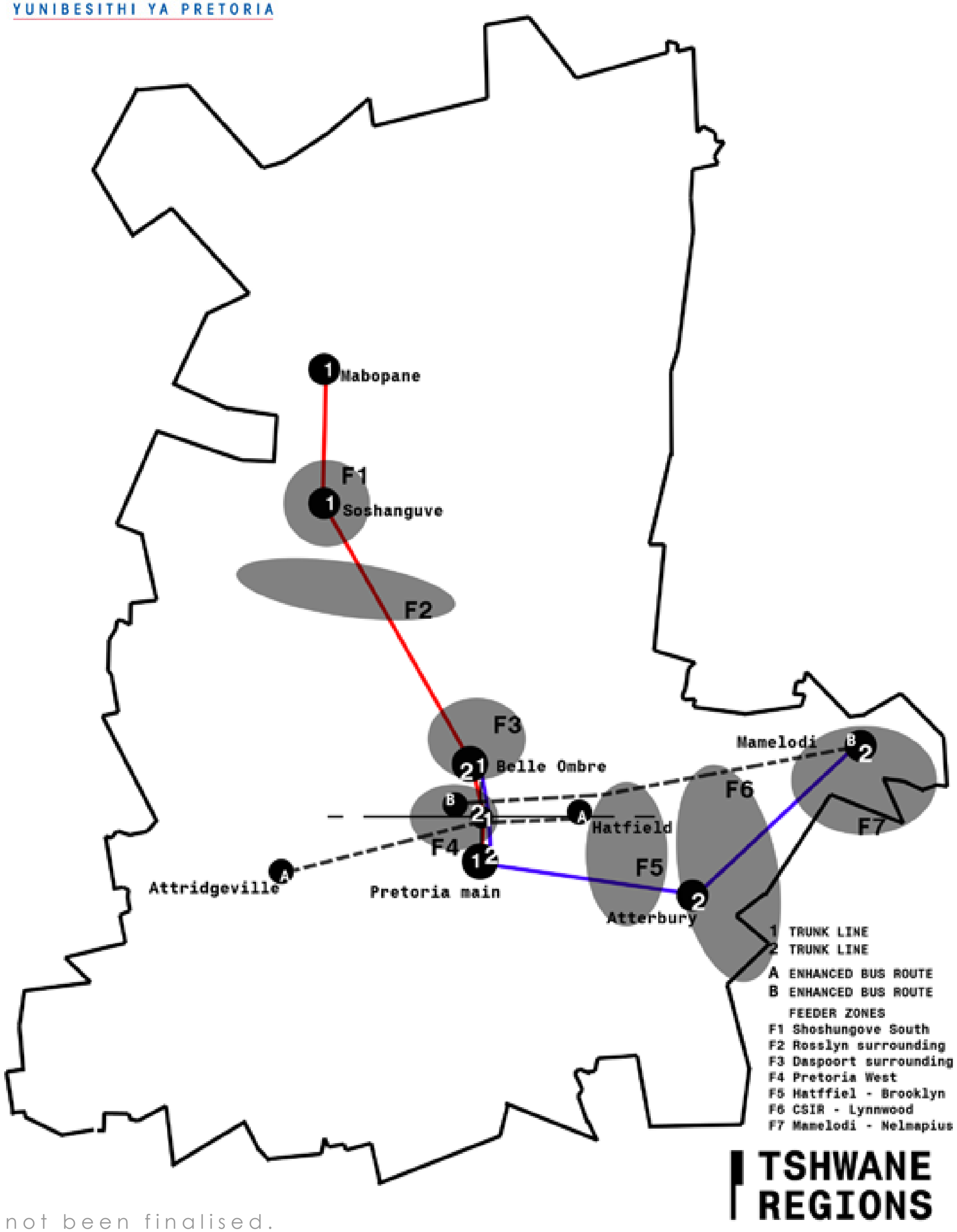


Figure 2-14: Routes and Feeder Zones in Tshwane [Source: Author]

*At the time of the study the planning for the BRT line 2 has not been finalised.

The anticipated number of commuters using the BRT during peak times will be
6 400 people per hour
[Line 1 Mabopane]
6 400 people per hour
[Line 2 Mamelodi] *

Peak period is normally from 5 am to 8 am [Advance Logistics Group 2007:76].

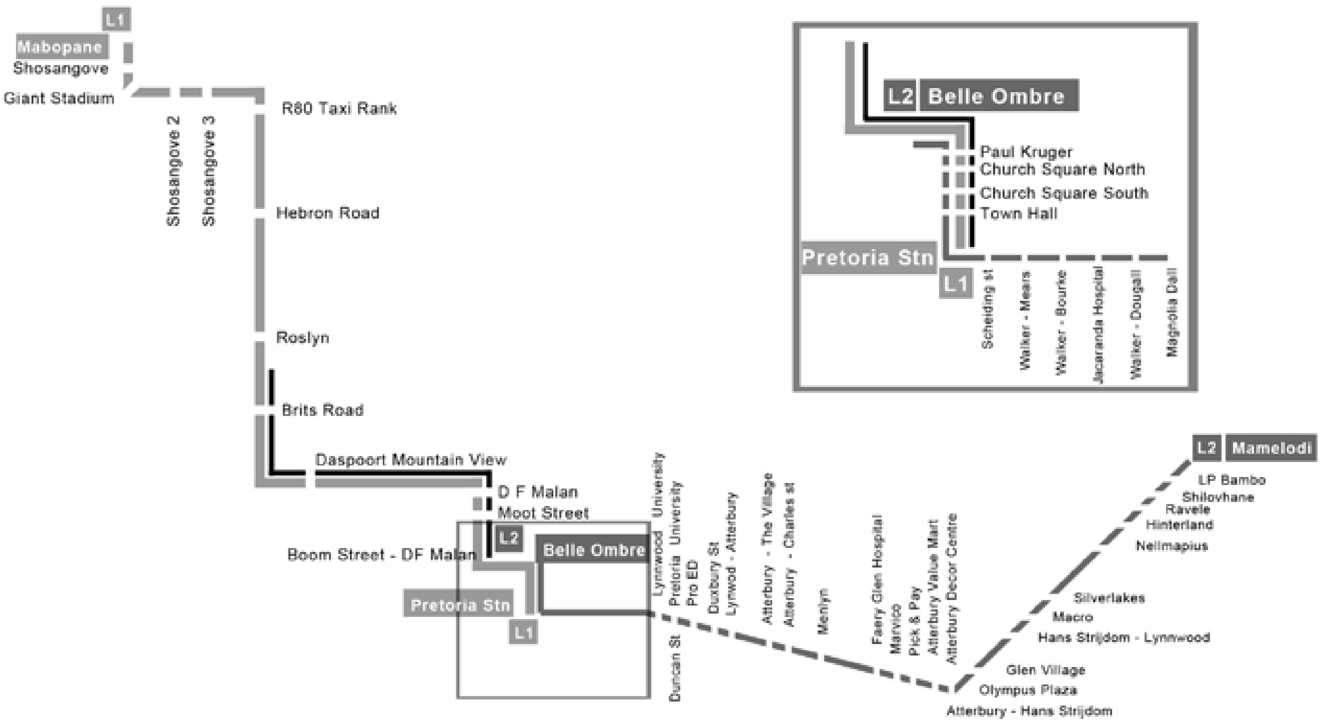


Figure 2-15: Schematic layout of Two BRT lines [Source Tshwane Bus Rapid Transit
* Note: For predicted users and station info refer to table 13-30, pg 307.

The Advanced Logistics Group [2008:5] also proposes an east-west access route that will connect Attridgeville with Hatfield and Mamelodi with a second route to the city centre. With these lines overlapping the most coverage is given to the city centre, improving the frequency of available transport [Advanced Logistics Group 2008:5].

The enhanced bus corridors will use normal low floor busses [refer to section 2.3.8 for BRT bus specifications] , travel in mixed traffic routes and have curb-side stations. The system will have express lines and a formalised timetable while free transfer between these lines and the BRT station will be accommodated
[Advanced Logistics Group 2008:49].

Feeder Zones are also proposed to ensure that the BRT Routes will be accessible; these feeder zones are to be serviced with smaller vehicles [The Advanced Logistics 2008:53]. By making use of feeder zones an adaptable and accommodating system can be provided, instead of a more expensive trunk lines to service the whole area.

The project proposes the use of the existing taxi/minibus infrastructure to act a feeder system for the BRT. The city of Tshwane has engaged in talks with taxi associations with the aim of achieving a partnership between taxi owners and the BRT system
[Laubser 2010].

2.3.5 BRT Terminal layout at the Pretoria Main Station

The site for one of the BRT terminals is the Pretoria Main Station. The station building was constructed in 1912 and is one of the first public buildings designed by Sir Herbert Baker [Lindeque 2001:04]. The building itself has historic architectural value, while the Station Square was constructed between 1912-25, has experienced many changes throughout its history. The World War I and World War II memorial and original walls on the square are still intact.

This is culturally and historically a very sensitive site. Unfortunately development on this site has been uncoordinated and has led to an illegible and fragmented site [Seabrook 2009:38].

Two proposals [illegible] by SSI and KM Architects and the other by KWP architects, that aim to renovate the forecourt of the Pretoria Main Station [Figure 14 -17].

The proposals all have very different intentions especially in relation to the station square garden and forecourt. The KWP plan aims to repair the existing stone walls while keeping most of the historical forecourt intact.

The plans by SSI and KM architects are more extensive, as they suggest a redesign of the whole station precinct. The proposal links Salvokop with the station by covering the railway platforms behind it. A parking garage is proposed on top of the railway track, with an over-scaled glass-domed mall/terminal building rising behind the station building.

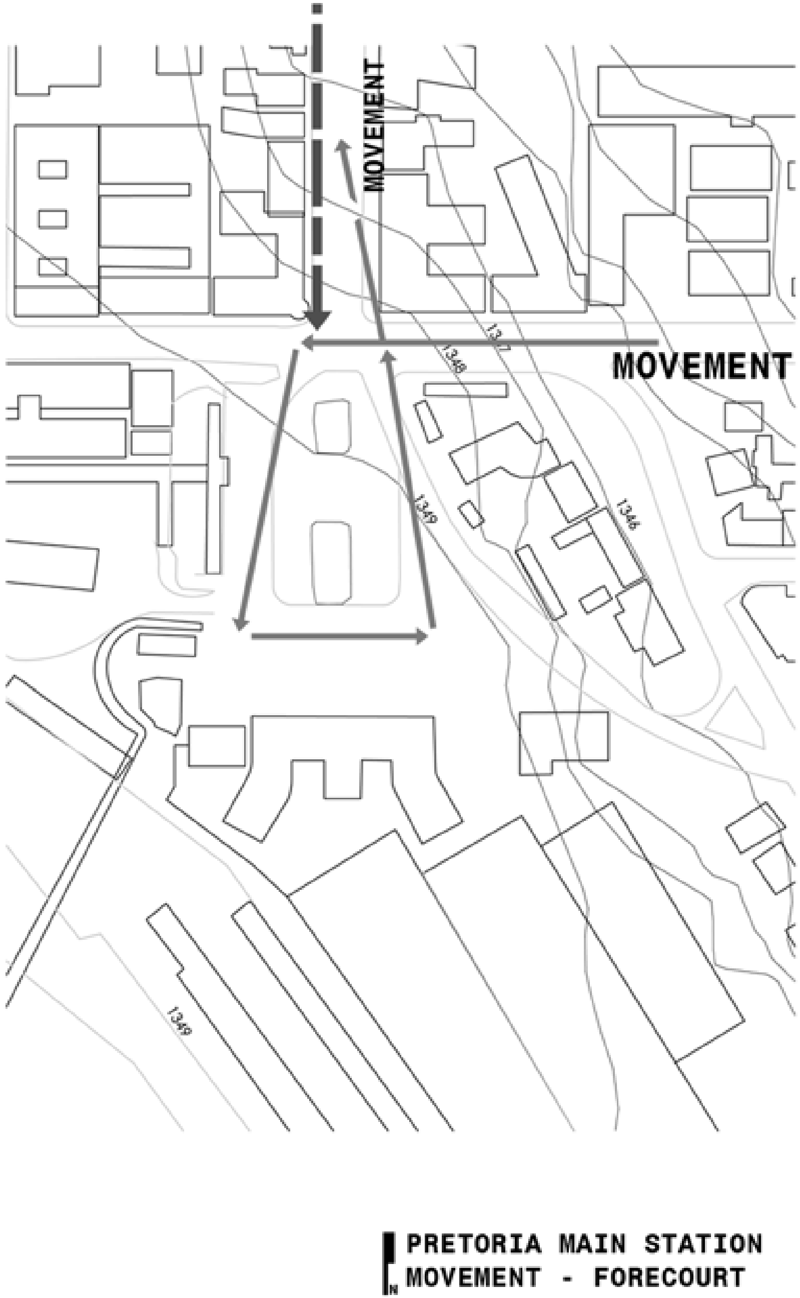
The forecourt is changed altogether, with a pedestrian underpass constructed where the Station Square is currently situated. Buildings are proposed on the eastern and western edge of the station forecourt which would mean the closure of Railway Road on the eastern edge [Figure 16 & 17]. The BRT stations are situated in the forecourt, with 2 options proposed for the western edge or on either side of the garden.

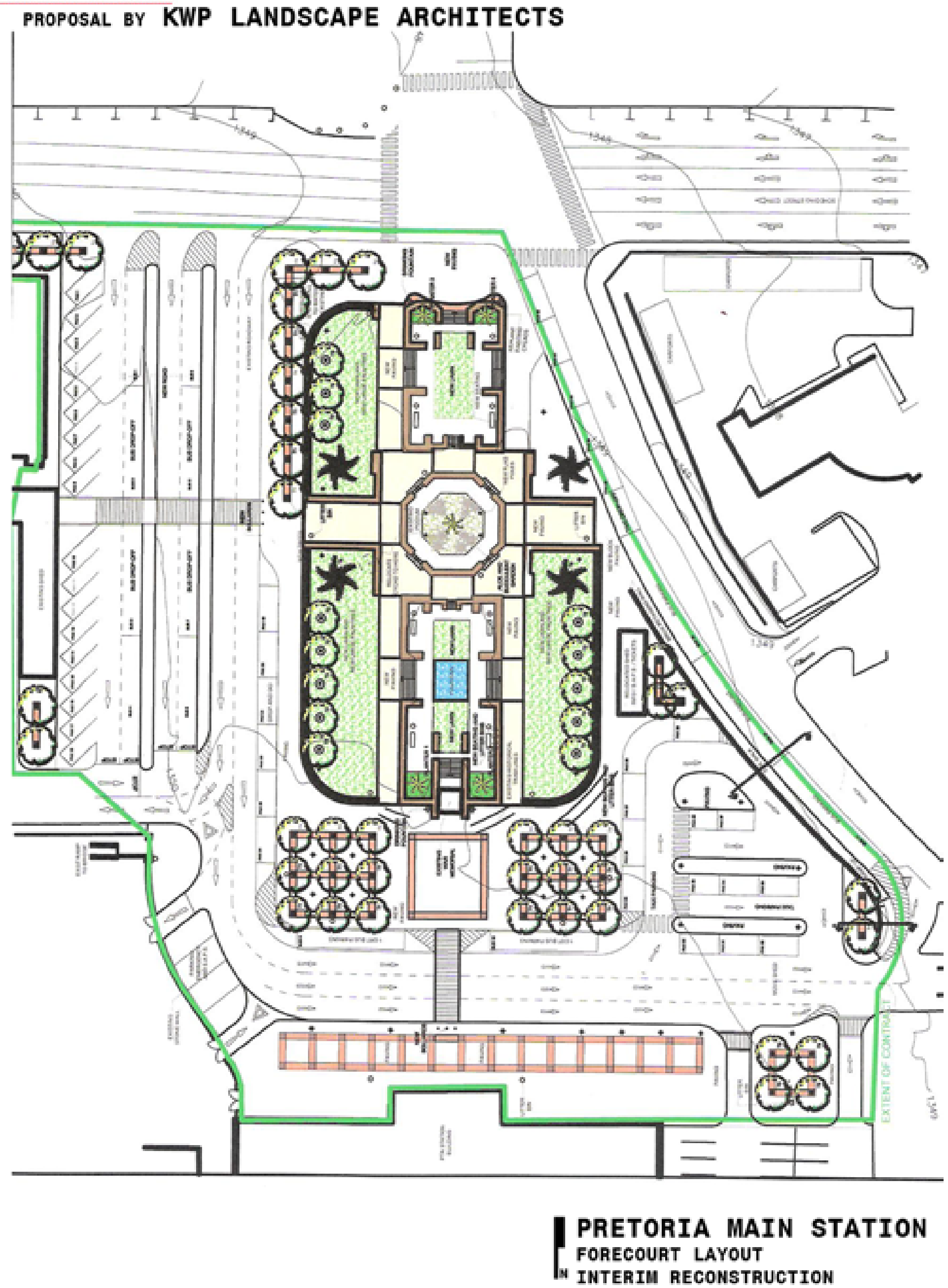
The proposal aims to change the scattered illegible nature of the station into a coherent whole. The pedestrian underpass is insensitive to the heritage fabric on site, while the proposed mall behind the station is over-scaled. The glass dome will also be an energy inefficient and unsustainable structure. The two options for the BRT stations are sensible and will be explored in the conceptual phase of the design.

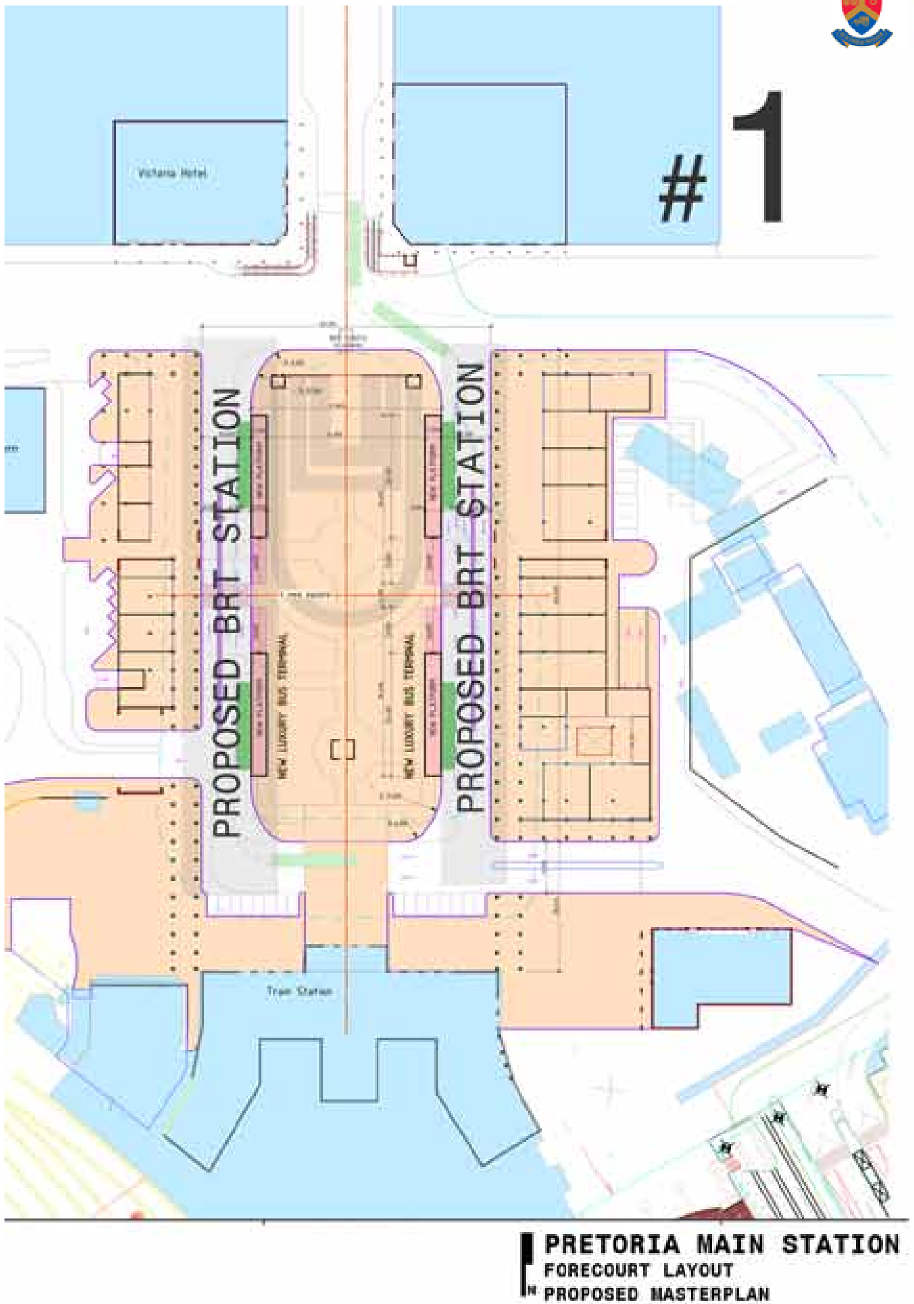
Figure 2-16: Proposal for station by KM architects [SOURCE: Anon]

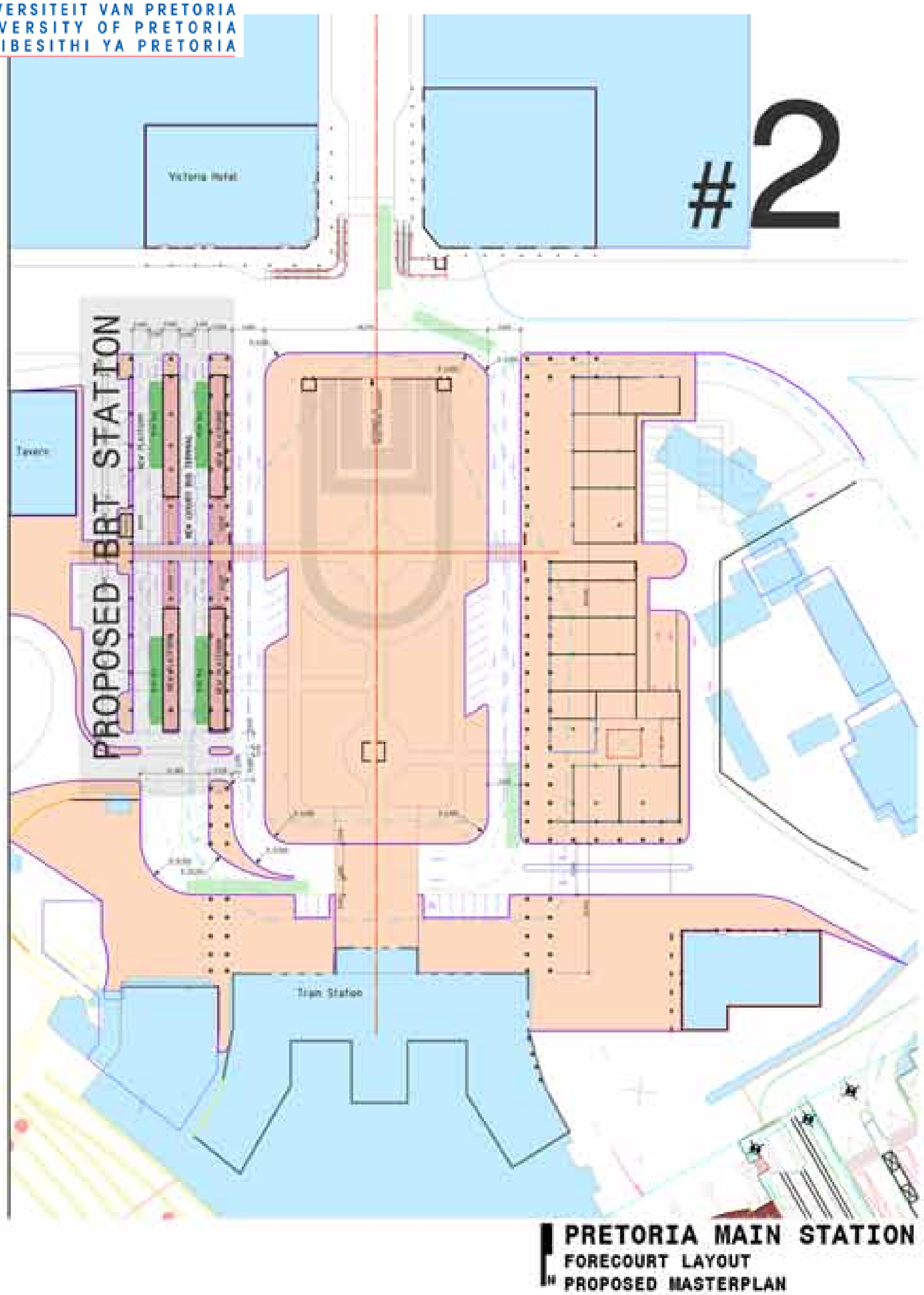
Figure 2-17: Movement in the forecourt [Source: Author]

Figure 2-18: Interim proposals for Pretoria Main Station [Source: KWP Landscape Architects]









PROPOSALS BY KM ARCHITECTS AND SSI

Figure 2-19: Proposals for Pretoria Main Station [Source: SSI and KM Architects]

2.3.6 Terminal buildings

Terminals are ideally located at the end of lines [Advanced Logistics Group 2008:58]. Bus depots should also be located close to the terminals to ensure efficiency. The bus depots are proposed to be located in Mabopane and Mamelodi [Advanced Logistics Group 2008:59].
In the Tshwane Bus Rapid Transit Operational Plan the following facilities are proposed to be incorporated at the bus terminals:

1. Information kiosks
2. Lost and Found Offices
3. Restrooms
4. Commercial facilities

[Advanced Logistics Group 2008:58]

These terminals must be treated as public service nodes that also provide a wide range of services such as health care and educational facilities.

Additional functions are best situated at terminal stations, these being more convenient for commuters ensuring that less travel is needed. Usually there is also more space at terminal buildings to accommodate more users and functions [Wright & Hook 2007:374].

Accommodating informal vendors along with formalised retail functions in terminal buildings has many advantages. It provides passive surveillance and integrates different income groups [Wright & Hook 2007:372]. Yet informal vendors must be controlled to ensure ease of movement and safety by keeping the bus runways clear.

Enough seating and resting places for commuters should be provided at stations and terminal buildings.

The intermediate staging area is proposed to be at Belle Ombre station. This will serve as rest room for drivers and will ensure that the BRT buses are always on time[Laubser 2010] . This can be used as an intermediate parking area within the city to service the transport system during peak times
[Wright & Hook 2007:393].

BRT systems use control centres, that monitor the whole system with a GPS tracking system. This ensures that the system works efficiently while being able to respond to sudden changes in movement and passenger needs [Wright & Hook 2007:393].

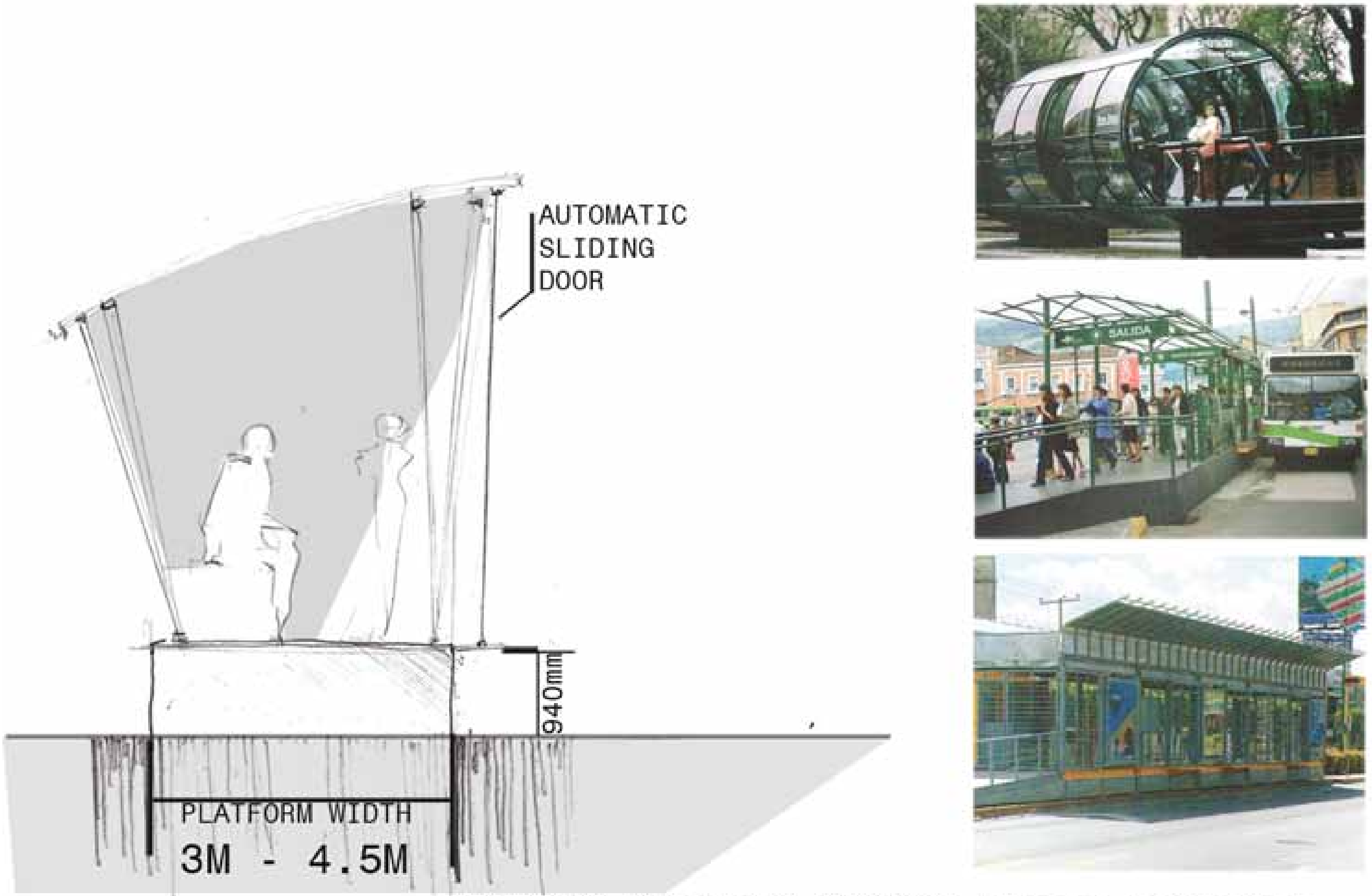
2.3.7 Station/platform parameters

BRT stations are usually placed on the median. Placing them on the curb side usually leads to the BRT system conflicting with the turning traffic, leading to congestion [Wright & Hooker 2007:185].

The designer should ensure that the transfer between station and modes is as easy as possible for the user. The user must be protected from the weather and should not have to walk too far. There must preferably not be any barriers between the different stations [Wright & Hooker 2007:230].

The platform parameters as articulated by the Tshwane Bus Rapid Transit Operational Plan [Advanced Logistics Group 2008:78] suggests the following:

1. **Station will be located on the median**
2. **The platform height should be 940mm above finished ground level.**
3. **The waiting area on the platform should be 1.7 times the length of the bus – 31, 45 meters at multi bay stations.**
4. **The platform should be 3 – 4.5 m wide, with entrances on both sides.**
5. **Doors should be 1100m wide.**
6. **Allowance must be made for seating even though the waiting period is short.**



GENERIC PLATFORM DESIGN EXAMPLES OF STATIONS

Figure 2-21: Generic Platform design and exemplary stations [Source: Rapid Bus Transit Planning Guide p 365, 366,369]

On line 1 [from Mabopane] the stations will require 3 bays to accommodate users while line 2 [Mamelodi line] only requires a single bay per station.

Platform size is dependent on the amount of passenger boarding during peak hours. A 1 m corridor can accommodate the movement of 2000 passengers per hour [pph] and the area needed for waiting passengers is 1 m2 per 3 passengers [Advanced Logistics Group 2008:78]. The platform length must be the 1.7 times full length of a bus between two continuous platforms. The BRT line 1 requires 3 bays per station thus the length of each station should be

Calculations for platform width [LINE 1]

The platform width:

WIDTH

WU [waiting passengers] = QP/total length of station / 3 ppm
=160/81.5 m/ 3
=0.65m

WC [circulating passengers] = 6400pph / 2000 pph
= 3.2m

WP [platform width] = 1 meter + WU [waiting passengers] + WC [circulating passengers]
= 1m + 0.65 + 3.2
= 4.85m

Calculation as per BRT planning guide [Wright & Hook 2007:362]

Thus platform size at the station should be 81.4m x 4.85m [for 3 bays].

QP - Maximum passenger queue [maximum commuters per hour / frequency of vehicles per hour]
PPH - Passengers per hour
PPM - Passengers per meter

In areas where the climate permits the use of naturally ventilated stations is an easy options to achieve comfortable indoor environments, yet in some climates air conditioning must be used [Wright & Hook 2007:368].

The stations must also have on site security and must be "closed stations". This ensures that off board payment can be done and that integrated fare systems can be adopted where the user only pays for the distance travelled or the zones travelled from [Advance Logistics Group 2008:88].

The station must have multiple doors, 3 doors per bus, to ensure that the transfer of passengers can happen as quickly as possible. These doors must be a minimum of 1100mm wide [Wright & Hooker 2007:263]. The use of mechanical doors ensures user safety and stops fare evasion [Wright & Hooker 2007:370]. The BRT system in Johannesburg only allows for the doors of the station to be opened by the Bus drivers.

Bicycles and pedestrians must also be incorporated within the design of these stations as to ensure the transfer between travel modes happens smoothly and easily [Advanced Logistics Group 2008:88].
These platform parameters are proposed to ensure user safety, comfort, on site security and ticket control [Advanced Logistics Group 2008:78+88].
The stations also require electrical energy to

support infrastructure such as lighting, fare collection and verification systems, as well as automatic doors and possible climate control [Wright & Hook 2007:372].

As projected by Pienaar et al [2007:427], during the 3 hour peak period in the morning a total number of 11 354 users [BRT only] will be coming on the northern line from Mabopani through Rosslyn to the Pretoria Main Station. Yet the system can only accommodate 6400 pph [Advanced Logistics Group 2008:9].

Provision will have to be made for a high number of users, moving quickly through the station. It is also clear that the amount of users would increase significantly in future. The most efficient stations have off-board payment points and platforms level with the height of the busses. This increases the efficiency of these stations from 3 777 pphpd [people per hour per direction] to 9 779 pphpd [Wright&Hook 2007:268].

Passing lanes at stations ensure that express lines are efficient [Wright & Hook 2007:263]. Mechanical systems can be used to guide busses at each station to ensure that the boarding of passengers is safe and secure. This is expensive but ensures that the system is efficient and fast [Wright & Hook 2007:258]. Pretoria stations will not make use of any guiding systems [Labuschagne 2010].

2.3.8 Vehicle size and type

The proposed bus type is the same as being used in Johannesburg BRT system. It is an articulated vehicle that has a central axle. **These vehicles are 18.5 meters long and have a floor height of 930 mm above ground level** [Advanced Logistics Group 2008:99]. The busses will contain Euro III engines that uses clean diesel for fuel [Advanced Logistics Group 2008:99].

As South Africa generates 95% of its electricity with coal power plants [IEA 2009:21], using cleaner low sulphur diesel as fuel is the lowest greenhouse gas emitting method available in South Africa at the moment [Wright & Hook 2007:85].

Figure 2-22: Articulated busses used on Johannesburg [Source: Author]

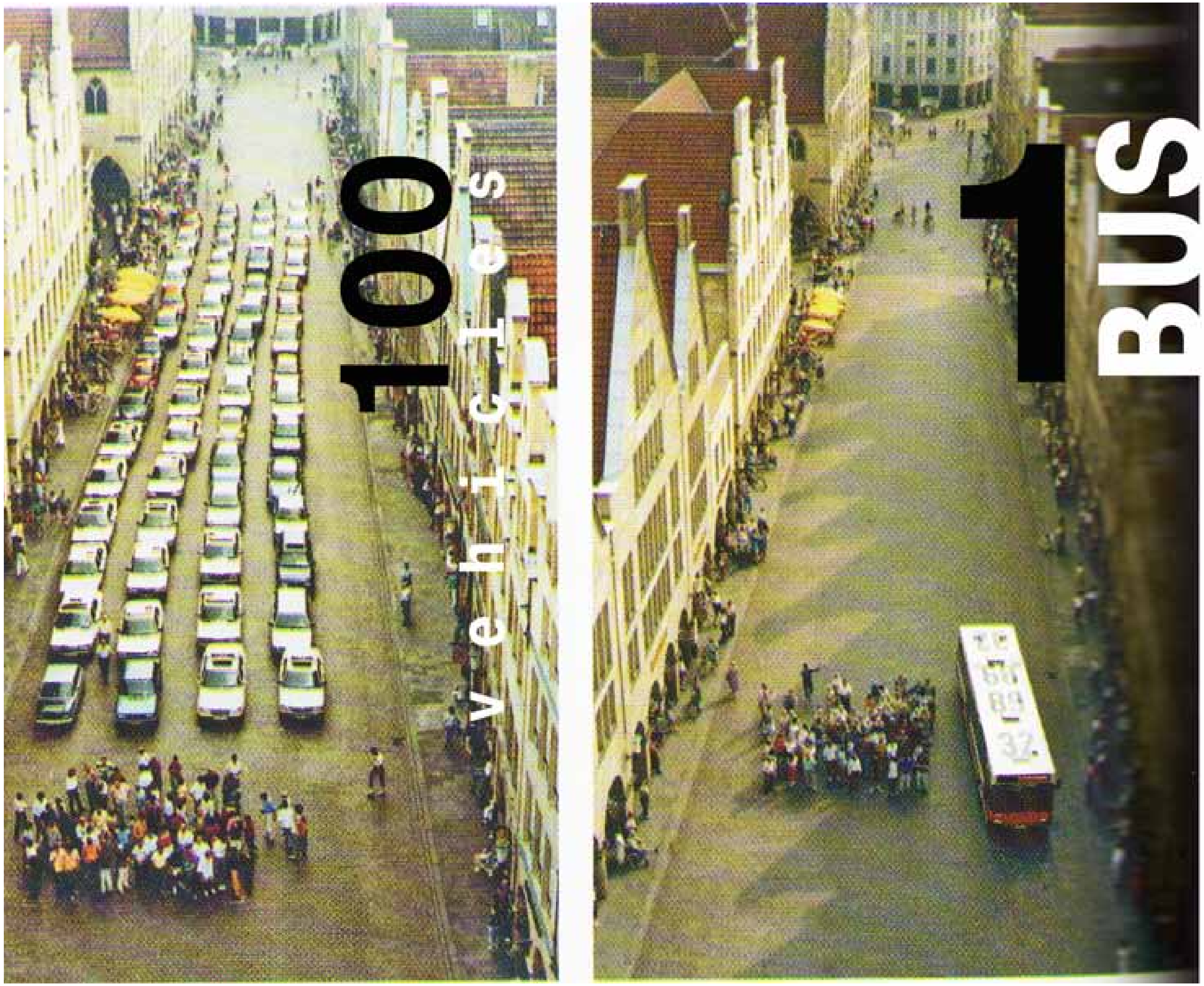


Figure 2-23: Busses displacing single occupant vehicles [Source: Wright& Hook2007 p 86]

These busses can carry up to 130 passengers and have 3 right sided doors that are 1100 mm wide [Advance Logistics Group 2008:99]. Having 3 doors per bus is the most efficient ratio. The system can be designed to have entrance and exit doors, yet many BRT systems do not make use of such a system [Wright & Hook 2007:264].

Articulated busses have a turning radius of 11.57m and are heavier than normal busses. The surface material at stations must preferably be concrete to accommodate the extra weight [Wright & Hook 2007:346].

2.4 CARBON CONTENT AND THE BUILT ENVIRONMENT

Architects have a specific role to play in the mitigation of climate change, as buildings are directly responsible for the depletion of natural non-renewable resources and the production of greenhouse gas emissions [Bennett et al 2003:03].

Globally buildings are responsible for emitting 9 billion tons of CO_2 eq per year, that amounts to 18% of global greenhouse gasses [Walker & King 2008:107]. Greenhouse gasses were expected in 2003 to rise globally with 15% for residential architecture, with a full 50% increase for commercial architecture for the period 1990 – 2010 [Bennett et al 2003:120].

South Africa emitted 345.8 million tons CO_2 in 2007 and this figure rose with 35.8% from 1990 – 2007 [IEC 2009:45]. This makes South Africa the largest producer of greenhouse gasses on the continent. The carbon footprint per capita for South Africa has only increased with 0.4% [between 1990-2007], to 7.27 tonnes CO_2 per capita [IEC 2009:92]. Compare to the average of 0.92 for Africa it is still very high, yet it is very average in comparison with developed countries [IEC 2009:90].

The total volume of greenhouse gas emissions can be divided into different sectors. The energy sector contributes 80%, while 20% is produced by agriculture and the urban environment [Du Plessis et al 2003:245].

In a report assessing the contribution of the energy sector the IEC [2009:49] stated that buildings produce 10% of the CO_2 in many developing countries, which amounts to 34,6 million tons of CO_2. The heating and cooling of the buildings and the use of mechanical equipment, for example lifts, contributes the biggest portion of this number [Du Plessis et al 2003:245].

At the time of the study specific carbon figures have not been available for Tshwane.

Even though the energy sector is one of the chief CO_2 producers, saving energy at a micro level will make a difference on energy consumption at a macro level [Bennett et al 2003:119].

Du Plessis [2003:245] gives the following reasons why commercial buildings are so inefficient:

a) The heating and cooling of the indoor environments.
b) No solar panels or innovative technology.
c) Little use of passive solar heating methods.
d) Bad lighting design leading to the use of artificial lighting throughout the day, adding to the energy use of the building.

Issues a, b and d can be addressed by designing more energy efficient buildings, which will not necessarily increase the building costs significantly. It is clear that the built environment has two components that produce CO_2 emissions. The first component is the construction phase and related embodied energy requirements. The second is the management of services and the energy consumption of the structures.

2.4.1 Achieving a low carbon building

In the article *A Low Carbon Built Environment* Jones [2009:381] targets three key areas of development: newly constructed buildings, existing building stock and infrastructure in the urban context specifically transportation, waste and services.

An holistic view is needed to achieve a low-carbon building, city or society, as greenhouse gas emitting energy consumption is closely intertwined with all aspects of mobility, housing and production. Societies will have to be restructured to wean themselves from a dependency on fossil fuels [Roaf et al 2009:256].

The following design guidelines are suggested to achieve a low carbon structure:

a) Respond to predicted effects of climate change on architecture

b) Reduce greenhouse gasses during the construction phase:

- **Focus on the material used for the construction?**
- **How is it extracted and manufactured?**
- **What transportation methods are involved and what distances are travelled?**
- **Focus on construction techniques and energy use.**

c) Reduce greenhouse gasses during the operational and maintenance stage of the building:

- **What systems are used to achieve a healthy indoor environment?**
- **What maintenance costs and needs would be required?**
- **How much CO_2 is developed during operational phase**

[Bennett et al 2003:121]

2.5 METHODS AND TECHNOLOGIES FOR LOW-CARBON INTERVENTIONS

2.5.1 Urban environment

A current international strategy for designing **more sustainable and energy efficient cities is to develop smaller, walkable medium to high density urban environments** [Du Plessis et al 2003:252]. **The integration of functions and facilities leads to easier access for city dwellers and a reduction in carbon emissions as less transport is needed** [Jones 2009:381; Alexander et al 1977:56].

The single zoning of areas discourages walking. The development of isolated areas is dismissed as irresponsible and unsustainable [GBCSA 2008:189 & Brain 2005:227].

GBCSA [2008:179+187] suggests that interventions must be within 400m from facilities such as greengrocers, ATM's, gyms, etc. and 1 km from public transport nodes.

The design of car orientated roads has led to the alienation of the pedestrian within cities and is counterproductive to the use of public transport [Brain 2005:227]. City block sizes and road widths play an important role in creating the perception that a city is walkable.

By making sure that city blocks are not oversized and establishing shorter distances around or through them will ensure that the pedestrian moves around easily within the city [Gehl 2006:111]. In Pretoria the use of arcades ensures the total distance for pedestrians is shortened significantly by allowing shortcuts through city blocks.

The use of open space is very important. Brain [2005:229] states that in many modern cities open space has always been regarded as left over space. The value of open space has been neglected and should be integrated with the development of green/ open spaces within the city.

These parks or **green open spaces have a cooling effect on the ambient temperature in areas greater than themselves**, and influence the greater urban context in a positive way [Dimoudi & Nikopoulou 2003:75].

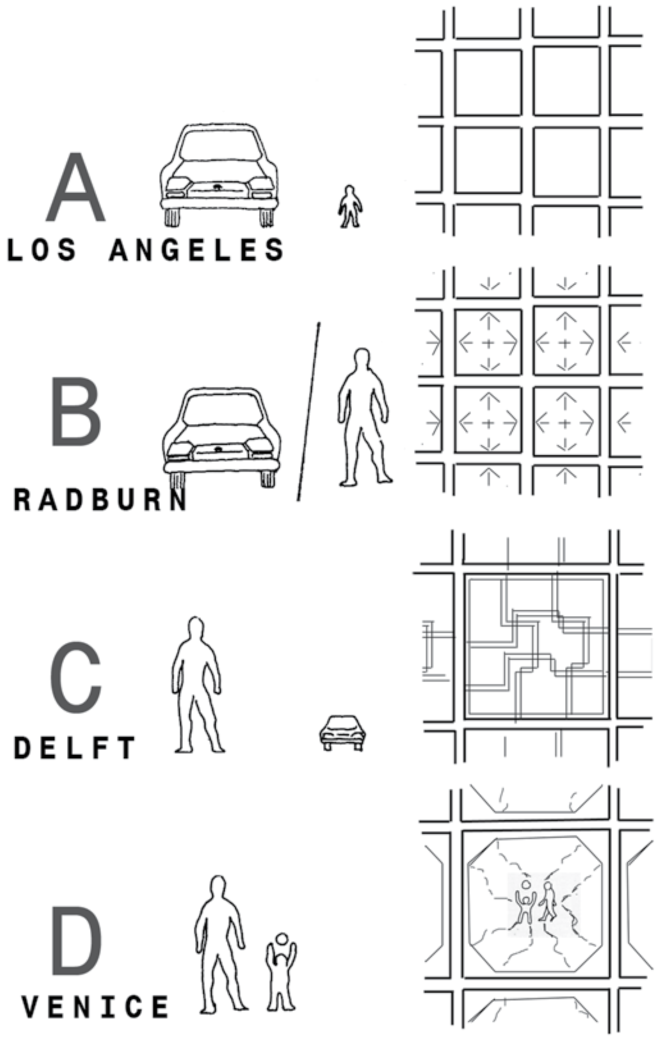


Figure 2-24: Size of block and street. [Source: Jan Gehl, p.110]

2.5.2 Adapting the site

The use of brownfield sites is a very important aspects addressed by the GBCSA. **By rehabilitating brownfield sites, greenfield sites and prime agricultural land, which act as carbon sequestration sinks, are protected.** The Green Star SA manual promotes the enhancement of the existing ecological character of a site to ensure that all manners of carbon sequestration are protected and encouraged [GBCSA 2008:273+289+298].

The adaptive reuse of existing buildings or facades, leads to the preservation of existing finite resources and reduces the greenhouse gasses emitted during the construction and transportation of goods [GBCSA 2008:223].

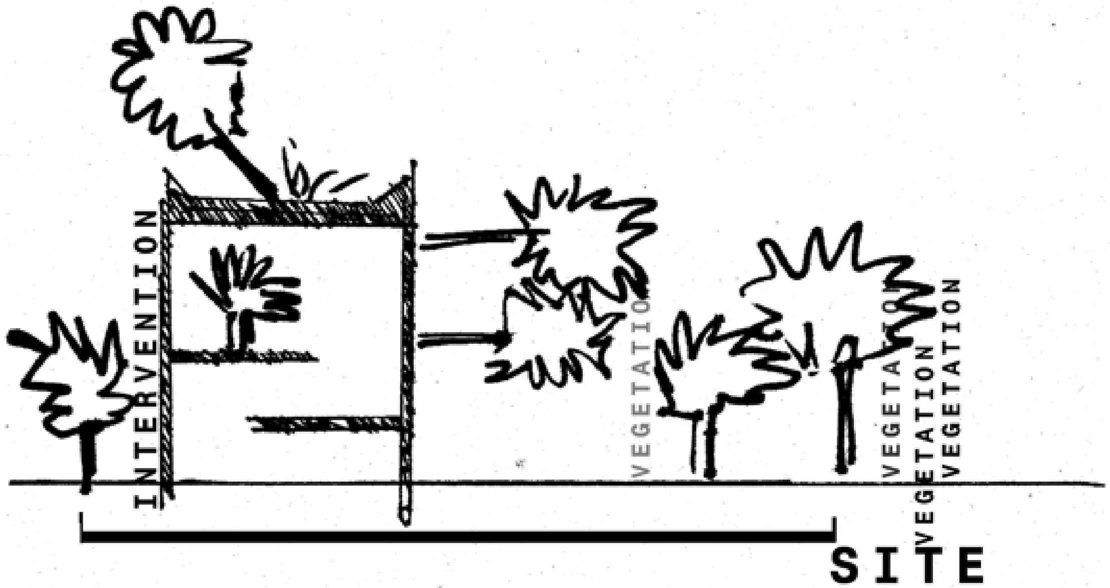


Figure 2-25: Integrating planting and the building [Source: author]

The embodied energy of reused material is much lower than that of recycled material. By salvaging materials more than half of the original investment is saved [Goldbeck & Goldbeck 1999:270].

Integrating planting within the site layout of the design will lead to significant energy savings. Trees cool the micro-environment by reducing the radiant load on the user of the environment. Through evotranspiration trees add moisture to the immediate atmosphere that cools the immediate environment [Dimoudi & Nikopoulou 2006:70]. Trees also shade buildings and windows, reducing the long wave transmission and heat exchange of buildings. In hot climates one could save up to 30% of heat load by painting the roof colour white and adding planting close to the building [Barnett & Brown 1999:12].

Within the site layout allowance should be made for cyclists to have easy access to the buildings. Safe storage for the bicycles must be provided. This will **encourage the use of more sustainable carbon free transport methods** [GBCSA 2008:173].

2.5.3 Working within the Building

One of the prerequisites of the Green Star SA Office Rating tool is to lower the energy use of buildings. "The design must demonstrate that its energy use is equal to or less than the national SANS 204:2008 'Energy efficiency in Buildings' prescribed levels..." [GBCSA 2008:133].

There are a few methods of addressing energy use within buildings, the first being passive design principles and the second being the use active technological methods. The third consideration is the building material itself and the embodied energy it contains and energy required for its maintenance.

Using passive design principles can lower the energy consumption, carbon footprint and greenhouse gas emissions of buildings [Omer 2007:2334].

By looking at local and vernacular architecture one can learn a lot about sustainable passive technologies. These tried and tested methods has been developed and perfected over time [Barnett & Brown 1999:11]. Passive design principles are essentially grounded in the existing context and available materials, yet with the expected climatic changes these vernacular technologies will need to be adapted.

2.5.4 Building-Passive design principles

Plan and position

The plan form and position of the building must be considered when designing a structure in Pretoria. During the winter period heat gain is essential, while during the summer period the structure needs to be shaded to ensure a cool internal temperature [Holm 1996:69]. **The optimum position for the structure would be to orientate it directly north [15° NE to 10° NW]** in order to ensure maximum solar control [SANS 204-2:33].

Landscaping and hardscaping

Heat island effects are generally found within urban areas. These are generated by large paved/hard surface areas or the roofs of structures [Haselbach 2008:68]. This can be mitigated by shading car parks and using open grid paving with planting. **The use of vegetated roofs or lighter coloured roofs** with high solar reflective index values ensures that he micro climate is cooled considerably [Haselbach 2008:69+73].

Ventilation

Natural ventilation and evaporative cooling are both ways of dealing with the indoor temperature and air quality within structures to ensure thermal comfort [Holm 1996:71-72; GBCSA 2008:41] One must keep in mind that natural ventilation influences the thermal comfort of the structure [GBCSA 2008:41].

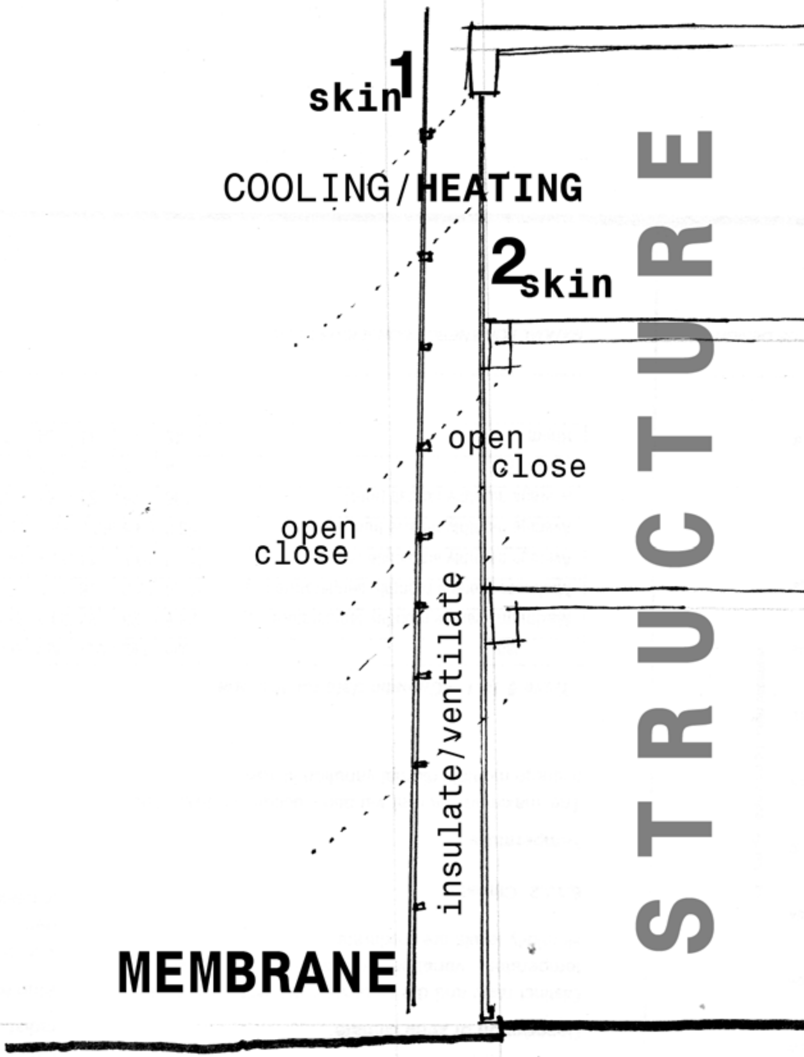


Figure 2-26: Making use of a double skin to accommodate heating or cooling of structure [Source: Author]

It is important though to design for the user to have control over the ventilation as over-cooling or heating can easily become a problem.

Artificial cooling and air handling consumes 50% of the total operational energy use of a building [GBCSA 135]. By making use of natural ventilation substantial CO_2 savings can be achieved.

One method of dealing with the ventilation, heating and cooling of structures is making use of double skins, where the membrane of the building becomes intelligent and responsive to the climatic conditions [Bisch 2002:259].

This method though will increase the embodied energy of the structure, while ensuring that the energy use throughout the building's life cycle is minimised. A double skin membrane can be used for daylighting control as well, controlling glare and lux levels.

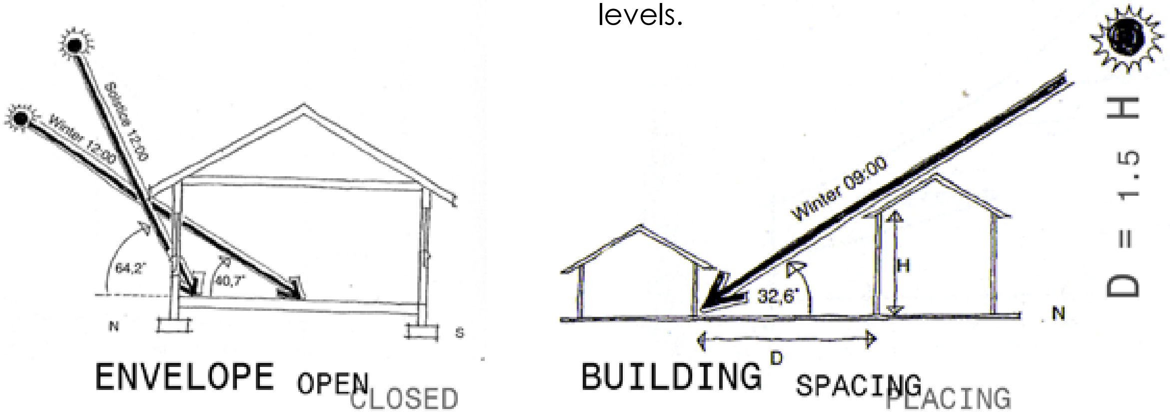


Figure 2-27: Allowing passive solar energy into the building structure [Source: Holm 1996, p71+72]

Lighting

Using natural daylight to achieve acceptable lighting levels within the structure is a strategy that can achieve a lower carbon footprint for the structure. While it lowers the building's energy consumption, a healthier and more productive indoor environment is created at the same time [GBCSA 2008: 63-64&135].

When natural lighting is utilised the designer must take care to eliminate glare within the building. Making use of southern diffused light an effective strategy without increasing glare. Ensuring that eastern and western light are adequately screened will eliminate overheating and glare [Holm 1996:7].

Thermal mass

Thermal mass is a very effective method of dealing with outdoor temperature changes. The flywheel action contributes to maintaining a comfortable average indoor temperature.

In Pretoria the thermal mass of a 220mm masonry wall will be sufficient to keep the indoor environment cool during the summer period. **Night cooling can be used, in summer, to ensure a cool structure during the day [Refer to Section 5 - Precedent 4]**. With a temperature increase of 4-6 ° C, caused by global warming, cooling will be needed during extremely hot periods.

During the coldest period in winter heating will have to be used in most structures [Holm 1996:71]. Fortunately climate change will lead to warmer winters, minimising the use of space heating .

2.5.5 Buildings -active systems

Renewable energy sources

One must have a more ecosystemic understanding of energy on site when addressing renewable energy sources, Jones [2009:381] advocates the use of hybrid systems to achieve an energy independent system: using solar, geo-thermal, photovoltaic, wind and biomass systems. **Diversity in nature achieves sustainability; the same approach can be taken with energy sources or systems within a building to ensure sustainability** [Kilber et al 2002:18].

Solar energy

South Africa has the great advantage of extensive sunlight; **the potential for the use of solar power in this country is enormous** [De Plessis et al 2003:252]. The average sunshine South Africa receives is 235h per month, with two thirds of the country having radiation of 7000MJ/m2 – 9500 MJ/m2 [Du Plessis et al 2003:241]. Solar energy can be utilized by employing three approaches: passive solar methods, active solar methods, and photovoltaic systems [Omer 2007:2342]. Passive solar methods were discussed in the previous section.

The use of thermal solar water heaters is a cheap and effective method of saving energy. Integrating this with photovoltaic systems could make an even bigger impact [Du Plessis et al 2003:252]. Photovoltaic systems are more expensive to install, but have a life cycle of 20-30 years [Omer 2007:2339]. Solar panels can generate up to 100 W/m^2, yet there are only 6,4 effective sunlight hours per day [allowing 0.64kWh/m^2 per day] [Holm 2001].

To ensure the optimal use of solar energy the building design must have a large roof or envelope sections facing north, fixed at a 30° angle [vertical panels are very inefficient on South Africa's latitudinal position] [Moraal 2010].

Wind energy

The wind energy harvesting potential in Tshwane is very low. The area experiences wind still periods for about 50% of the total time. As indicated in the wind rose wind speeds rarely achieve levels beyond 25km/h [Holm 1996:70].

Lighting

Energy can be saved by making use of CFLs and LED lighting technology [Walker & King 2008:246]. One should take care not to overdesign the lightning levels but rather making use of task orientated lighting. The GBCSA advocates the maintenance of illuminance levels to a maximum of 400 LUX [GBCSA 2008:75].

Figure 2-28: Wind rose of prevailing winds in Tshwane [Source: Holm 1996, p70]

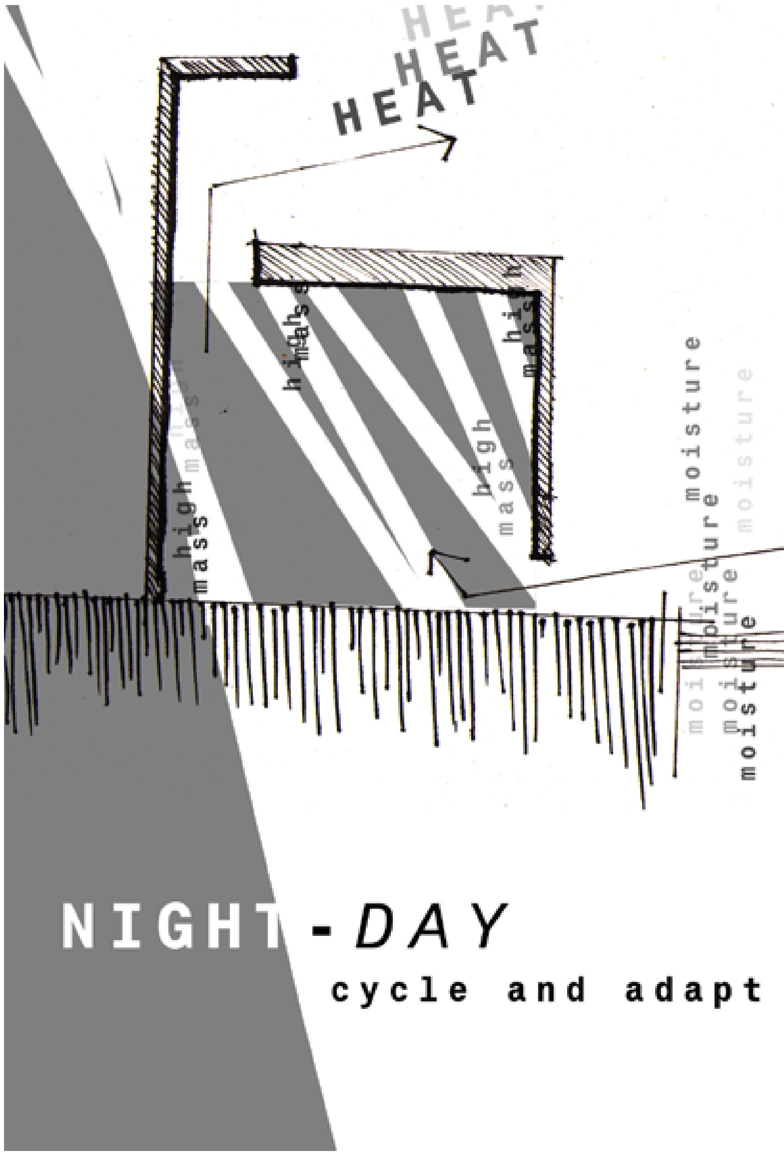


Figure 2-29: Making use of evaporative cooling, high mass and night cooling to ventilate the structure [Source: Author].

By making use of flexible lighting zones and movement sensors, much lower energy consumption levels can be achieved [GBCSA 2008:153].

Ventilation

Pretoria has a very mild and temperate climate, with an average maximum average temperature of 24.81 °C and lowest minimum temperature rarely below 4.8 °C. This means that active air-conditioning is not needed for most building types. **The use of evaporative cooling is very effective during overheated periods while mechanical ventilation might be needed to achieve adequate ventilation rates** [Holm 1996:71+72].

Yet as discussed in section2.2.2, the future increase in air temperature [of up to 6°C] will lead to the need of more efficient ventilation systems and methods.

By making use of a diverse system that incorporates a series of different strategies the adequate temperatures can be achieved [Kilber et al 2002:18]. This method has been used in the CH2 building in Melbourne, as discussed in Chapter 5.

Evaporative cooling

Evaporative cooling is an effective method for lowering the ambient air temperature. **The air quality is improved by adding moisture without adding extra heat. In the process the air temperature drops** [Holm 1996:12].

Geothermal heating or cooling

Air temperature and fresh air quality can be controlled by means of underground ducts that utilise the geothermal qualities of soil. **By pumping fresh air through an underground duct the air temperature can be cooled in summer and heated in the winter** [Bisch 2002:259].

Night cooling

Night cooling ensures that radiant beams are cooled at night through natural or mechanical ventilation. This method is used in the CH2 house in Melbourne [CH2 s.a.:03]. By using heavy structural materials as heat sinks the cooled structure would absorb excess heat that is generated during the day.

Mechanical cooling and heating

When the only option is to use an HVAC system one should not specify ozone depleting refrigerant gasses. As greenhouse gasses HFC's and CFC's have up to 8000 times more heating capacity than CO_2, making the use of these gasses very dangerous [Miller 2004:282]. Rather choose to use hydrocarbons or ammonia based refrigerants [GBCSA 2008:311]. Yet a low carbon structure must preferable not make use of an HVAC system at all.

2.5.5 Material use

Choice of materials
When choosing materials for a project, the life cycle of the building must be understood. Match the choice of material and building structure to the rhythms of nature – using the analogy of a weed like structure and tree structure. **Make use of easily replaceable and simple structures if the building or site is disturbed regularly, and choose a more [tree like] structure if it is permanent** [Kibert 2002:285].

This can be taken one step further, where the structure itself is understood in terms of long life cycle and shorter life cycle components. By choosing and grouping different materials and functions together, certain materials can easily be dismantled and recycled while the more robust sections are kept in place [Odum 2002:52-55]. This entails understanding the different materials and their life cycles [Van der Ryn et al 2002:243]. Use of composite materials makes the dismantling of the structure more energy intensive, in which case one should ensure that dismantling is always possible afterwards [Bisch 2002:262].

With declining global resources, one should consider new and innovative building materials while limiting the amount of materials used. LEED proposes that rapidly renewable materials be used as building materials [Haselbach 2008:196].
These can be animal based products or plant materials.

The advantage of using plant materials lies in the fact that throughout the photosynthesis process carbon sequestration occurs which already contributes to a lower CO_2 content in the atmosphere. When plant material is used as building materials their carbon content is taken out of the carbon cycle
[Berge 2010:34].

Reuse and recycle
The ultimate method of dealing with materials is to reuse and recycle them. Ultimately, if need be, they should be biodegradable [Bennett e al 2003:97]. This ensures that the embodied energy of the material is much lower than that of virgin materials [GBCSA 2009:228+31].

Materials that can be recycled and reused could either be whole building components such as doors and windows etc. or the materials themselves such as

a) bricks reused as building units
b) crushed bricks and mortar for onsite landfill
c) timber, steel and aluminium
d) foam or packaging for insulation
[GBCSA 2008:33; Haselbach 2008:189]

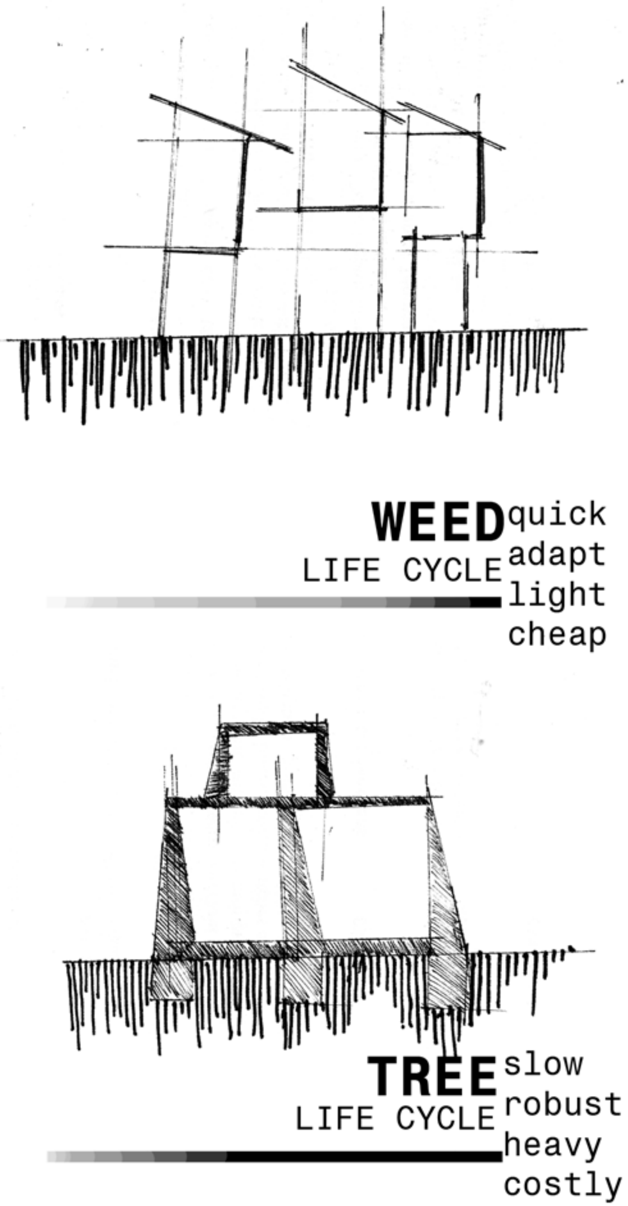


Figure 2-30: The type of material determined by their lifecycles [source: author]

Building waste makes up one third of the world's total waste and its removal uses large amounts of fossil fuels [GBCSA 2009:228+31]. By reusing building materials large amounts of building waste is diverted from landfill sites. This leads to the lowering of transport energy used during construction while methane produced in landfill sites is also lowered.

Embodied energy *
By determining the embodied energy of materials a designer can start choosing a structural system and materials to ensure a design with a low embodied energy. The values also guide the designer to choose which material to recycle and which to keep for the full lifecycle of the building.

Concrete
Concrete is a versatile durable product, yet it requires a lot of cement to ensure its structural strength. The cement is responsible for 90% of greenhouse gasses generated by the production of concrete [GBCSA 2008:238]. Cement has a low embodied energy of 5.85MJ/kg, yet the cement industry is responsible for 5% of global man made greenhouse gasses [Kendall et al 2007:1]. This can be linked to the fact that materials with low embodied energy are usually used in large amounts.

When choosing concrete as a building material, it's optimum use of concrete must be considered. To reduce the quantity of cement used in concrete, oversized and recycled aggregrate can be used. Fly ash cement makes use of industrial waste [a by product during the production of steel] as an admixture to reduce cement usage. In this way 30% cement can be saved [GBCSA 2008:235; 238].

When using robust, durable materials such as concrete, the concept of dematerialisation should guide the process – this would mean using structural systems innovatively to ensure that less materials are used [Bisch 2002:252].
The disadvantage of using concrete is the fact the recycling of the structure after its life cycle is an energy intensive and difficult process [Fernandez 2006:208].

Steel
Steel is a strong, ductile, durable and lightweight structural material [Fernandez, 2006:109]. Unfortunately steel has a very high embodied energy. Industries are developing decarbonation strategies leading to a cleaner process and large amounts of steel are being recycled [Fernandez 2006:112]

* NOTE: See appendix for list of embodied energy and life cycle of materials

Steel has a very good post-consumer recycle and recovery rate ensuring that its embodied energy is lower [GBCSA 2008:241 & Fernandez 2006:126]. In South Africa 70% of all steel products are recycled while larger structural steel sections produced by big producers have a recycled content of 20% [GBCSA 2008:244].

Steel components can be constructed off site leading to a fast and accurate construction process, meaning less waste is produced on site. Wastage on site can easily amount to 10% of the total material used [Holm 1996:84]. **Steel can easily be disassembled and reused.**

Timber

Timber is a renewable construction material with a very low embodied energy. Timber can easily be reused and adapted for many uses during its lifetime [GBCSA 2008:251]. It is also a natural material that is used for carbon sequestration processes.

One should keep in mind that the irresponsible exploitation of natural renewable resources is detrimental to development. When opting to use timber ensure that all new timber comes from a FSC [Forest Stewardship Certified] timber producer alternatively use recycled timber [GBCSA 2008:251]. Eighty percent of South Africa's timber is FSC certified, thus sustainable forests are within easy reach of all building projects [GBCSA 2008:253].

Unfortunately timber is not such a robust material and can easily degrade due to high usage and overexposure to a harsh climate. The maintenance of timber is very high to ensure a long life cycle [Wegelen 2006:4.3].

Masonry

Masonry is a widely used material in developing countries that requires very little processing. It has a high thermal mass and is durable. The structural system is also flexible to accommodate small shocks and changes [Fernandez 2006:205].

There are many different types and methods of producing masonry units, ranging from burnt clay bricks to hollow concrete blocks, each having its own embodied energy value. The embodied energy can range from 4.75 MJ per clay brick to 1.32 MJ eq for a hollow concrete block.

Many industries are improving the process of production to ensure that their environmental impact is minimised. The only industry that is not improving is the burnt clay brick industry of which 60% are still using "clamp Kilns" extensively which is a very inefficient method that produces high carbon emissions [Du Plessis et al 2003:252].

Bricks can be recycled into separate units, which in certain situations can contribute to sustainability by providing labour [Berge 2000:207].

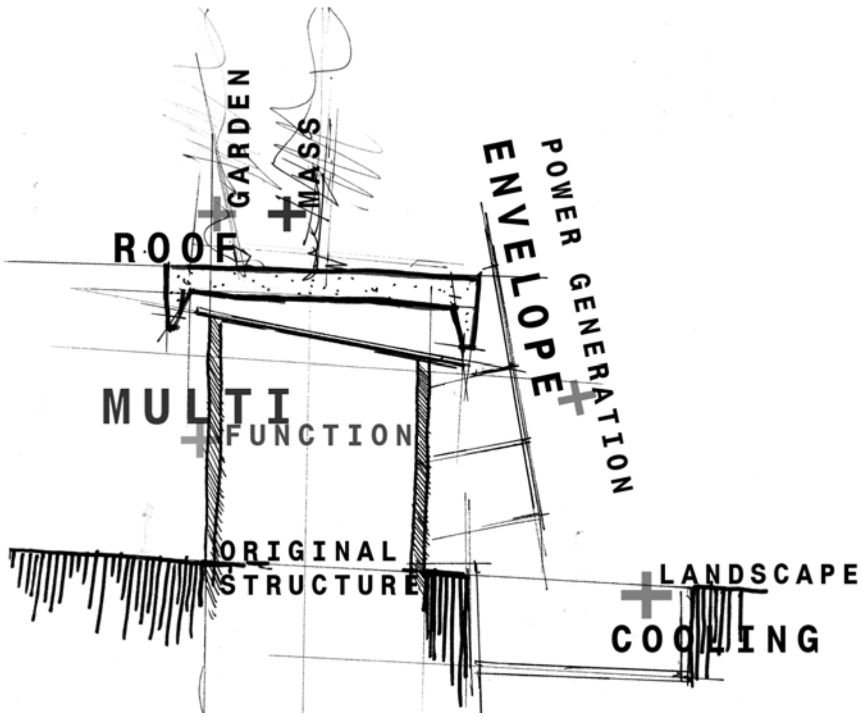


Figure 2-31: Methods of achieving multi functional components [Source: Author]

2.5.6 Innovative materials & techniques

Decarbonisation

The decarbonisations of structures **is a concept whereby carbon absorbing materials or plant materials are integrated with building components. These components subsequently becomes a carbon absorbing structures** [Van der Ryn & Pena 2002:243].

Materials, such as calcium based materials, can also become decarbonising which sequestrate CO_2 during their life cycles.

Decarbonising materials can recapture between 25% to 50% of the carbon released during its extraction and production, lowering the carbon footprint of these materials [Berge 2006:34]. Novacem is a UK based company that has developed a cement product that absorbs 100 kg more CO_2 per ton cement than what is emitted during its production [Novacem homepage 2010]. Unfortunately a similar product is not available in South Africa at present

Dematerialisation

Dematerialisation can be **defined as a method of minimising the use of materials for the construction of structures**. This could either be done by using less material or by optimising building components with multiple functions [GBCSA 2008:261; Van Ryn& Pena 2002:233]

2.5.7 Local sourcing of materials

The local sourcing of materials leads to a lower embodied CO_2 footprint for these materials. The GBCSA [2008:267] proposes that 20% of building materials be sourced within 400km while another 10% be sourced within 50km.

The type of material that is transported is also important to consider, this influence the transportation energy used.

Type of material	Energy [MJ]		
	Production	Transportation	
		50 km	100km
Sand [m^3]	0.0	87.5	175
Crushed aggregate [m^3]	20.5	85.5	175
Burned clay bricks [m^3]	2550	100	200
Portland cement [tonnes]	5850	50	100
Steel [tonnes]	4200	50	100

Table 2-03: Table indicating the different amounts of energy used for transportation of building materials. [Source: Jagadish *et al*, p 5]

It is clear from Table 2-03 that the type of material that is transported makes a big difference to the energy consumption. Transporting low embodied energy materials like sand or aggregate is not a very sustainable practise, as the production thereof is much less than its transportation. The transportation of masonry is the most inefficient, thus sourcing masonry locally is crucial.

The transport type is also of importance. Electrical rail transport uses 0.2 MJ/ton/km while road based diesel transport uses 2.2 MJ/ton/km [Berge 2006:17]. This project will not address the methods by which materials are transported to site.

2.5.8 Conclusion

It is clear from the methods discussed that there are different approaches to ensure a low carbon building, each resulting in specific effects and costs. **It is important to think holistically and systematically about the whole construction process and lifecycle of the structure**. By understanding the full life cycle of the building and its materials the designer can make more informed choice.

NOTE: These figures are only approximate and only applicable for the India

2.6 ENVIRONMENTAL RATING SYSTEMS

The built environment has great potential for delivering long term environmental improvements. Apart from changing the impact of construction and the buildings, architecture can also contribute to the behavioural change of the users and society [GBSCA 2008:ix].

Currently there are a series of barriers that create unsustainable and inefficient structures. One of the issues that has been recognised is the split in incentive between the owner, designer, contractor and developer. The parties involved usually start out with good intensions but these are usually lost through the construction and building management process [GBCSA 2008:ix].

2.6.1 What is a rating system.

An environmental building rating system is a voluntary assessment process [GBCA 2010]. Internationally, certain construction projects are required by legislation to be assessed. In certain states in the USA publicly funded buildings must be assessed, the same applies for housing projects in the UK [Stancich 2009:1].

Rating systems allow for third party assessment of the environmental design and performance of a building [GBCA & USGBC 2010]. The rating systems focus on the design, construction and management of the building and building process [BREEAM 2010].

In the process the different professionals in the building industry are bought together, establishing a common language them. The rating system assigns responsibilities to the various parties involved [GBCSA 2008:xiii]. In the process a complete sustainable building design is developed [GBCA 2010 & GBCSA 2008:9].

A series of lifecycle environmental impacts is identified by these rating systems. The aim is to minimise them through innovative and best environmental practises [BREEAM & GBCA 2010].

The existing rating systems aim to establish a benchmark according to which projects can be judged. The benchmark is usually higher than what regulations require [BREEAM 2010]. Only the leaders in the sustainable building environment are acknowledged; as only 4, 5 and 6 star rated buildings are certified [GBCA 2010 & GBCSA 2010].

This would encourage a constant improvement in standards and will foster innovation in design and construction practises.

2.6.2 Rating systems and climate change

The World Green Building Council [WGBC] has a list of principles to guide the council itself as well as green building councils worldwide. These principles address a wide range of issues: from the triple bottom line of sustainability and establishing transparent leadership to inclusive processes of developing sustainability worldwide.

There are eleven principles, of which two address climate change specifically.

a) The WGBC aims to respond to climate change with all scale, capacity and speed.

b) The effectiveness in creating strategies to reduce greenhouse gas emissions must be improved.

[WGBC 2010]

These have been incorporated into the principles and rating systems of green building societies worldwide.

The Greenstar SA requires as a prerequisite that the energy use for the design is calculated to demonstrate that its energy use is equal to or less than the national SANS 204:2008 "Energy efficiency in Buildings" prescribed levels [GBCSA 2008:133].

The LEED rating system has a carbon commitment, stating that it advises the reduction in use of fossil fuels. It suggests the use of renewable materials and energy sources which do not emit greenhouse gasses [Haselbach 2008:19].

The rating system has the following prerequisites related to climate change:

a) The structure must demonstrate that its energy use complies with the ASHREA standard

b) All CFC refrigerants must be phased out of HVAC systems; these gasses are harmful to the ozone layer in the troposphere.

[LEED rating system version 2.1]

The rating systems addresses various issues that lead to lower carbon buildings if complied with.

2.6.3 World Green Building Council

Most rating tools in the world are affiliated with the World Green Building Council, which means that information and knowledge is shared globally, improving the efficiency of sustainable initiatives.

The World Green Building Council was founded in California in November 1999. The first countries involved were Canada, Russia, the United Arab Emirates, the United Kingdom, Spain, Australia and the United States of America.

The Council was developed to increase collaboration between leaders in the global construction industries which will enable sustainable environments, - economies and - societies can to developed.

The WGBC recognises the following rating systems:

Australia – Green Star Australia
Canada – Canada LEED
Germany – German Sustainable Building Certificate
India – IGBC Rating System & LEED India Green Building Rating Systems
Japan – CASBEE
New Zealand – Green Star NZ
South Africa - Green Star SA
United Kingdom – BREAAM
United States – LEED Green Building Rating System

2.6.4 Choosing a rating system

The Green Building Council of South Africa works closely with the Green Building Councils of Australia, the UK and the USA. This collaboration is speeding up the development of different rating systems for South Africa. The current Green Star SA Office Rating System is based on the Green Star Australia Office Rating System [Buch 2010].

Using foreign rating tools without adapting them is not advisable. Even though sustainability is a global concern, good sustainable practices are not necessarily the same for all areas and societies [Haselbach 2008:1]. The Green Star Office Rating Tools has been developed and adapted for South Africa context. This means that it will be an appropriate guide for this project.

If one needs to use a foreign rating tool, the Green Star Australia is a good choice, as there are numerous similarities between Australia and South Africa. The GBCSA adapted sections of this rating system to the South African context while the rest was directly adopted. When working with buildings that do not have rating systems in South Africa the GBCSA suggests that one uses the Green Star Australia as guide [Buch 2010].

2.6.5 Methodology

The Green Building Council of Australia found that 40% of the total emissions in the built environment are caused by offices and hospitals [s.n. 2008:1]. Therefore the GBCA decided to focus on developing rating systems for these two building types first. Currently the only rating tools that can be used are the Green Star Australia Retail tool and the Mixed Use tool. There is a pilot retail tool available for Green Star SA.

BREEAM, a rating tool from the United Kingdom, allows for international projects to be rated, but will need to be adapted to local regulation and conditions. These changes range from environmental issues & weighting, detail of construction, products and materials to local regulations [BREEAM 2010]. BREEAM has a Retail ating tool and an Other Building rating tool available. According to BREEAM the Other Building rating tool needs to be adapted and changed to accommodate the building type [BREEAM 2010].

There are LEED rating tools available for schools, hospitals, homes, cores and shells, neighbourhoods, commercial [pilot tool] and commercial interiors [pilot tool] [USGBC 2010]. None of these have specific use for the proposed building type and context except for the commercial tools.

For this project the Green Star SA Office Rating Tool will be used and adapted,. As the building type is a BRT station none of the existing rating systems are directly applicable for this project.

GREEN STAR SA – OFFICE
The Green Star SA Office Rating Tool addresses the following categories:

1) Management
2) Indoor Environment
3) Energy
4) Transport
5) Water
6) Materials
7) Land use + Ecology
8) Emissions

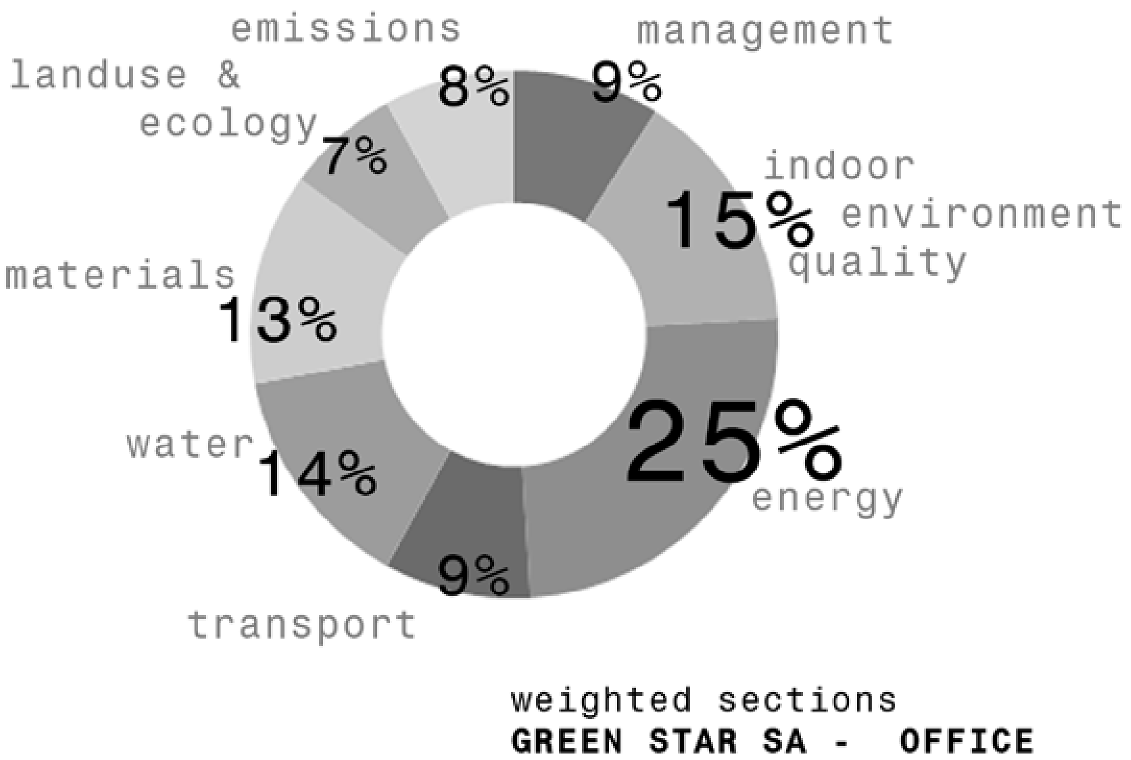
All these sections are weighted to give a single score. From this score the performance of the structure can be developed. In future, as rating tools are developed for different building types, the weightings of the different sections would change for the specific building type [GBCSA 2008:x].

Note that in Graph 2-04 that energy is the most important section of the rating tool, followed by indoor environment and water. This might differ if a different building type is used. Yet for the design of a low carbon BRT station energy is a major concern.

The sections that are most applicable in assessing or achieving a low-carbon building are Energy, Transport, Materials, Emissions, sections of Indoor Environment Quality, the construction waste management section of Management.

For this project, only the prototypical BRT station will be assessed, as it will theoretically be constructed throughout Tshwane.

The station building will not be assessed, but the rating tool will be used as a guide to address the embodied energy and carbon footprint of the structure.



Graph 2-04: Amounts that each section counts to the full score [Source: Author]

2.7 CONCLUSION

A good solution:
...solves more than one problem, while not making new problems...
... is good in all respects...
... accepts its given limits...
...and uses what is at hand...
[Barnett & Brown 1999:13]

Adapting for climate change clearly requires a good solution. This means understanding the problem holistically and adapting our cities, societies and lifestyles.

Achieving this good solution means planning before planning – pre-planning the planning process. From this a sufficient framework and holistic understanding can be developed. An understanding of the present urban context, historical and cultural context will be integrated with the good solutions and ratings to provide a framework within which the design can develop.

3 — A CHANGING CONTEXT

3.1 SOUTH AFRICA

Many South African cities developed and changed into segregated and isolated cities under the Apartheid regime, isolating these suburbs from town centres. This was deliberately done to segregate the South African population according to race [Du Plessis et al 2003:243].

This process led to unsustainable cities with isolated suburbs. Necessitating a sustainable, affordable and reliable transport system that bridges the gap created during the Apartheid era. The Bus Rapid Transit systems can assist in reconnecting and empowering dislocated communities in South Africa.

Johannesburg has implemented the BRT system, while Cape Town and Pretoria are in the process of developing and implementing it. In the long term all major cities in South Africa will employ this system.

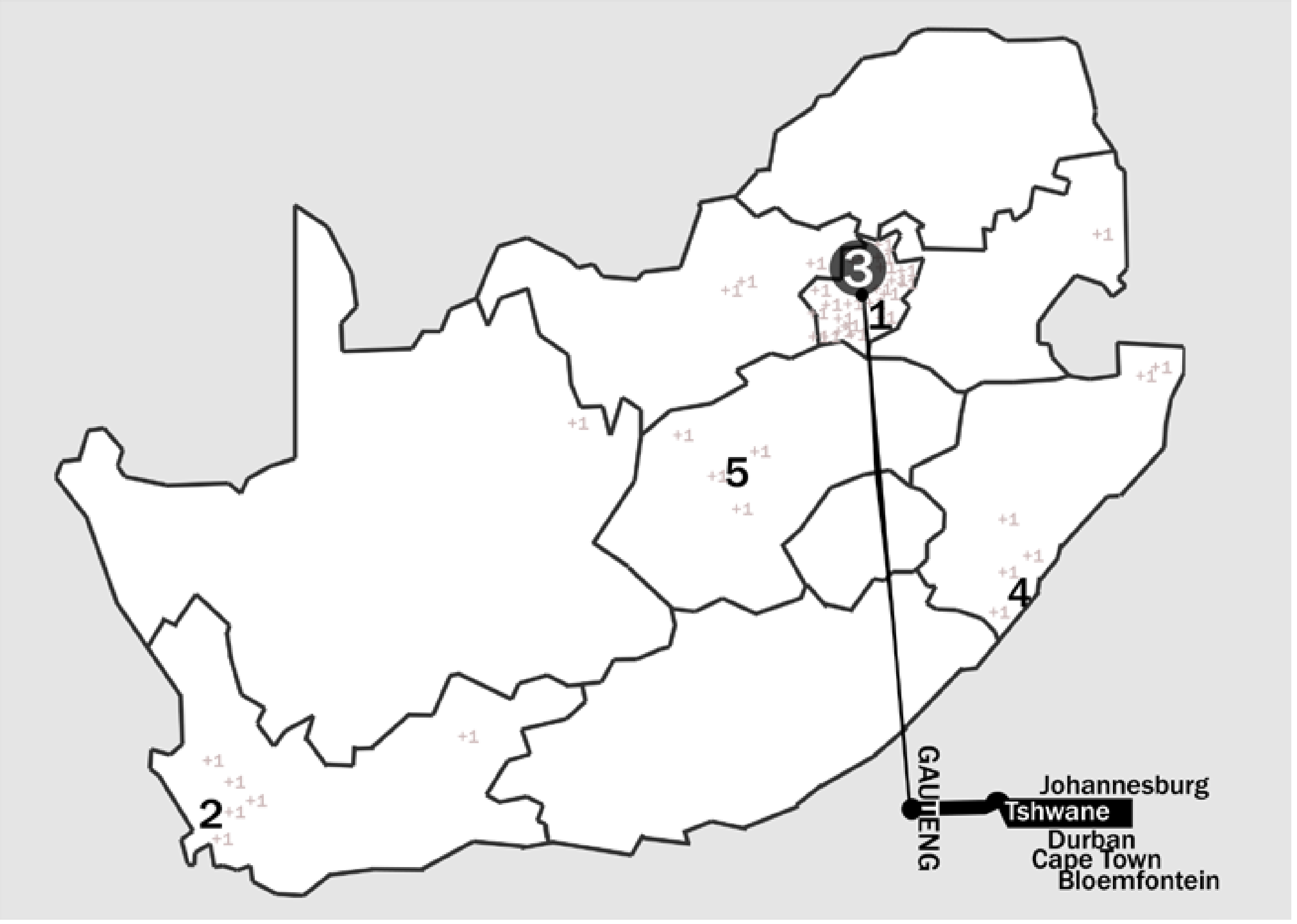


Figure 3-01: BRT systems developing throughout South Africa [Source: Author]

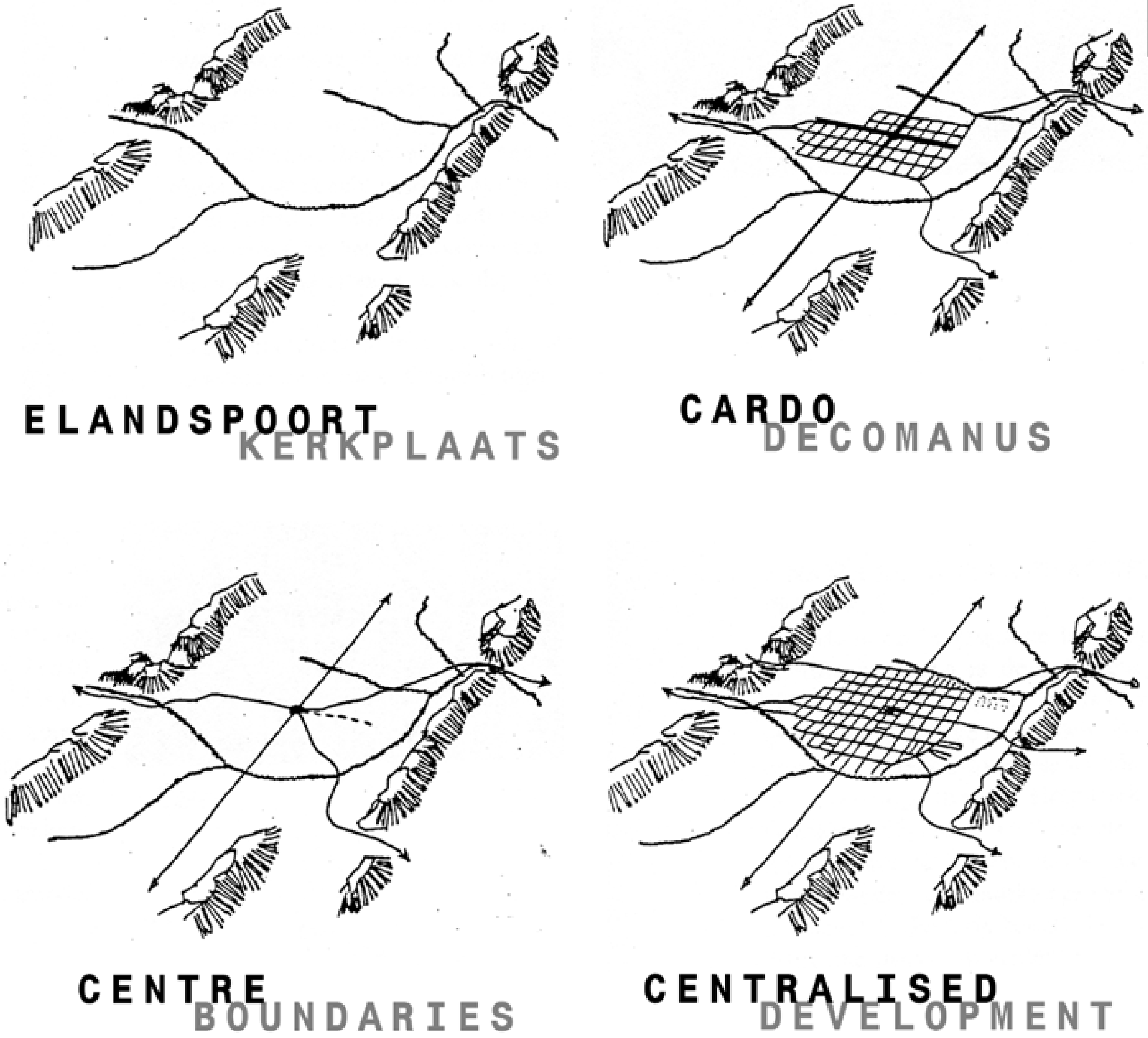


Figure 3-02: The development of Pretoria [Source: Jordaan 1989, p27]

3.2 CHANGING FROM PRETORIA TO TSHWANE

Tshwane has experienced a series of changes throughout its history. It developed from a centralised city to a massive low-density sprawling city.

TRIBE AND CHURCH

Pretoria was declared a town in 1855. It developed around a central kerkplaats situated on the Elandspoort farm [Bakker 2004:04 & Holm 1998:61]. It developed as a centralised dense city contained within its natural boundaries [Holm 1998:60].

CENTRE AND BOUNDARIES

The original city layout was coordinated between two rivers, the Apies and the Steenhovenspruit acting as boundaries on the eastern and western edges. The northern and southern boundaries were formed by the koppies and hills Thaba Tswane and the Magalies berg. The centre of this area clearly lined up with the natural gateways ["poorte"] formed by the natural landscape [Jordaan 1989:26-28]

URBS QUADRATA

The layout of the town of Pretoria was a "conscious and significant act", a very ordered and Calvinistic approach to understanding human development in the natural landscape [Holm 1998:59+62].

The Cartesian town layout with the cardo and decumanus maximus crossing at the town centre links the town centre with the four compass axes and the edges of the town [Jordaan 1989:26].

The town centre, currently Church Square, is situated on the two axes as a very important point within the city.

Moving parts apart

With the discovery of gold in the Transvaal in 1885, Pretoria changed into a thriving capital city [Holm 1998: 59]. Thriving suburbs developed to the east and west leading to significant changes in building types and city size. It also led to the implementation of the railway system in the ZAR to accommodate the new industries and mines [Bakker 2002:12].

This compact and centralised city changed significantly during the Apartheid era, under the Group Areas Act [1923] the city was fragmented into segregated areas [Chipkin 1998:160]. This was aimed at segregating people into racial zones seperated with buffer zones [Du Plessis et al 2003:243].

The urban centres were exclusively reserved for white Europeans, while black people were only allowed temporary residence within these areas [Chipkin 1998:152].

This led to displaced, overcrowded urban areas called tribal reserves, which were isolated from the resources of the city [Chipkin 1998:160]. At the moment these districts house the population with the lowest income and is situated the furthest from the city centre [Du Plessis et al 2003:243].

This spatial layout has led to heavily subsidised public bus and rail transport systems, which because of the decentralised low-density nature of the city are highly inefficient and unsustainable [Du Plessis et al 2003:243].

ADDING UP THE PARTS AND PAST

In 2000 the municipal area of Pretoria changed its name to the City of Tshwane effectively doubling the urban area leading to a highly fragmented and divided, low density metropolis [Berstein & Mcharthy s.a:1].

The City of Tshwane is currently developing strategies and putting frameworks in place to address the backlog of development in its northern suburbs. The Tshwane Integrated Development Plan [2006-2011] proposes that the focus should be on developing infrastructure and transport systems in these areas [TIDP 2006:167].

The Bus Rapid Transit system will play a major roll in achieving this aim.

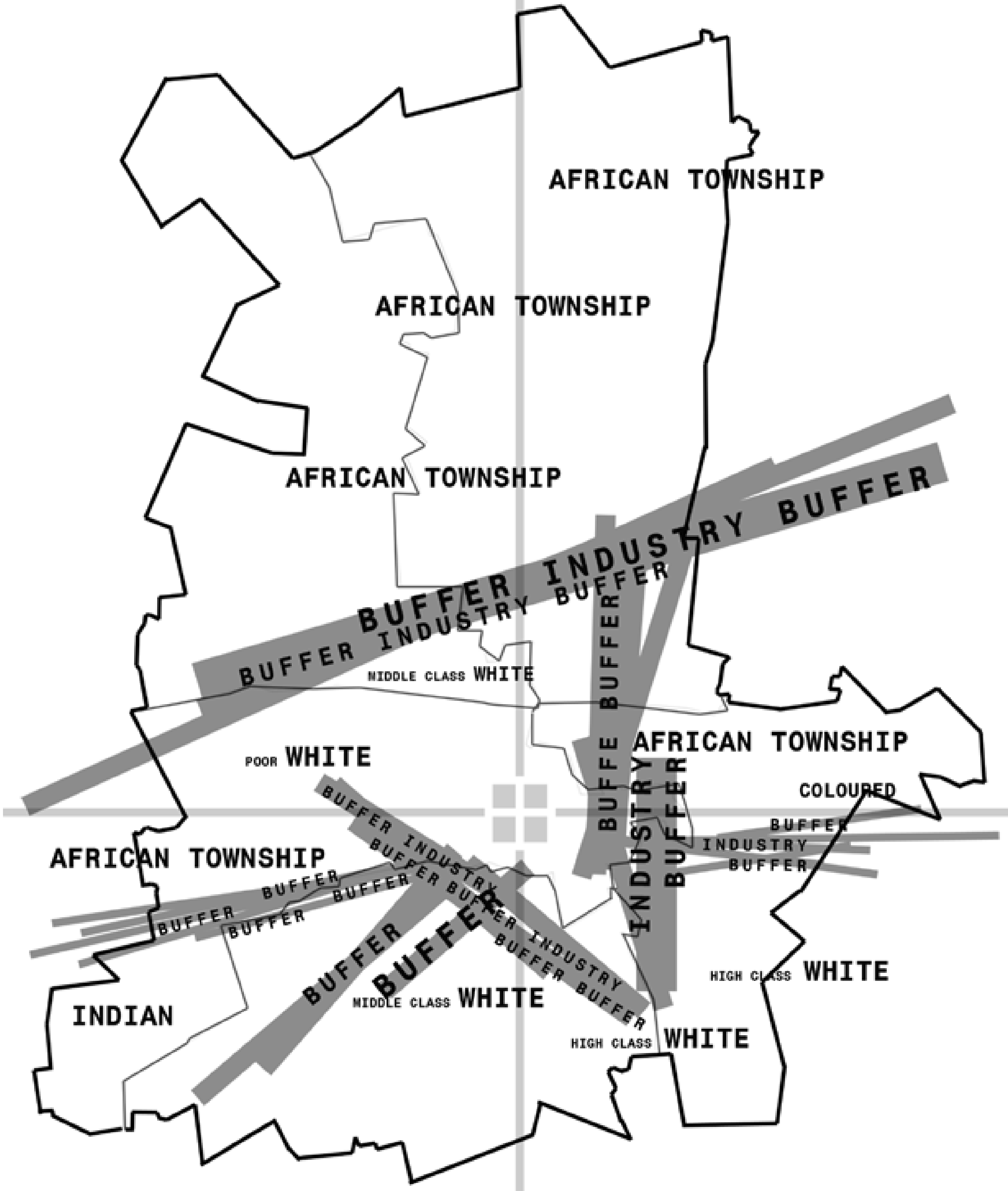


Figure 3-03: Fragmented, decentralised city after Apartheid urban planning [Source: Author]

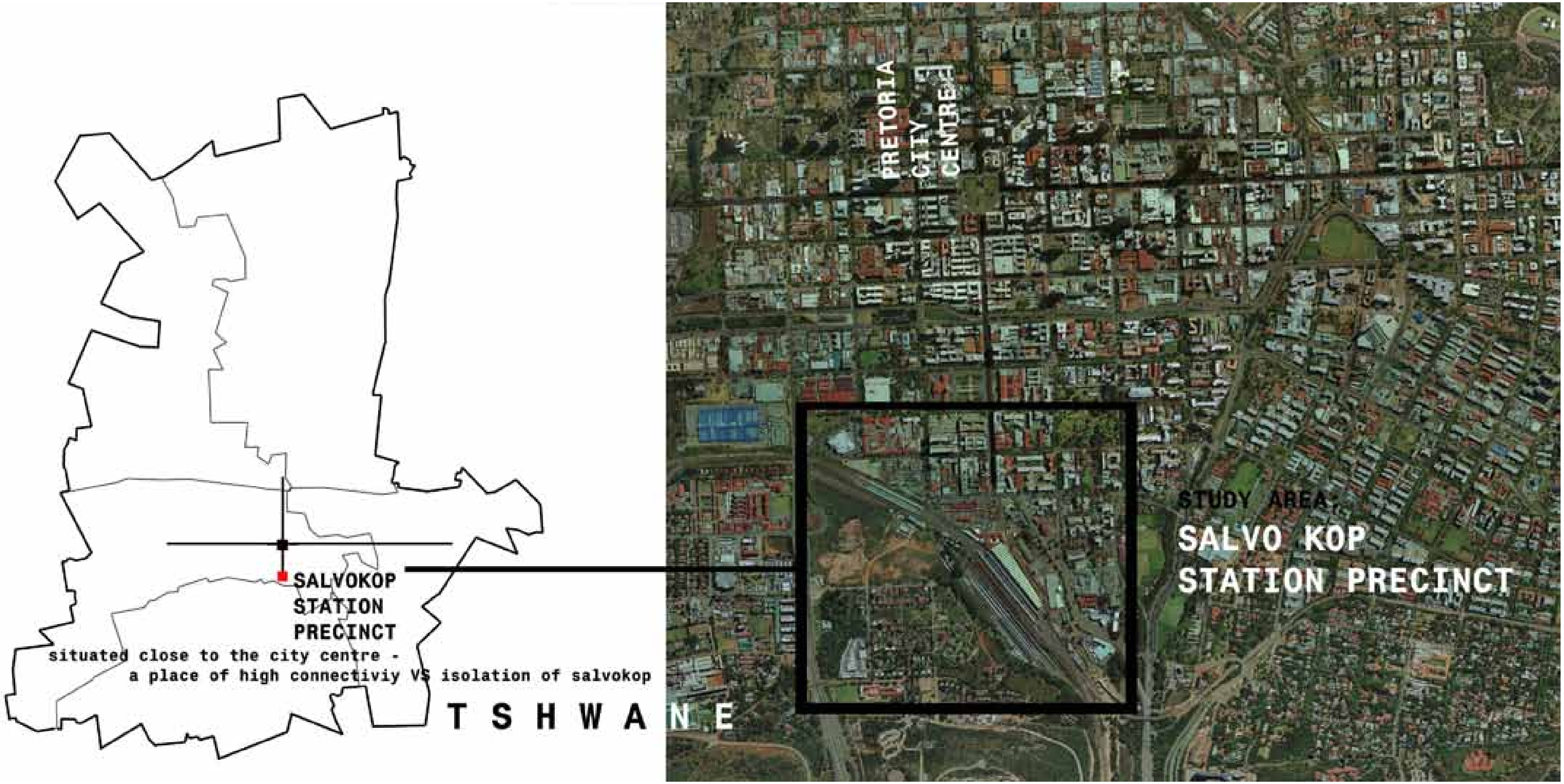
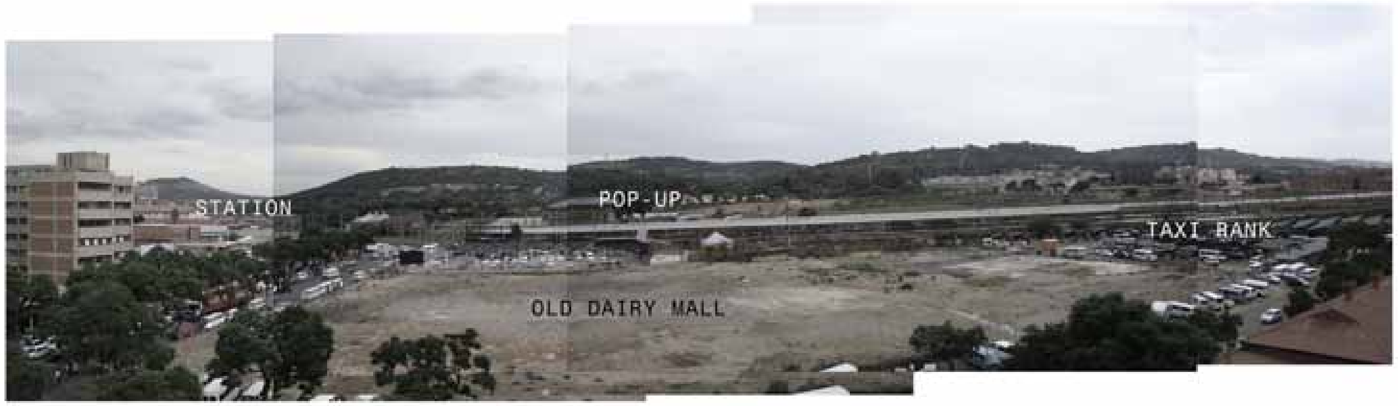


Figure 3-04: Position of precinct within city of Tshwane [Source: Author]

3.3 SALVOKOP – STATION PRECINCT

BRIDGE CONNECTION

EASTERN VIEW



NORTHERN VIEW

Figure 3-05: Panoramas of site and precinct [Source: Link framework, 2010]

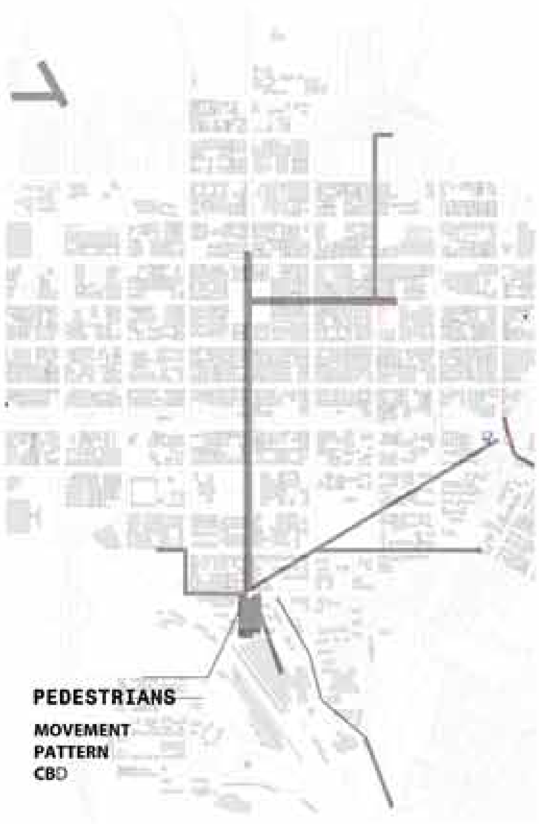
Salvokop and Station precincts are located close to the city centre of Tshwane. Even though the Salvkop precinct borders Pretoria Main Station, which is a major transport node in the city, the area itself is very isolated.

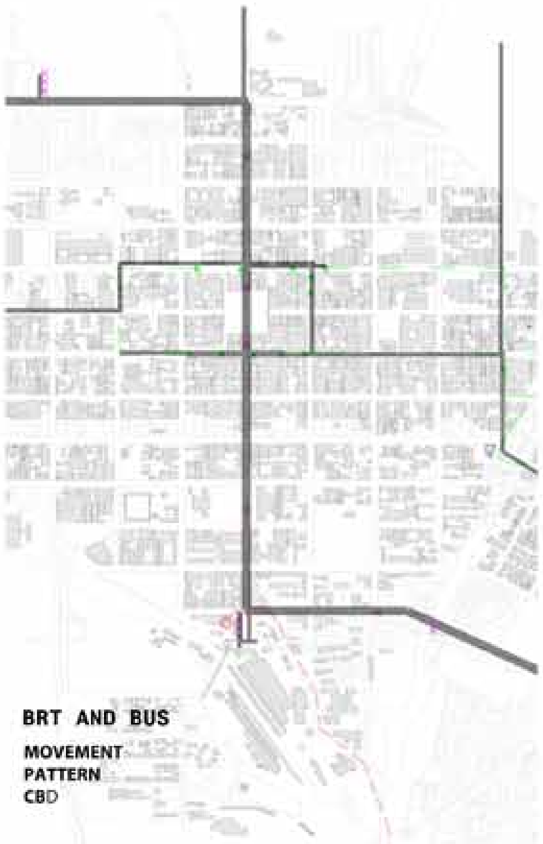
The precinct has the potential of developing as a residential and mixed use area close to the city, and can at a later stage accommodate high-density office developments.

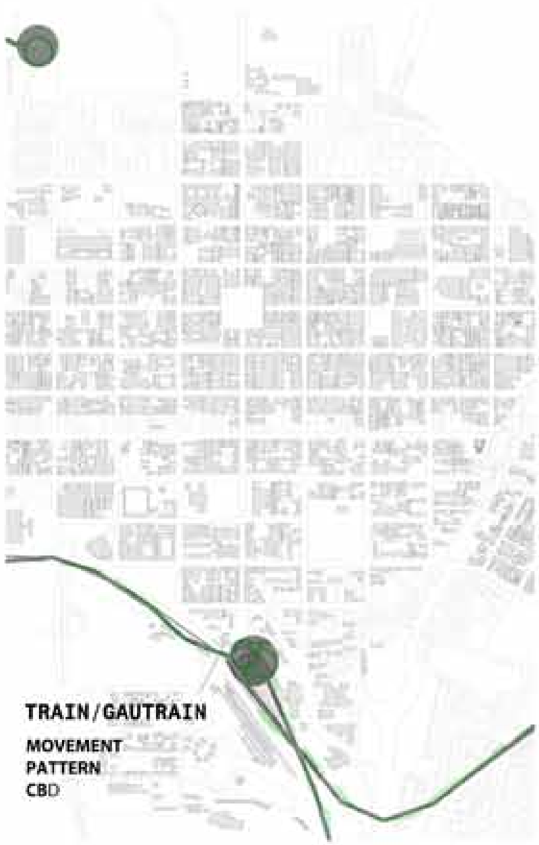
Currently the whole of Salvokop is owned by Department of Public Works and is zoned as farmland. All the current residents rent their houses from the owner, while there are many illegal subletting and residents also living within the area [Labuschagne 2010].

The site historical value which can impede development and needs to be dealt with through a sensitive yet growth orientated mind set.

With the increase in transport systems and connectivity in the area, substantial development can be expected over the next 30 years.


PEDESTRIANS
MOVEMENT
PATTERN
CBD


BRT AND BUS
MOVEMENT
PATTERN
CBD


TRAIN/GAUTRAIN
MOVEMENT
PATTERN
CBD


VEHICULAR
MOVEMENT
PATTERN
CBD

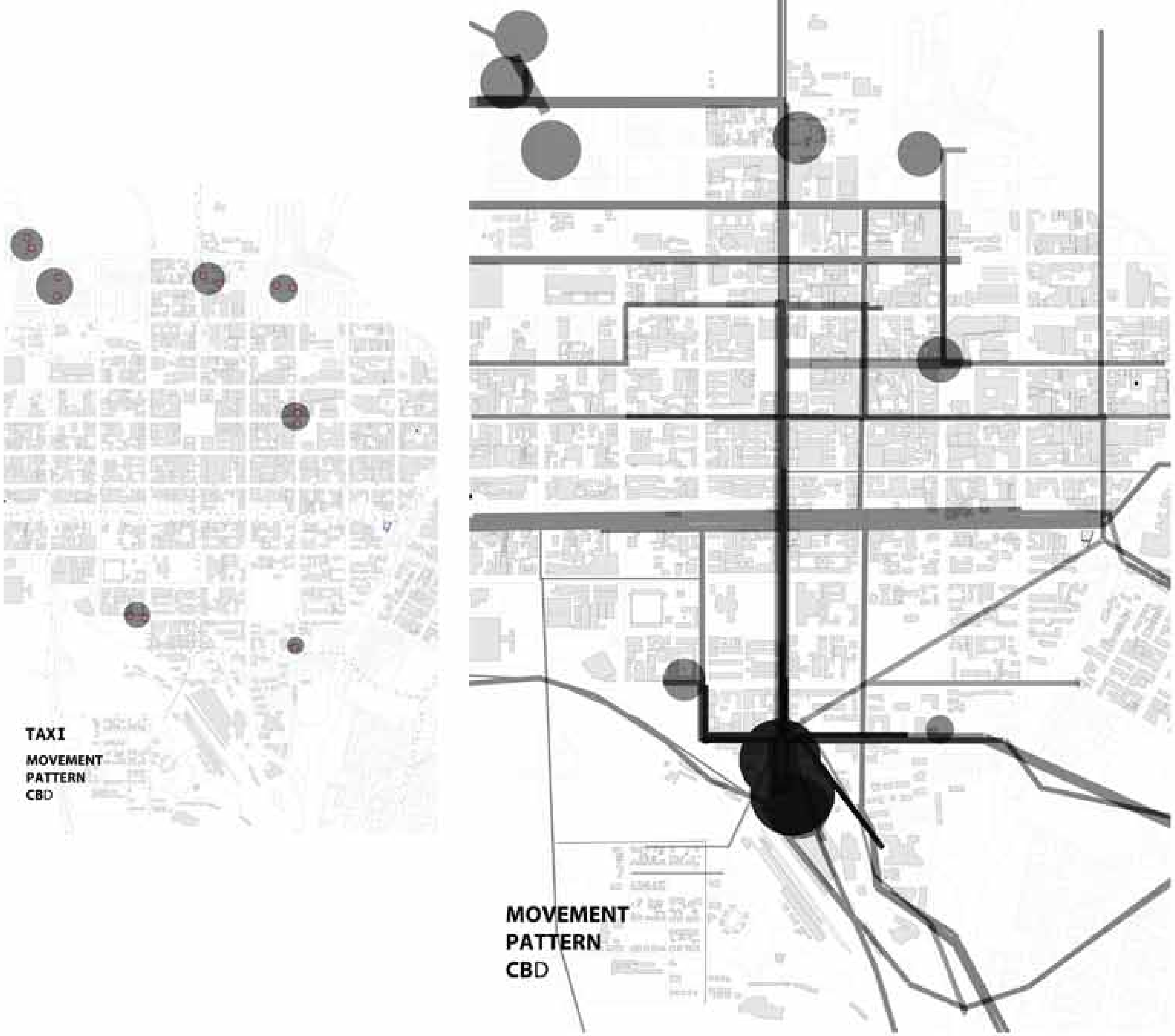


Figure 3-06: Mapping of movement patterns within the city [Source: Author]

3.4 SITE - PRETORIA MAIN STATION

The site for the project is the Pretoria Main Station. It is a very busy modal interchange that is planned to accommodate a wide range of different modes of transport such as the Gautrain, long distance busses, taxi's, Metro Rail and the future BRT systems.

The site is on a very prominent location and is the termination point of the cardus maximus that links the site with heart of the city [Holm 1998:61]

The site has rich architectural and historical value and forms part of the living heritage of the city. The precinct has been used for rail transport since 1894 [Bakker 2004:04]. The station building itself is the first public building by Sir Herbert Baker and was constructed in 1912 [Lindeque 2001:04].

The development following the construction of the station building was nevert coordinated leading to an illegible, over congested and fragmented site [Seabrook 2009:38]. The station building has not been adapted to the new changes in transport systems and will have to be adressed.

Figure 3-07: The site [Source: Author]

Figure 3-08: Entrance front of Pretoria Main Station [Source: Author]

Large number of pedestrians move through the site every day, but the Station Square does not accommodate them and acts as a barrier to cross movement. The landscaping is very uncomfortable and not user friendly. Excessive heat is generated on the site by the large amounts of dark, hard surfaces and little green landscaping.

The bridge connection to Salvokop is very dangerous at night, even though it provides the only pedestrian access to the area.

Currently Bosman Station is being used as a stop; yet it is a very dangerous station without safe pedestrian access. This station is proposed to be closed and moved to the main station by the LINK framework.

Three new transport systems will soon be added to the site: the BRT, Gautrain and Gautrain feeder system. According to a traffic impact study done in 2002 [Gauteng Provicial Government 2002:08] there will be an initial increase of 2113 commuters per hour during peak time utilising the Gautrain.

If the BRT users are added to this equation the number of people will increase to 6000 per hour

The Gautrain system plans to use its own feeder system to facilitate commuters. It will use low-floor busses , 35 and 55 seater Euro III busses. This service will run from 06:00 – 21:00 at a frequency of 18 min [Gautrain Website].

The author proposes that a series BRT express lines be developed as a feeder system for the Gautrain leading to a more integrated transport and efficient system.

With the addition of the transport systems the number of passengers moving through the Pretoria Main Station would increase significantly, building on its legacy as a gateway into the city and as a site connected to the rest of Africa and the world.

Figure 3-09: Entrance to Gautrain and Old Accounting building [Source: Author]

3.4.1. Perception and social context

Currently the station is mostly used by low-income communtes who travel up to 90 km a day. The perception exists that the station only accommodates the lower income groups. Safety and comfort as well as the reliability of the transport systems will have to be addressed to change this perception and ensure that the BRT system and Gautrain are utilised by a wider range of users.

The metrorail starts at 3 am in the morning and the last train runs at 19:30. Thus the site is busy for a large period of the day. The BRT system is also proposed to run until 21:00 at night [Laubser 2010]. There are currently very few 24 hour amenities for commuters during the very early and late hours.

There is a rich diversity of small commercial enterprises on site. With the development of the area the danger exists that this small grained diversity will be lost.

The quality of the station and station square will have to be improved to ensure the sustainability of the site and transport system.

Figure 3-10: Commuters waiting for the train [Source: Author]

3.5 PHOTOGRAPHIC ANALYSIS

Figure 3-11: Current users of the public transport system[Source: Author]

Figure 3-12: Existing vendor stalls, Old Tavern and empty regional bus station [Source: Author]


Victoria Hotel

Figure 3-13: Views of station building, garden square, Victoria Hotel and bridge entrance [Source: Author]

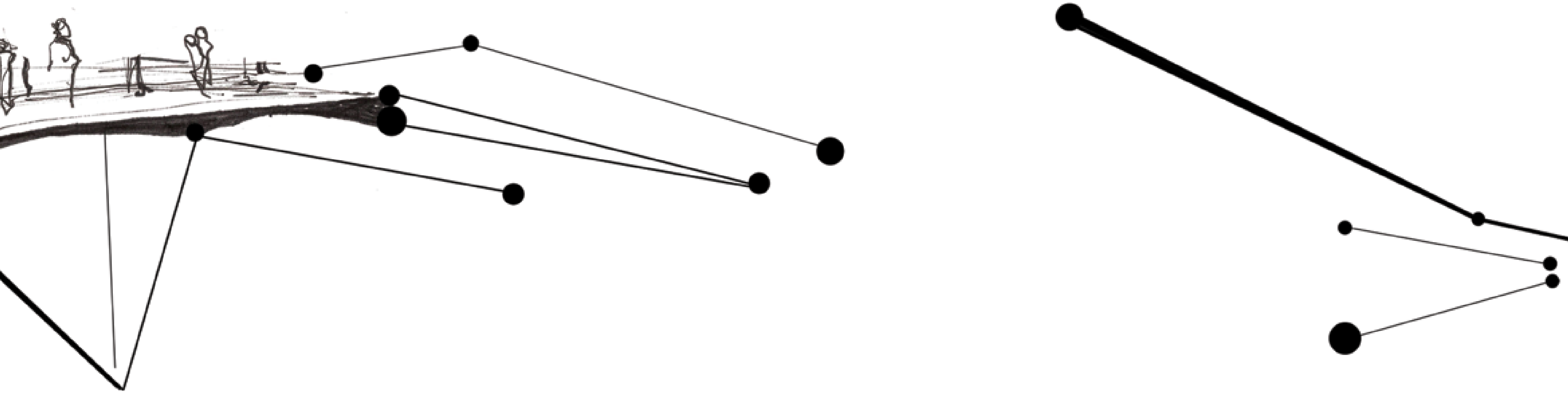
3.6 CONCLUSION

Pretoria Main Station: a place of connectivity that has declined into a disconnected series of systems. An integrative intervention that links parts and systems on site is needed to harness the potential and enhance the value of this gateway into Tshwane.

Figure 3-14: View of the station Station and Station Square [Source: Author]

4

FRAMING THE PROJECT



4.1 THE 'LINK' FRAMEWORK

Climate change mitigation needs to be employed on many scales, from an urban scale down to the building details. **The LINK framework aims to develop a sustainable community by addressing transport, production, movement patterns and densities in Salvokop and Station precinct.**

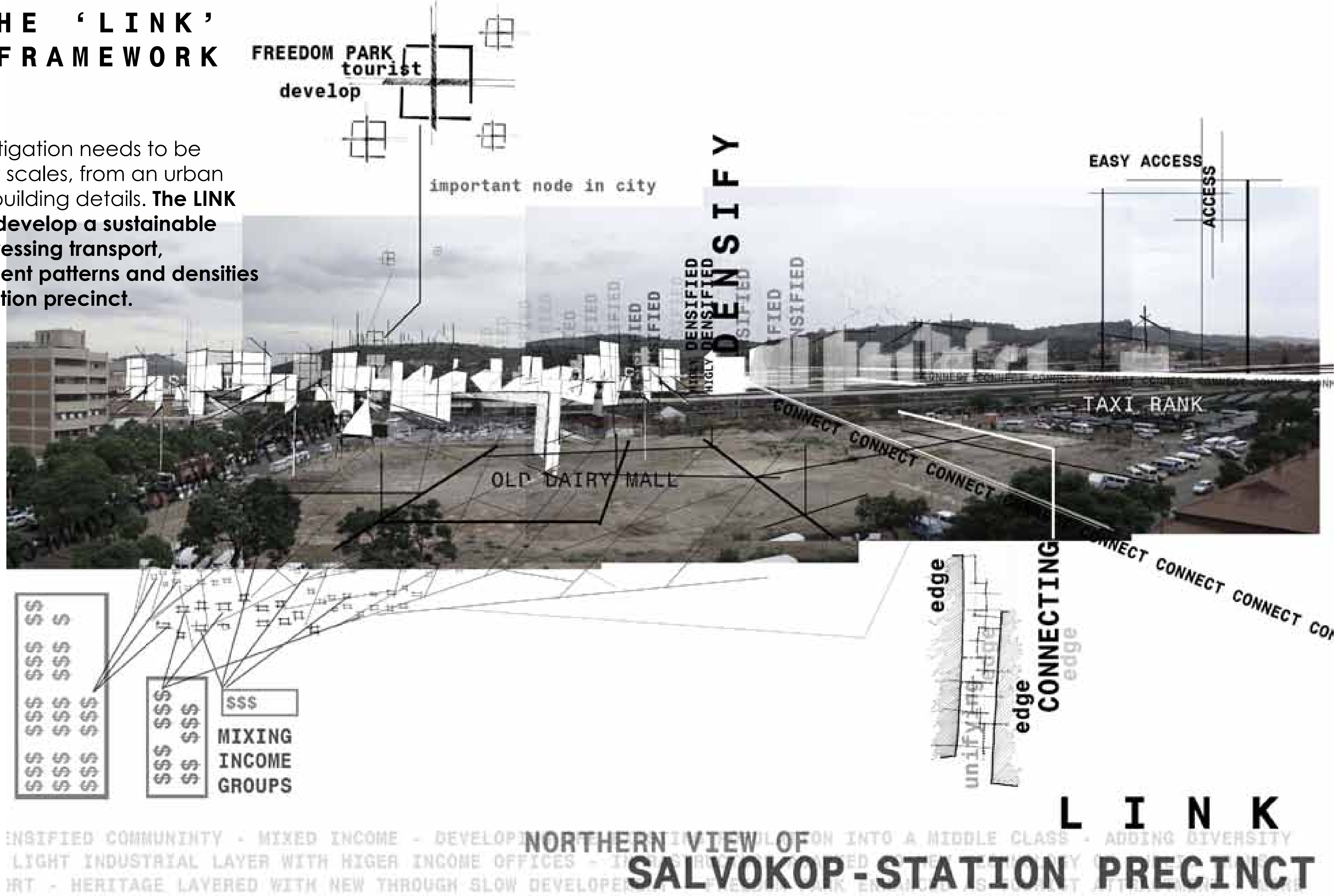


Figure 4-01: The vision for the precinct - developing the barrier [Source: Author]

4.1.1 Analysing the existing frameworks

Figure 4-02: The three frameworks impacting on the study area [Source: Author].

Three existing frameworks have been analysed and taken as starting points for the development of the LINK framework. These frameworks are

- **a) The Tshwane Open Space Framework**
- **b) The Rekgabisa Tshwane Framework**
- **c) The GAPP Culmatrix Framework for Salvokop [GCFS].**

Each of these frameworks has a certain vision for Salvokop. The Rekgabisa Tswhane framework is currently being implemented, whereas the GCFS framework has never been implemented. The Tshwane Open Space Framework is very vague regarding Salvokop but has significant implications for the development of the area.

Tshwane Open Space Framework
This framework was developed in 2005, as an **holistic [city wide] approach to densification which conserves the existing public open spaces and green networks within the city**. It promotes a healthy pedestrian friendly city with open spaces that convey a sense of place [TOSF vol 2 2005:4-6].

The framework divides open spaces within the city into 10 typologically classified areas. Each area is discussed on a macro scale, giving guidelines for development within these areas.

Within Salvokop and the station precinct the following areas have been identified as important public open spaces or networks:

Railroad - [grey way]

Pretoria City Hall - [Red node]
Pretoria Station/
Salvokop/
Freedom Park - [Red node]

Paul Kruger Street - [Red way]
[TOSF VOL 3 2005:59-63]

In essence the framework proposes that the design must enhance the process of place making, while preserving the historical character of these places.

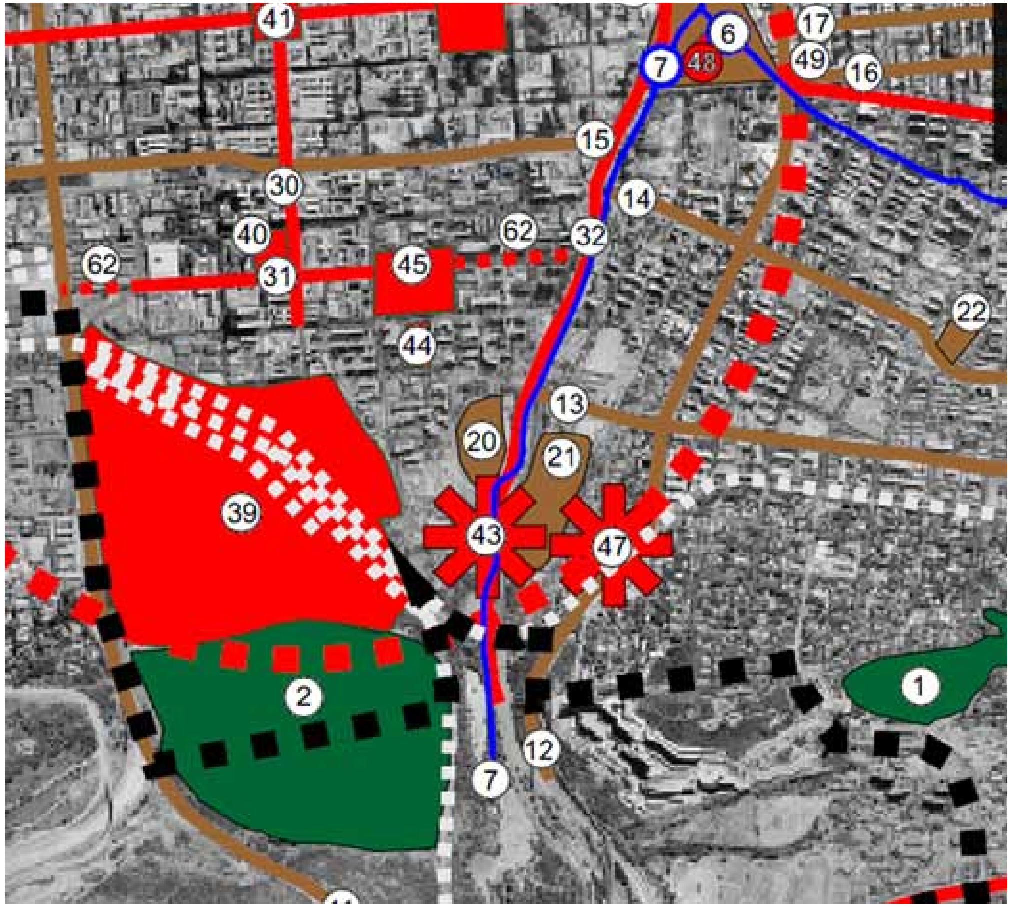


Figure 4-03: Detail of TOSF's vision for Salvokop
[Source: TOSF, p 107]

Large commercial enterprises and light industrial facilities are prohibited within these identified areas. The railroad has to be treated as a grey way where the infrastructure must be maintained with no development allowed over or under it [TOSF VOL 3 2005:59-63].

This framework is very vague on what must be done in Salvokop. Preserving the whole of Salvokop and Paul Kruger street as red ways and nodes will be impede development of the area. A compromise must be researched between the conservation of heritage areas/ buildings and development these precincts.

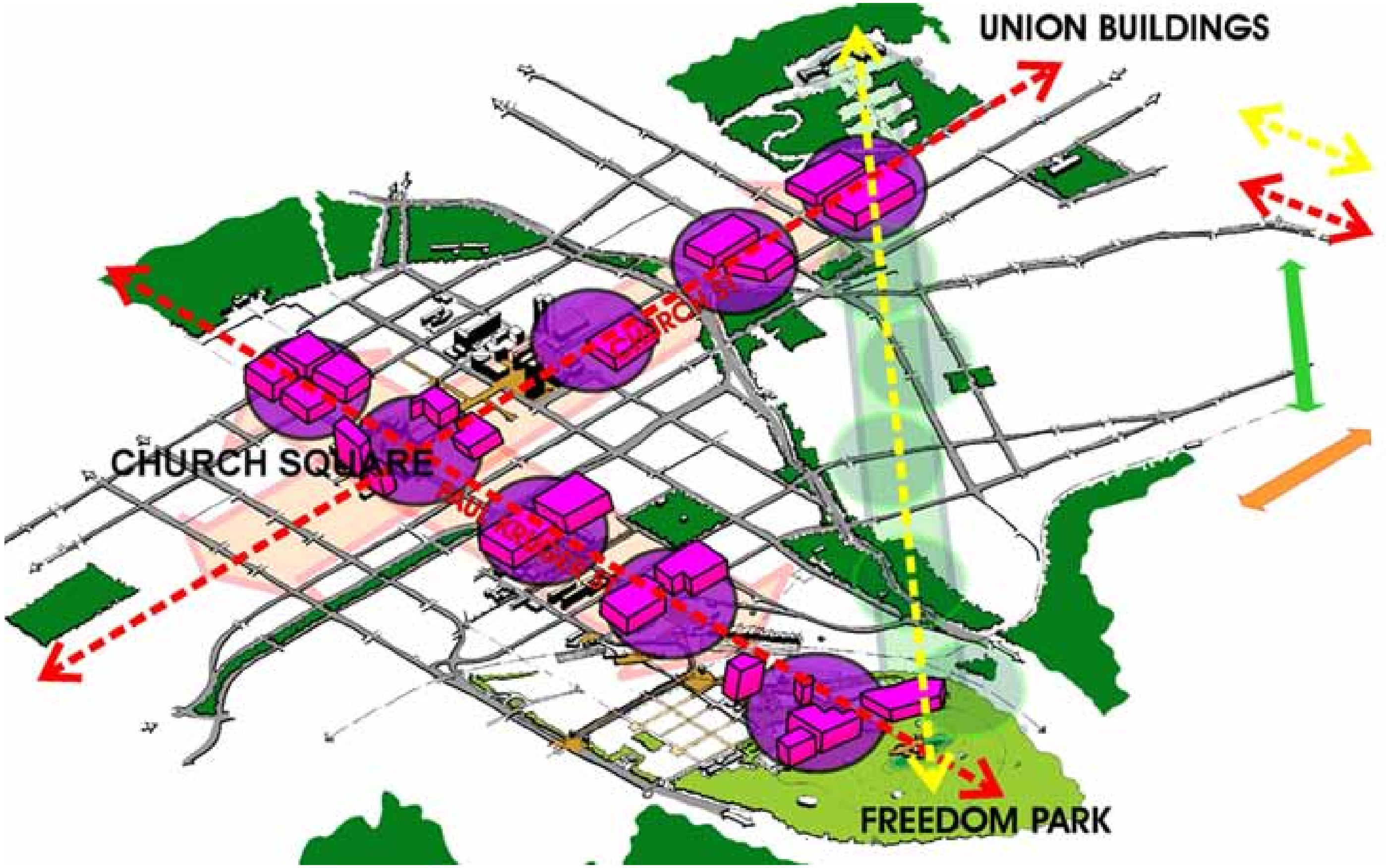


Figure 4-04: The vision of the Rekgabisa Tshwane framework [Source: Rekgabisa Tswane, p. 6]

Rekgabisa Tshwane

The Rekgabisa Tshwane Framework was developed in 2006. **It aims to reinstate the presence of National Government within the city centre, becoming a catalyst for private investment as well as preventing further decay within the city centre.**

This process will assist broader social and economic development. The framework focuses on the two physical axes [Cardo and Decomanus maximus], as well as the visual axis between the Union Buildings and Freedom Park.

Development along these axes is aimed at improving the physical environment and urban security. Developments must promote safe and healthy public spaces while increasing accessibility to government departments.

The framework proposes a public square and marshalling ground within Salvokop as well as the improvement of the Station Square. Salvokop is identified as part of the Southern Gateway into the city centre. the link between Salvokop and the city is not adressed.

Culmatrix Salvokop Framework
The Culmatrix Salvokop Framework was drawn up in 2003 to **assist the sustainable and sensitive development of Salvokop.**

The framework was developed in detail for the whole area. The northern edge was earmarked as a light industrial area, with dense housing added on the western edge. The existing NZASM houses were proposed to be redeveloped as a town centre, while the south eastern edge was proposed as a mixed use development area as shown in Figure 4-05.

A new vehicular bridge is also proposed to reconnect Salvokop with the city [Figure 4-05], Unfortunately it is proposed within a historically sensitive area. The proposal extends the Cardus Maximus into Salvokop forming a high street on the axis [Figure 4-05].

The framework prescribes the preservation of existing building stock as well as retaining existing or historical functions. Thus all new interventions must be in accordance with the Burra Charter, where the new functions must be sensitive and compatible with the historical functions of the site [Burra Charter Article 7; Bakker 2003:01]

The Culmatrix Salvokop Framework does not particularly deal with the issue of dislocation. The linking of Salvokop to the city will be vital for the sustainable development of the precinct.

Figure 4-05: The proposed framework for Salvokop, by GAPP [Source: Culmatrix]

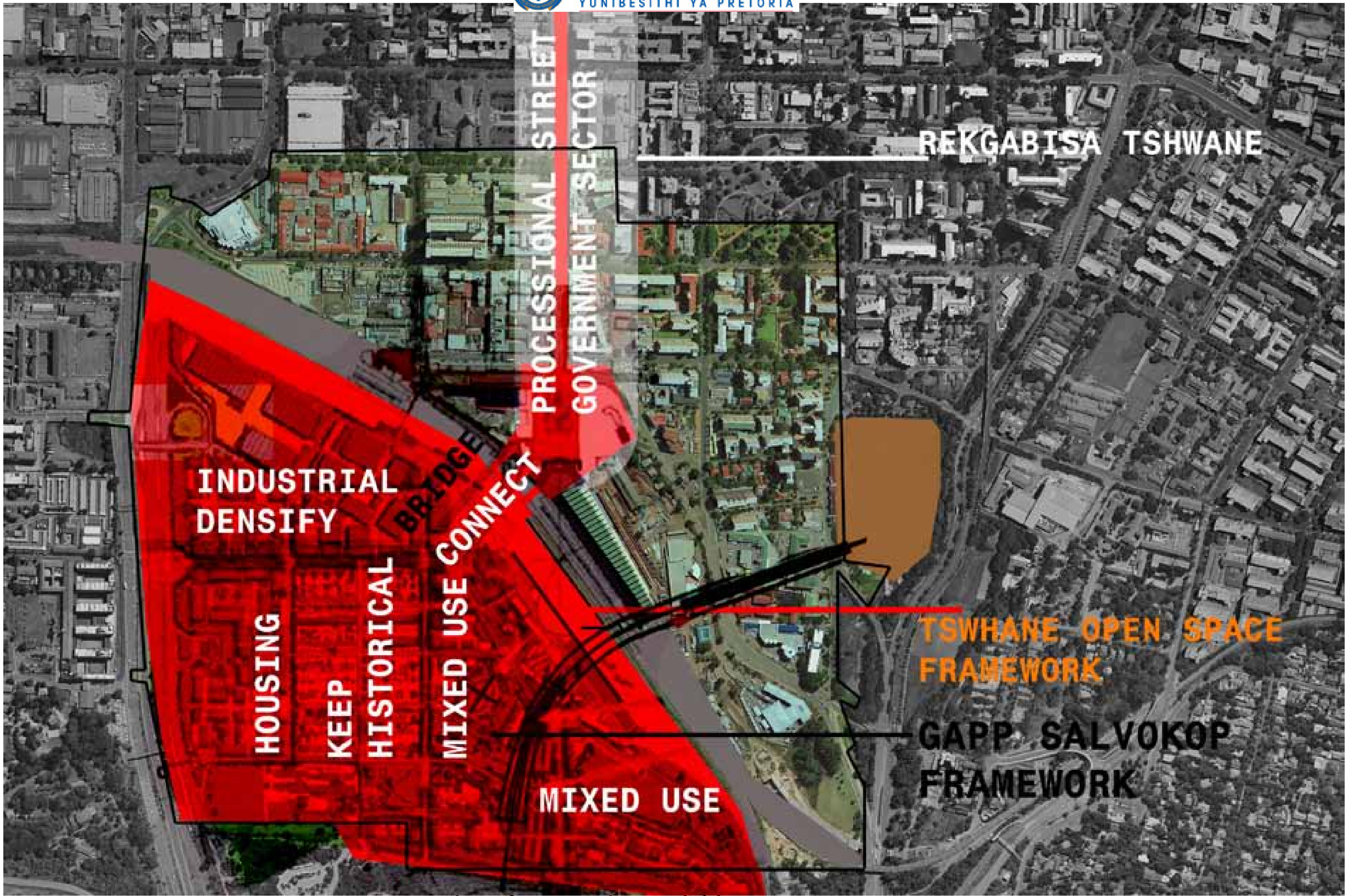


Figure 4-06: A synergy of the three frameworks in the study area
[Source: Author]

Three frameworks overlaid

These three frameworks were integrated into a more cohesive framework that focuses on the area linking Salvokop and the city.

4.1.2 "LINK" - framework

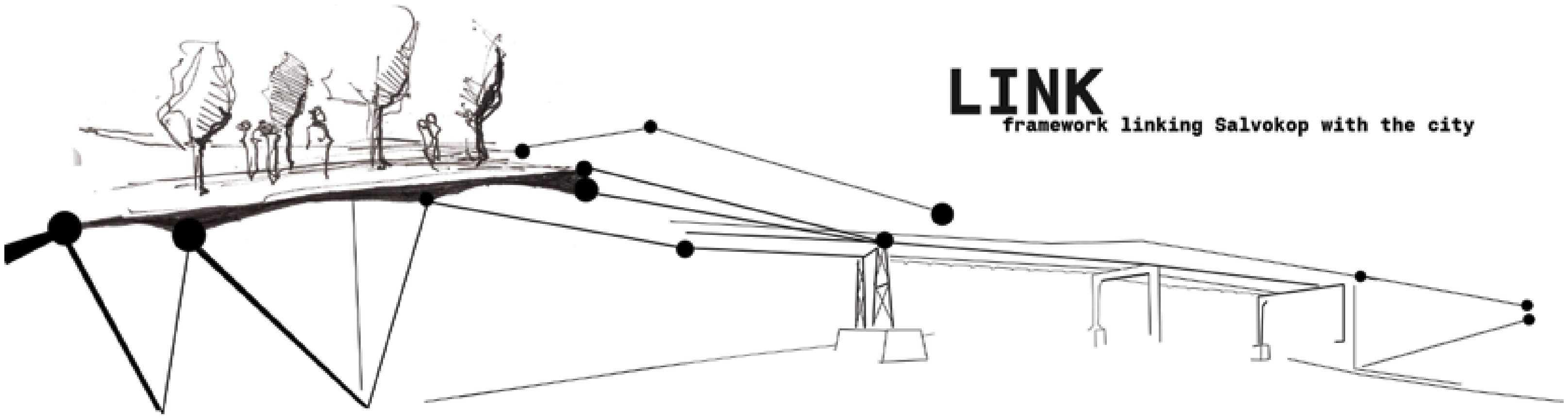


Figure 4-07: The vision for the precinct- linking Salvokop [Source: Author]

**The framework proposes to use the existing barriers as opportunities for linkage.
By changing the barriers into a seam of movement and energy, a safe and healthy environment for the inhabitants and users of Salvokop and the station precinct can be developed.**

Figure 4-08: Zoning and layout of Salvokop and the Station precinct [Source: Author]

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Precinct development

The framework proposes that the Salvokop precinct be developed slowly over time, while the Station precinct will be densified and develop at a much faster rate.

When a layered approach is used to develop an underdeveloped area over a long period the existing inhabitants who have taken ownership of the precinct can be retained [Jacobs 1977:285]. This means working with existing positive forces within the precinct and developing a middle class out of the existing slum dwellers [Jacobs 1961:290]. This form of grassroot development also contributes to the education of a part of society that generally does not understand sustainability [Newman& Jennings 2008:87].

The station precinct is proposed to be densified by predominantly offices and retail development, thus renewing the area west of the Station.

Within Salvokop dense residential and mixed use development zones are proposed. The existing brownfield sites will be developed with layered production and mixed use developments.

Phasing
The four stage phasing of the framework is planned over a 20 year period.

Start

First establish government functions in Salvokop.
Establish pedestrian and vehicular links.
Develop the high street and town centre.
Develop area west of station and densify – rebuilding existing derelict structures

3+

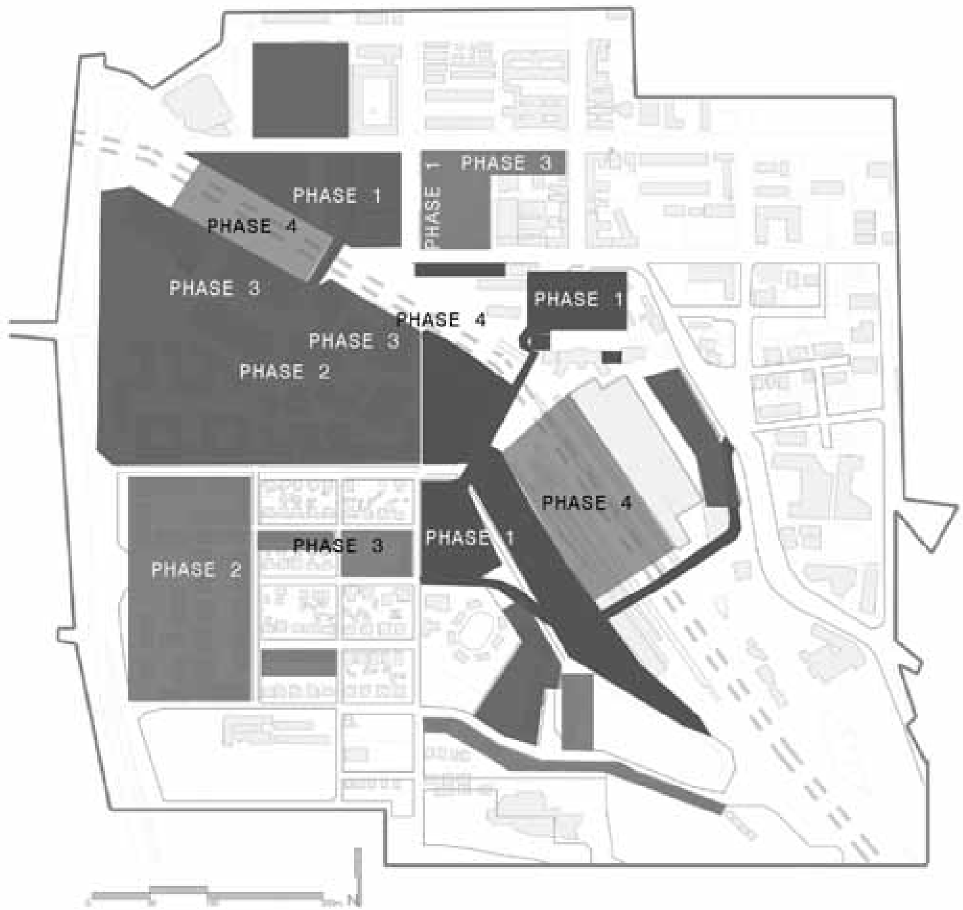
Develop the new Smart industries, production and commercial zones.
Densify western edge with housing.
Develops station to bridge the gap between Salvokop and city.
Develop area west of station and densify – up to 6 -10 storeys

10+

Layer development of existing houses.
Develop northern edge of Salvokop with office, retail and entertainment areas on top of the smart industries.
Add more pedestrian bridges added and last direct vehicle tunnel.

20+

Densify the whole area with offices and commercial uses.
Develop building rights on top of the railway with mix use functions. Emphasis on developing entertainment functions within bridge buildings.



DEVELOPMENT PHASING

Figure 4-09: Phasing of the LINK framework [Source: Author]

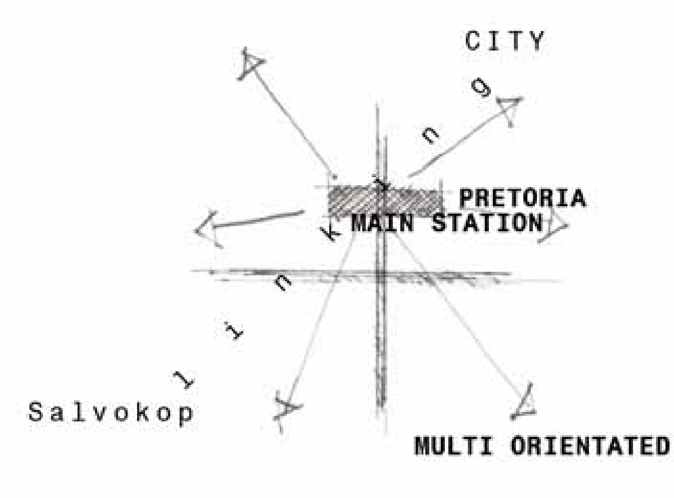


Figure 4-10: Station orientation
[Source: Author]

Proposed interventions

Transport Nodes

The current station platforms are proposed to be developed as a linking structure between the city and Salvokop. A second entrance and parking are proposed for the southern edge of the station, while taxi and future BRT stations are proposed to be housed within Salvokop.

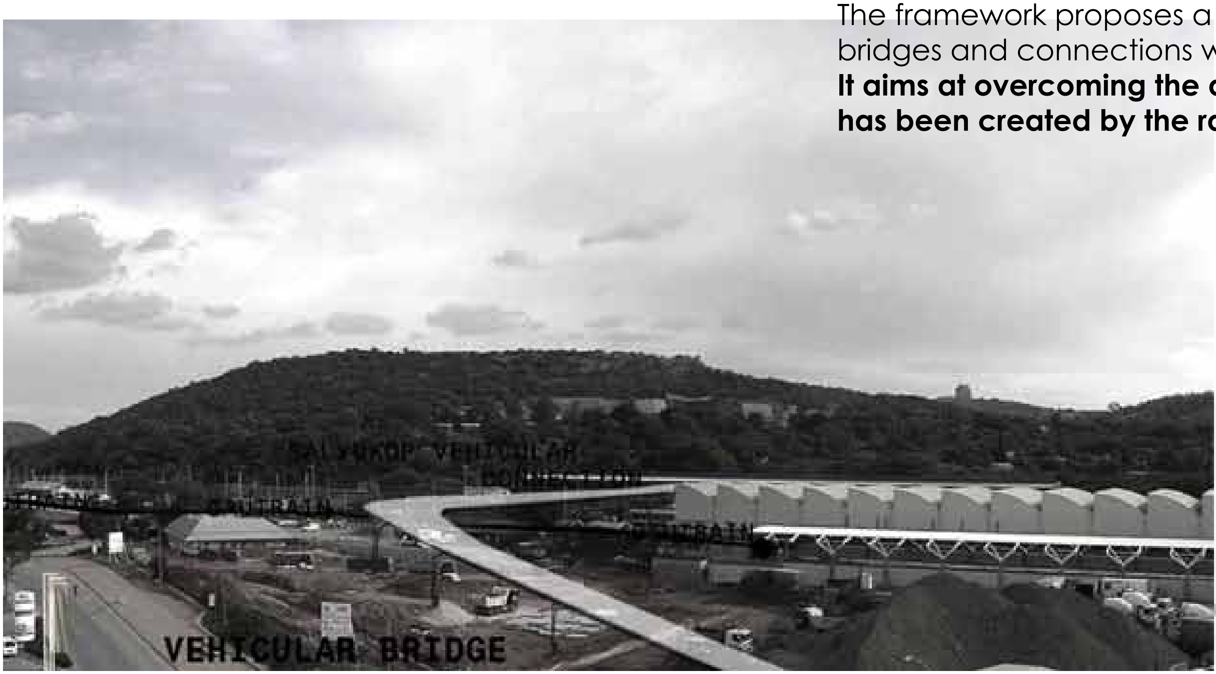
In the process the station will become a multi orientated structure that links the immediate and distant areas within the city, ensuring that the transport node is well connected to all sectors of the city [Alexander 1977:92].

Bridge connections

The framework proposes a series of bridges and connections with the city centre. **It aims at overcoming the dislocation that has been created by the railway line.**

Three new vehicular entrances into Salvokop are proposed, ensuring easy access into the production area. An eastern bridge will provide more energy on the newly planned high street of Salvokop. A third tunnel will be built within 10-20 years with new bridge building typologies developing in response.

To combat slum development on the border between the two precincts [Jacobs 1961:271], **two skypark/pedestrian bridges are proposed in the initial phases, while over time the building bulk themselves will bridge the railway line, leading to the restitching of the barriers.** This will ensure the border area between Salvokop and the Station Precinct develops as a vibrant busy area.



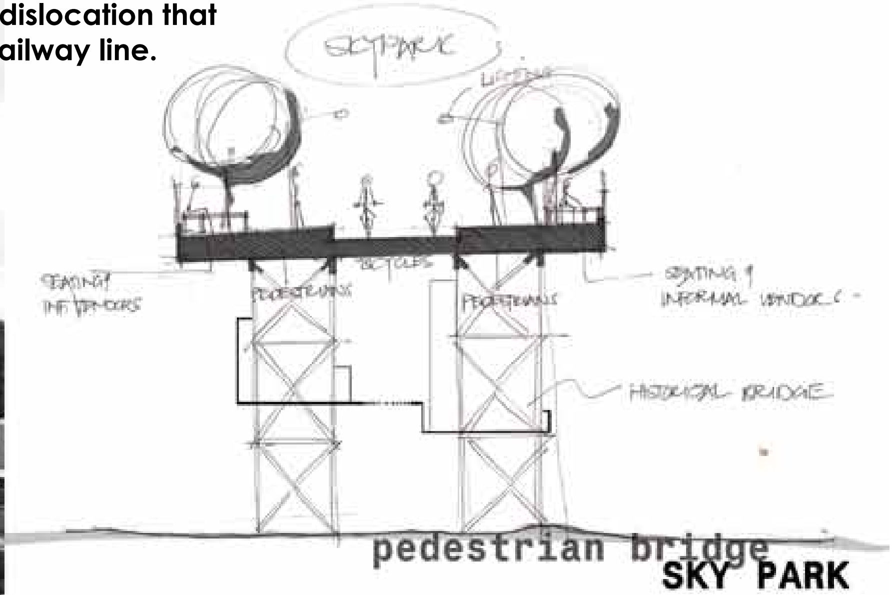


Figure 4-11: Connecting Salvokop [Source: Author]

By adding distinct functions energy can be harnessed and directed to the isolated areas in Salvokop [Jacobs 1961:280-283]. At the end of all the pedestrian bridges retail or civic functions are proposed, ensuring that the bridges will be safe and used regularly. This will lead to passive surveillance and busy, vibrant borders. These border conditions then become “seams” that will have a positive influence on the neighbouring areas.

Historical and slower layered development
To ensure diversity in the precinct the framework proposes retaining the historical structures within the precinct. The mixed ages of building stock[Jacobs 1961:162] ensures the inhabitants can redevelop the area themselves [Jacobs 1961:207]. This will also lead to diversity and a mixture of users of varies tastes and income levels [Jacobs 1961:207].

The layering of development on the historical will ensure a slow enough development, yet a highly dense and diverse precinct will be developed in 10-20 years.

Mixing functions and increased densities
The framework proposes the mixing of functions within the precinct. By establishing a government sector in the precinct the initial investment and development will be ensured. The introduction of commercial sectors, transport interchanges, and a smart industry / production sector is aimed at providing work and income to the existing inhabitants. The added functions will attract developers and new affluent groups to the area.

Housing will then be added to ensure that sustainable densities are achieved. It has been found that denser cities consume fewer resources per capita, leading to more efficient systems and retaining the existing bioregion of the city [Newman & Jennings 2008:87].

The framework proposes a smaller scale of a diverse selection of functions within the precinct [Jacobs1961:266]. **Diversity and vibrancy close to the historical centre will be achieved by smaller mixed-use areas and by layering new development over the existing historic fabric. Only the northern edge will be developed with large plot sizes and building bulk.** Large over-scaled players such as big banks, insurance companies and franchises will be accommodated on the northern edge, or rather kept within the city centre and Station precinct.

The framework aims at retaining the inhabitants of the area and growing the middle class, enriching the precinct and ensuring that a sense of ownership is retained within the area [Jacobs 1961:299].

Figure 4-12: Existing houses in Salvokop [Source: Author]

Pedestrian/ bicycle routes and block size
The framework proposes the accommodation of **cycling and pedestrian routes along the existing streets. This in conjunction with the placing of transport interchanges will discourage the use of private transport** [Brain 2005:227].

By retaining the existing smaller block sizes in Salvokop the movement of pedestrians will be accommodated and encouraged, ensuring that areas within the precinct are not isolated by allowing more movement through the streets. This will increase the passive surveillance within the area, making it a much safer place to stay [Jacobs 1961:195].

Green structure
A green structure is proposed throughout the precinct. The southern edge of the precinct as bordered by a conservation site, within which Freedom Park is situated. The green structure throughout the precinct will form part of the proposed cycling and pedestrian routes.

The framework proposes keeping the existing trees in Salvokop while adding as much as possible green spaces and vegetation within the city and on the pedestrian bridges. This will contribute to climate change mitigation through cooling and carbon sequestration [Newman & Jennings 2008:86].

Smart Industries and production
The heterotrophic[1] nature of urban economies has led to cities changing from local to global economies. In the process all production and consumption has become unsustainable [Newmann & Jennings 2008:38]. **The framework aims to bring the production of user goods back into the city, through clean/smart industries and production.** This refers to smaller scale producers of goods such as clothing, furniture and electronic assembly.

This endeavour will respect the original functions of the site as a starting point from which the area can develop [Burra Charter article 7; Bakker 2003:01] as proposed in the GCSF-framework.

The book *Cradle to Cradle* [Mcdonough & Braungart 2002:114] suggests a paradigm shift were products are more easily recycled and reused. In essence "products of service" should be created. Yet at the moment most of the products used in cities are produced in countries like China. By bringing small scale production back into the city a more sustainable form of consumerism can be practised [Newman & Jennings 2008:41].

The smart industry zone will densify in time with office developments and mixed use functions added to the existing. **This process can create a diverse precinct within the city, providing much needed work for the inhabitants as well as utilising and developing diverse forms of skills.**

Note 1: **Heterotrophic** - refers to an ecosystem that does not produce sufficient energy to meet its own needs but is dependant on sources outside the system [Newmann & Jenning 2008:38]

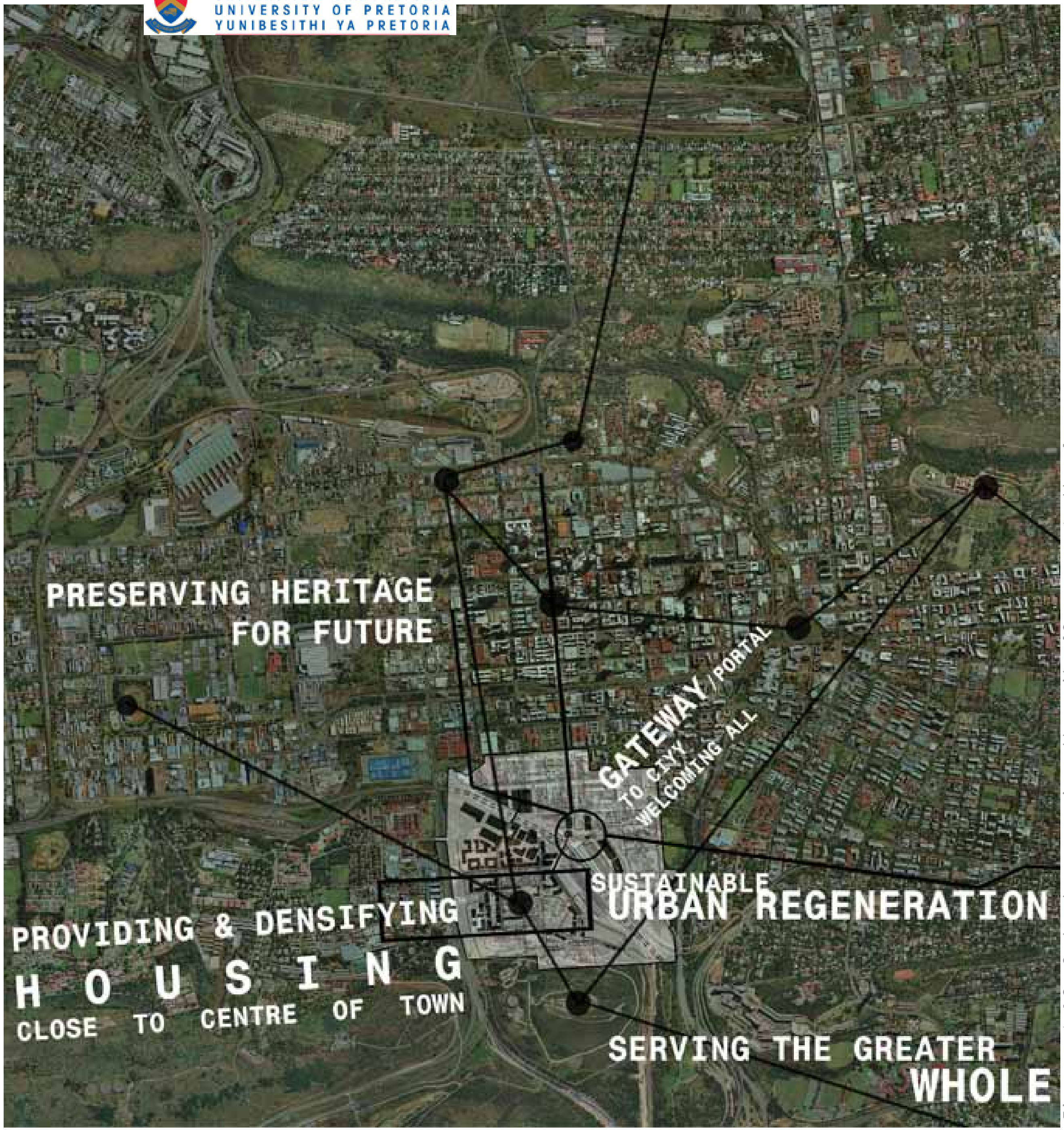


Figure 4-13: Salvokop serving the city [Source: Author]

Conclusion

By linking the precinct to the greater urban whole and allowing the energies from the city to develop and regenerate the area. Salvokop will in turn serve the city in the future.

4.2. HISTORICAL SITE FRAMEWORK

4.2.1. Statement of Significance

Place
The intervention is situated on a very important point within the City of Tshwane. **It acts as a termination point for the cardus maximus [Holm 1998:61] which links up with the heart of the city.**

The precinct forms part of the living heritage of the city: it has been used as a transport interchange since 1894 [Bakker 2004:04]. Even though it has undergone many changes over the years, the precinct played a significant role in the industrial and economic development of both the city and the country [Bakker 2004:2;6].

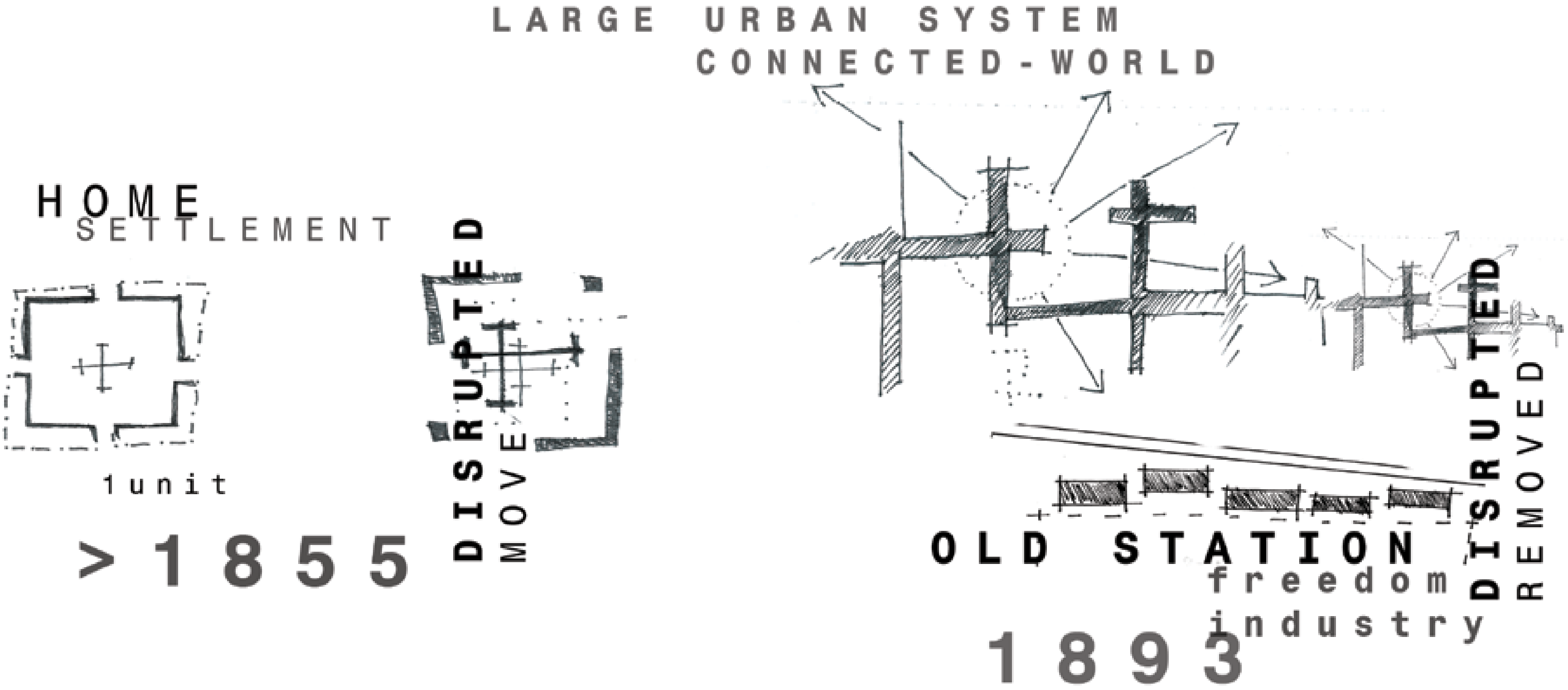
As a symbol of freedom, this interchange played a vital role in ensuring the sovereignty of the Transvaal Republic [ibid]. While currently it acts as a gateway to the sprawling metropolis of Tshwane.

The Station Square
This monofunctional neo-classical forecourt, has undergone significant changes over the years and has shown a robust character with the potential to enhance the gateway into the city. **The square acts as an approach to the neo-classical station building and still displays the WWI & WW II memorial.** The square used to carry important symbols of the city.

The square needs to be readdressed as it is currently a dislocated, isolated open space which only serves a visual function and acts as thoroughfare for commuters.

Pretoria Main Station
It is a building of historical architectural value, **with the main facade lining up symmetrically with the cardus maxmimus, creating an important vista within the city.** The façade, especially the porte cochere and station tower act, as symbols of importance and vision.

The station building will need to be readdressed to ensure the sustainability and success as a transport interchange accommodating different transport systems.


LARGE URBAN SYSTEM
CONNECTED-WORLD
HOME
SETTLEMENT
1unit
>1855
DISRUPTED
MOVE
OLD STATION
freedom
industry
1893
DISRUPTED
REMOVED

4.2.2 SITE: DEVELOPING FROM HOME TO STATION

Figure 4-14: Depiction of the development and key moments of the site [Source: Author]

According to oral history the first people to settle in Salvokop were members of a Setswana tribe. They lived to west of Salvokop where the jail is currently situated. The tribe was called the Bakgatla (Tswana family group) of kgoši 'Andries' Moepi, and was moved to Makua [close to Garankuwa] by President Paul Kruger. The reason for their removal was never stated, but it could have been to make space for the development of the station precinct.

The completion of the railway line to Lourenzo Marques in 1894 ensured the sustainability of the gold mines in Johannesburg, as now the Transvaal Republic had access to the international market [Bakker 2004:2+6]. It provided job opportunities and was at that time the biggest industrial intervention in the Transvaal Republic.

After the Anglo Boer War the NZASM rail system and company was taken over by the Central South African Railway [CSAR/SAR&H].

As envisioned by Cecil John Rhodes the railway system of South Africa was developed at a marked pace. **The station and railway system started to have a significant effect on Salvokop and the rest of Pretoria – leading to the development of hotels, offices, goods yards etc [Bakker 2004:3].**

As Pretoria developed the railway line started servicing industries in the west and east of the city. In 1948 the industrial and freight facilities at Pretoria Main Station were moved to the Koedoeskop and Capital Park stations [Bakker 2004:5]. **Currently the Pretoria Main Station only accommodates commuters.**

During the Apartheid era Bosman street station was constructed [1955-1959] as an act of racial separation. Pretoria Main Station was declared a whites only area, while the black African population was forced to use Bosman Street Station [Astrup 2004:29].

Currently Bosman Street Station is still being used as a commuter stop, though it does not have safe pedestrian access.

With the addition of the Gautrain and BRT system the number of passengers moving through this station will increase significantly.

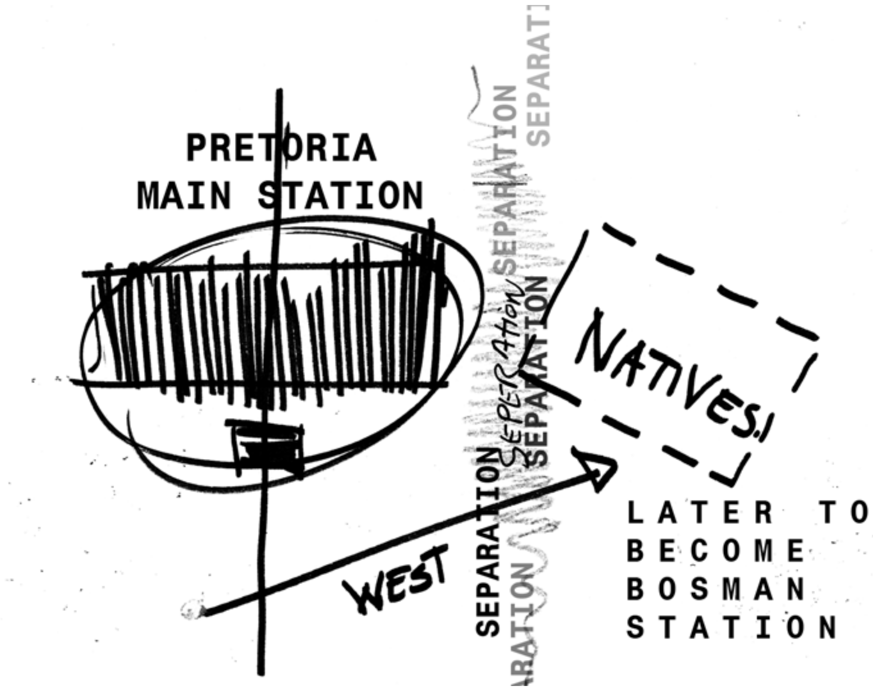


Figure 4-15: The station for the "natives" to the west [Source: Author]

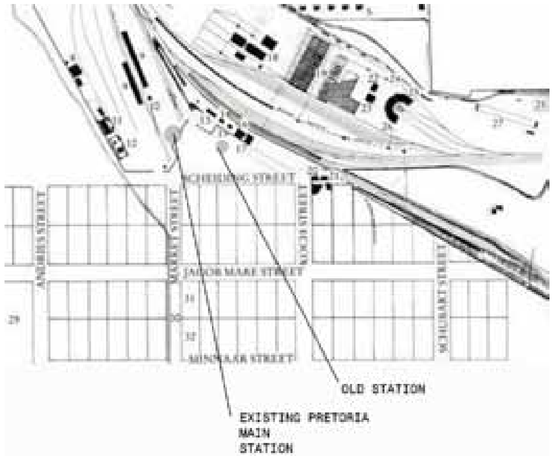


Figure 4-16: Plan of the urban layout 1894 [Source: UP archives; De Waal collection]

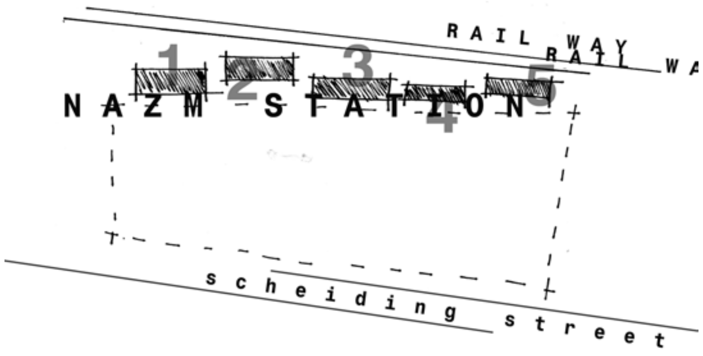


Figure 4-17: Schematic layout of the old station [Source: Author]

The Old Station

The first NAZM station buildings were constructed in 1881and consisted of **five buildings: one corrugated parcel office and four red brick structures [Bakker 2004:12].** These structures housed the service buildings, ladies' & general waiting rooms and refreshment rooms. The layout of the station was done in such a manner as to create a square to the south of Scheiding Street [Bakker 2004:13]. **These were only single storey structures and were very pragmatic in their design and layout.**

As indicated in Figure 4-16 the station buildings themselves were not place on the axis of Market Street. They were located to the west of the existing station building.

Figure 4-18: The first station buildings constructed in 1894 [Source: UP archives; De Waal collection]

Pretoria Main Station

The construction of the Pretoria Main Station started in 1909 and was completed by 1912. The station structure was designed by Sir Herbert Baker, as a termination point on the central axis of Market street [Paul Kruger street] [Baker 1912:xviii]. **It is an eclectic Renaissance structure strongly influenced by the availability of local materials [Le Roux & Botes 1992:26].**

The three-principled facade was designed with a central arched porte cochere and deeply arched logias on either side [Baker 1912:xviii]. **The entrance is not overscaled and imposing but kept to human scale [Keith 1998:91].**

The hall has high clerestory windows, which allow for natural lighting and ventilation, the mass of the structure contributes to a very cool and thermally sound building [Baker 1912:xvv]. All floors and ceilings were constructed from wire-woven reinforced concrete. The base of the columns and walls are clad with granite [Baker 1912:xvv].

The central hallway, acts as a movement corridor with a very open hollow design typical of Herbert Baker buildings [Keith 1998:91]. The dining hall and server were placed in the eastern wing and the baggage and parcels in the western wing [Baker 1912:xvv].

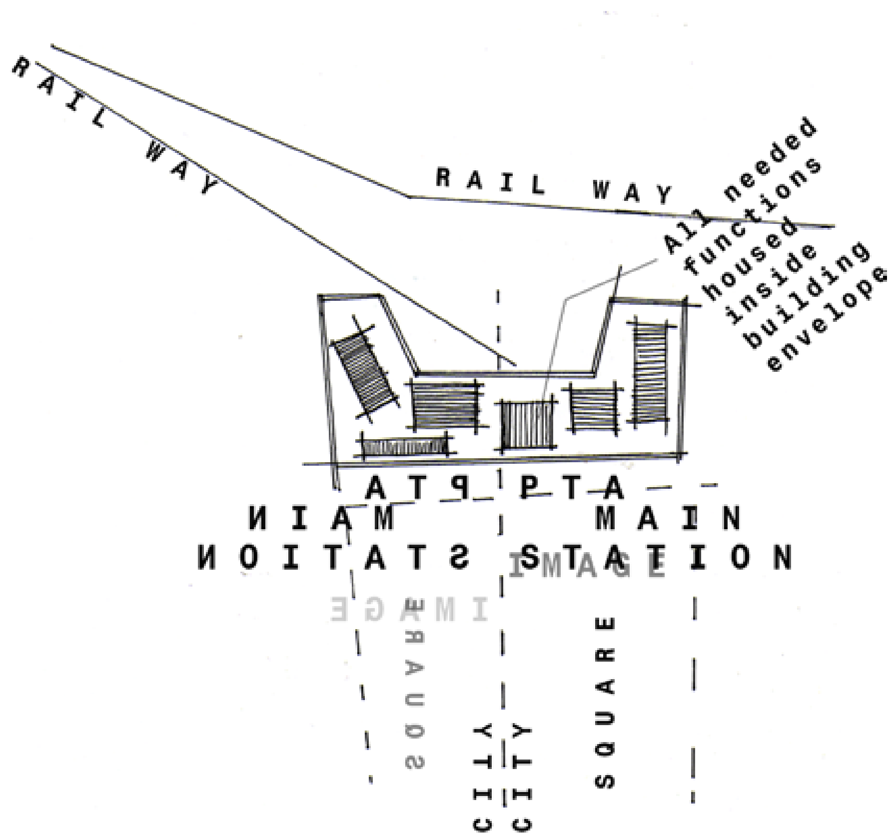


Figure 4-19: Schematic layout of Pretoria Main Station [Source: Author]

West of the main building a separate building was erected for the “natives” thus racial separation was a design consideration from the start [Baker 1912:xvv]. Baker also intended for a government department to be housed in the station building on the second and third floors [Baker 1912:xvv].

The three-storeys-high building was constructed from flatpan sandstone, quarried in the Free State, while the original Italian type tiles were manufactured in Vereeniging [Baker 1912:xviii]. The stone walls are currently to be painted. On investigation it was found that the paint could not be removed.

A sealant was originally added before the stone walls were painted. It has degraded the stone to such an extent that water penetration will be a major problem in future [Lindeque 2002:3].

The timber roof structure was originally constructed from Scandinavian pine and consisted of exposed dual pressed rafters seated on a concrete encased roof beam [Lindeque 2002:8]. The roof had to be reconstructed after it was destroyed in a fire in 2001.

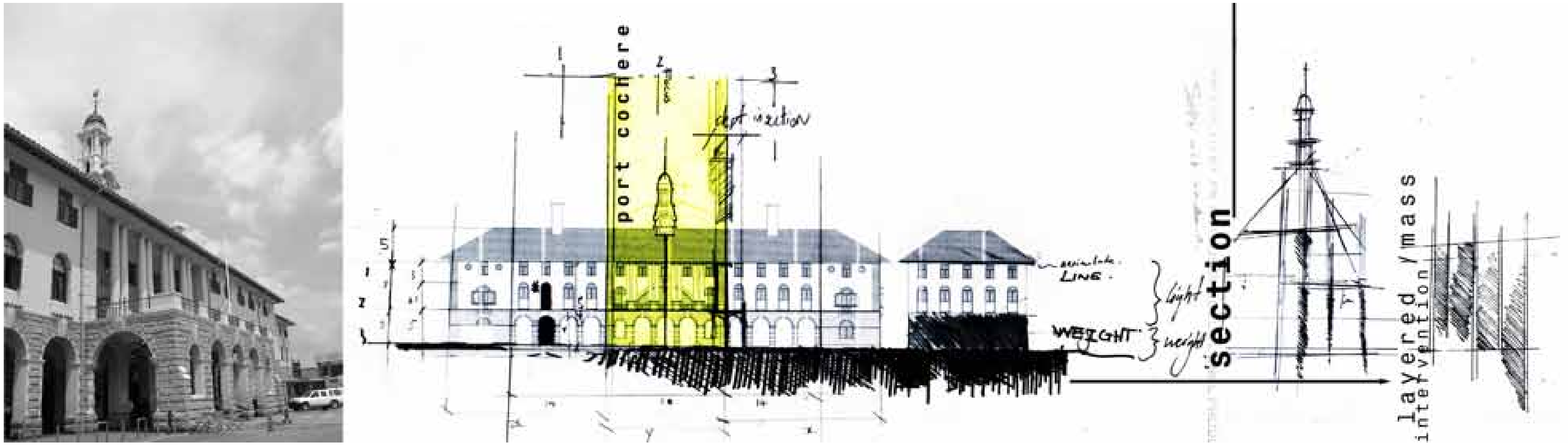


Figure 4-20: Facade of the station [Source: Author]

Development of the Station and Station Square.

The Station Square as undergone many changes over the years. The Station building itself was completed in 1912, while the Station Square was added between 1912- 1925.

In October 1925 the Paul Kruger statue was re-erected on the square. The statue was moved from Princess Park to the Station Square [Bakker 2003:4+17]. In 1954 it was moved to Church Square where it is still located [Astrup 2004:28].

The sunken gardens were constructed in 1946 in preparation for the visit of the Royal family of King George IV and Queen Elizabeth [Bakker 2004:4]. **In front of the Station building the World War I and II memorial was erected, where it still remians.** It is not clear when it was built.

In 1947 the bridge connecting Salvokop with the station was constructed and only white people were allowed to use it [Bakker 2004:19].

On 19 February 2001, angry train commuters set fire to the station buildings. The reason behind the protests being train delays and the lack of service delivery [Lindeque 2001:1]. The whole of the roof structure and the clock tower was destroyed while the ground floor suffered extensive smoke damage [Astrup 2004:32].

Figure 4-21: The Station Square before 1954. [Source: Unknown]

Figure 4-22: [Next page]Changes and adaptations in history [Source: Author]

The first and second floors of the office section survived intact [Lindeque 2001:3]. The restoration of the station buildings started on 25 June 2001 and was completed in June 2002 [Astrup 2004:32].

Currently the Gautrain station is being constructed, though it doesn't appear to be integrated with the station building.


REMOVE
0
0
ADD
CIRCA
1911
1932
1932
1880
1880
1946
CIRCA
>2002
1925
CIRCA
2005
1890
2005
CIRCA
1920
>2002
1946
1912
1932-2002
1890
1912
CIRCA
>2002
1923
CIRCA
>1912
1912
2001
1947
2010
1910
CIRCA
>1937
TIME
change

4.2.3 Conclusion _ Manner of intervention

The approach to re-developing the station precinct and the new BRT terminal building will follow general principles of sustainable design and general conservation principles :

- **Existing historically valuable building stock will be retained**
- **The public space will be reinterpreted with a new layer of meaning that is compatible with historic function**. It will be developed to combat the heat island effect and function as an air conditioning zone for the BRT terminal building.
- **The station precinct is proposed to be changed as a whole to an integrated transport node**.

In accordance with the Burra Charter:

1. The Pretoria Main Station Building will be reintegrated with the new station site layout, while ensuring that the new functions are be compatible with the existing function [Article 7].
2. All historical material will be retained and reused on site [Article 9].
3. New work will look distinctly different [Article 19].
4. Station Square and connection into the Main Station Building will be reinterpreted and adapted through layered approach that is reversible[Article 1] .

5. The whole urban setting and related culturally significant material will be retained [Article 8].

Place
In order to develop the new movement layer on the existing, **important points on the site [referring to historical, removed and future points] will be linked**. This aims to integrate and include all aspects of users and systems on the site.

The cardus maximus will be enforced by clearing the vista up Paul Kruger street.

Station Square
The Station Square will be reinterpreted – by linking it with the existing and new interventions. **The new movement layer will be superimposed on the existing. Historical components will be reinterpreted to be more accessible to the public.**

The intervention aims to develop a "background" structure that will define the edge of the Station Square. The background layer will consist of a series of skins that will change and adapt to season and time.

Pretoria Main Station Building
As the façade of the Station building is an important historical symbol/component both on an urban scale and to the immediate context, it will be retained by the intervention.

This solid façade will be reinterpreted within the new structure as two new entrance points – responding the stereotomical nature of the façade.

The hollow open layout of the building will be retained and reinterpreted within the new structure. This new structure will be open in a similar way, becoming more a movement space than a building.

The articulation of the entrance with its arched logia and porte cochere will be interpreted at the new entrances as a manner of developing a structural system and facade.

The intervention will follow a layered ecosystemic approach
_adding layers to ensure diversity of old and new,
leading to a flexible and adaptable site.
[components only to be removed to accommodate
new movement layer or clear axis of cardus maximus].
_these layers will be linked to generate a new intervention.

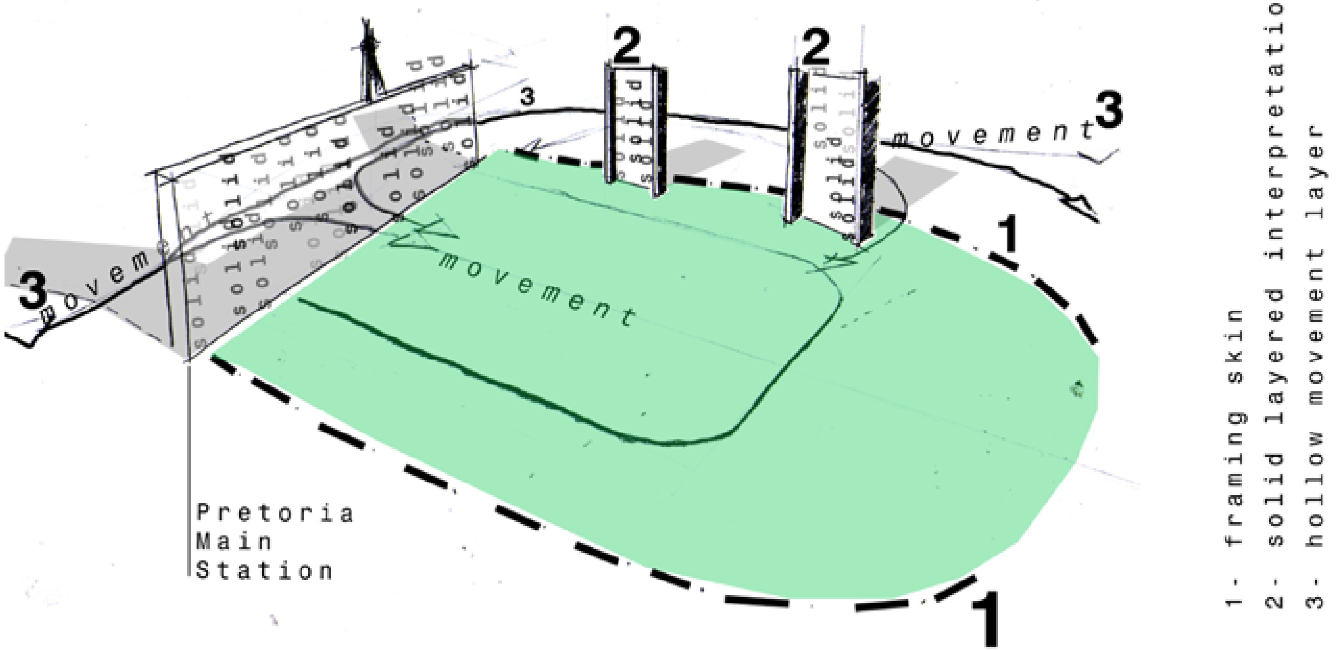


Figure 4-23: Three layers of intervention - responding to the existing station and its context [Source: Author]

4.3 FRAMEWORK – LOW CARBON STRATEGIES/ TECHNOLOGIES AND APPROACHES

In order to achieve a low-carbon building, design strategies, systems and technologies must be identified to guide the design process. These will be classified as passive and active strategies, and have been adapted and identified to specifically suit the site and nature of the project.

4.3.1 Passive design approaches.

Solar orientation
The architect must always **aim to ensure that the building is orientated north [15° E and 10° W of North]** [SANS 204-2:33]. As the building must frame the Station Square, link to Salvokop Bridge and fit the BRT stations into the site – most of the structure will not achieve that aim. Office functions that require little movement of the user need to be orientated correctly as the indoor environment is critical in these zones. The indoor thermal comfort as prescribed by the Green Building Council ranges from 22-29 °C for summer, while 19-26 °C in winter [taking an average increase of 3 ° C cause by climate change into consideration][GBCSA 2008:87].

As the building is situated in the "highveld" – thermal heat gain will still be important in winter while the shading of windows and large sections of high mass walls are essential in summer [Holm 1998:69]

Landscaping and the heat island effect
The designer must make use of as much planted landscaping close to the building as possible. **The Station Square, east of the intervention, should be utilised to cool the immediate environment and air-condition the summer winds that are harnessed for ventilation** [Haselbach 2008:69+73; Dimoudi & Nikopoulou 2003:75].

Light coloured roof materials must be used and western walls must be shaded to minimise thermal heat gain in heavy materials [Haselbach 2008:69+73; Roaf et al 2009:55].

Natural Ventilation.
Rooms must be as narrow as possible to ensure good cross ventilation, preferable keeping the eastern ventilation openings lower for cool air to filter into spaces [Van Lengen 2008:49]. **A room should not to be deeper than 5 times its height [Halliday 2008:258].** Higher floor to ceiling heights will contribute to a better indoor environment and allow hot air to rise above the user [Van Lengen 2008:273].

A central walkway should be used to promote a stack effect [refer to CH2 precedent]. This will ensure that spaces adjacent to the walkway ventilate efficiently by using the thermal energy generated by commuters during busy periods [this principle was used in the Beddington Zero Energy Developement in Brittian] [Peason 2000:47].

Natural lighting
As much as possible **diffused natural lighting must be allowed into the structure;** to ensure this the central roof structure must be high enough [Holm 1996:7]. **The outer skin of the structure must ensure that all glare is eliminated from the indoor spaces**. Plant screens, natural landscaping, building components and movable screens can be used to ensure good lighting in indoor spaces.

4.3.2 Active systems

Architects are in control of the passive strategies and technologies used in buildings. These can have a significant influence on the efficiency of the building [Holm 2010]. Active systems must only be used passive strategies and technologies are not adequate. For this project active systems will be used for space heating, mechanical ventilation and selective energy generation.

Generating energy
Photovoltaic energy is the only viable renewable energy to use in Pretoria. **The project will aim to generate enough photovoltaic energy for its lighting needs.** This can also be integrated with the national electricity grid, which will lessen the strain on the use of non-renewable resources [Holm 2010].

The solar voltaic panels will be integrated with the roof sheeting as a dematerialisation strategy to achieve material efficiency [GBSCA 2008:261].

Ventilation systems
The building will use a **series diverse systems to ventilate the structure and ensure adaptability and efficiency of the "whole" [refer to CH2 precedent study]**. The different systems will be adapted to the season/ time and outdoor environment.

Water will be used as a phase-changing material for space heating, in solar water heaters, or integrated with a rock store for cooling/heating.

The Station Square will be used to pre-cool and filter the air, the air will be collected at the reflective pools that are proposed for the gardens. The ventilation system will use an earth tube and rock store to condition the air before servicing the different spaces within the building[1].

The rock store will also be cooled during the night to ensure the stored coolth can be used during the day.

4.3.3 Conclusion

By laying down these strategies beforehand the designer can make decisions with more ease during the design process. The strategies will guide the process and ensure that an energy efficient and sustainable building is achieved.

1. Note: The use of an earth tube and rock store for ventilation was discarded during the process as it will not be efficient for cooling purposes

4.4 FRAMEWORK – LIFE CYCLE ASSESSMENT: MATERIAL CHOICE

Bennett et al [2003:126] propose the use of life cycle assessments as a means of addressing the green house gas emissions and embodied energy of architecture. This would mean the full understanding and quantifying of the resources used and emission that are produced by the structure.

In essence, life cycle assessment can be defined as follows:

> **...[It is] formulated to assess the non-site-specific potential environmental impacts of a product regardless of where, when or who uses it.**
>
> [Bennett et al 2003:98]

Life cycle assessment analyses the whole construction and building management process. It focuses on the extraction of material as well as the manufacture, construction, maintenance through to the recycling and dismantling of these materials [Milne & Reardon s.a.:1].

It takes all the material inputs and outputs generated throughout the whole life cycle of the structure into consideration [Graedel 1998:3].

It is important to note that if a structure is used for an extended period its embodied energy becomes less important [Holm 1996:84]. In such a case the energy used during the operational stage of the structure needs to be addressed.

To ensure that a structure has a low embodied energy content, the designer should focus on locally sourced and recycled material, while always designing for the eventual dismantling of the structure [Milne & Reardon s.a:4].

4.4.1 Material choice

LIFE CYCLE ASSESSMENT

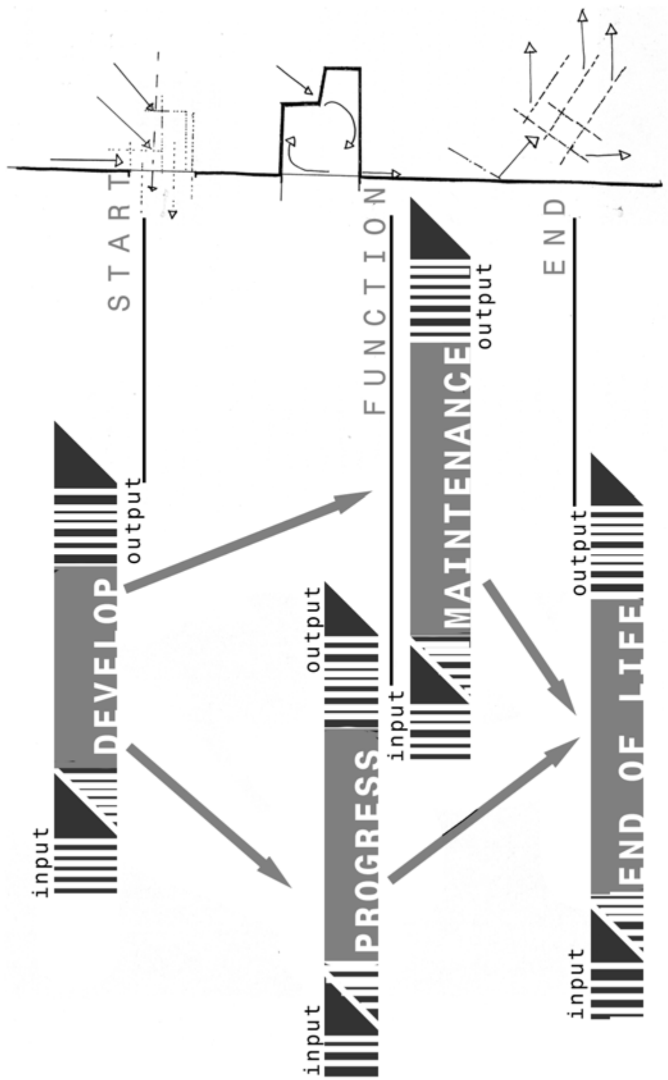


Figure 4-24: The different processes to take in account when doing a life cycle assessment [Source: Author].

Life Cycle Performance
The life cycle assessment of a specific material assesses the following

- **A) Where the materials is extracted from**
- **B) What manufacturing processes it has undergone**
- **C) What transport methods were used**
- **D) The construction processes used**
- **E) The maintenance of the material**
- **F) The recycling or disposal of the material**

[Halliday 2008:118-131]

In order to assess the life cycle performance of a specific material
the following steps are to be taken:

A_1. Be clear beforehand of what processes or materials are analysed
A_2. Decided what aspects of these materials or processes are going to be analysed and quantified

B_1. Do an inventory analysis beforehand to assess all inputs and outputs

C_1. Assessment must be done over whole life cycle

D_ 1. Interpret the results.
[Greadel 1998:21-23]

The interpretation phase is of vital importance to ensure that conclusions and adaptations can be made in future. The data used for the assessment must be new and updated and it is always good to go to suppliers for information regarding specific materials [Milne & Reardon s.a.:4].

Cradle to ... Cradle?
In assessing the whole lifecycle of materials the concept of "cradle to grave" was developed. This refers to:

- **the extraction of the raw material**
- **the transportation of the raw material**
- **the manufacturing process and all energy used in the factories**
- **the transport to site**
- **the construction process and the energy consumed by it**
- **the maintenance of the material [during its operational stage]**
- **the disposal of the material**

[Jones & Hammond 2008:1]

Definitions of other timescales:

1) **Cradle to Gate _ from extraction of material to the finished product [excluding site and construction]**
2) **Cradle to Site _ from extraction of the material to its transportation to site**

Embodied energy
The embodied energy of a material can be defined as the total amount of energy that has been used over a specific timescale [Jones & Hammond 2008:1].
Many studies have been done regarding the embodied energy of materials, but most focus on the cradle to gate period [Jones & Hammond 2008:4].

In conventional buildings the embodied energy of materials usually make up 10-25% of the total embodied energy over its whole life cycle. Lately the development of energy efficient buildings has led to the embodied energy of materials reaching up to 50% of the total embodied energy over the whole lifetime [Berge 2006:19].

Carbon footprint - carbon released
The carbon footprint of a material refers to **the total amount of carbon released into the atmosphere during the life cycle of the material**. It is closely linked to the embodied energy of the material, yet these quantities can differ [Jones & Hammond 2008:1].

The carbon footprint depends on the primary energy source used during production as well as the transport method used to transport materials. 95% of South Africa's total energy supply is generated by coal fired power plant [IEC 2009:21], thus the relation between the embodied energy and carbon foot print is closer.

Methodology
The life cycle performance of selected materials are analysed. **The materials are chosen specifically to be used in the design of the prototypical BRT station. The carbon footprint, embodied energy, maintenance and transport are analysed.**

At the time of the study the embodied energy of specific materials in a South African context has not been made publically available. The study uses figures that have been developed in the UK, and reported in the *Inventory of Carbon & Energy* [2008], by Geoff Hammond and Craig Jones.

Cradle to gate figures were used, as specific information on the manufacture, transport and construction methods is not available for this study. The possible energy saved through recycling and reusing was not calculated as the energy and carbon footprint of these processes will differ vastly in the future from what is currently available.

The transport figure was derived from Bjorn Berge, and taken as 2.2 MJ/ton km [Berge 2006:20], thus 0.0022 MJ/kg km.

The material distance travelled was only worked out fot the manufacturers closets to the Pretoria Main Station site.

The figure for pre-cast concrete has been calculated and adapted by using the difference from the energy calcular [Austrup 2009;104].

4.4.2 Material assessment

The choice of materials researched was done according to what is foreseen to be used in the prototypical BRT station. The cradle to gate cycles of steel, aluminium, concrete, masonry, glass and insulation materials were researched.

Timber is excluded from the material selection due to the fact that it requires a high amount of maintenance. It will not be a suitable material for an environment that needs to accommodate up to 6000 people per hour [Advanced Logistics Group 2008:09]. The harsh climate in Pretoria also causes a lot of damage and exposure to the timber, unless it is sealed and detailed correctly [Wegelen 2006:4.3].

Structural material- High Mass
As indicated in Table 4-01 it is clear that **concrete blocks have the lowest embodied energy and carbon footprint per square meter of all the materials researched.** Concrete blocks have a compressive strength of 7 or 14 Mpa respectively [Wegelen 2006:7.9]. The walls will have to be plastered and painted and will require maintenance through the years. The blocks can be manufactured close to the site, ensuring a low embodied energy over the cradle to grave life cycle.

The second option is to use normal clay brick masonry. The transport energy for clay brick masonry is also low as there are many manufacturers close by.

The first two options will have to be maintained regularly, yet adding 50.4 MJ/m2 after 50 years to the total embodied energy, plastered and painted masonry walls still perform a lot better than off-shutter concrete or face brick walls.

Reinforced off-shutter concrete performs better than face brick, but a face brick wall will be easily recycled or reused at the end of its life cycle. Unfortunately recycling masonry still requires a lot of time and labour [Berge 2006:207].

All these materials are manufactured at sites close to Pretoria.

Structural material – Lightweight
The use of recycled Steel and aluminium will ensure low embodied energies for the structures. The recycle rate of steel and especially of aluminium is very high. The recycling process also requires much less energy, aluminium requires as little as 7% of the initial energy [Berge 2006:79].

Recyclability and use of recycled materials also depends on the expected life cycle of the structure. If the structure will last 100 years one should rather opt for recycled materials. The recyclability of materials becomes important if the structure will change frequently [Jones & Hammond 2008:07]. **For the BRT stations the designer must ensure that the steel and aluminium sections are demountable.**

As analysed in Table 4-01 stainless steel sections require high amounts of energy to manufacture. Even though it requires little maintenance the saving is still minimal. One should opt to use as little stainless steel as possible. It is still a good material for handrails and areas that come in close contact with users as it is easy to maintain and clean [Wegelen 2006:8.9]

It is clear that **lightweight structures will be more energy intensive, as the per meter quantities of steel structural sections are very much the same to that of per square meter concrete walls/floors**. Yet these lightwieght materials are much easier to recycle. Parts of the station that will change frequently will have to be designed using lightweight demountable materials

The steel manufacturer closest to Tshwane is in Van der Bijlpark, at a distance less than 400 km as indicated by the GBCSA as the maximum distance materials travel to be classified as locally sourced [GBCSA 2008:267].

Aluminium smelters are situated further away from the site. Virgin aluminium will have a very high embodied energy and carbon footprint as the smelters are in Coega, Port Elizabeth and Richard's Bay [AFSA 2010]. One can opt for recycled aluminium products from a producer situated in Benoni, which is within 400km from the site.

On the whole these are the most energy intensive and carbon producing materials.

Roof Sheeting

In terms of roof sheeting polycarbonate sheeting initially outperforms corrugated steel sheeting as well as galvanised sheeting. Polycarbonate is the strongest and most durable of all translucent plastics [Weeglen 2006:9.8]. Yet the durability of polycarbonate as roof sheeting is a problem as in many instances plastics suffer from degradation very quickly. This can be caused by many factors of which ultraviolet rays are a major contributor [Berge 2006:153-154]. Polycarbonate roof sheeting is normally guaranteed for only 10 years [www.safintra.co.za].

After 50 years polycarbonate roof sheeting has double the embodied energy content than galvanised roof sheeting.

It is clear in Table 4-01 that galvanised corrugated metal sheeting saves enough carbon and energy over the long run to justify its use instead of normal sheeting.

Corrugated steel sheeting recycles much easier than polycarbonate sheeting. Polycarbonate can only be downcycled to a lower type material and is not biodegradable [Berge 2006:155].

Choosing galvanized roof sheeting proves the most efficient over a longer time period.

Translucent sheeting
Glass sheeting does the best in terms of embodied energy and carbon footprints of translucent materials . Yet oil based products such as poly methyl methacrylate [perspex, PMMA], polypropylene and polycarbonate sheeting will be more durable in heavily used environments.

Polycarbonate is the toughest of all these products and up to 200 times stronger than glass [Weglin 2006:9.7 & Polyglass product info]. PMMA has a maximum lifespan of only 40 years [Berge 2006:155]. The supplier of polycarbonate sheeting does not state how durable their product is yet a lifespan of 40 years can be expected [roof sheeting is only guaranteed for 10 years].

Glass can be made of 50% recycled glass, but laminated glass cannot be recycled to be used as window glass [Berge 2006:103]. Thus the recycling possibilities of glass is limited, as laminated toughened glass will have to be used to ensure its robustness. Plastics generally lose their quality once they are recycled and current technologies only allow them to be downgraded [Berge 2006:155].

PPMA will be the best choice, as the product is ultraviolet resistant and very robust [Wegelen 2006:6.15]. This will be vital in a high traffic environment, and under changing climatic conditions where high levels of insolation will occur.

Thermal insulation
As analysed in Table 4-01 the **best choice for insulation will be mineral wool or fibreglass insulation panels,** even though expanded polystyrene is manufactured closer to the site. The lightweight quality of the materials makes transportation energies much less.

Mineral wool is biodegradable while fibreglass insulation can be recycled [www.valmic.co.za]. All the products require no maintenance if detailed and constructed correctly.

Aluminium foil [sisalation] can also be used, yet the embodied energy of this materials is not available for assessment.

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	Material	Composition	Energy /Carbon Cradle to gate MJ/kg	kgCO2/kg	Typical quantity per square meter	MJ/m2	kgCO2/m2	Transport Origin	Energy MJ/kg	Total CO2 per trip CO2 kg	Maintenance Finish PER SQUARE METER	5 years MJ/m2	kgCO2/m2	10 years MJ/m2	kgCO2/m2	50 years MJ/m2	kgCO2/m2	End of life
STRUCTURE HIGH MASS	**PRECAST CONCRETE**	Cement Aggregate Steel Fly ash	3.7	0.39	300mm depth	**2.68**	**283.5**	Hercules VanderBijl park[5%] Total	0.0152 0.0152 0.0304		Off shutter							Downcycle
	REINFORCED CONCRETE	Cement Aggregate Steel Fly ash	2.42	0.256	300mm depth	**1742.2**	**184.32**	Hercules Van der Bijl park[5%] Total	0.0152 0.0152 0.0304		Off shutter							Downcycle
	CONCRETE	Cement Aggregate Fly ash	1.39	0.209	200mm depth	**667.2**	**100.32**	Herculus	0.0152	225	Off shutter							Downcycle
	CLAY MASONRY	Clay	3	0.22	220 mm wall 15mm plaster	1254 28.2 **1282.2**	91.96 3.9 **95.86**	Kameel drif	0.0484	34.32	Plaster&Paint	5.04 **10.08**	0.27 **0.54**	10.08 **20.16**	0.54 **1.08**	25.2 **50.4**	1.35 **2.7**	Downcycle & Reuse
	CLAY MASONRY	Clay	8.2	0.52	220 mm wall	3 427.60	217.36		0.0484		Facebrick							Downcycle & Reuse
	CONCRETE BLOCKS	Cement Soil Aggregate	0.81	0.098	200mm wall 15mm plaster	307.8 28.2 **336**	37.24 3.9 **41.14**	On site	8%??0.464		Plaster&Paint	5.04 **10.08**	0.27 **0.54**	10.08 **20.16**	0.54 **1.08**	25.2 **50.4**	1.35 **2.7**	Downcycle
STRUCTURE LIGHT	**STRUCTURAL STEEL**	Iron	36.8	2.78	178x102x19	**883.2**	**66.72**	VanderBijl park	0.304		Handpainted	4.7 **9.4**	0.24 **0.48**	9.4 **18.8**	0.48 **0.96**	23.5 **47**	1.2 **2.4**	Recycle&Reuse
	STRUCTURAL STEEL	Iron Recycled	29.44	2.22	178x102x19	**706.56**	**53.28**	VanderBijl park	0.304		Handpainted	4.7 **9.4**	0.24 **0.48**	9.4 **18.8**	0.48 **0.96**	23.5 **47**	1.2 **2.4**	Recycle&Reuse
	ALUMINIUM	Bauxite Extruded	214	11.2	178x102x19	**5 136**	**268.8**				Handpainted	4.7 **9.4**	0.24 **0.48**	9.4 **18.8**	0.48 **0.96**	23.5 **47**	1.2 **2.4**	Recycle&Reuse
	ALUMINIUM	Bauxite Extruded Recycled	34.1	1.98	178x102x19	**818.4**	**47.52**				Handpainted	**4.7** **9.4**	**0.24** **0.48**	**9.4** **18.8**	**0.48** **0.96**	**23.5** **47**	**1.2** **2.4**	**Recycle&Reuse**
	STAINLESS STEEL	Steel Chromium	56.41	6.15	178x102x19	**1 353.84**	**147.6**	Vande Bijl park	0.304		Polished finish							Recycle&Reuse
Roof						MJ/m2	kgCO2/m2											
	METAL SHEETING	Iron	31.5	2.51	IBR	**212.7**	**16.95**	VanderBilj park	0.304		Painted	7.32 **14.64**	0.382 **0.764**	14.65 **29.3**	0.764 **1.528**	36.6 **73.2**	1.91 **3.82**	Recycle&Reuse
	GALVANISED METAL SHEETING	Iron	39	2.82	IBR	**263.3**	**19.04**	VanderBilj park	0.304		Painted							Recycle&Reuse
	POLYCARBONATE SHEETING	Bisphenol	112	6	IBR	**97.4**	**4.8**	Johannesburg										Downcycle
SHEETING						MJ/m2	kgCO2/m2											
	GLASS	Sand Silica	23.5	1.27	10mm sheet	**56.4**	**3.04**	Springs	0.2		Wash and clean							Recycle
	POLY METHYL METHACRYLATE	[general plastics]	80.5	2.53	6mm sheet	**454.02**	**14.27**				Wash and clean					Lifespan < 40 years		Downcycle
	POLYPROPYLENE	Injected moulding [opaque]	115	3.9	6mm sheet	**648.6**	**22**				Wash and clean					Lifespan < 10 years		Downcycle
	POLYCARBONATE SHEETING	Bisphenol Injected moulding [opaque]	112	6	6mm sheet	**631.7**	**33.84**	Johannesburg			Wash and clean					Lifespan < 40 years		Downcycle
	Wire mesh	Rolled	36	2.83	weight per meter													
INSULATION						MJ/m2	kgCO2/m2											
	MINERAL WOOL	Quarts Soda Dolomite Lime Sand	16.6	1.2	25mm thickness	**24.9**	**1.8**	Springs	0.2		No Maintenance							Biodegradable
	EXPANDED POLYSTYRENE	Oil based styrene	88.6	2.5	40mm thickness	**70.88**	**2**	Silverton			No Maintenance							Downcycle [non biodegradable]
	FIBREGLASS	Glass wool Resin	28	1.35	50mm thickness	**15.4**	**0.74**	Springs	0.2		No Maintenance							50% recyclable
	ALUMINIUM SHEETING	Aluminium	217	11.5														
	ALUMINIUM SHEETING	Aluminium Recycled	27.8	1.67							No Maintenance							Recyclable

Note: Embodied energy quantities were aquired from Jones & Hammond - Inventory of Carbon & Energy - 2008
These figures are applicable for the UK
The densities were aquired from B Berge - The Ecology of Building Materials - 2006 and Product Manufactures
The paint figures were adapted from Plascon paint products

Table 4-01: The embodied energy of construction materials, and their transportation and maintenance [Source: Author]

4.4.3 Embodied energy of a typical prototype

Figure 4-25: Embodied energy and carbon footprint of Rea Vaya Station
[Source: Author]

Building ID: **Rea Vaya BRT Prototypical Station**
Location: **Johannesburg, South Africa**
Architects: **Ikemeleng Architects, Osmond Lange Architects & Planners**
Client: **City Council of Johannesburg**
Date: **2009**
Area: **158 m^2**

The carbon footprint and embodied energy of the structure has been analysed .

The materials were analysed for a cradle to gate period. Only basic core materials were analysed:

- Concrete
- Glass
- Steel
- Stainless steel
- Masonry
- Insulation – basic – fibreglass

The following have not been included:

- Urban Infrastructure
- Electrical equipment
- Sanitary fittings
- Signage and fittings
- Foundations and substructure
- Doors and doorframes

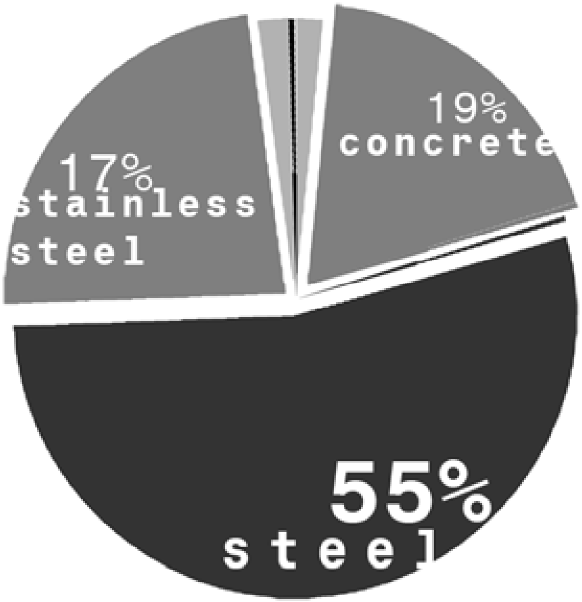
Embodied energy _Case study REA VAYA

NOTE: This is only an interim calculation and will be checked .

Material	Component	Size m3	Density kg/m3	Weight kg	Embodied Energy MJ/kg	Carbon footprint kg CO_2/kg	Embodied energy MJ	Carbon Footprint kg CO_2	COMPONENT TOTAL EE MJ	COMPONENT TOTAL CF kg CO_2
Infill aggregate	Infill base 800 deep	87.95	2000	175 900	0.1	0.005	17590	879.5	17590	879.5
Concrete	Ramp	3.38	1900	6 422	1.39	0.209	8926.58	1342.198	204722.4	23192.97
	Plinth/Base	28.9	2400	69 360	2.42	0.256	167851.2	17756.16		
	Floor 100mm	9.2	1900	17 480	1.39	0.209	24297.2	3653.32		
Masonry	Ramp Paving	2.37	1900	4 503	0.81	0.098	3647.43	441.294	3647.43	441.294
Alumium	Doorframe [not calculated]								0	0
Steel	Steel "vastrap"@ bus entrance	0.036	8000	288	29.44	2.22	8478.72	639.36	612027.5	41491.84
	I-beam Colums	0.3	8000	2 400	29.44	2.22	70656	5328		
	Roof beam	0.23	8000	1 840	29.44	2.22	54169.6	4084.8		
	Purlins @ 700 centres	0.12	8000	960	29.44	2.22	28262.4	2131.2		
	Bracing member	0.19	8000	1 520	29.44	2.22	44748.8	3374.4		
	Corrugated roof [1.6mm thick]	0.26	8000	2 080	39	2.82	81120	5865.6		
	Corrugated Ceiling [1.6mm thick]	0.26	8000	2 080	31.5	0.256	65520	532.48		
	Steel fascia	0.08	8000	640	29.44	2.22	18841.6	1420.8		
	Steel door frame	0.03	8000	240	29.44	2.22	7065.6	532.8		
	Steel gate [not calculated]	0	8000	0	29.44	2.22	0	0		
	Structural window frame	0.8	8000	6 400	29.44	2.22	188416	14208		
	Window bead	0.19	8000	1 520	29.44	2.22	44748.8	3374.4		
Stainless Steel	Handrail	0.12	7500	900	56.41	6.15	50769	5535	192922.2	21033
	Seat-rest	0.262	7500	1 965	56.41	6.15	110845.65	12084.75		
	Stainless steel office	0.05	7500	375	56.41	6.15	21153.75	2306.25		
	Boarding balustrade	0.024	7500	180	56.41	6.15	10153.8	1107		
Glass	Glass elevation	0.78	2400	1 872	35	2	65520	3744	77868	4449.6
	Glass door@ BRT boarding door	0.1	2400	240	35	2	8400	480		
	Glass panel @ kiosk office	0.01	2400	24	35	2	840	48		
	Emergency exit	0.037	2400	89	35	2	3108	177.6		
Insulation	Ceiling	11.07	11	122	28	1.35	3409.56	164.3895	3409.56	164.3895
					TOTAL		1108539.69	91211.3015		
					Area		158	158		
					per meter		7 016.07	577.29		

Abreviations: Embodied energy [EE], Carbon Footprint [CF]

Table 4-02: Embodied energy and carbon footprint of prototype station [Source: Author]



Embodied Energy

Energy consumption per materials

1.8%	1- Infill
19%	2- Concrete
0.2%	3- Masonry
55%	4- Steel
17%	5- Stainless steel
7%	6- Glazing [Glass]
0.1%	7- Insulation

Graph 4-01: Embodied energy per material as contained proportionately in the station [Sourrce: Author]

Conclusion - interpreting the analysis

It is clear from the lifecycle analysis that all buildings have a high embodied energy and carbon footprint – even if it is a small structure.

The steel structure represents the highest portion [54 %] of the total embodied energy of the prototypical station, thus steel should be used sparingly.

Concrete takes up 19% of the total embodied energy, yet it takes up 24 % of the total carbon footprint. Even though it has a low embodied energy per kilogram ratio, the large volumes that are used in the structure amount to a high total.

Stainless steel still has a high embodied energy. Even though very little is used in the station, it makes up 24% of the total embodied energy. The use of stainless steel should be avoided.

Insulation has a relatively low embodied energy in relation to the impact that it has on the indoor environment.

This prototype will be used as benchmark for the development and design of a low carbon BRT station. Out of this life cycle assessment an eco-effective solution can be developed. a design that maximises the positive qualities, while minimising the harmful or wasteful factors [Mcdonough & Braungard 2002:77]. Reducing the embodied energy content and carbon footprint of the prototypical station.

4.5 CONCLUSION

From these frameworks a design can be generated that responds to the urban context, ensures a structures that contributes to the urban and social sustainability and creates a safe and healthy environment as proposed by the LINK-framework.

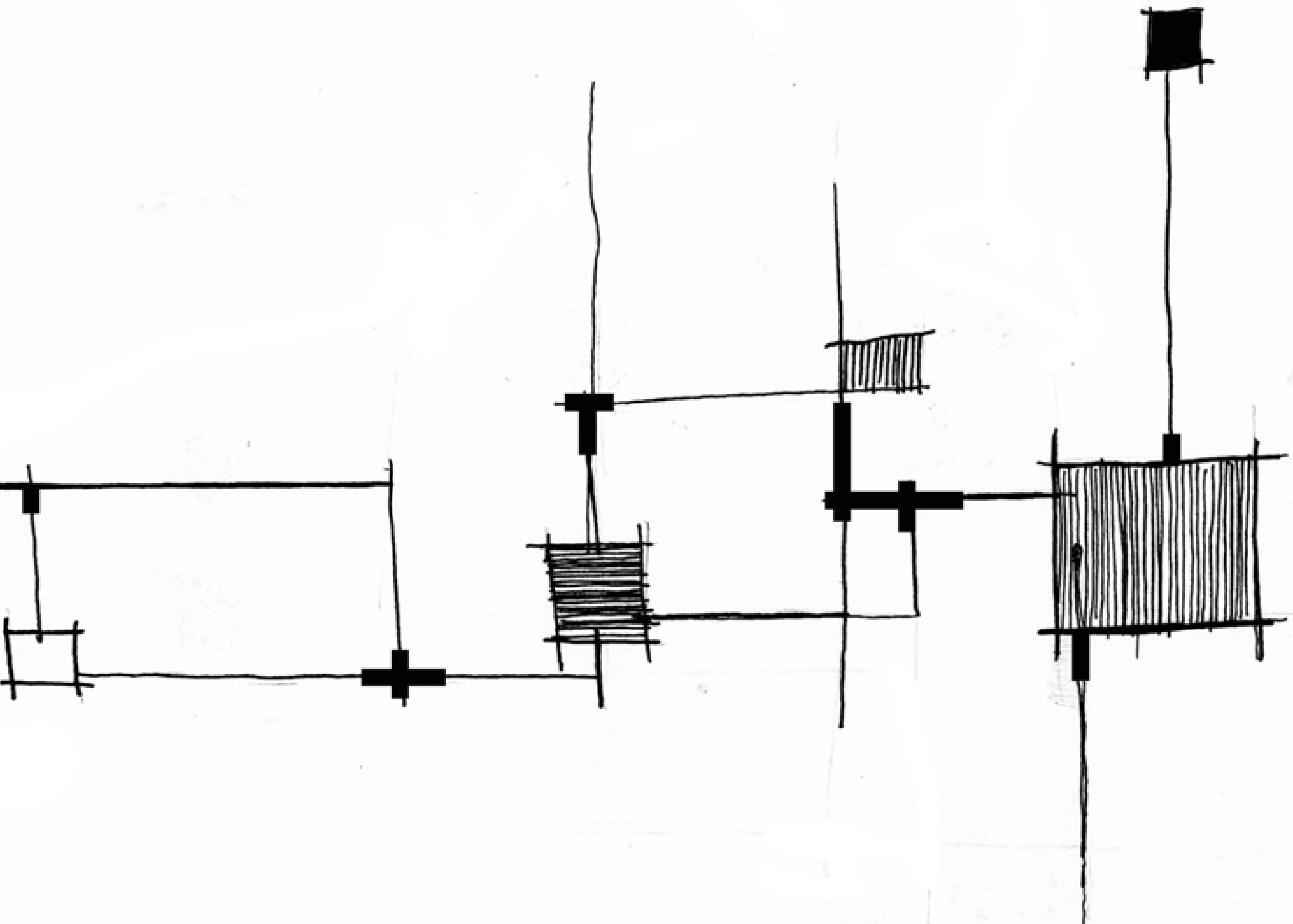
The historical framework will be used to guide the manner of intervention to ensure that the new development and intervention respects the existing while adding a new layer of function and architecture that promotes development and much needed change.

Low-carbon technologies and strategies will be used to inform the design from the early stages of the design process

Using the analysed BRT station as a benchmark the prototypical BRT station will be assessed and checked to ensure its sustainability. The material analysis will guide material choice for the project.

5

PRECEDENTS STUDIES

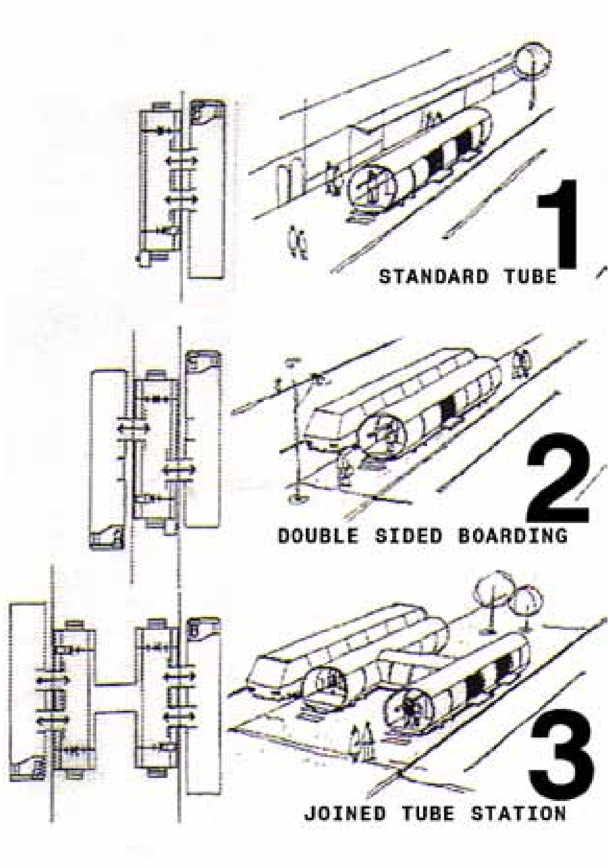


Precedents are chosen for certain qualities or aspects that will be analysed and incorporated in the design process. The aim of assessing precedents is to learn from existing projects.

The following aspects will be analysed:

a) Material use
b) Plan layout
c) Movement through the space
d) BRT prototypes
e) Energy use
f) Indoor climate regulation
g) Site response

5.1 CURITIBA BRT STATION



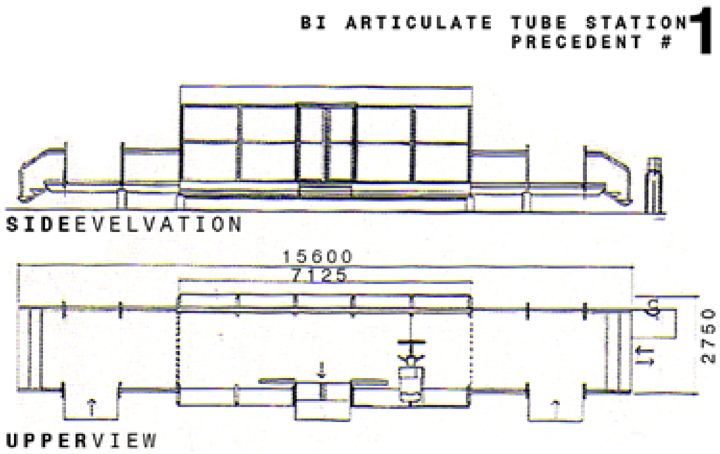


Figure 5-01: Adaptable stations [Ruano 1998, p.40]

Figure 5-02: Plan and section of station [Ruano 1998, p.40]

ID:	BRT Station Prototype
Location	Curitiba, Parana State, Brazil
Architects:	Unknown
Client:	City Council of Curitiba
Date:	1990's
Area:	30 m^2
System:	

1974 – BRT system introduced
Transport 1.6 million people per day
Bi-articulated bus vehicles
Single ticket for all routes
[off board payment]
Saves 27 million litres of fuel per year
[Goodman et al 2005:75].

Location
Placed on the median or street curb side.

Plan/Form
The simple linear plan, is an iconic and legible object in urban space. The station allows only for one controlled entrance with turnstile. The use of polypropylene sheeting ensures a visually open structure. The prototypes can be adapted to accommodate different amounts of bus bays

Material use
Polypropylene, steel, steel mesh, concrete foundation and footing.

Ventilation& Services:
Station is naturally ventilated, edges are open or covered with screen mesh. Curitiba has a temperate coastal climate with a high humidity, making these stations comfortable except for high humidity levels.

Polypropelene walls allow for natural lighting, yet artificial light installed for night. Steel sheeting roof material allows for shading during the day.

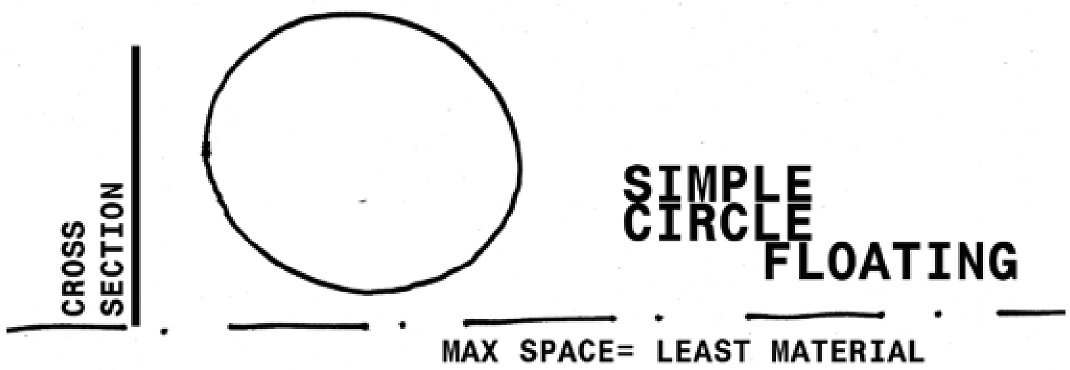


Figure 5-03: Conceptual section [Source: Author]

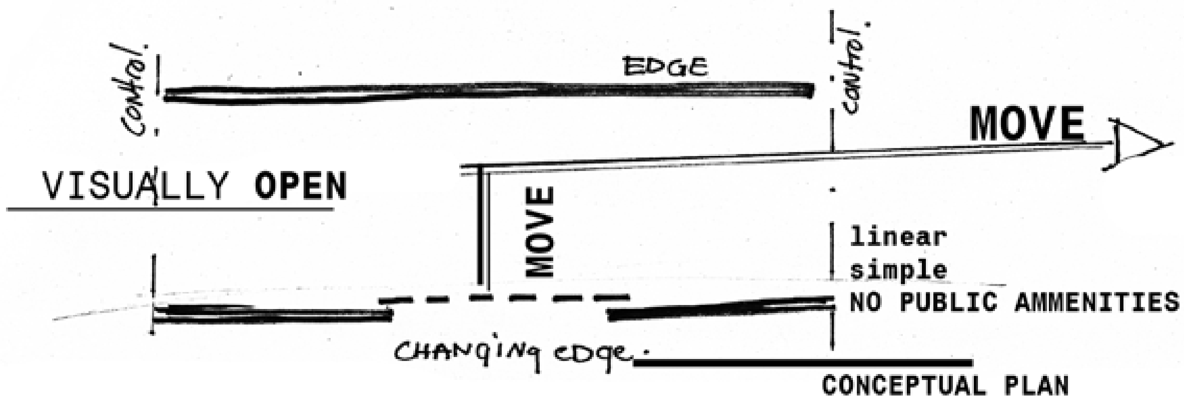


Figure 5-04: Movement and plan [Source: Author]

Embodied energy of material:
All structural material and cladding were analyzed:

[Excluding foundation, handrails and service material, construction energy]
[These number are according to Central Europe's materials source: Jones & Hammond 2008]
[All steel is assumed to be recycled]
[Only selected materials area analysed- this is not the full embodied energy of the prototype]

Concrete [Base +footing]	= 7.9 m^3	18 960 kg	= 30 716 MJ
Polypropelene[6mm]	= 0.18 m^3	162 kg	= 18 630 MJ
Steel Roofsheeting [3mm]	= 0.053 m^3	424 kg	= 12 483 MJ
Steel structure [150 dia 5mm hollow round section]	= 0.76 m^3	6080 kg	= 178 995 MJ
		Total	= 240 824 MJ
		Total	= 8 027 MJ/m^2

Critique

The prototypes are small enough to adapt to the urban environment and are human scaled. The use of a circular form allows for maximum space with minimum material use. A lot of natural light is allowed into the structure. These structures might overheat in a hot humid climate.

The use of large polypropylene sheeting makes these structures very safe as passive surveillance is easy. No proper seating is provided, yet transport system is very efficient. Commuters do not have to wait for long periods in these stations.

This is a very successful iconic prototype for the city.

Figure 5-05: Placing of station on street edge [Source: www.greatbuildings.com, accessed14 March 2010]

Figure 5-06: Photographs of Rea Vaya Prototype [Source: Author].

5.2 REA VAYA BRT STATIONS

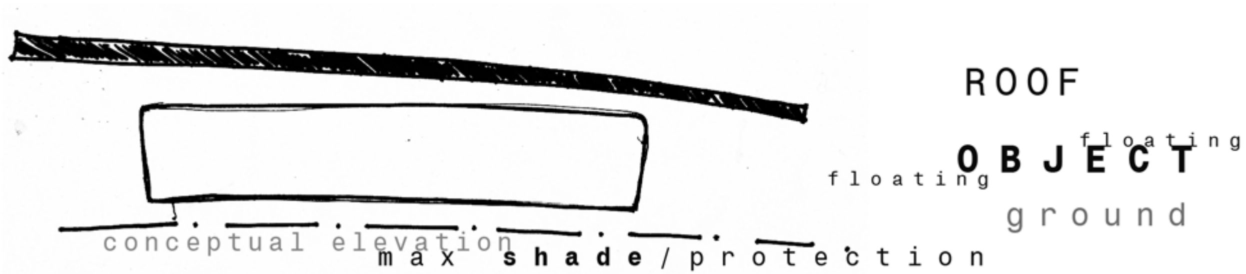


Figure 5-07: Conceptual elevation of BRT station [Source: Author]

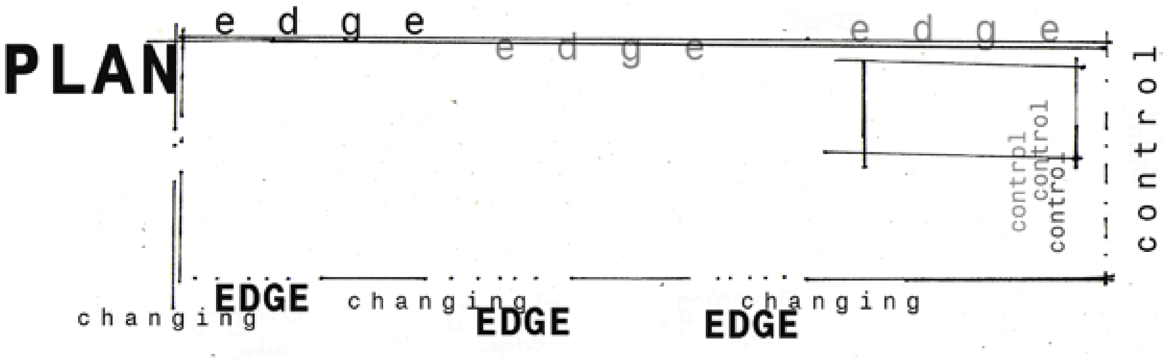


Figure 5-08: Conceptual plan layout [Source: Author]

ID:	Rea Vaya BRT stations
Location	Johannesburg, South Africa
Architects:	Ikemeleng Architects, Osmond Lange Architects & Planners
Client:	City Council of Johannesburg
Date:	2009
Area:	158 m^2
System:	
	2009 – BRT system introduced
	Bi-articulated bus vehicles
	Paper ticket payment system

Location

The prototypes are planned to be placed on the median, with single sided entrance station as well as double sided entrance stations. These stations are the same prototypes while the width of the two prototypes differs.

Plan/Form

The prototype is a simple linear plan with a single entrance. The single layered roof structure is elaborate and over scaled yet provides ample shade. There is also an office for the station master within the station.

Material use
Concrete, steel, glass and a stainless steel office, corrugated steel roof sheeting.

Ventilation& Services:
The structure is naturally ventilated station with artificial lighting. This ensures cool summer temperatures inside while winters in the Highveld can be very cold making the indoor temperatures very low.

Critique
The prototypes are over scaled and too large to easily fit within the urban network and road network. The use of natural ventilation ensures low energy use. The use of large glass sheeting ensures that the stations are safe while using passive surveillance. The large roof structure and overhangs provides sufficient shade on hot summer days.

Embodied energy of material:

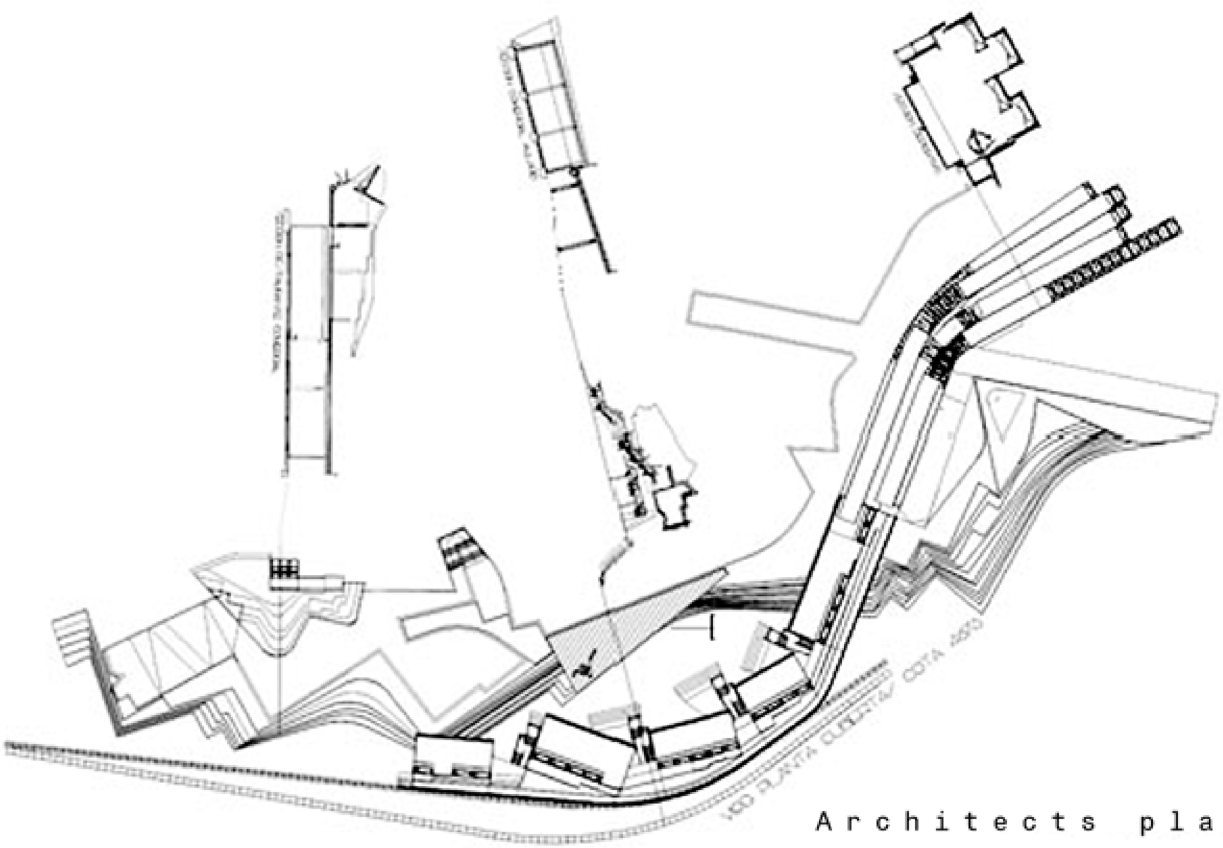
All structural material and cladding were calculated :

[Excluding foundation, handrails and service material, construction energy]
[These number are according to Central Europe's materials source: Jones & Hammond 2008]
[All steel is assumed to be recycled]
[Only selected materials area analysed- this is not the full embodied energy of the prototype]

Concrete [Base +footing]	= 41.48 m^3	99 552 kg	= 161 275 MJ
Glass sheeting [6mm]	= 1.04m^3	2 496 kg	= 37 440 MJ
Steel Roofsheeting [3mm]	= 0.507m^3	4 056 kg	= 119 246MJ
Steel structure [150 dia 5mm hollow round section]	= 1.52 m^3	12 160 kg	= 357 990 MJ
Stainless steel office	= 0.08	576 kg	= 32 492 MJ
		Total	= 708 443 MJ
		Total	= 4 484 MJ/m^2

5.3 CAMPUS OF THE UNIVERSITY OF VIGO

ID:	Sports complex and entrance into the campus
Location	Vigo, Spain
Architects:	EMBT Architects
Client:	Universidad de Vigo, Cidada, Universitaris. S.A
Date:	1999-2003
Area:	-



Architects plan

Figure 5-09: Plan and sections of intervention [Source: Architects' Website - www.mirallestagliabue.com].

Design
The design addresses the spatial qualities that are required by the university's faculties as well as their future needs. The design incorporate between these different functions on site.
Functions:

- Ring road,
- Car parks,
- Extensions to each Faculty,
- Integrated services, reforestation, a
- Waste water collector.

The design joins the different functions into a single structure. Through joining these functions and adapting the structure to the landscape a spatial experience of movement and a changing landscape.

The immaterial aim/objective of the design: The students must experience the site, its stillness and the use there of [Mirrales 2010].

Plan form
The plan is elongated and linear that binds all the different functions together.

Threshold
The architect makes use of trees to form a threshold entrance into the building complex. The use of trees and reforestation makes deepens the threshold and enforcing the experience of change and separation.

Figure 5-10: Model of intervention, adapted to site [Source: Architects' Website - www.mirallestagliabue.com].

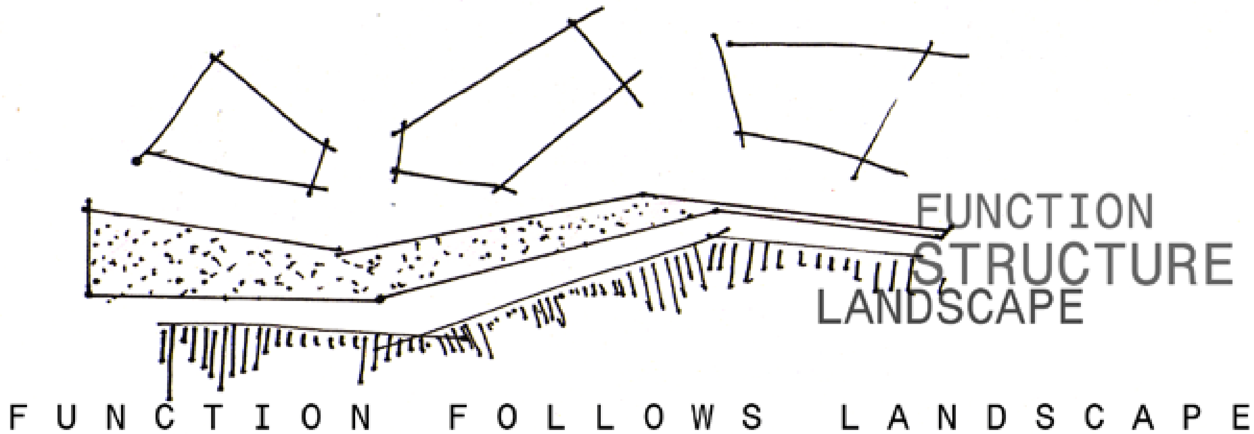


Figure 5-11: Plan adapted to landscape and linking functions [Source: Author]

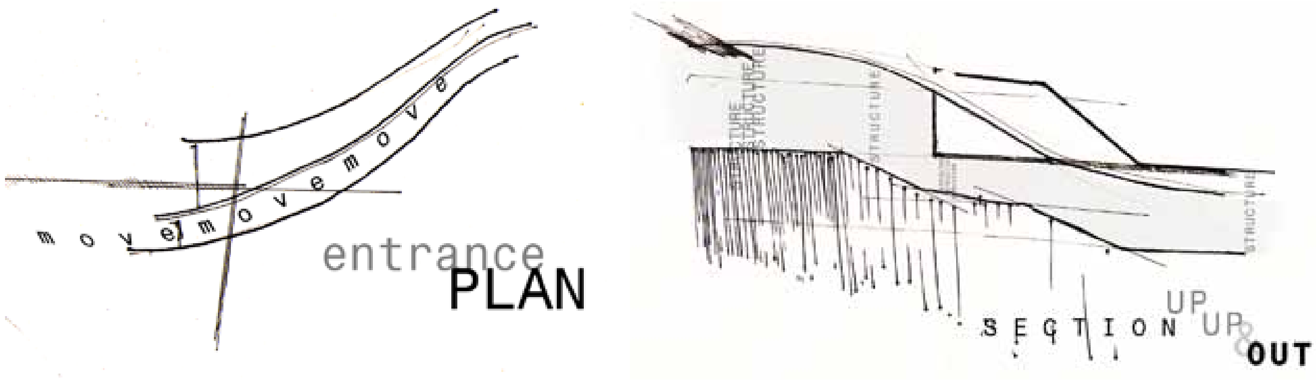


Figure 5-12: Conceptual plan and sections, structure conveying movement and change [Source: Author]

Entrance and movement

The planted forest in front of the building's entrance acts as the first threshold into the structure. The plan opens up and draws the user into the building, with high overarching roofs.

The architect makes use of level changes and changing ceiling heights to enhance the spatial experience of movement and change.

The design is embedded in the existing landscape while adapting and folding itself to the landscape.

The entrance into the structure is a series of large very high roof structures. The height gives identity to the entrance and makes the complex more legible to first time users.

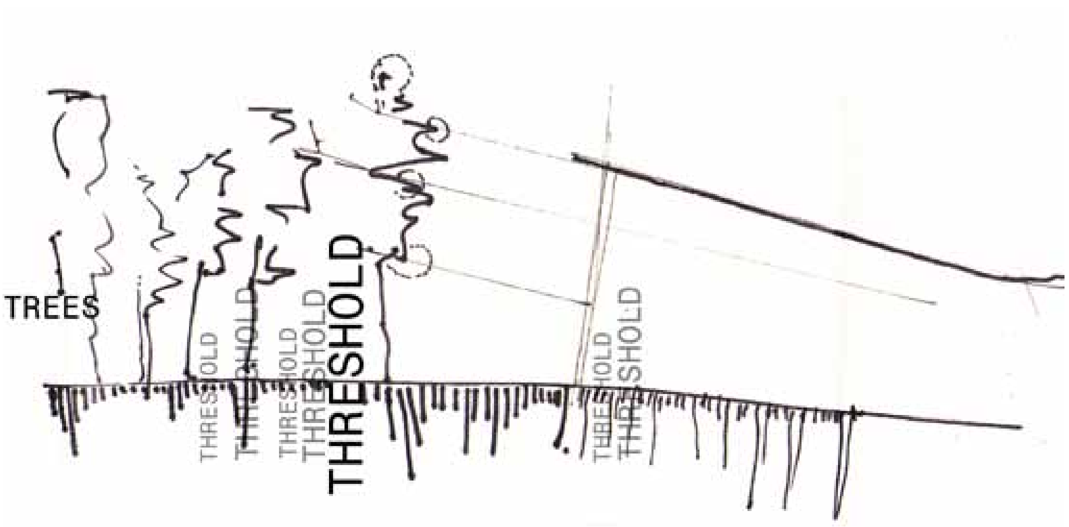


Figure 5-13: Threshold to entrance to building [Source: Author]

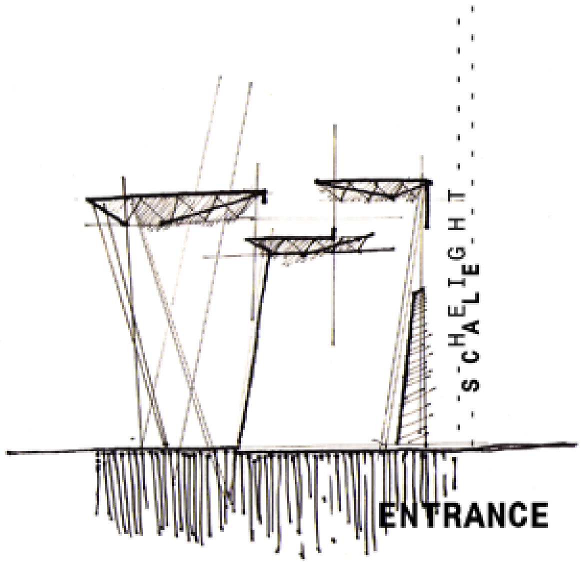


Figure 5-14: Entrance very large scale [Source: Author]

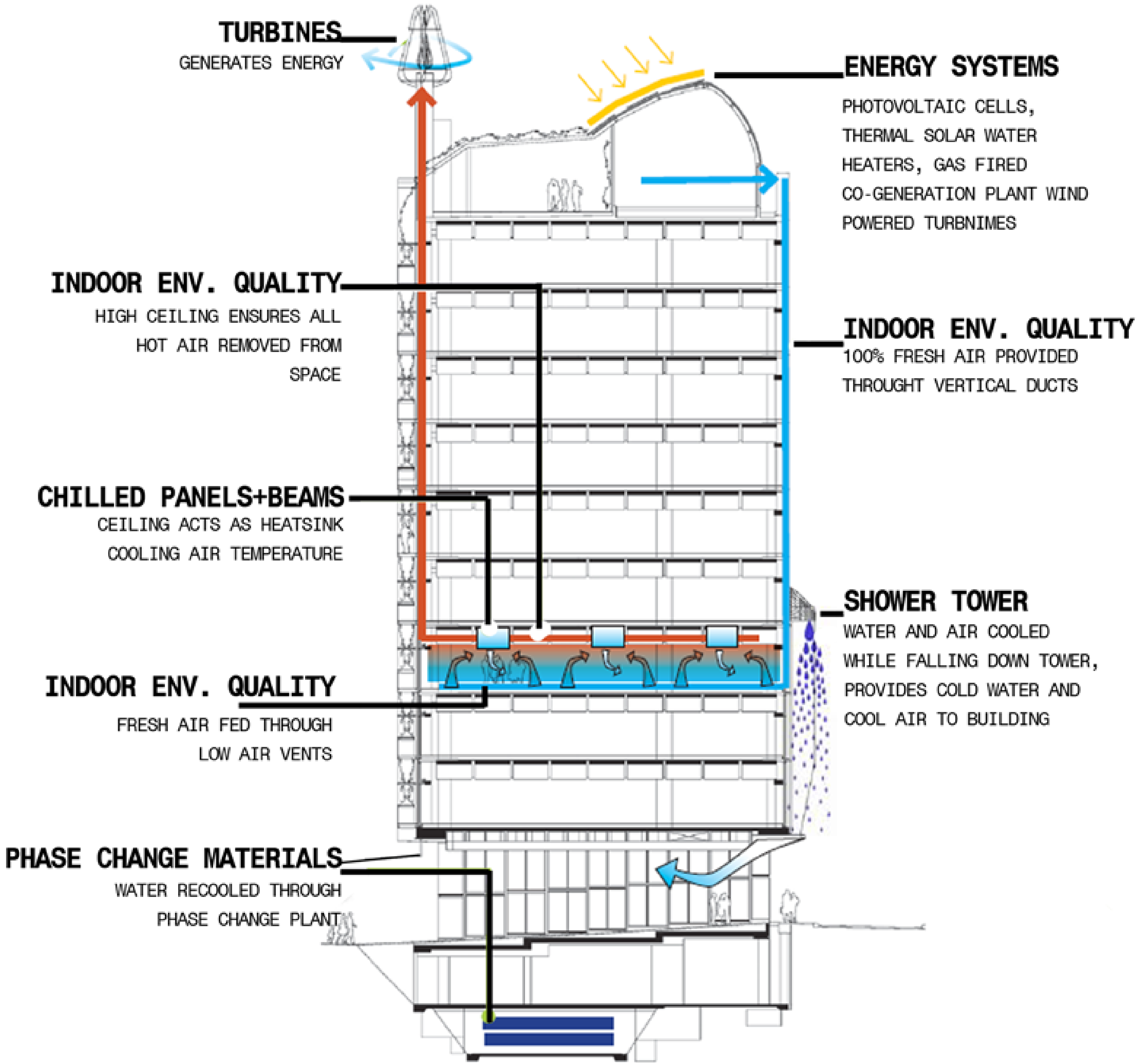


Figure 5-15: Ventilation and energy systems working in an integrated whole [Source Melbourne city council website: [http://www.melbourne.vic.gov.au/Environment/CH2/aboutch2/Pages/AboutCH2.aspx].

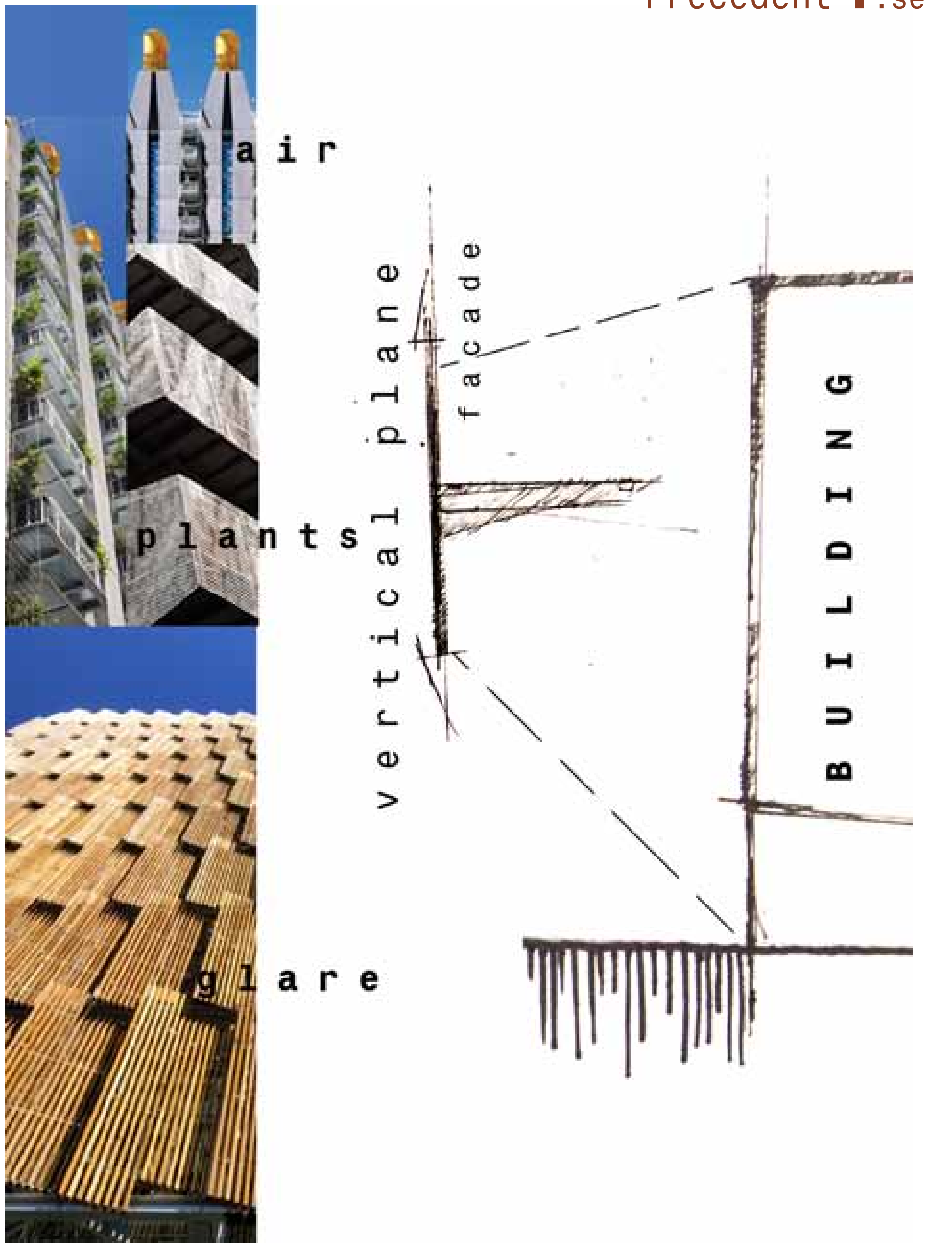


Figure 5-16: Facade detail [Source: Author]

5.4 CH2 BUILDING, MELBOURNE

ID: Multi Storey office building
Location: Melbourne, Australia
Architects: City council planners and Design Inc
Client: City council of Melbourne
Date: 2006
Size: 10 storeys

Systems

All systems are integrated and works as an ecosystemic whole as indicated in Figure 5-15 [Design Inc 2010]. By making use of a series of different systems these systems can adapt to different times of the year to provide comfort throughout the different seasons [Melbourne 2010:1-4].

The vertical planes of the structure are utilised as planting and evaporative cooling elements as innovative facade manipulation in dense urban areas.

Ventilation:

During the summer period the structure makes use of evaporative cooling to ensure cool humidified air is circulated throughout the building. The building uses 100% ventilated fresh air. The hot air is extracted through a wind turbine on the northern elevation of the structure.

Cool fresh air is supplied through a displacement ventilation system with floor grills and heat extractors in the ceiling space. This minimises the energy use of the ventilation system.

Night cooling purges the structure from heat that built up during the day. This method also stores coolth within the structure that would absorb heat during the day. Cooling requirements are reduced with 20% by this method [Melbourne 2010:02].

Material use
Concrete beams are exposed in the structure to act as chilled beams. These beams are cooled with water that are used as phase changing materials and chilled in the basement. These beams act as heat sinks absorbing heat energy within the structure during the summer period.

Facade
The use of a double or smart facade that adapts, opens/closes and ventilates the structure. The systems and infrastructure of these systems [planting, louvers, ducts, and water pipes] can be seen as a second skin that envelopes the structure. This in essence regulates the structure's indoor environment [Design Inc 2010].

Energy use
The building makes use of a hybrid approach to energy generation ranging from photovoltaic panels, solar thermal heaters, wind turbines to gas fired energy turbines. By reducing the building's energy consumption with 50% the use of alternative energy sources becomes a viable option.

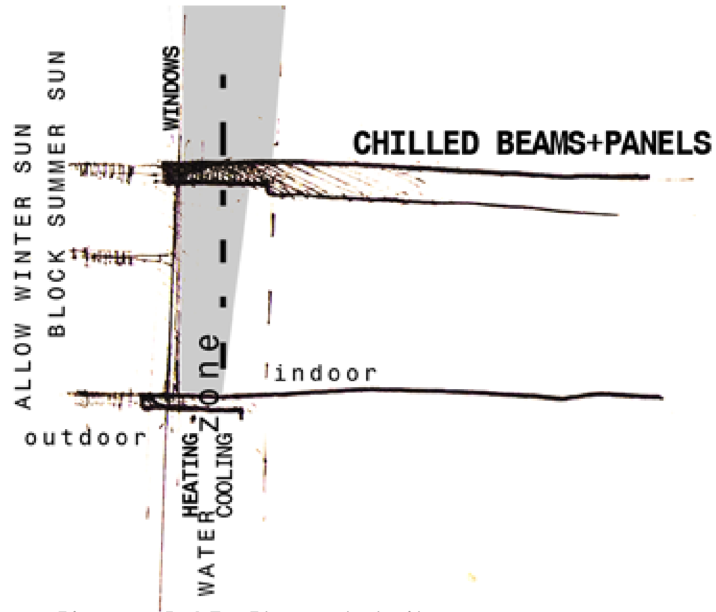


Figure 5-17: Floor detail
[Source: Author]

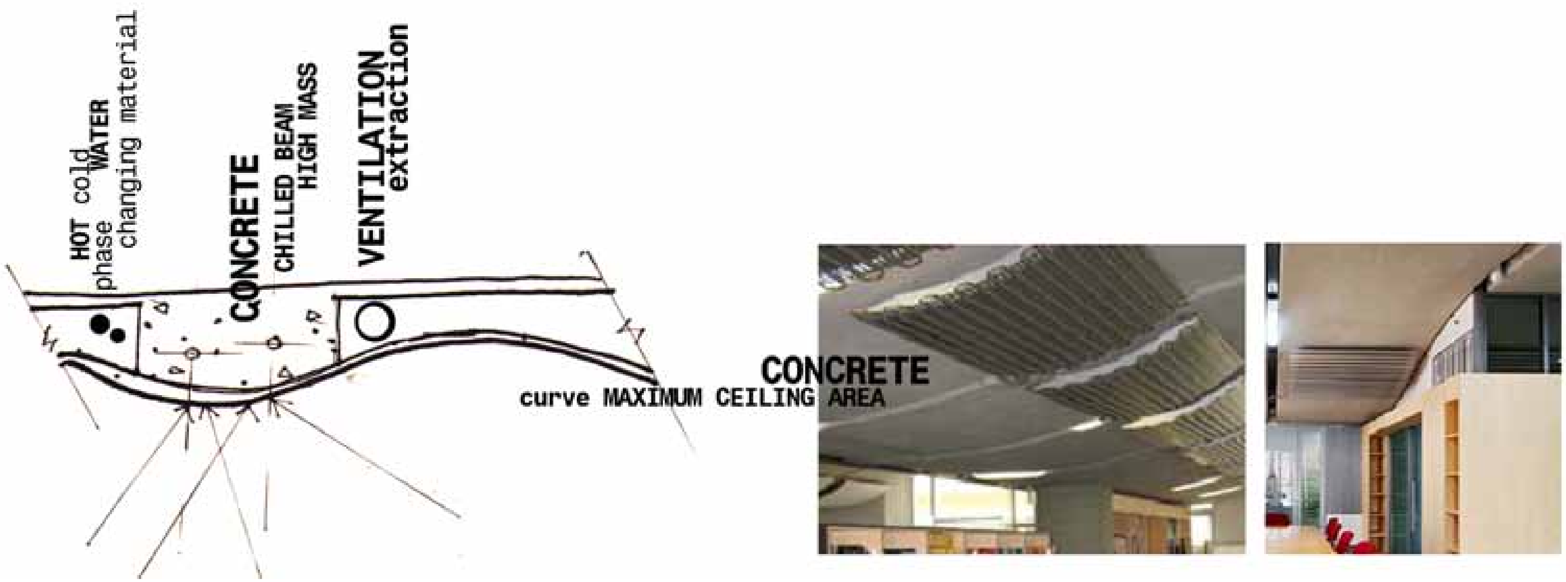


Figure 5-18: Ceiling detail
[Source: Author]

5.5 ORIENTE STATION

ID:	Multi modal transport inter change
Location:	Lisbon, Portugal
Architects:	Calatrava Valls – Santiago
Client:	City of Lisbon
Date:	1993-1999
Area:	-

Figure 5-19: Dense urban context of station [Source: Google Earth]

Context and aim
The context for the station is a very dense urban area. By piercing the existing embankment the architects aimed link two dislocated areas of the Olivias district. This area houses the working class and a light industrial area.

This station links different modes of transport:
- Long Distance trains
- Commuter Rails
- Metro Rail
- Cars
- Coaches

The station serves as a link between Lisbon, Portugal and Europe.

Plan form
The site layout is planned along integrating transport routes. The coach and vehicle platform were orientated perpendicular to the train routes. The station becomes a gateway into the Expo grounds by connecting the ground level to the two edges of the site.

Levels and integration & Movement
The station is a multi level station with different forms of transport integrated on many levels [Spier 1998:43]. These levels are visually connected, enhancing the experience of movement through the building. The architect uses escalators with the double and triple volumes above these movement spines. Moving through the building becomes a travelling experience in itself.

Al the transport systems are self contained in order to ensure that each transport systems works efficiently, while the interchange between these transport is possible [Abache 2001].

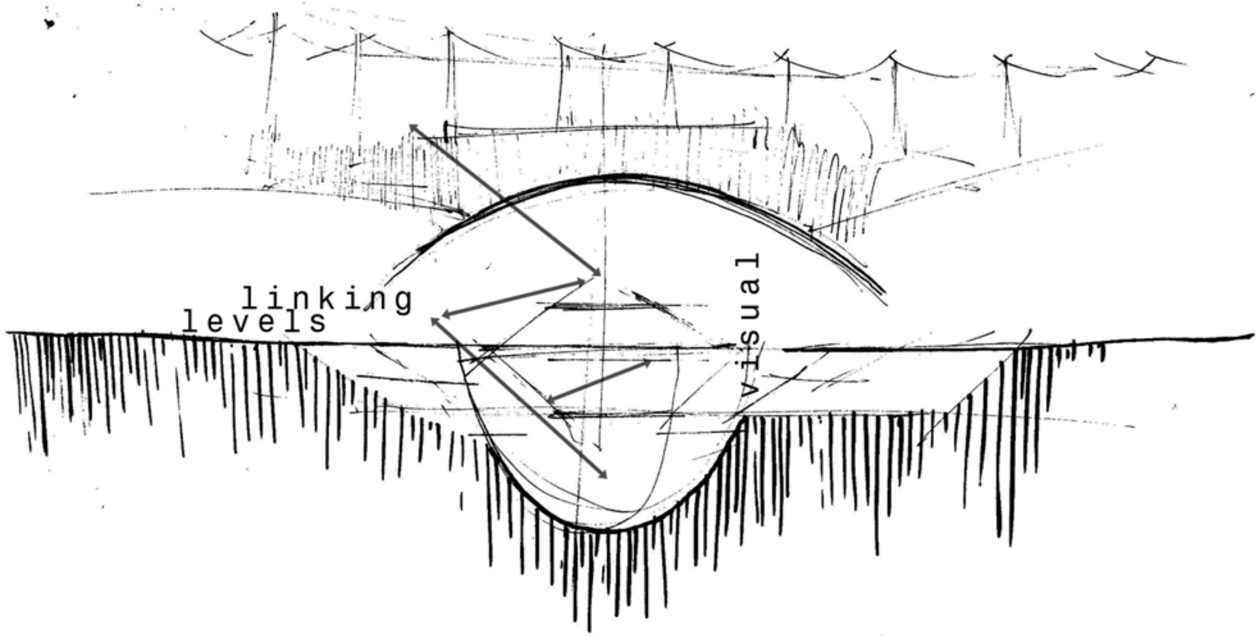


Figure 5-20: Movement between the levels of transport [Source: Author]

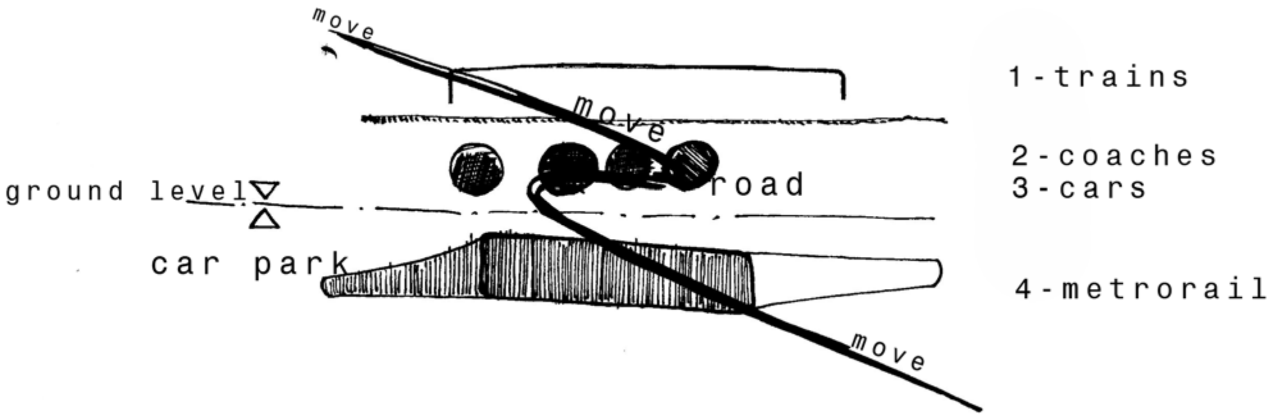


Figure 5-21: Conceptual section through the station building [Source: Author].

Material use

Roof canopy over the stations platforms [concourse] was designed according to a Gothic understanding of structure and light. The Gothic arches with the use of glass roofing and steel canopies give the potentially bulky roof a very light quality.

The sculptural use of concrete [floating bridges, lifts, bridge connections and elevators] gives the whole roof structure and main concourse a very light quality. In a way the lightness of the structures seems to disregard the load of the trains and transport systems.

The material use is concrete, steel and stonework paving.

Figure 5-22: Images of station structure and materiality [source: [www. images.travelpod.com]

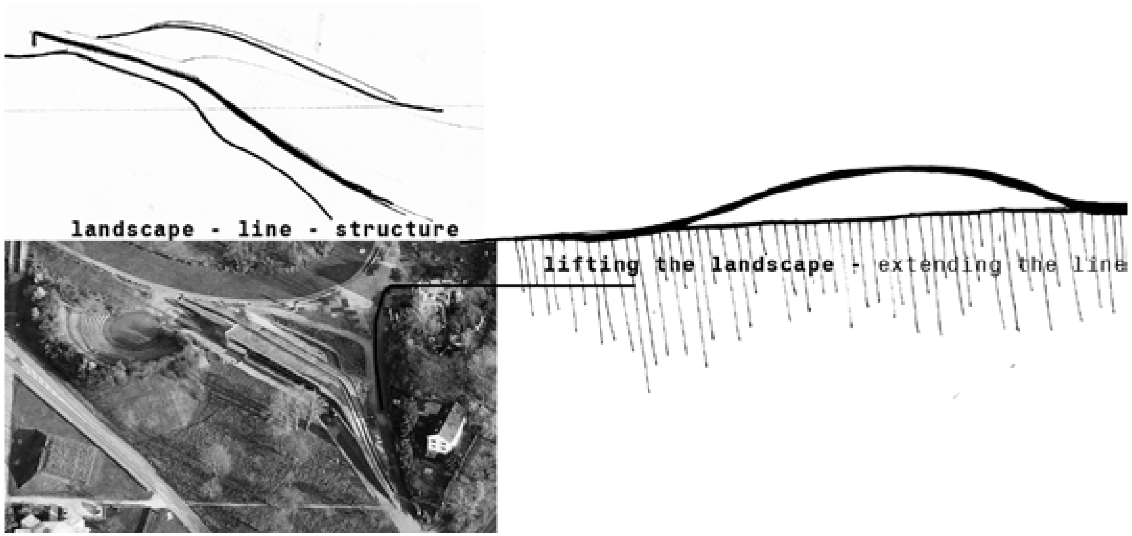


Figure 5-23: Intervention lifting the landscape and lining up with it [Source: Images from Architect's website, www.Zahahadid.com; drawing: Author]

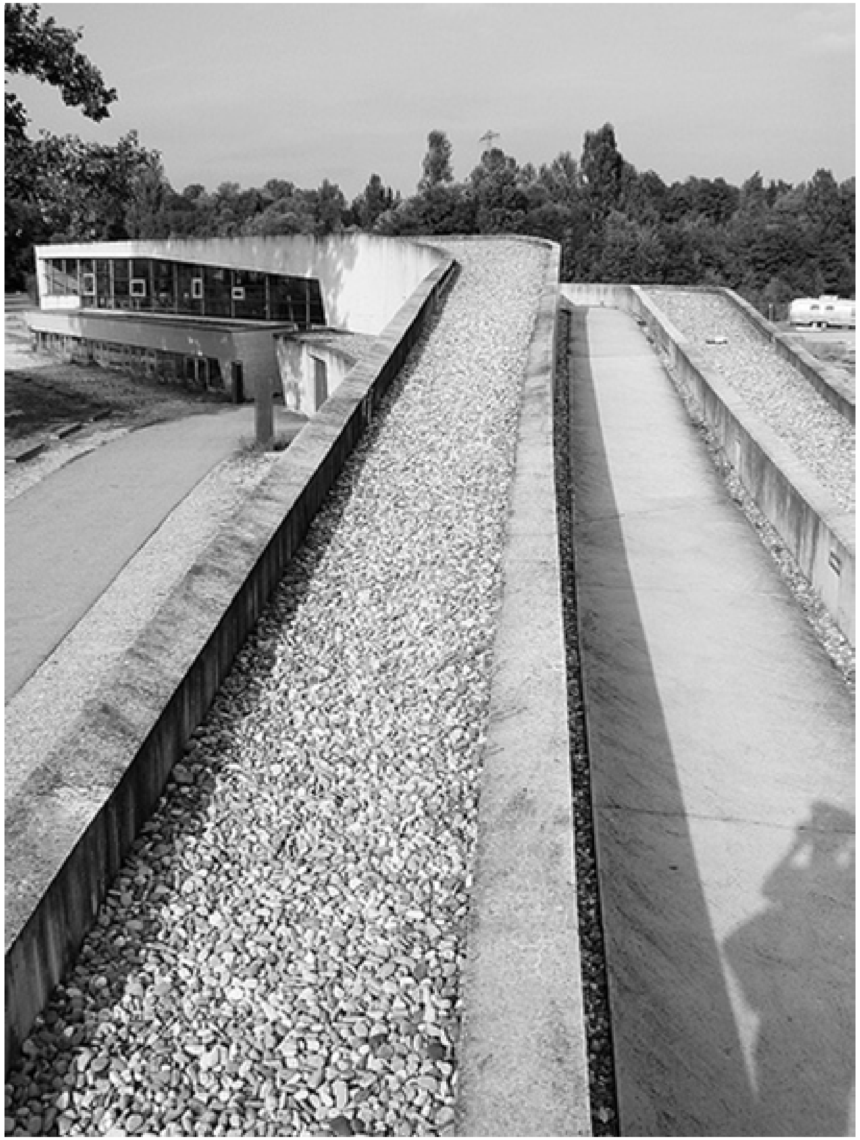


Figure 5-24: Image of Landscape Formation One , liniearality achieved through careful detailing of the wall and handrail [Source: Image from Architect's website, www.Zahahadid.com]

5.6. [A] LANDSCAPE FORMATION ONE.
[B] MAXXI: NATIONAL MUSEUM OF XXI CENTURY ARTS

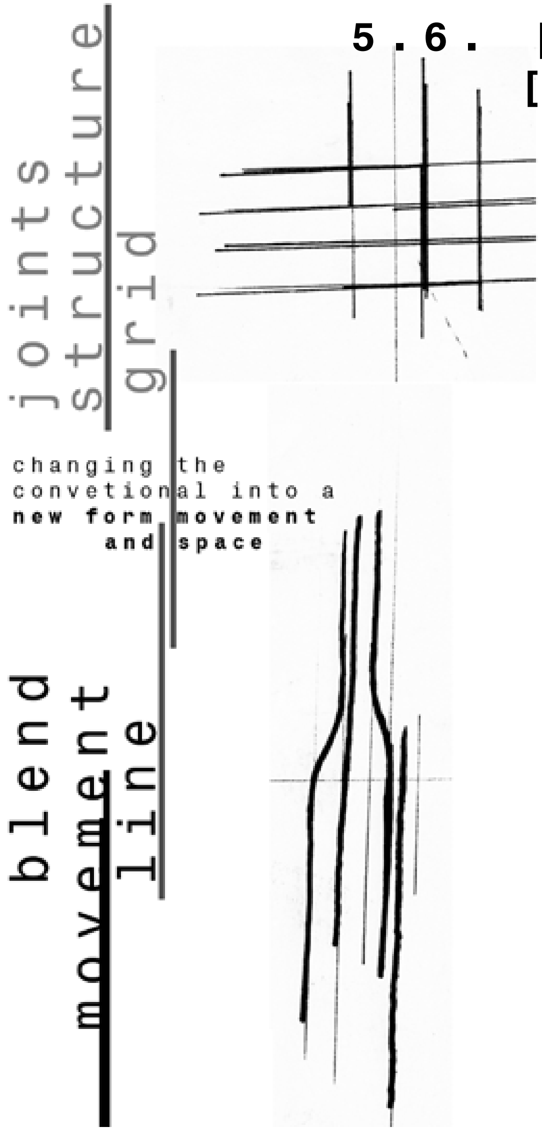


Figure 5-25: Adapting to movement through bending the lines [Sources Author]

ID:	[a] Landscape intervention	[b] Museum
Location:	[a] Weil am Rhein, Germany	[b] Rome, Italy
Architects:	Zahah Hadid architects	
Client:	[a] -	[b] Italian Ministry of Culture
Date:	[a] 1999	[b] 2008 [design 1997]
Area:	[a] m2	[b] 30 000 m2

Design
The design of these two projects both convey a form generation through line and change of movement on a planning level. Both these projects achieve a sense of fluidity in spatial definition.

Generation form
[a] Landscape formation number One.

Develops a main threshold and movement spine that crosses over the structure itself, without one actually entering the structure.

It is developed out of the landscape itself, following existing footpaths. The building itself becomes more of a landscape than conventional building itself.

The form itself speaks of movement and adaptability.

A series of linear elements from the structure.

[b] MAXXI: NATIONAL MUSEUM OF XXI CENTURY

The Museum is planned as a continuous line that wraps around the site and the existing architecture.

The main movement corridor, is generated of continues linear elements, that merge smoothly into the next element. In essence no corners are created and a continuation of space is achieved

The subtle change in the width of walkways/ corridors conveys the change in thresholds and space. The change in width starts to divide space more efficiently without creating a forced plan.

The building plan is reduced to only a few separate elements. Joints between these elements become very important to address. The joints become puncture points for windows or joints for doors and services.

A simplicity of form and space is achieved through the continuity of building elements

Figure 5-26: Interior perspective of MAXXI: Museum [Source: Architect's website www.zahahadid.com]

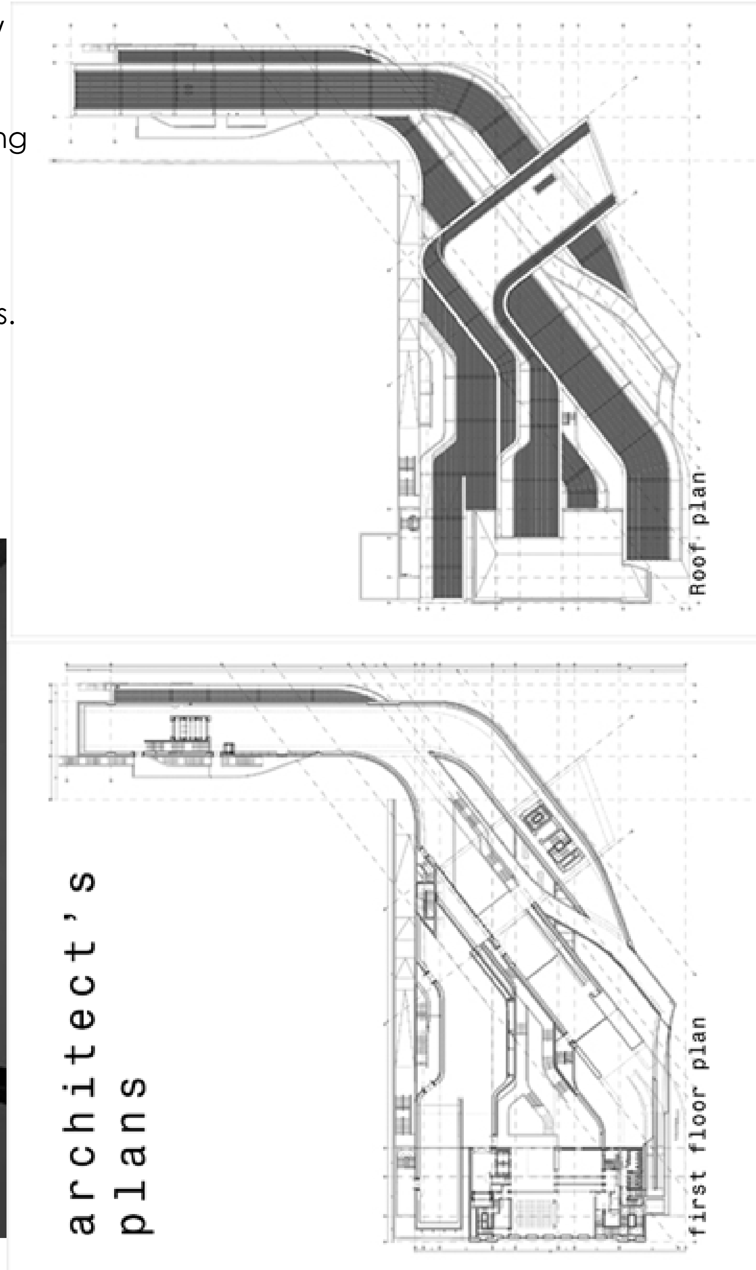


Figure 5-27: Plans of the MAXXI museum [Source: Architect's website www.zahahadid.com]

Structure, finish [fluidity]
In both examples the structure, wall material, lighting and floor patterns follow the line of movement and direction.

In many ways the wall is a simple vertical element, but fluidity is achieved, through the careful detailing of joints and manner by which shadow lines are created.

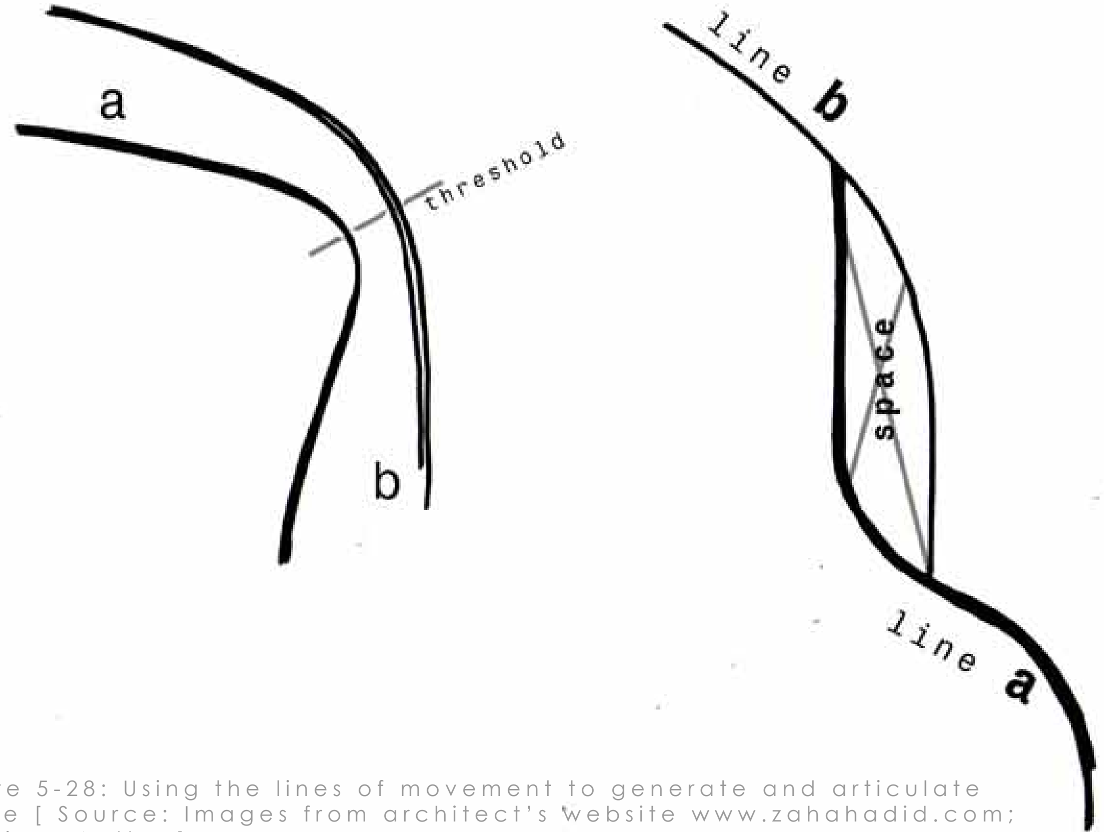


Figure 5-28: Using the lines of movement to generate and articulate space [Source: Images from architect's website www.zahahadid.com; drawing: Author]

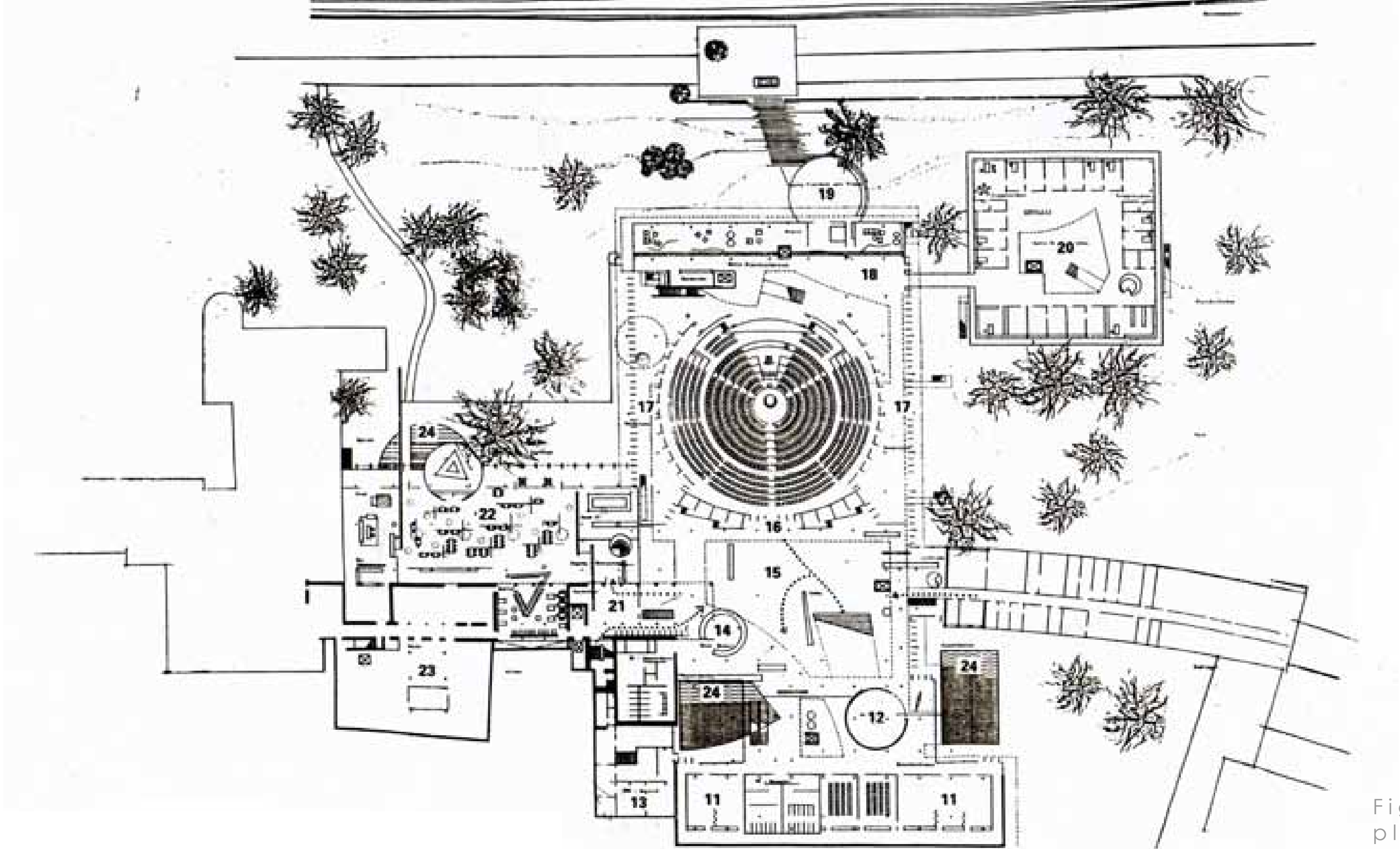


Figure 5-29: Groundfloor plan [Source: Architectural Review 1993, p 27]

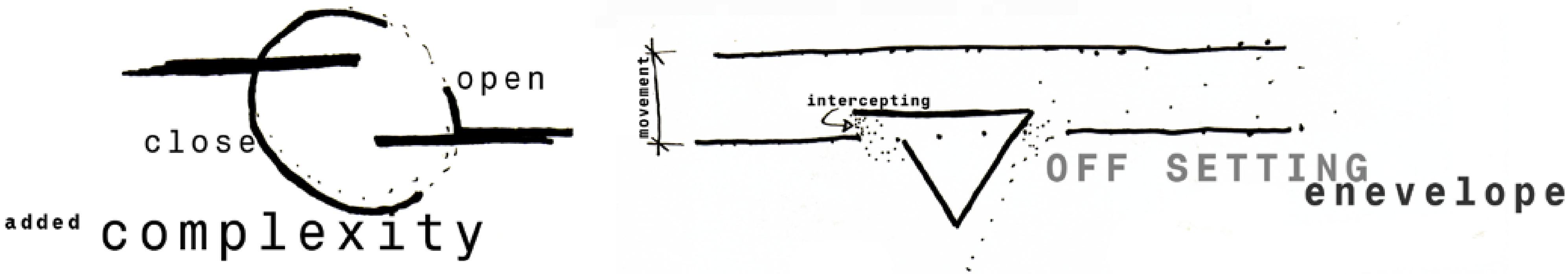


Figure 5-30: Forms adding complexity to the space and movement [Source: Author]

5.7 NEW PARLIAMENT BUILDING

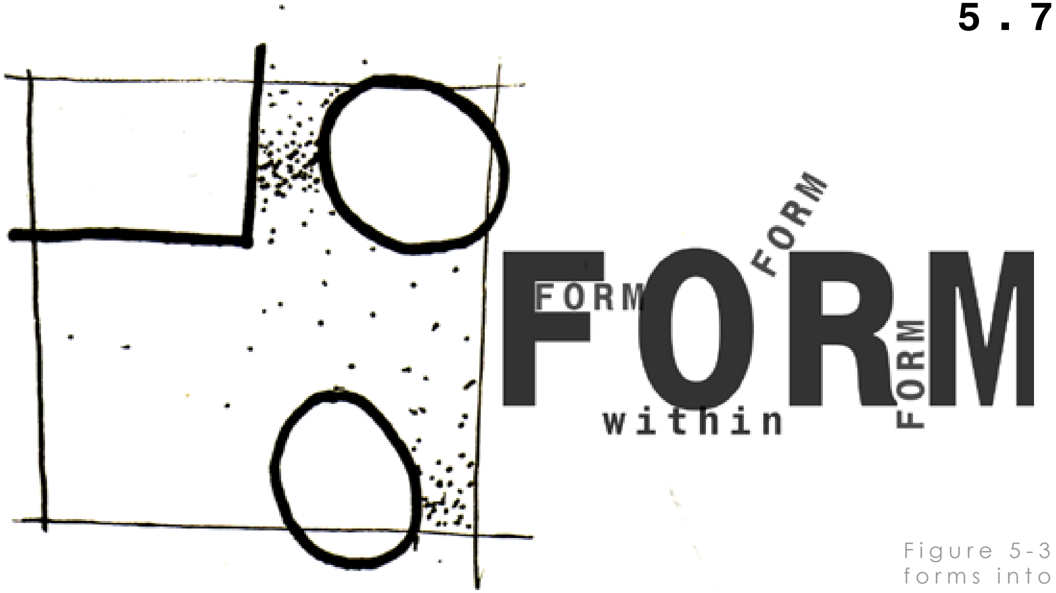


Figure 5-31: Placing forms into space [Source: Author]

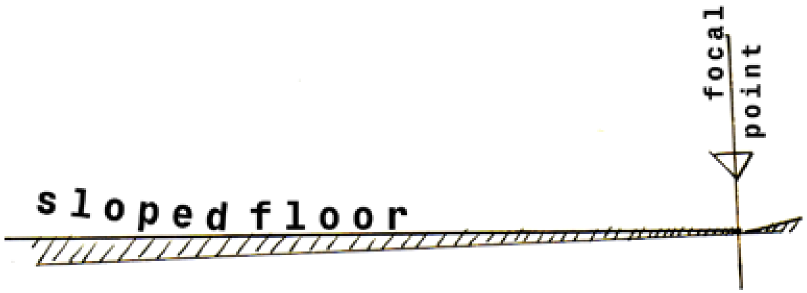


Figure 5-32: Sloping to groundplane to movement and focus [Source: Author]

ID: Civic building

Location: Bonn, Germany
Architects: Behnisch Architekten

Client: German government

Date: 1992
Area: -

Design and movement
The Architect makes use of objects placed into space to manipulate movement. The slope of the floor and roof membrane inform the focal points within the space.

Use of geometric form with in a contained space starts to convey and manipulate movement. While entrance into spaces are articulated with the offset of geometric shapes within spaces.

The subtle opening and closing of the geometric shapes start to articulate the space and reading of intended movement.

_ 6

PROJECT INTENSION & CONCEPT

"Design can be defined...as the hinge that connects culture and nature through the exchanges of materials, flow of energy and...land use"

[Guy 2002:228]

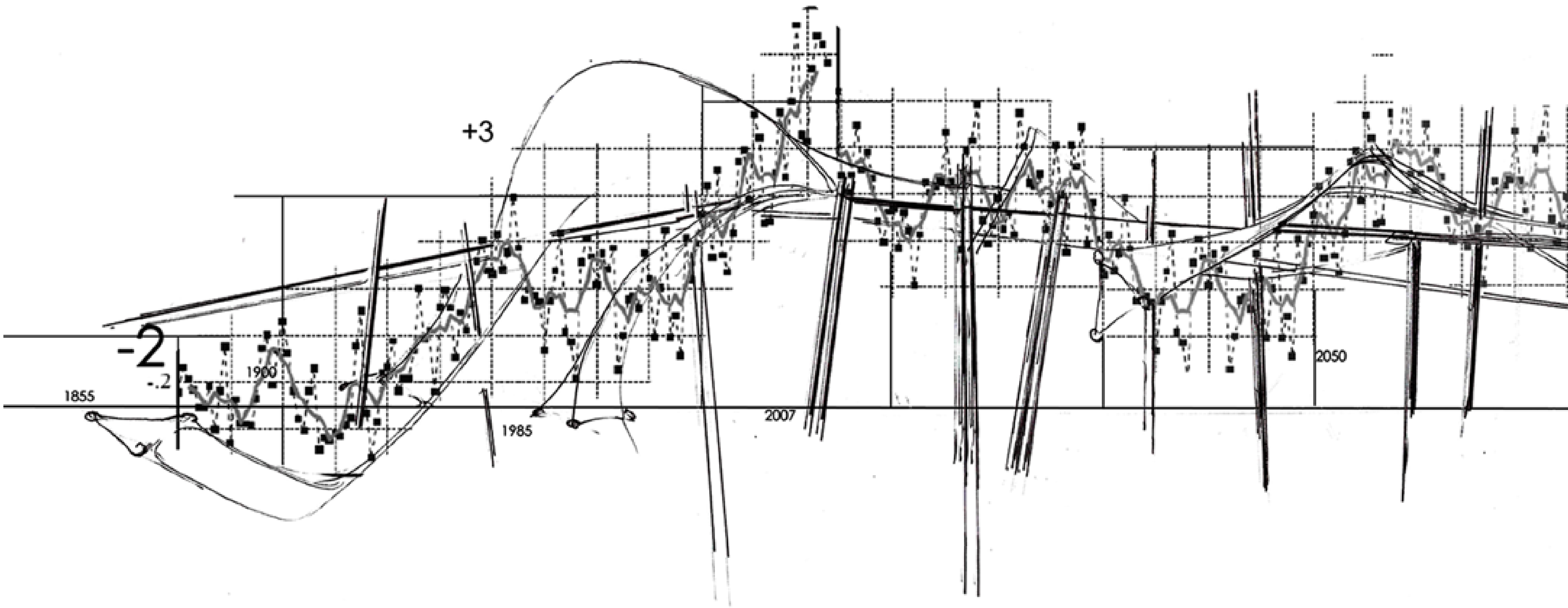


Figure 6-01: Initial intension drawing: movement, carbon and connecting to the site [Source: Author]

6.1 DEFINING THE PROJECT AND SITE

6.1.1 Project intention

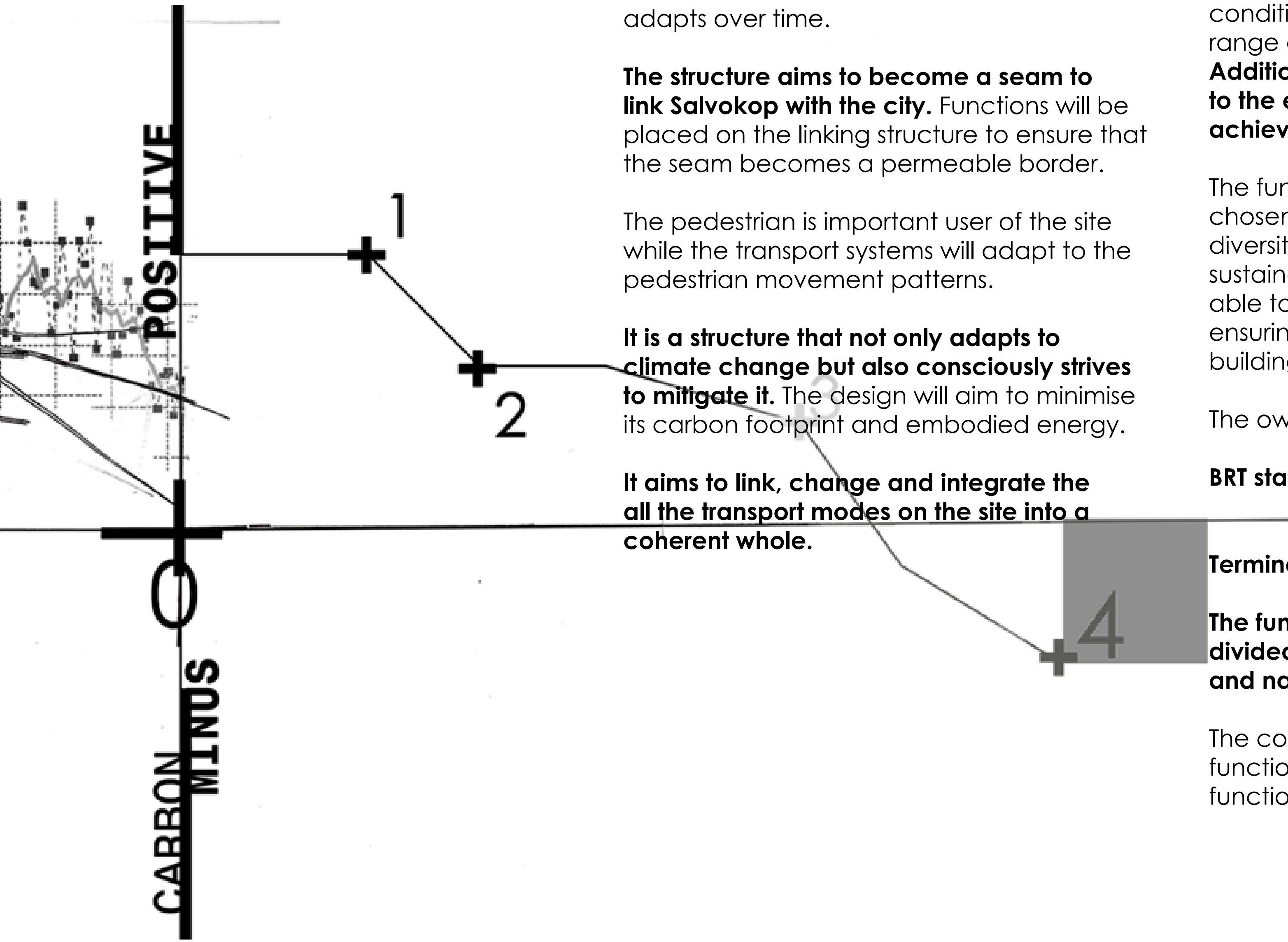
The intension is to design an intervention that responds to the historical context, deals with current cultural and social context and adapts over time.

The structure aims to become a seam to link Salvokop with the city. Functions will be placed on the linking structure to ensure that the seam becomes a permeable border.

The pedestrian is important user of the site while the transport systems will adapt to the pedestrian movement patterns.

It is a structure that not only adapts to climate change but also consciously strives to mitigate it. The design will aim to minimise its carbon footprint and embodied energy.

It aims to link, change and integrate the all the transport modes on the site into a coherent whole.



6.1.2 Accommodation and function

The design of a BRT terminal building aims to integrate all the different transport modes. It strives to upgrade the current physical and social condition of the station to ensure that a wider range of users make use of public transport. **Additional functions and programs will be added to the existing to ensure a 24 hour lifecycle is achieved on site.**

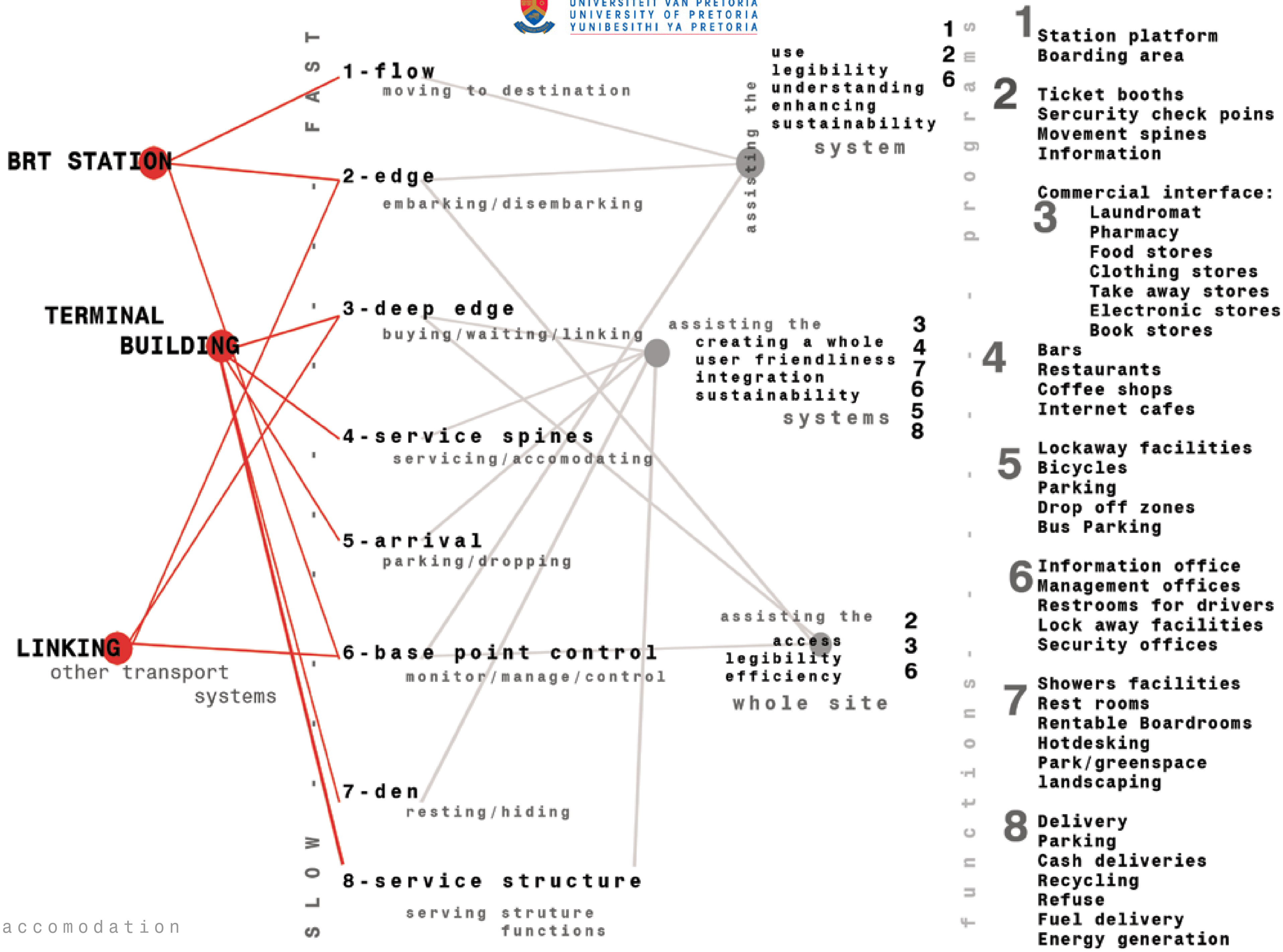
The functions for the intervention will be chosen to complement each other, providing diversity and achieving social and economical sustainability. The structure will also need to be able to adapt to changing functions and users ensuring a long productive lifecycle for the building.

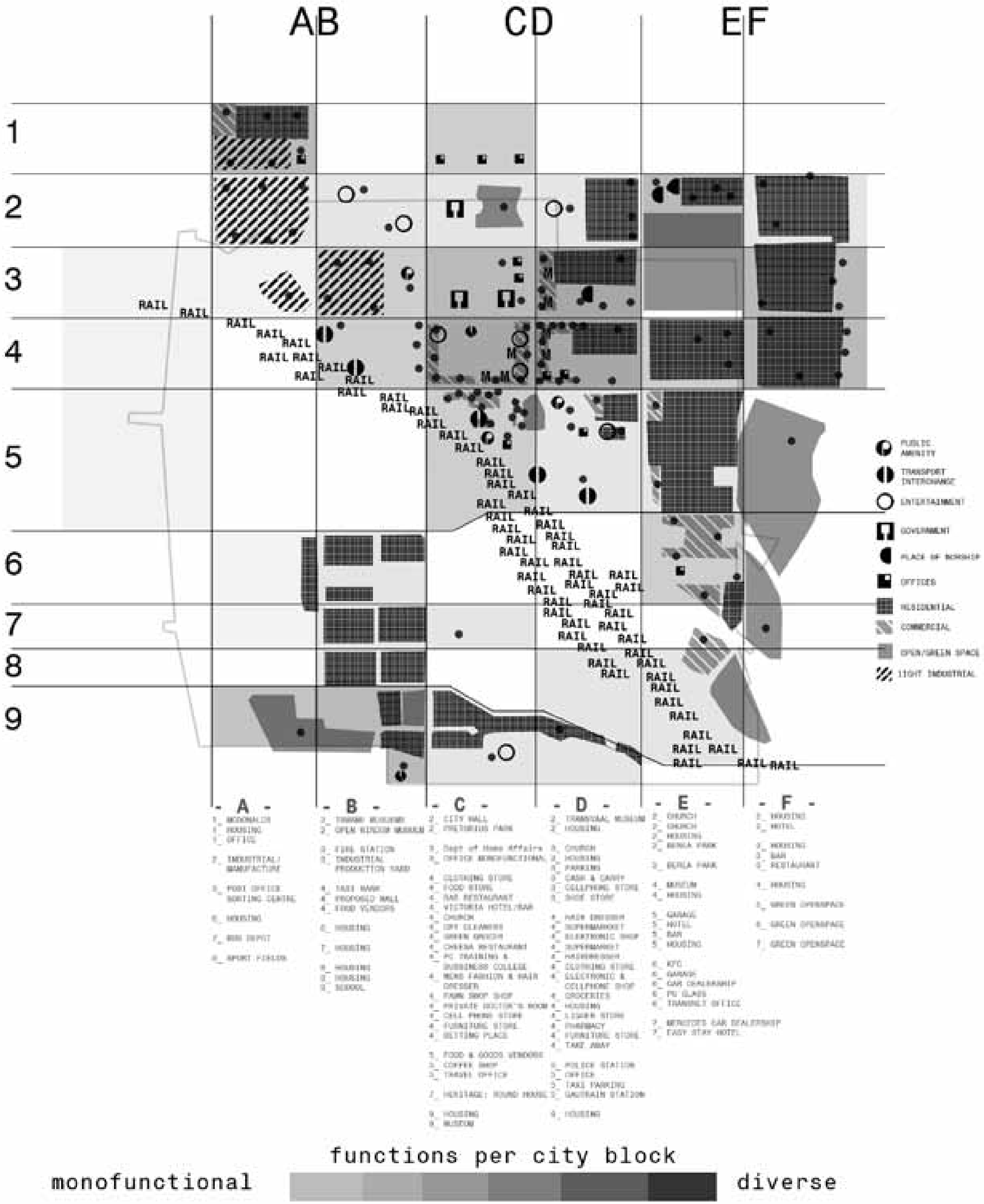
The owners or client for the project are:

BRT stations - City of Tshwane Department of Public works and Infrastructure [Transport Devision]
Terminal Building - Transnet, Intersite.

The functions proposed for the structures were divided into core groups referring to the speed and nature of the needed functions.

The concept will be developed around these functional zones. The structure will adapt to these functions.


BRT STATION
TERMINAL BUILDING
LINKING
other transport systems
F A S T
S L O W
1-flow
moving to destination
2-edge
embarking/disembarking
3-deep edge
buying/waiting/linking
4-service spines
servicing/accomodating
5-arrival
parking/dropping
6-base point control
monitor/manage/control
7-den
resting/hiding
8-service structure
serving struture functions
assisting the
use
legibility
understanding
enhancing
sustainability
system
1
2
6
assisting the
creating a whole
user friendliness
integration
sustainability
systems
3
4
7
6
5
8
assisting the
access
legibility
efficiency
whole site
2
3
6
programs - functions
1 Station platform
Boarding area
2 Ticket booths
Sercurity check poins
Movement spines
Information
3 Commercial interface:
Laundromat
Pharmacy
Food stores
Clothing stores
Take away stores
Electronic stores
Book stores
4 Bars
Restaurants
Coffee shops
Internet cafes
5 Lockaway facilities
Bicycles
Parking
Drop off zones
Bus Parking
6 Information office
Management offices
Restrooms for drivers
Lock away facilities
Security offices
7 Showers facilities
Rest rooms
Rentable Boardrooms
Hotdesking
Park/greenspace
landscaping
8 Delivery
Parking
Cash deliveries
Recycling
Refuse
Fuel delivery
Energy generation



6.1.3 Mapping the site

In order to place and develop the intervention on site, the site has been analysed and mapped in terms of

- **Functions & Diversity**
- **Points of importance & Views**
- **Movement, Edges & Safety**
- **Vegetation and Micro Climate**

Figure 6-02: [Previous Page] Linking programme speed and articulation [Source: Author]
Figure 6-03: Functional types and diversity of the precinct [Source: Author]

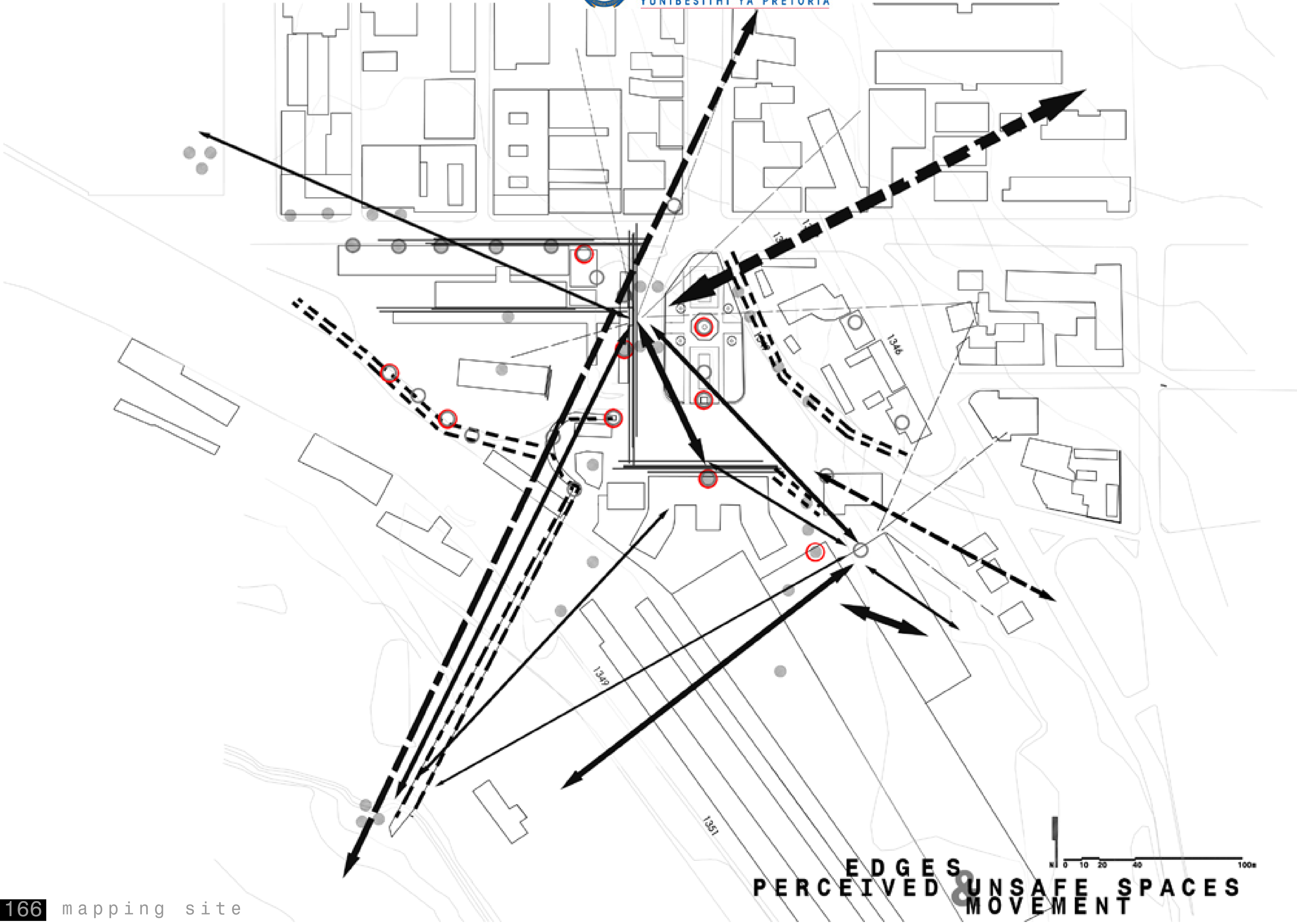


Figure 6-04: Mapping edges, movement and perceived safety [Source: Author]

Figure 6-05: Mapping views and important current and historic points [Source: Author]

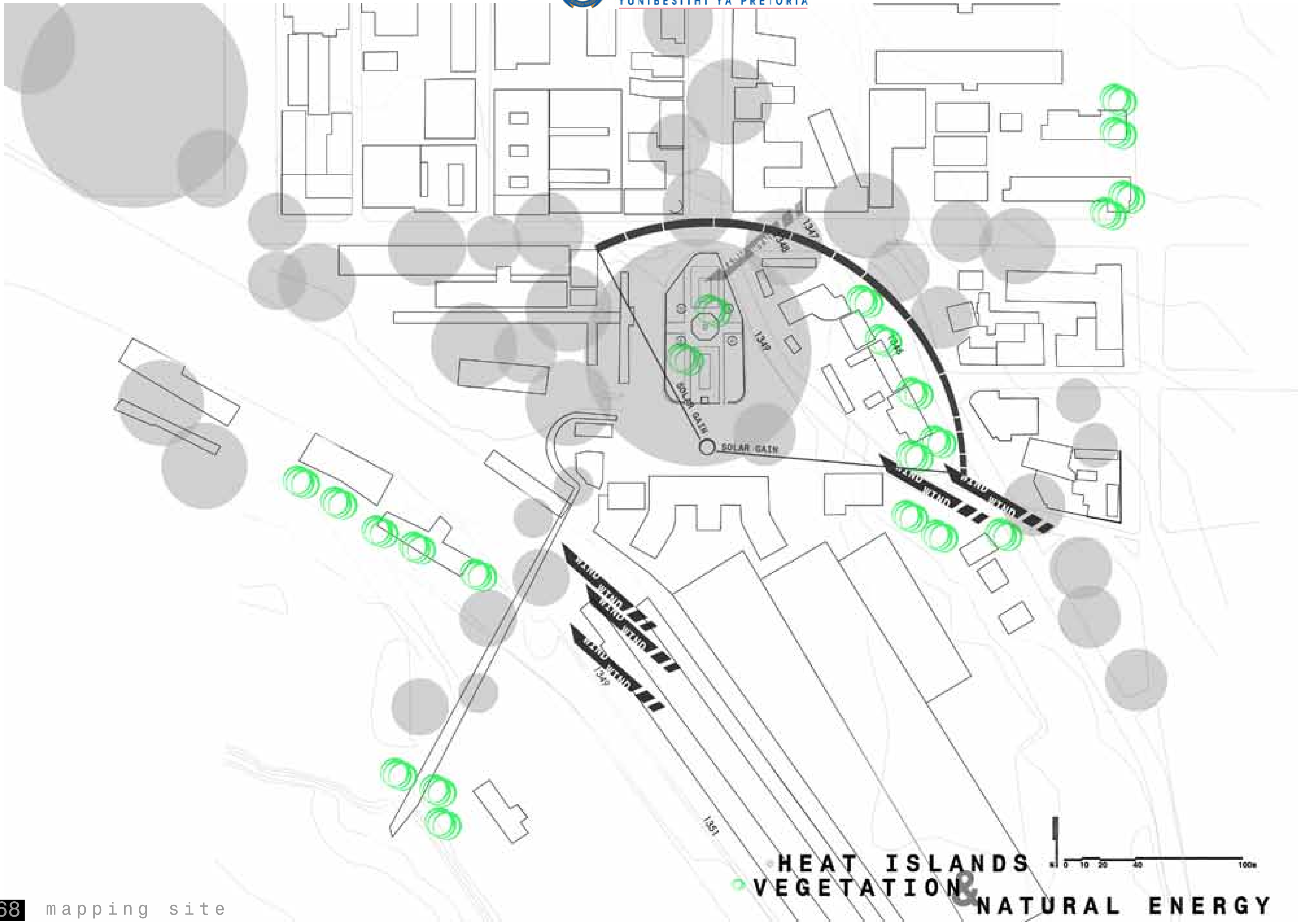


Figure 6-06: Mapping Vegetation, Heat islands and Natural Energy [Source: Author].

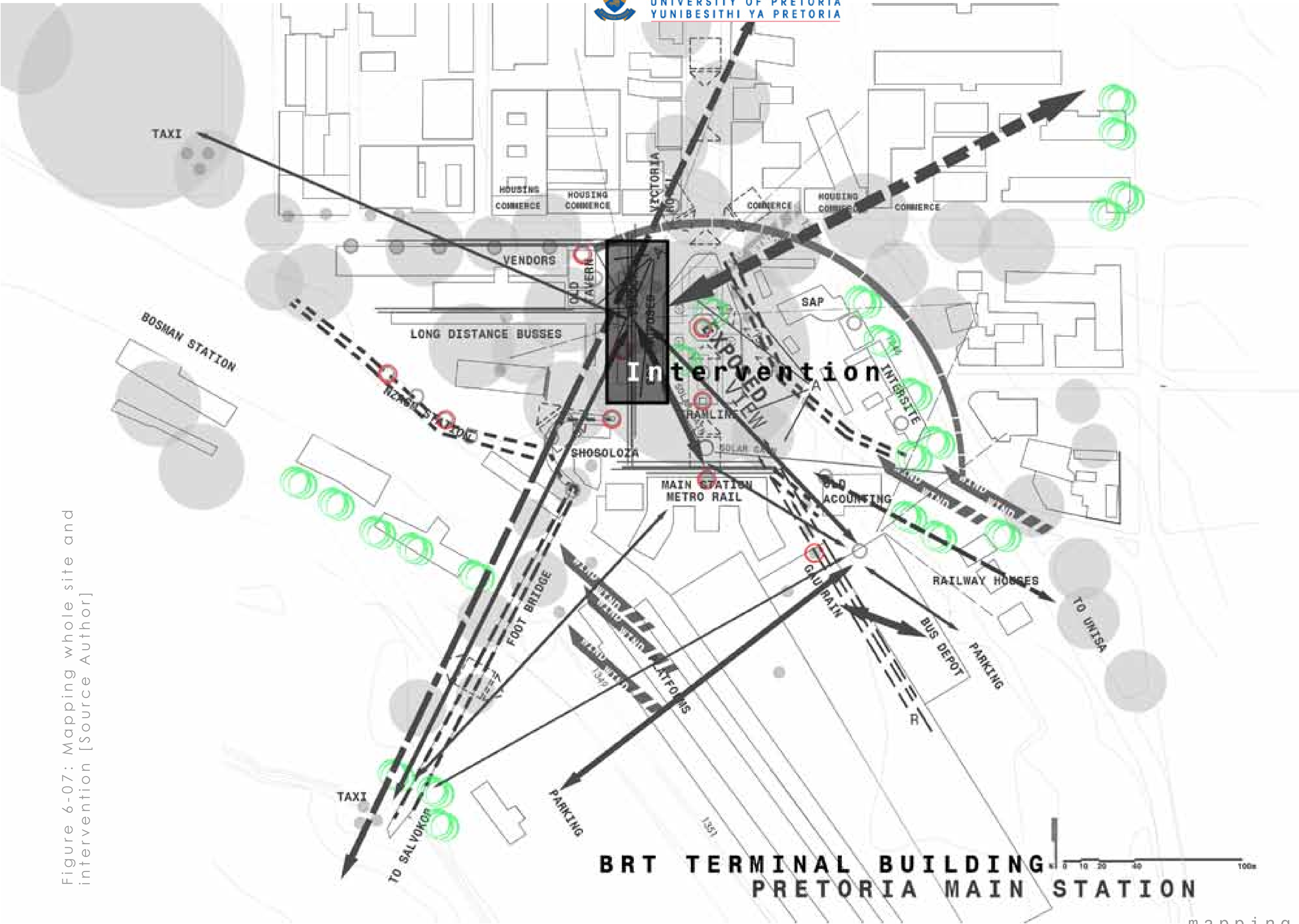
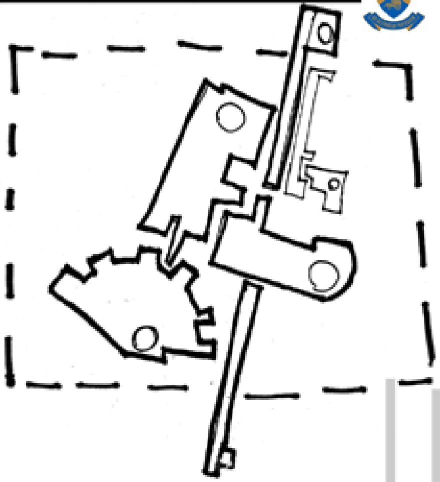


Figure 6-07: Mapping whole site and intervention [Source Author]

INFORMANTS

a- Framework
b- Hisotical + cultural
c- Programatic
d- Energy efficient
e- Low carbon

1 ecosystemic



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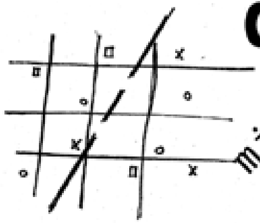
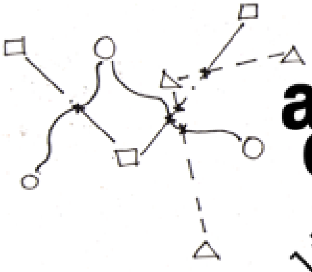
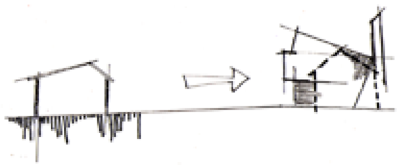


d mixing functions

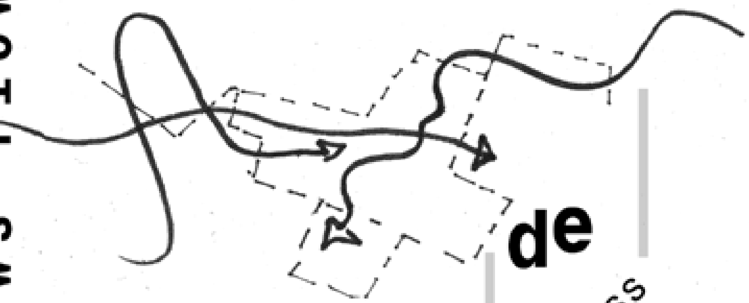


a c linking transport modes



b d adding function

2 form follows flow



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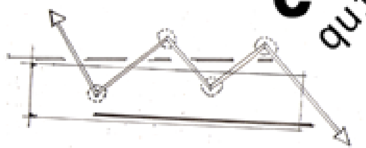

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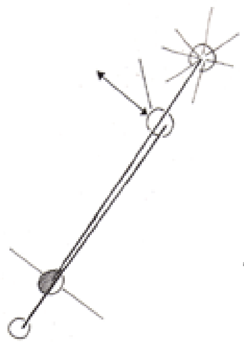


a b c linking

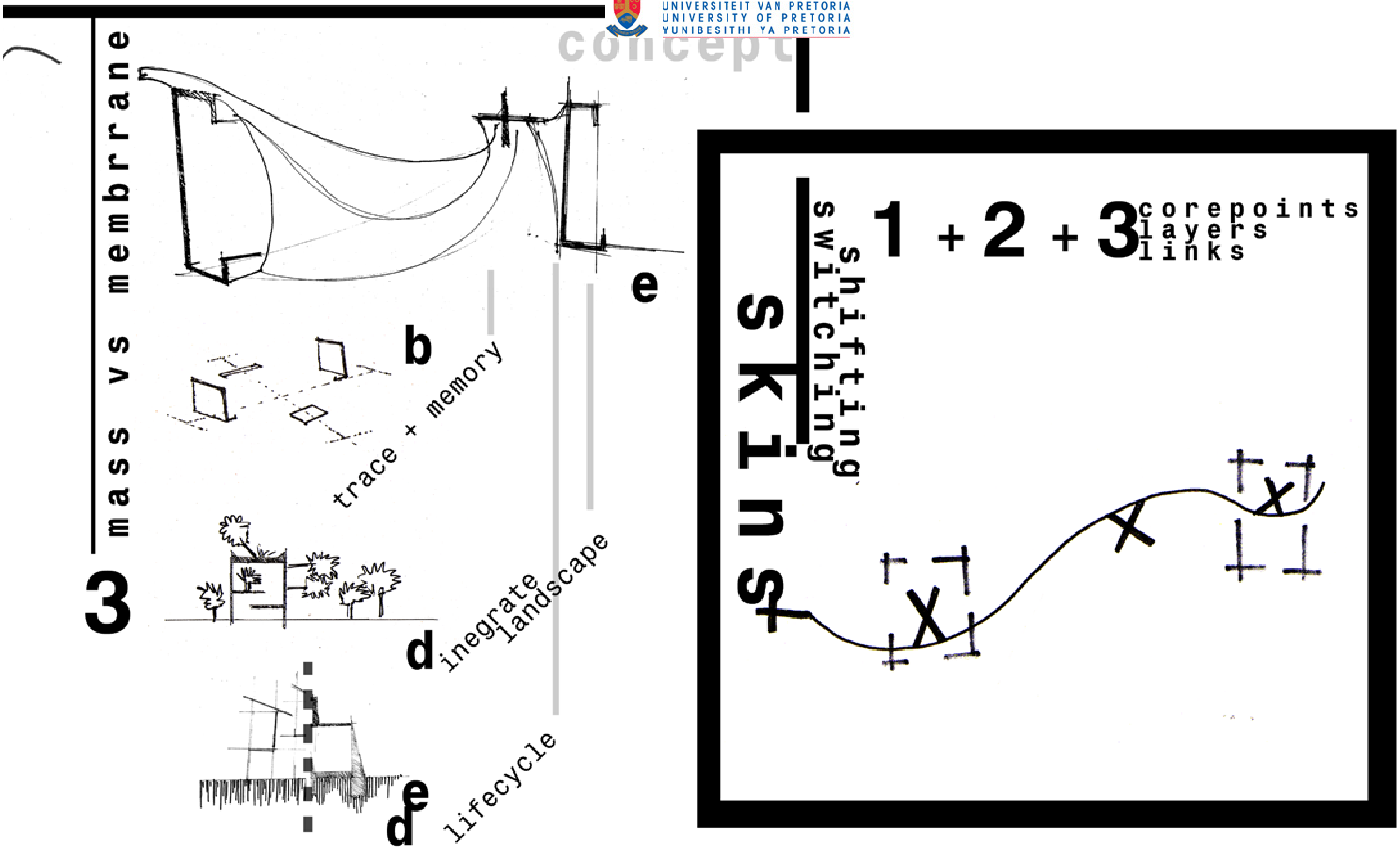


Figure 6-08: Informing the concept and design
[Source: Author]

6.2 INFORMANTS AND CONCEPT

As depicted in Figure 6-08 a range of informants were used to develop a concept. These were combined into three overarching informants:

Form follows flow

_ Accommodating movement of site, people, natural energies.
[MOVEMENT]
_ As framework proposes linking Salvokop to accommodate flow.
[LINKAGE]
_ Historical components are adapted to the flow of the site.
_ Linking the old and new, structure and landscape.

Ecosystemic whole

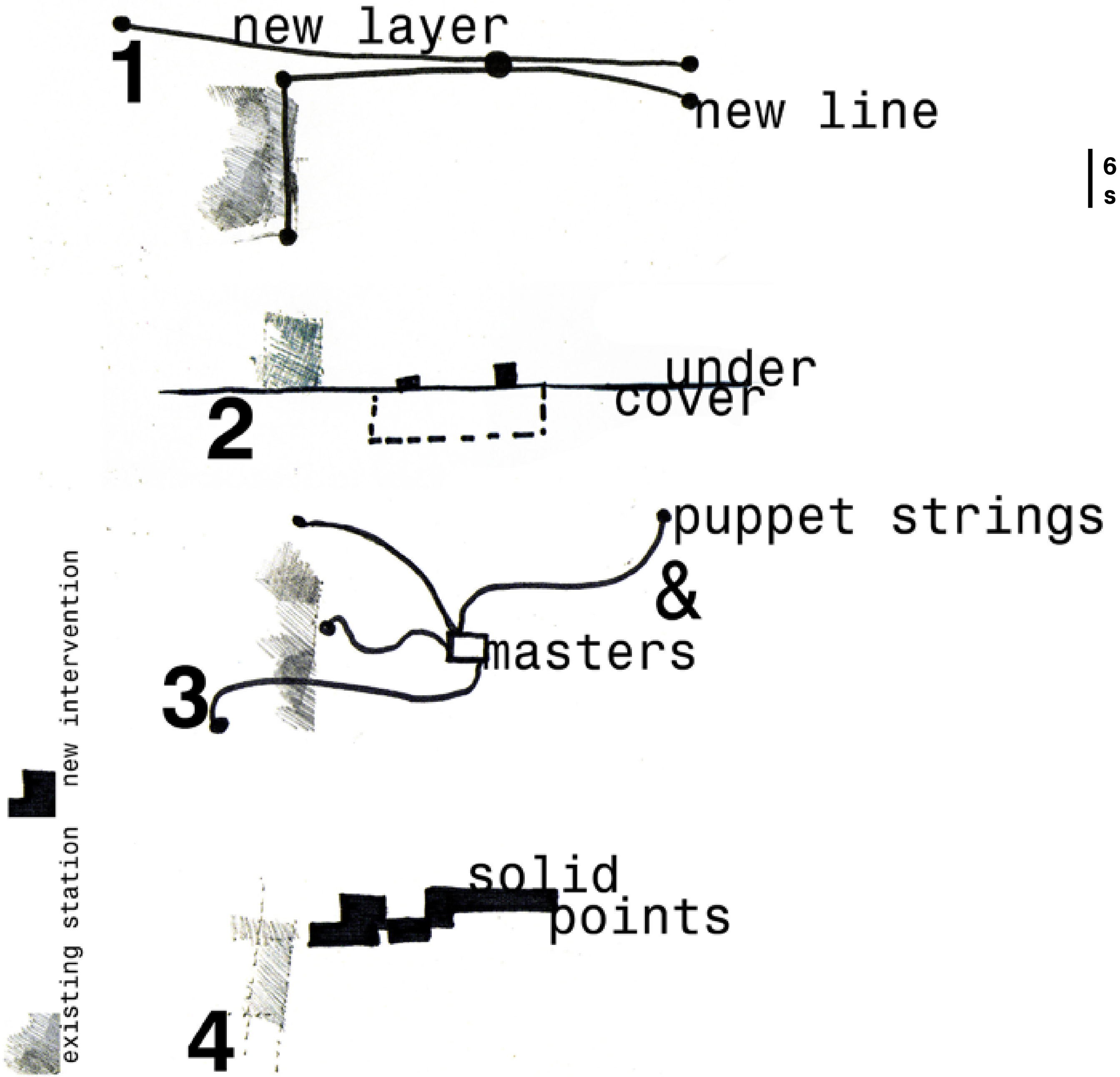
_ Add or removing – understanding the whole to achieve diversity .
_ Adding new function with the old functions.
[Diversity leads to an adaptable & sustainable whole]
_ As the framework proposes – placing function on the border ensures movement and diversity across the border.
_ Mixing functions on site – ensuring sustainability.

Mass vs Membrane

_ Layering landscape and structure.
_ Layering structure and component
_ The layering of life cycles, weight, function and movement.
_ Layering adaptable and fixed components.
_ Layering the old with new sensitive membrane that covers existing.
_ Old landscape is covered by new landscape

Out of this an adaptable, robust and sensitive structure will be developed.

Figure 6-09: [Opposite page] Series of conceptual approaches developed and tested. [Source: Author]



6.2.1 Testing series of concepts.

Four conceptual approached were tested and adapted to the site.

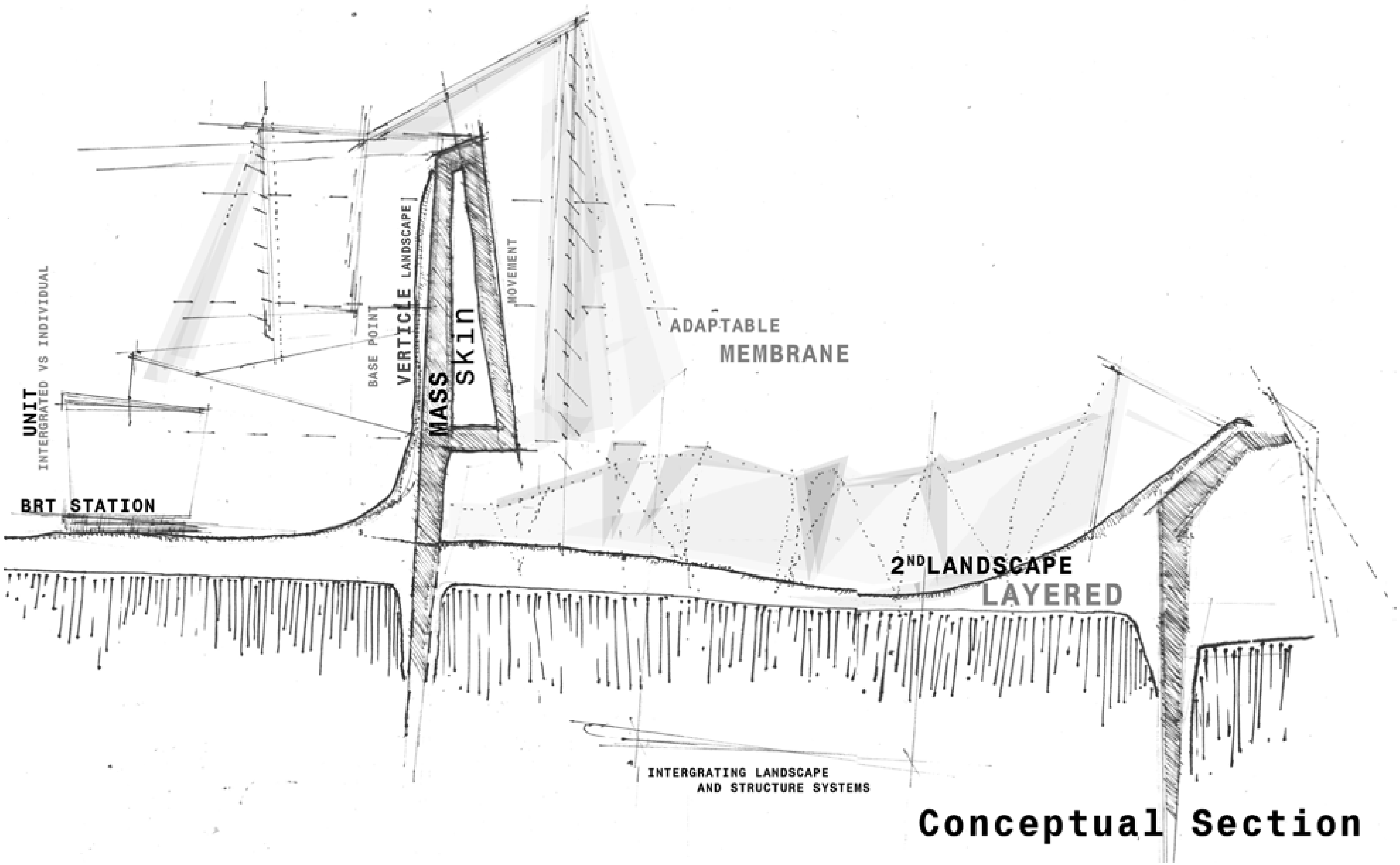
Concept 1: An extensive integrating structure and landscape layer was explored, yet it was deemed to too big and elaborate to layer the whole site.

Concept 2: Placing station underground and removing pedestrians from ground level was established as too expensive and energy intensive. It will also remove needed people movement and energy from urban realm.

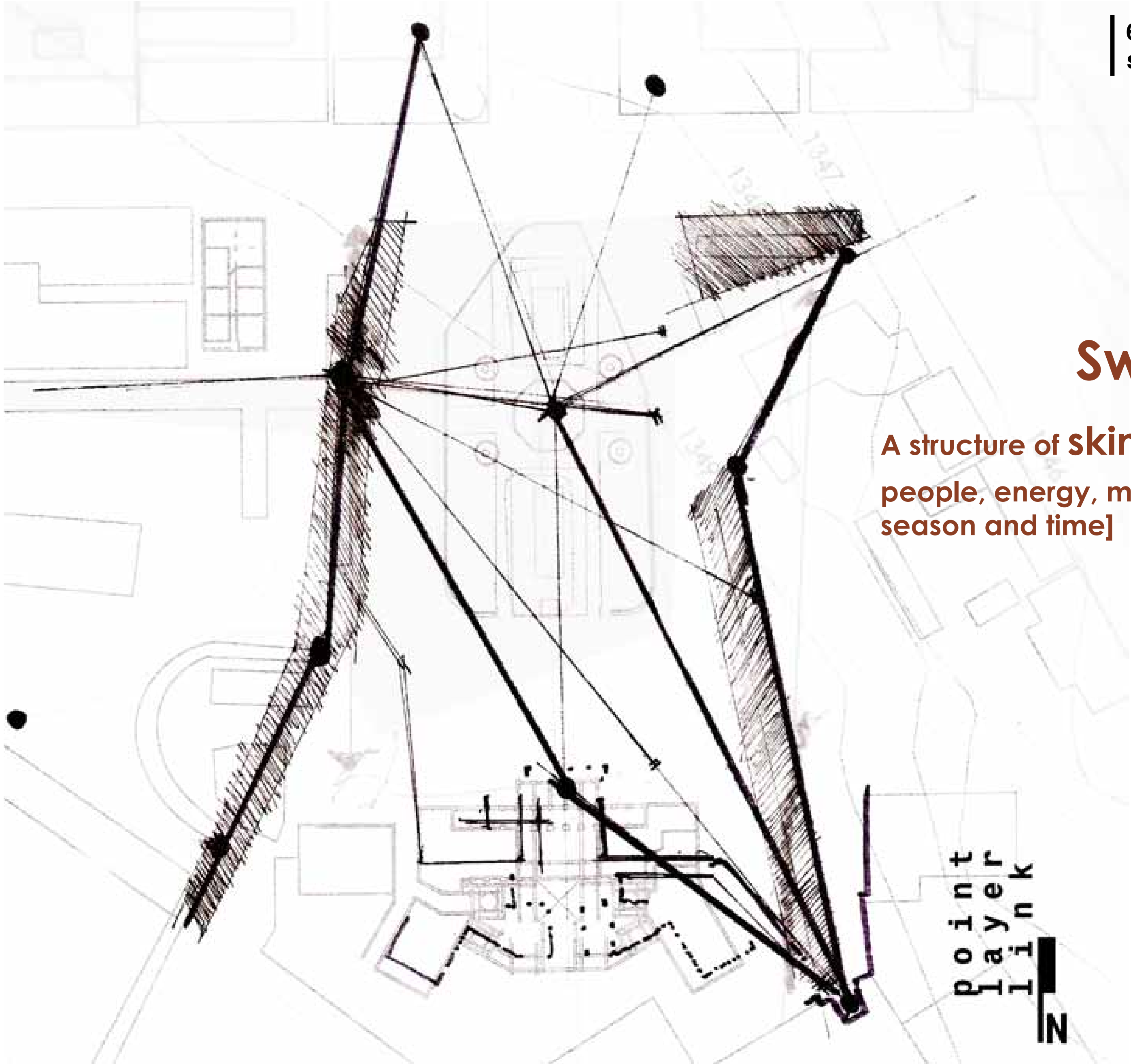
Concept 3: The approach of placing structures on axis will be too imposing on heritage yet linking all the transport systems with an through an adaptable method can be exploited and used.

Concept 4: A more compact approach will be more sustainable and efficient, yet do not integrate the whole site and all transport systems.

From these four conceptual approaches a final integrative concept was developed.



Conceptual Section



6.2.2. Conceptual statement

The concept is developed around **solid points**, **the link** and **the layering of all**. It integrated the initial concepts one, three and four into a whole.

Switching/shifting skins.

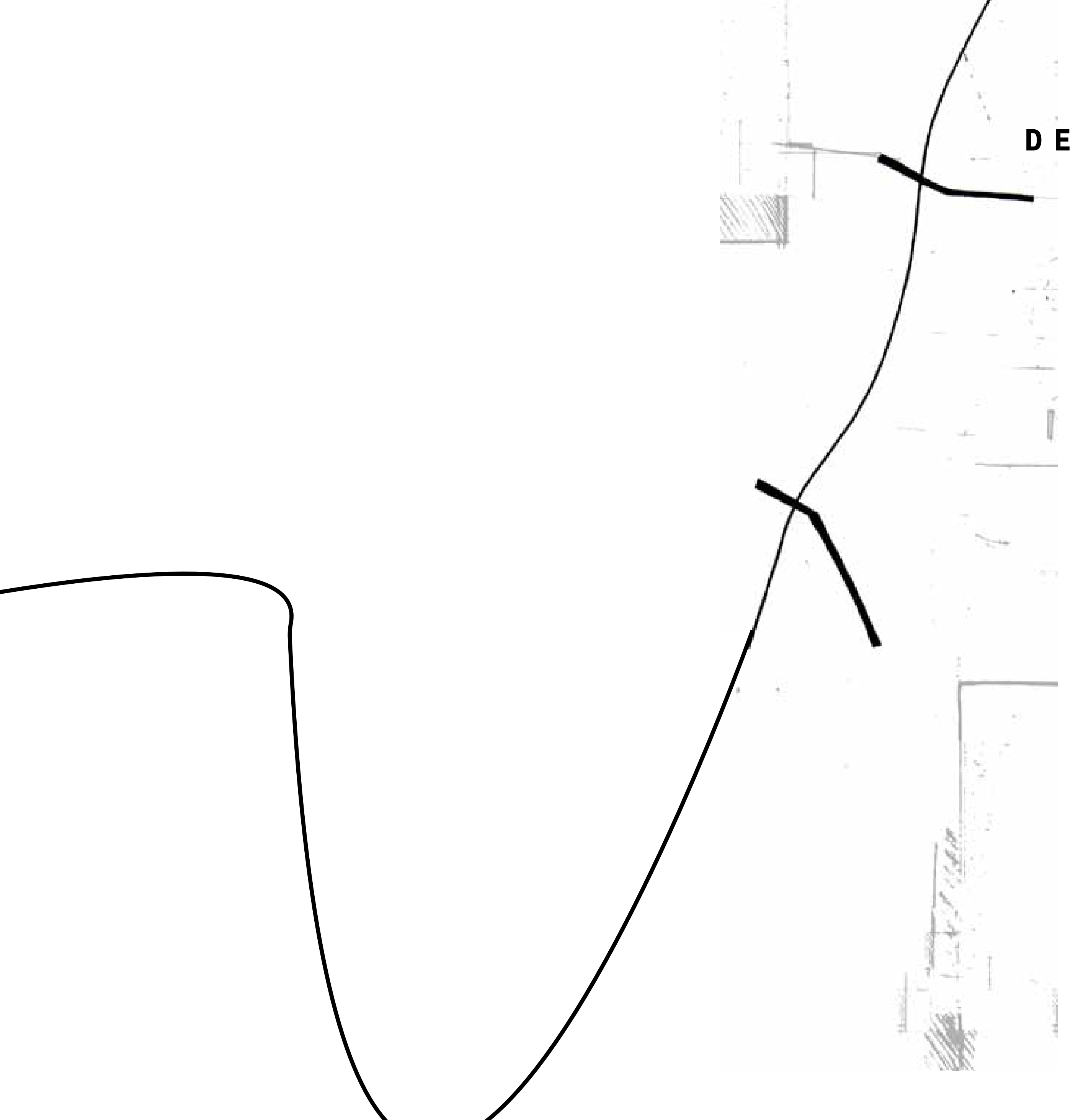
A structure of skins [layers] that links [the flow of site, people, energy, movement] and adapts [to change, season and time]

Figure 6-10: [Previous Page] Conceptual section [Source: Author]

Figure 6-11: Conceptual plan and intervention [Source: Author]

6

DESIGN DEVELOPMENT



The design of a BRT terminal building integrated the low carbon construction theories with an architectural response to the expected climate change in the urban environment.

The design also exploited the opportunity of linking with the Salvokop precinct by developing a functioning bridge structure.

The first step was to accommodate the new BRT transport system. This had a significant influence on the building's orientation and placement. This was done from the principle that in order for a public transport system to work,the transfer between the different systems must be as efficient as possible [Alexander 1977:92;183].

Once a good quality mass transport system works, more pedestrian orientated areas will develop around the stations and corridors [Newman & Jennings 2008:133]. This will lead to large amounts of greenhouse gasses being saved.

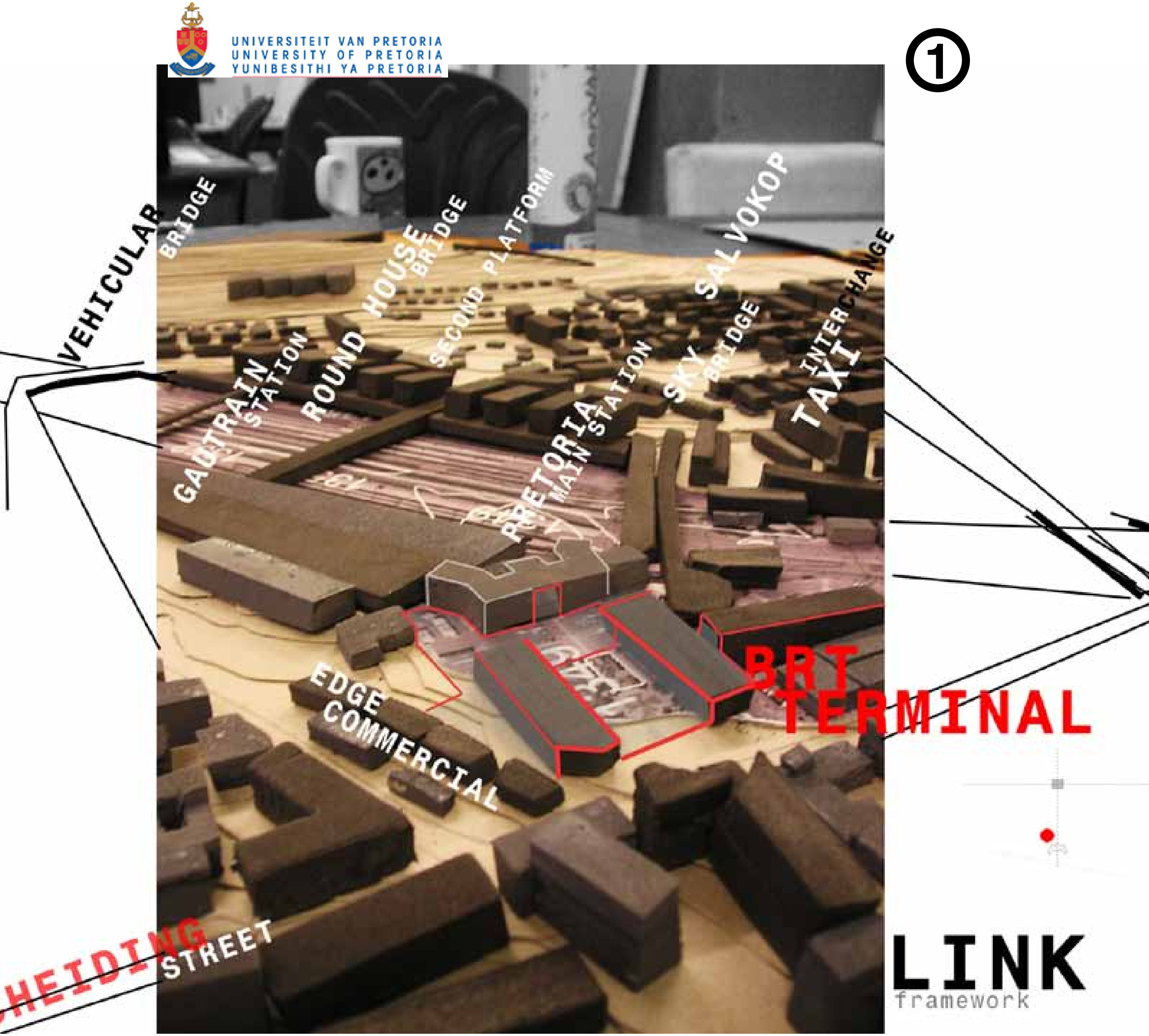
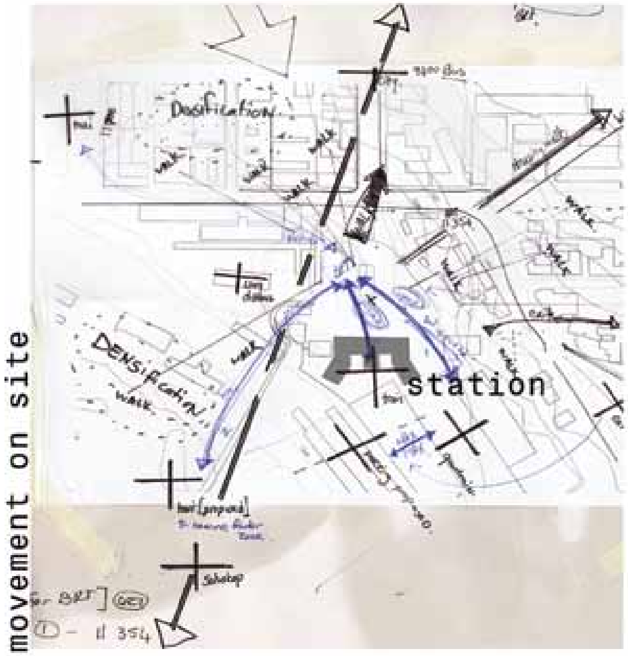
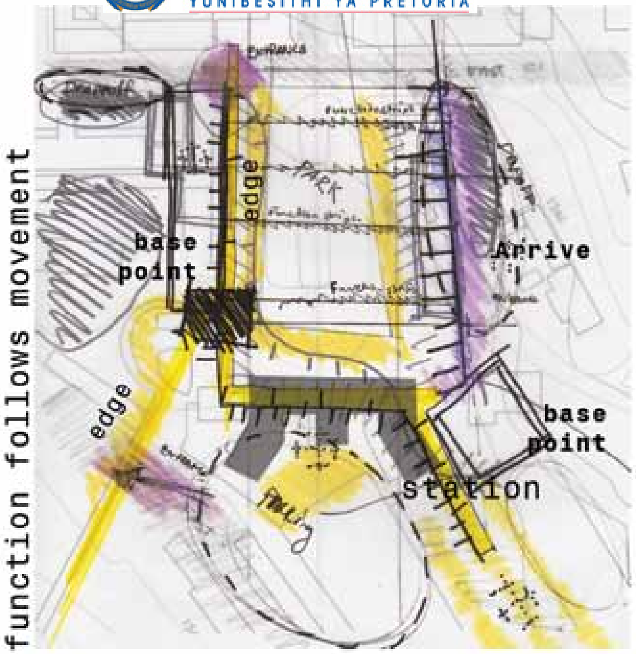


Figure 7-01: Design development 1: Framework [Source: Author]





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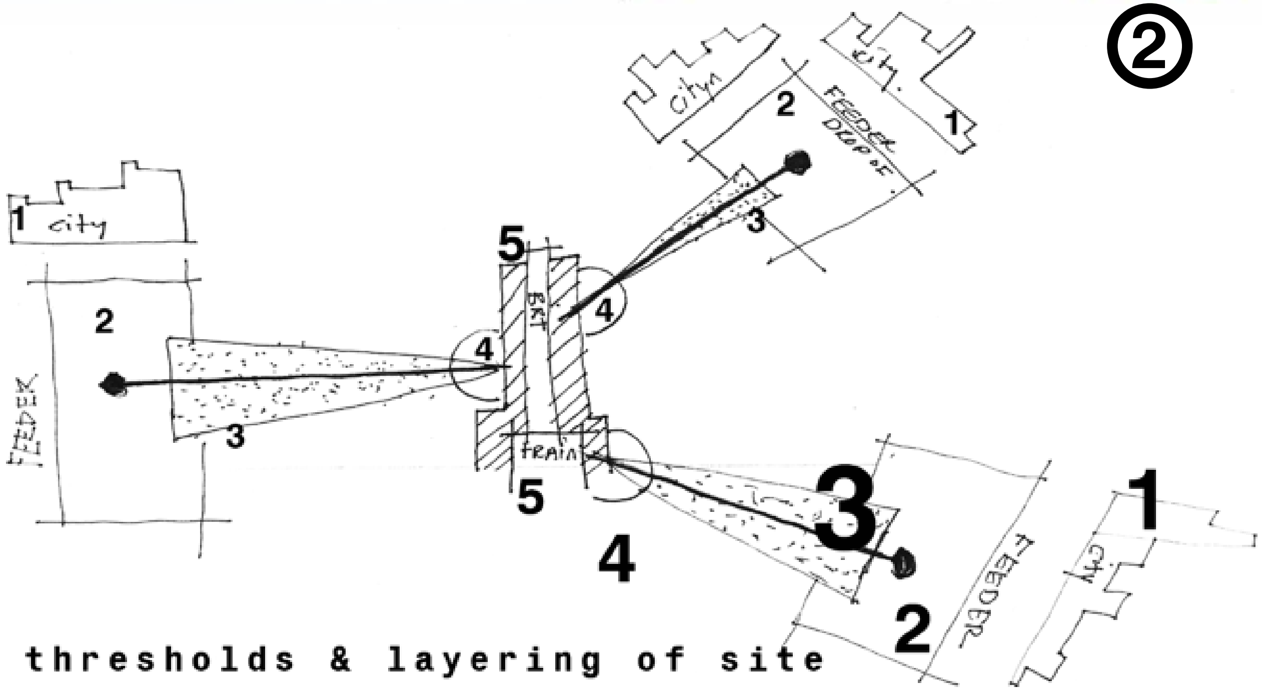

Figure 7-02: Design development 2: Movement on site [Source: Author]

Figure 7-03: Design development 2: Functions on site [Source: Author]

Figure 7-04: Design development 2: Thresholed into intervention [Source: Author]

1- Precinct layout as proposed by LINK framework - informing the design decisions

2- Mapping of potential space use, speed of movement and functions on site.
Arriving on the site and through a series of thresholds and layers, use a central spine to link it all.

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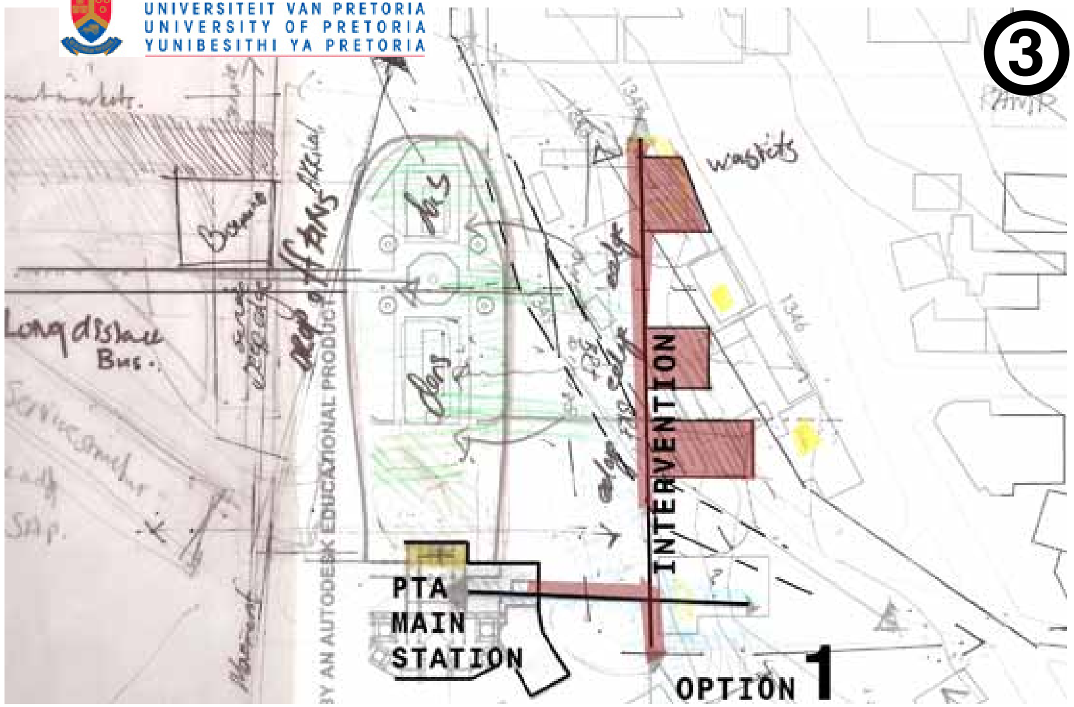
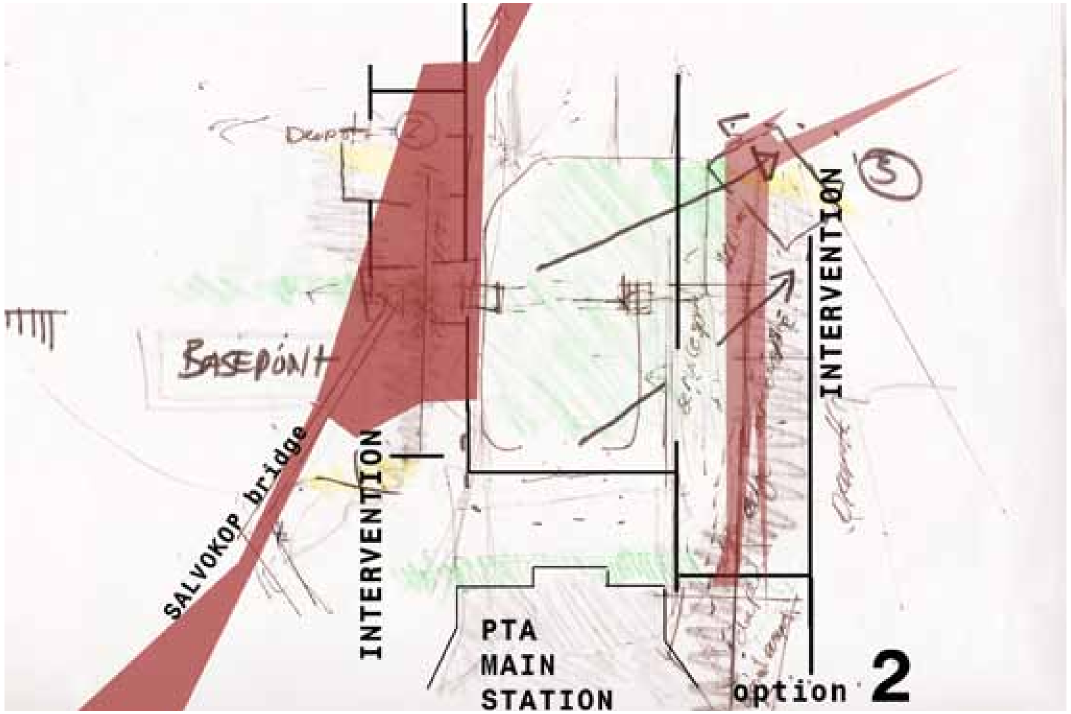
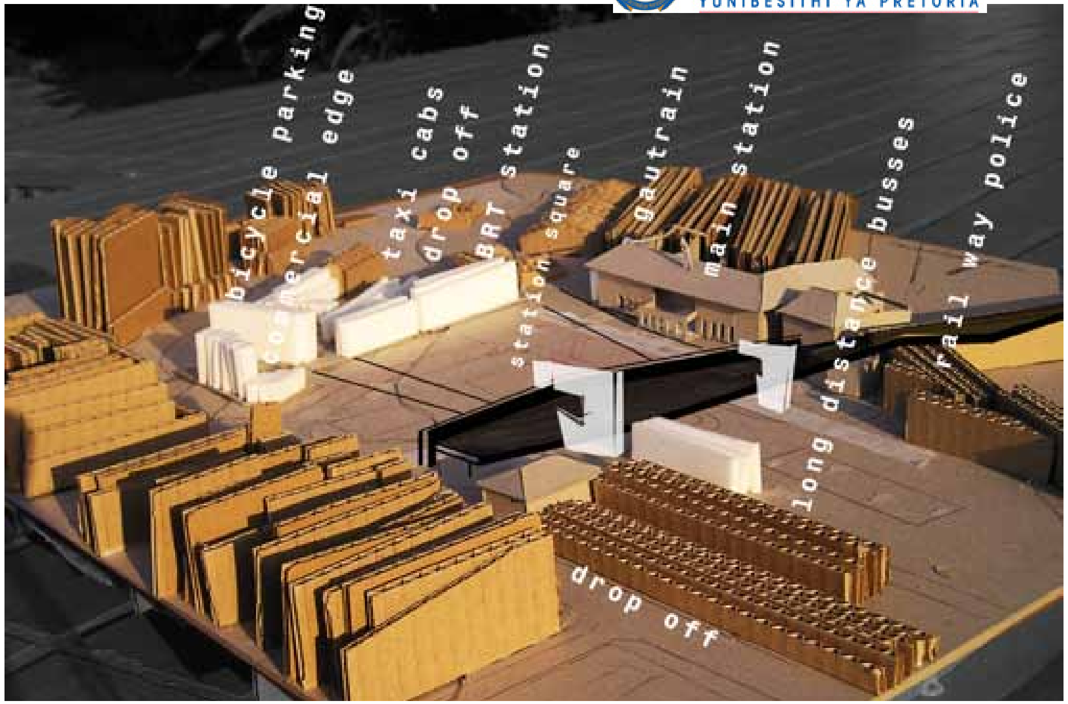




3- Explored two options of where to place the intervention on site. **OPTION 2 was chosen with bridge connection and retains most energy generated by movement on site.**

Option 1 _proposed an underground station on eastern edge of the station square gardens.
Option 2 – proposed two stations that frame the gardens – all on grade while integrating the bridge with the design.

Figure 7-05: Design development 3: Options 1 + 2[Source: Author]



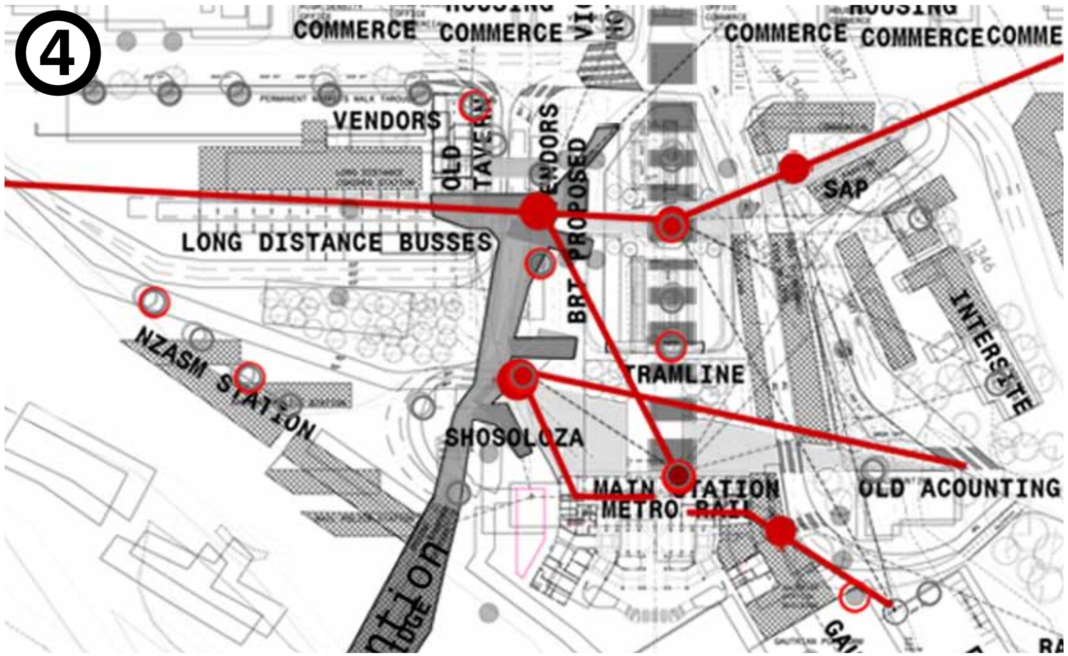


Figure 7-06: Design development 4: Whole site & intervention [Source: Author]

Figure 7-07: Design development 4: Linking site with historic and future points [Source: Author]

4-

The square design was developed around the linking of important points **[present, past and future points]** and placing a new movement layer on the site.

From this important intervention points were mapped and developed.

The block layout was developed to accommodate the ease of transfer, while retaining the cultural and historical value of the station buildings, station square and historical buildings.

The Station Square were reinterpreted as functional public space and "air conditioning unit" for the intervention.

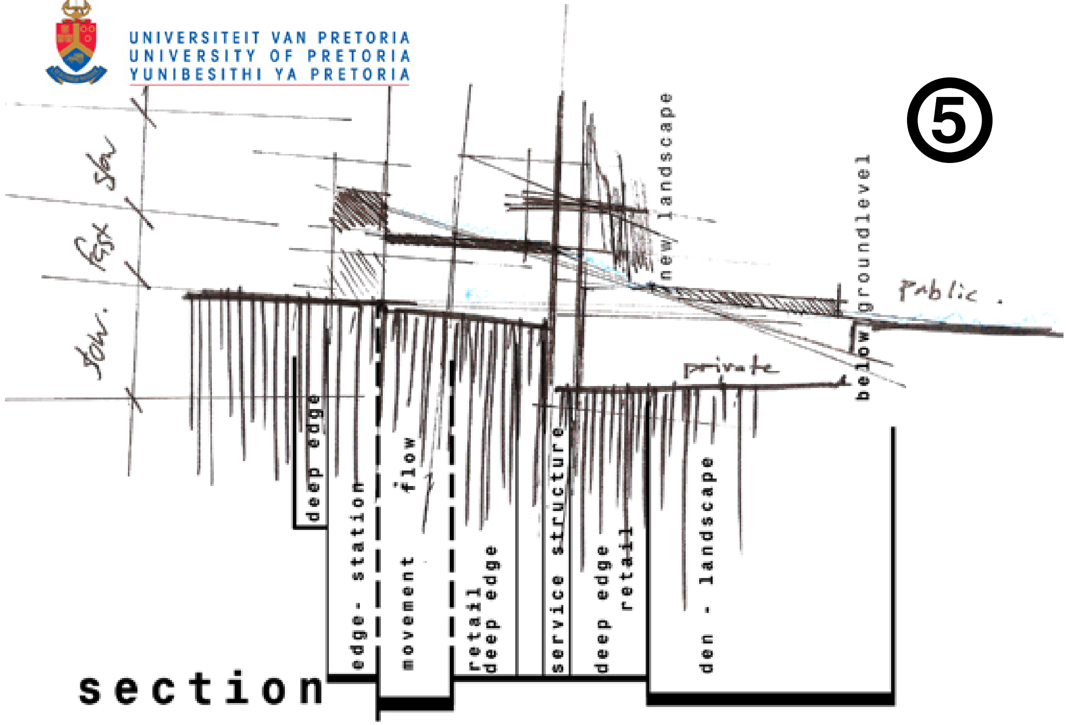


Figure 7-08: Design development 5:
Design developed #1 _section
[Source: Author]

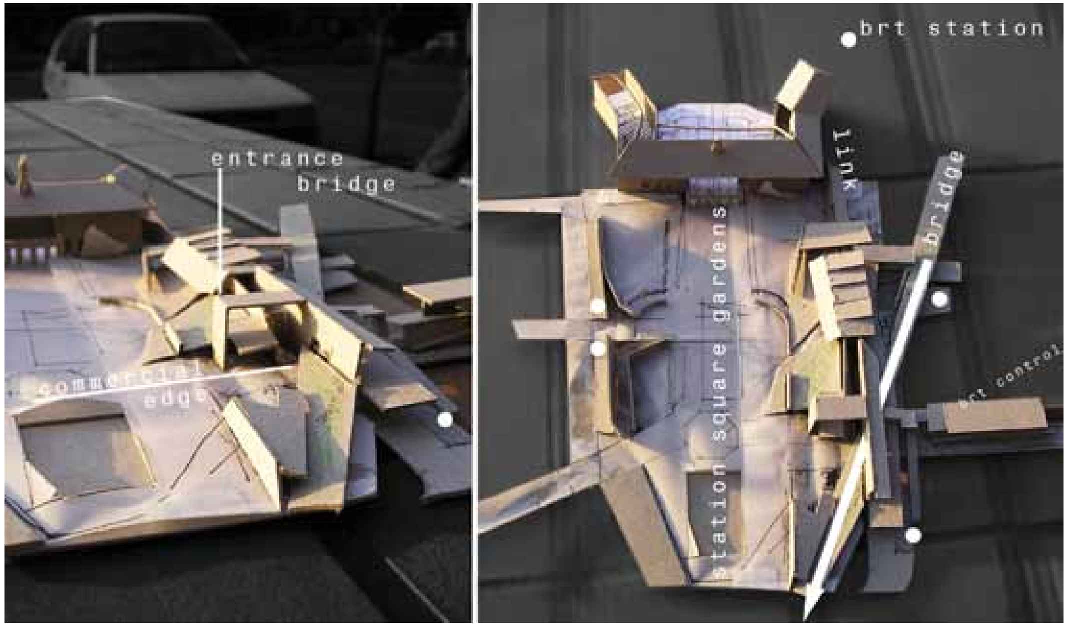
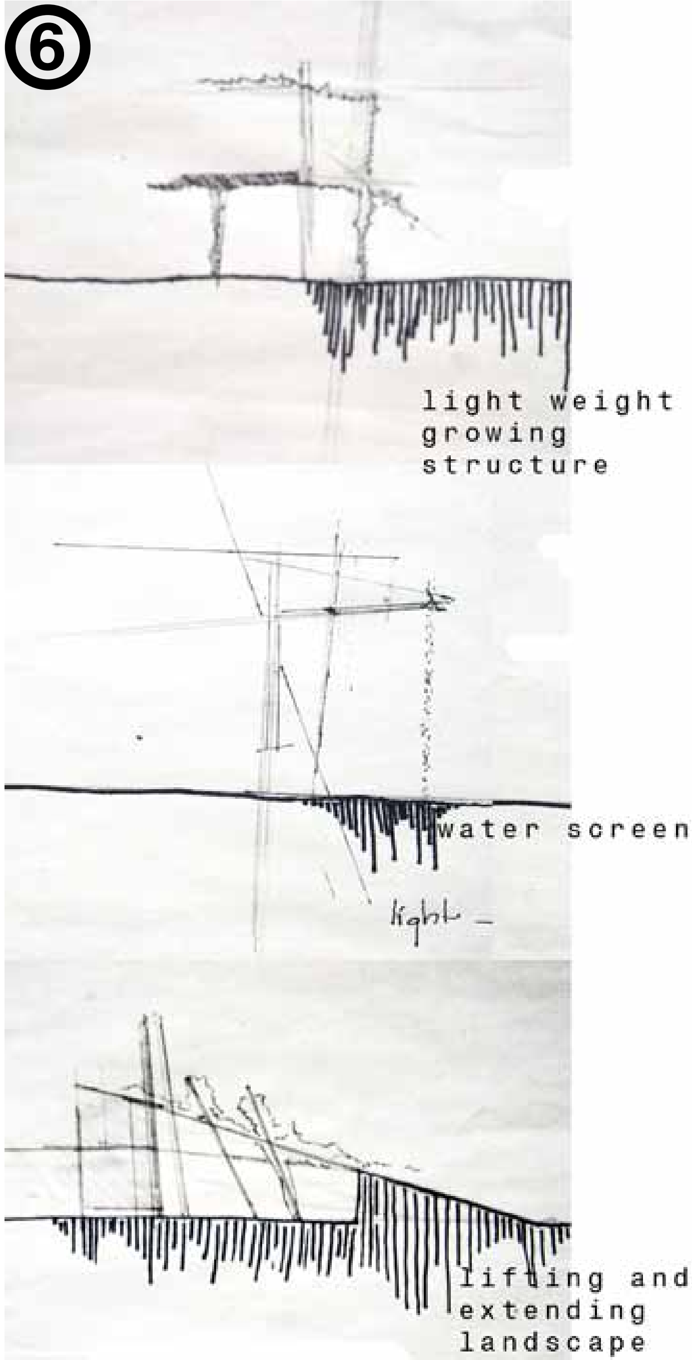


Figure 7-09: Design development 5:
design developed #1 _model
[Source: Author]

5- Design linked with Salvokop bridge – guiding pedestrians into the Station Square. Part of the structure was proposed to be underground, underneath the Station Square
- it was not used as the impact on the square was too imposing and space is limited.



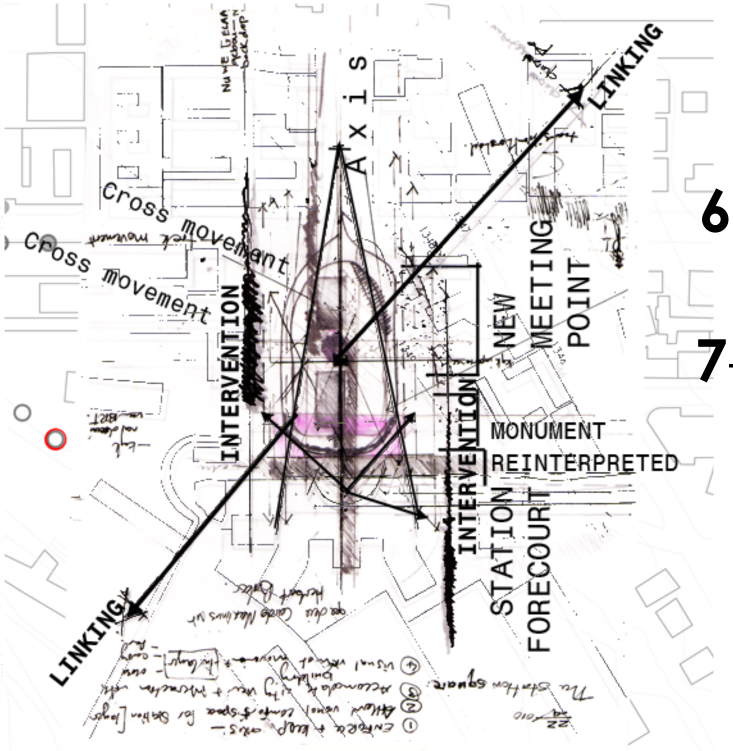


Figure 7-10: Design development 6: integrating planting and landscape in structure[Source: Author]

Figure 7-11: Design development 7: Enforcing the axis[Source: Author]

Figure 7-12: Design development 7: Zones of the station square gardens [Source: Author]

6- Landscape lifted as new layer linking with bridge level. All movement functions on top of each other.

7- The station square gardens reinterpreted:
linking the landscape with buildings and functions.

Enforcing existing axis by opening and moving existing museum [material and content retained on site] and developed new functional zones in landscape.

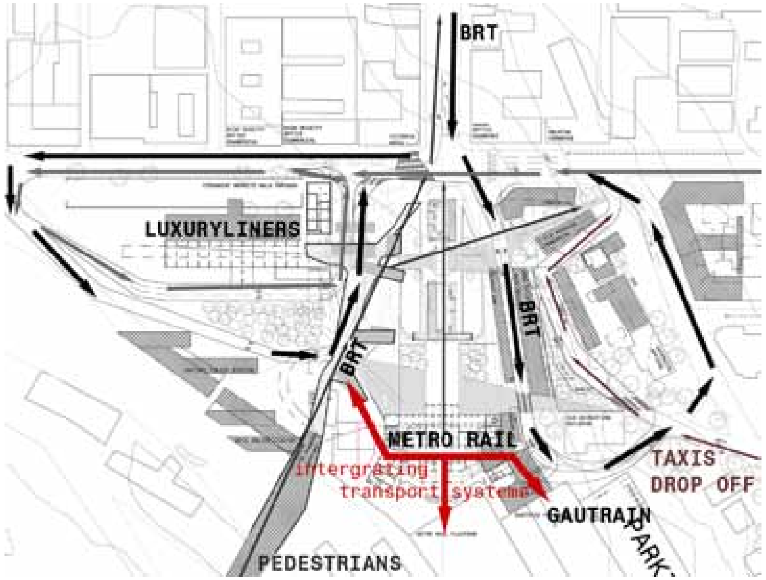


Figure 7-13: Design development 8: Movement on the site [Source: Author]

⑧

Figure 7-14: Design development 8: initial landscape design [Source: Author]

8- Landscape design developed to integrate the different transport systems and points
– A second planted layer was added as a floating layer @ 60° angle grid [responding to the angle of the station eastern en western wing].

The second angle layer was discarded.

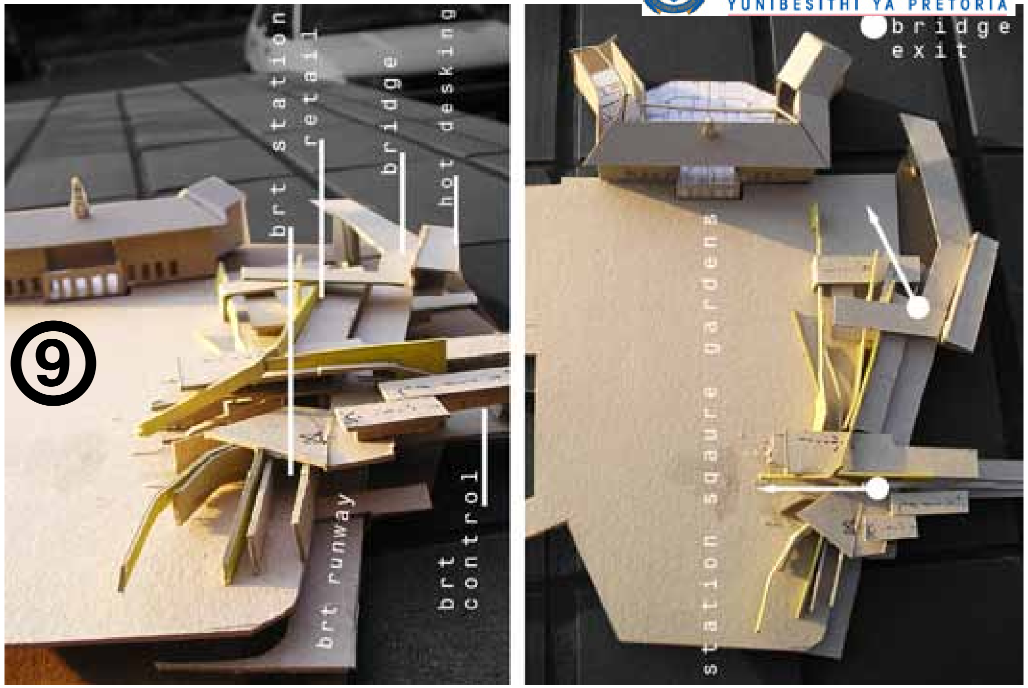


Figure 7-15: Design development 9: Design developed #2 _ Model
[Source: Author]

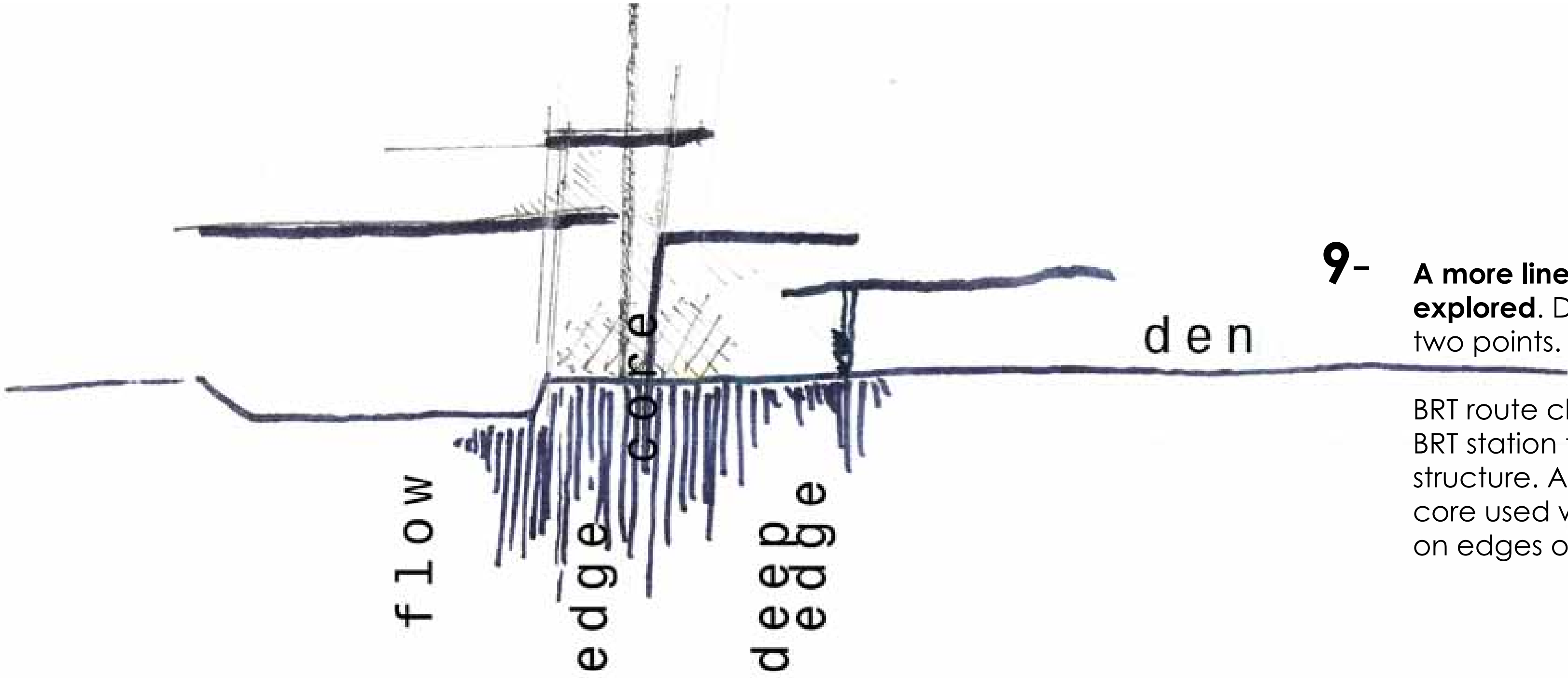


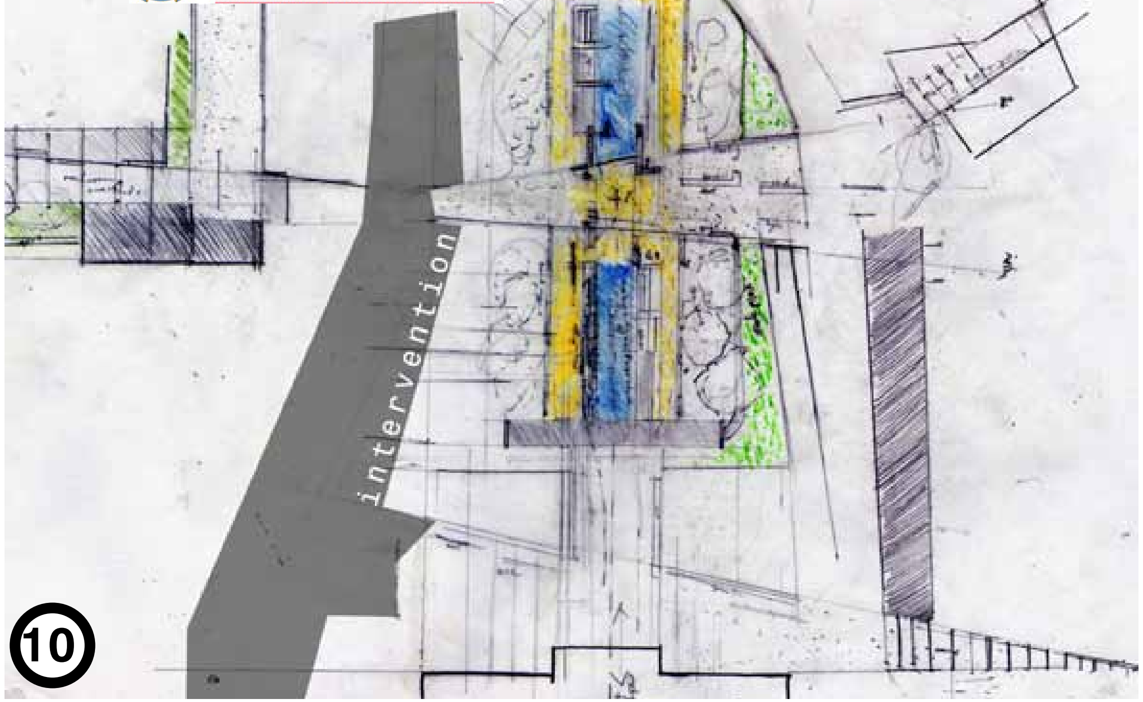
Figure 7-16: Design development 9: Cross section through building.
[Source: Author]

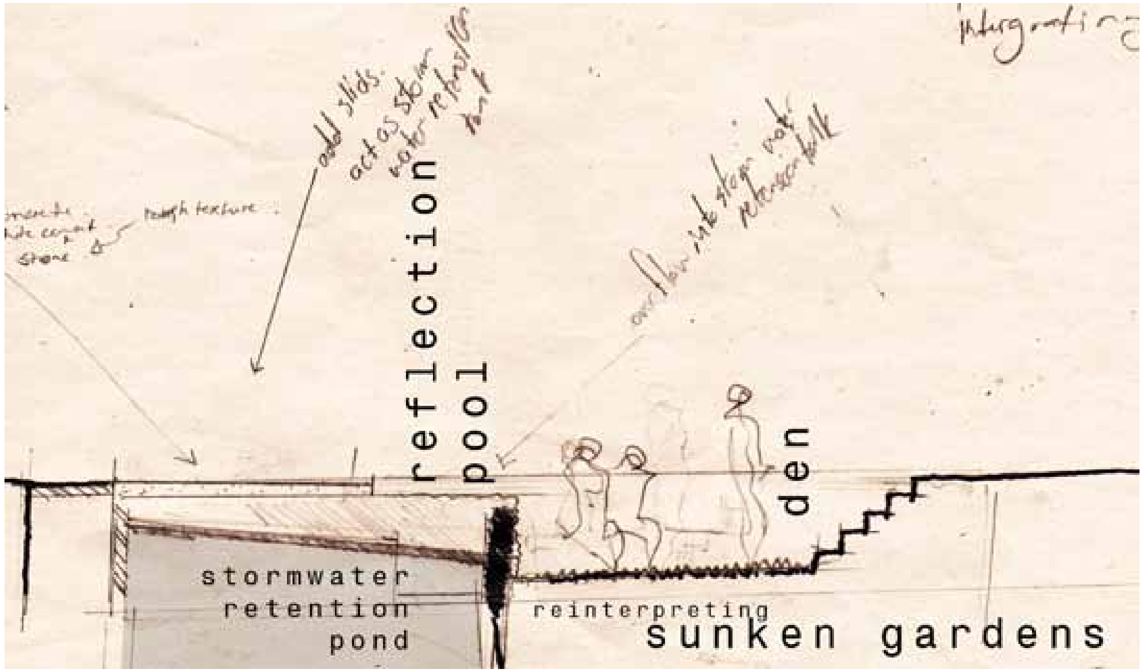
9- **A more linear and layered design explored**. Design still centred around two points.

BRT route changed to allow for BRT station to link with rest of the structure. A central service core used with pedestrian walking on edges of structure.

Figure 7-17: Design development 10: intervention responding to Station square gardens[Source: Author]

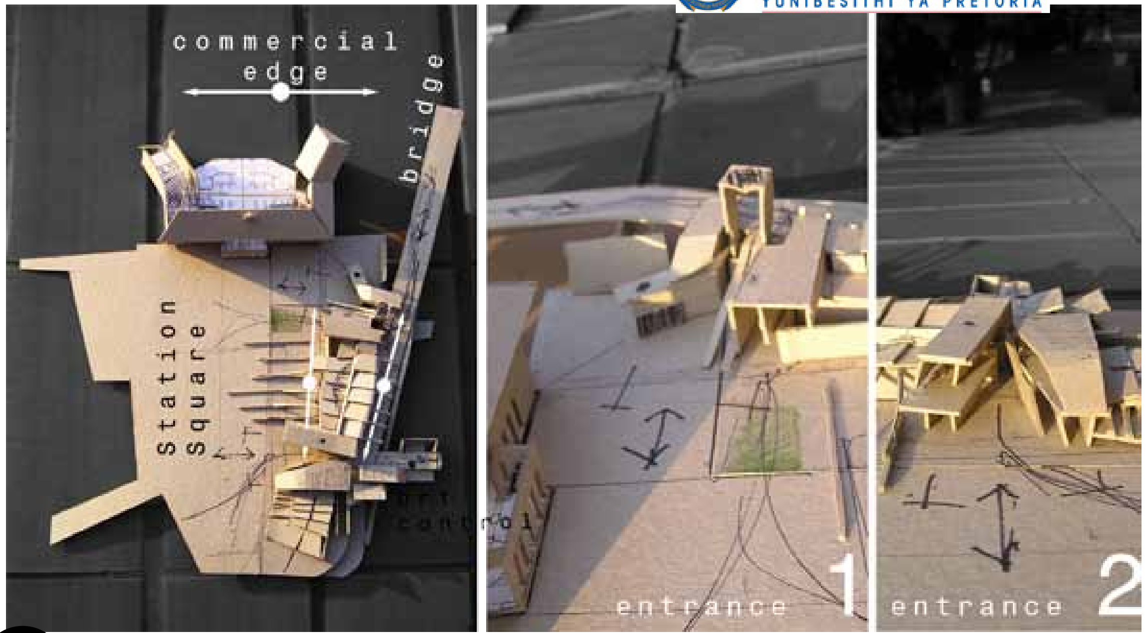
Figure 7-18: Design development 10: Sunken gardens detailed [Source: Author]





10- The Station Square was developed to inform the design. Design adjusted to respect existing Neo Classical design, by adding a more subtle movement layer on top.

Sunken gardens reinterpreted as reflective ponds / stormwater retention ponds.



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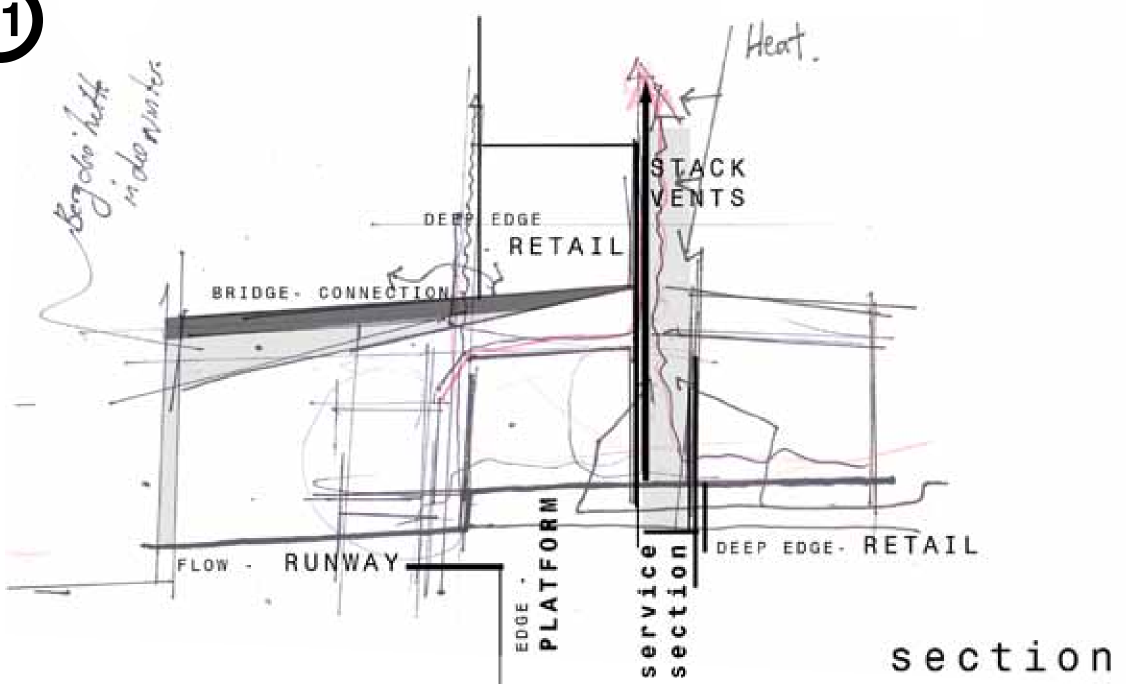


Figure 7-19: Design development 11:
Design developed #3 _ Model
[Source: Author]

Figure 7-20: Design development 11:
Cross section through building.
[Source: Author]

11- Explored the use of cross sectional structural beams.

The service edge is integrated with the ventilation system – ensuring enough air movement to ensure cross ventilation.

Movement is still manipulated around the building – in essence creating a “street” edge next to the intervention.

Figure 7-21: Design development 12: Elevation planted - ribs [Source: Author]

12- Elevation explored as a screened structure from which the cross-sectional beams protrude.

13- Building entrances integrated into landscape. Entrance used a directional objects that guide the user through structure. Bridge structure changed into a more movement design – precedent studies of work of Zaha Hadid and Gunther Behnisch.

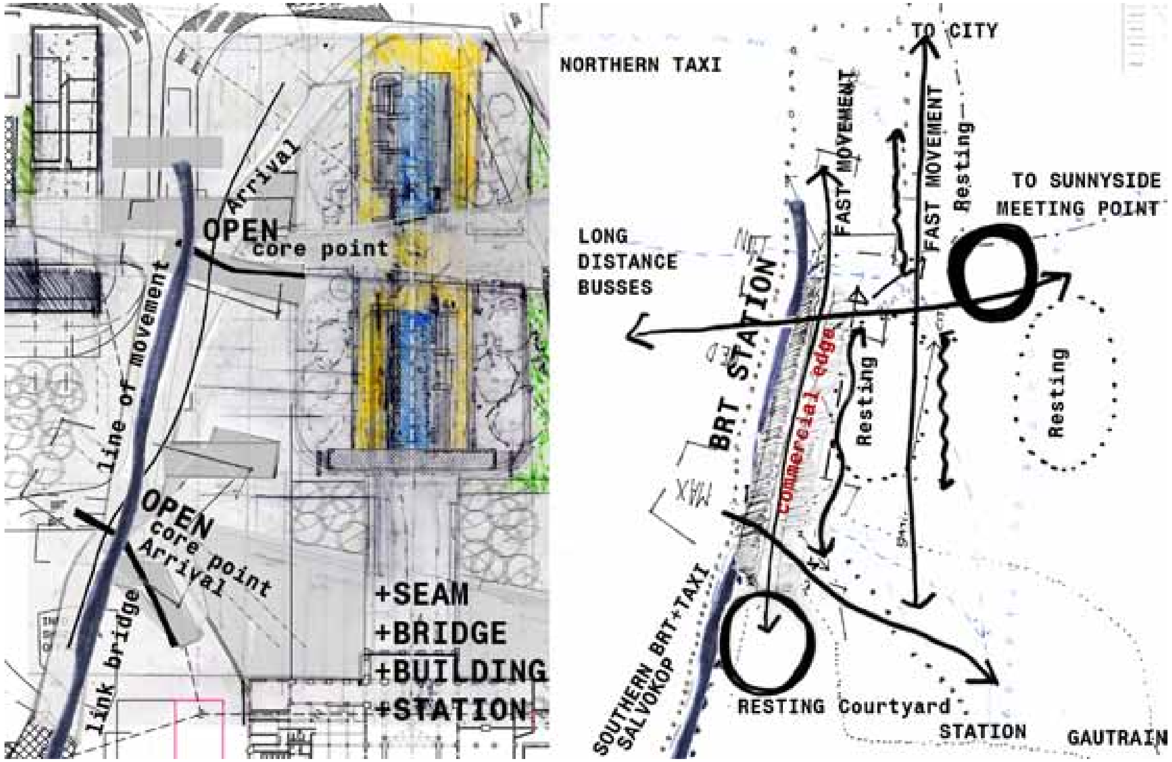


Figure 7-22: Design development 13: Entrance points and movement through intervention [Source: Author]

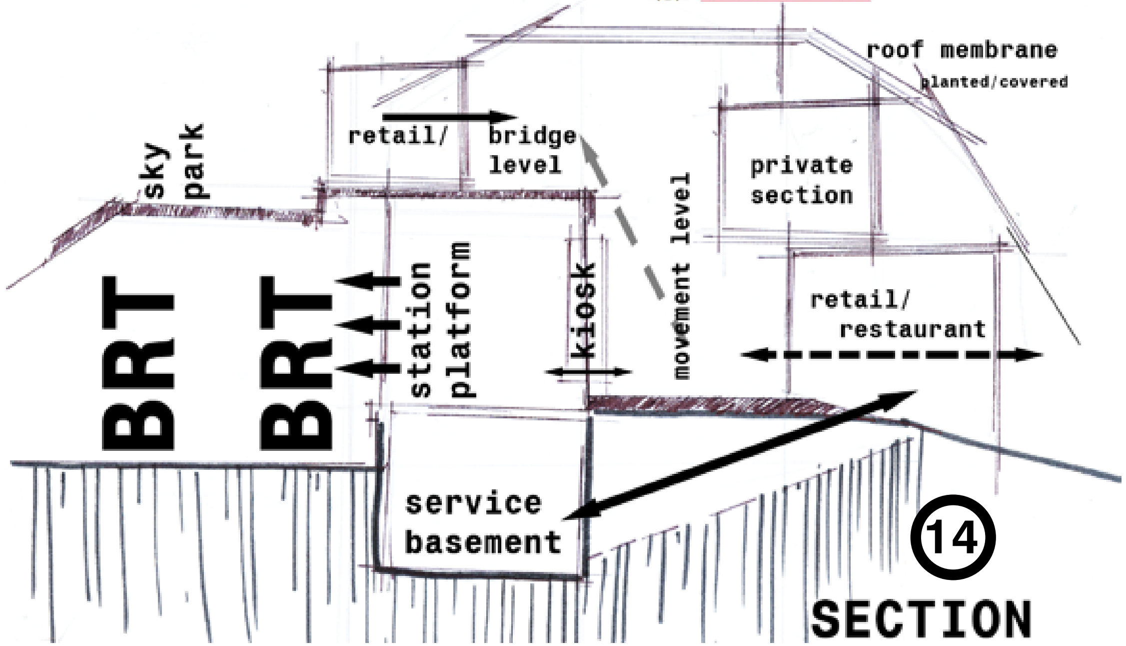


Figure 7-23: Design development 14: Schematic Section [Source: Author]

14- The design adapted to allow for the user to enter the structure and creating a spatial experience of movement between the layers/skins. This also protects the user from the natural elements.

The central walkway used a chimney for stack ventilation, while semi basement added to accommodate the services.

15- The roof structure was adapted to a linear structure, while integrating planting and polycarbonate roof sheeting with the roof structure.

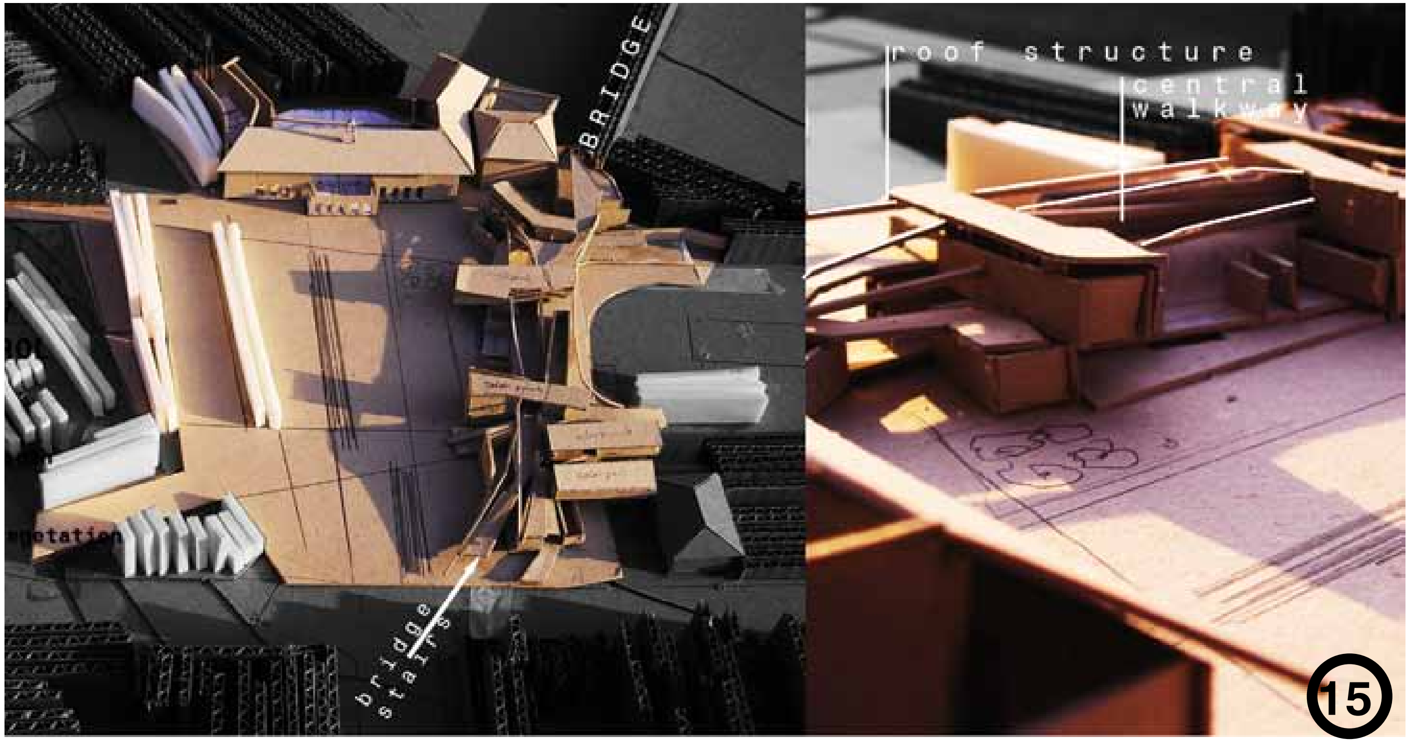
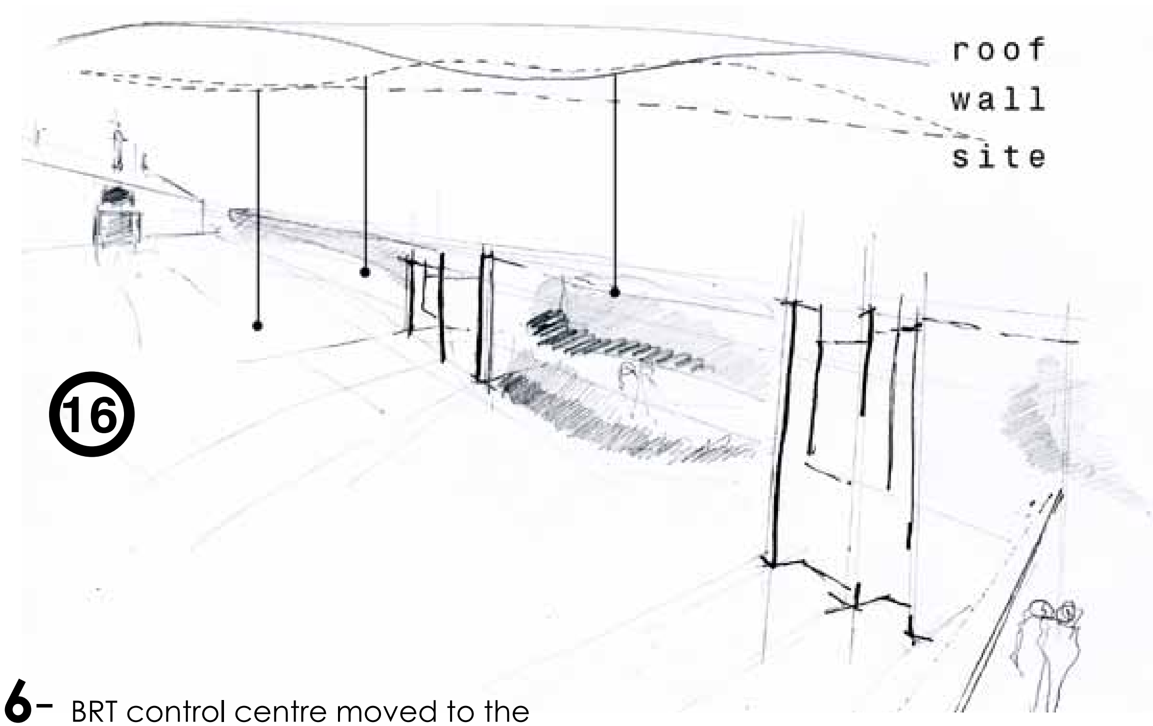
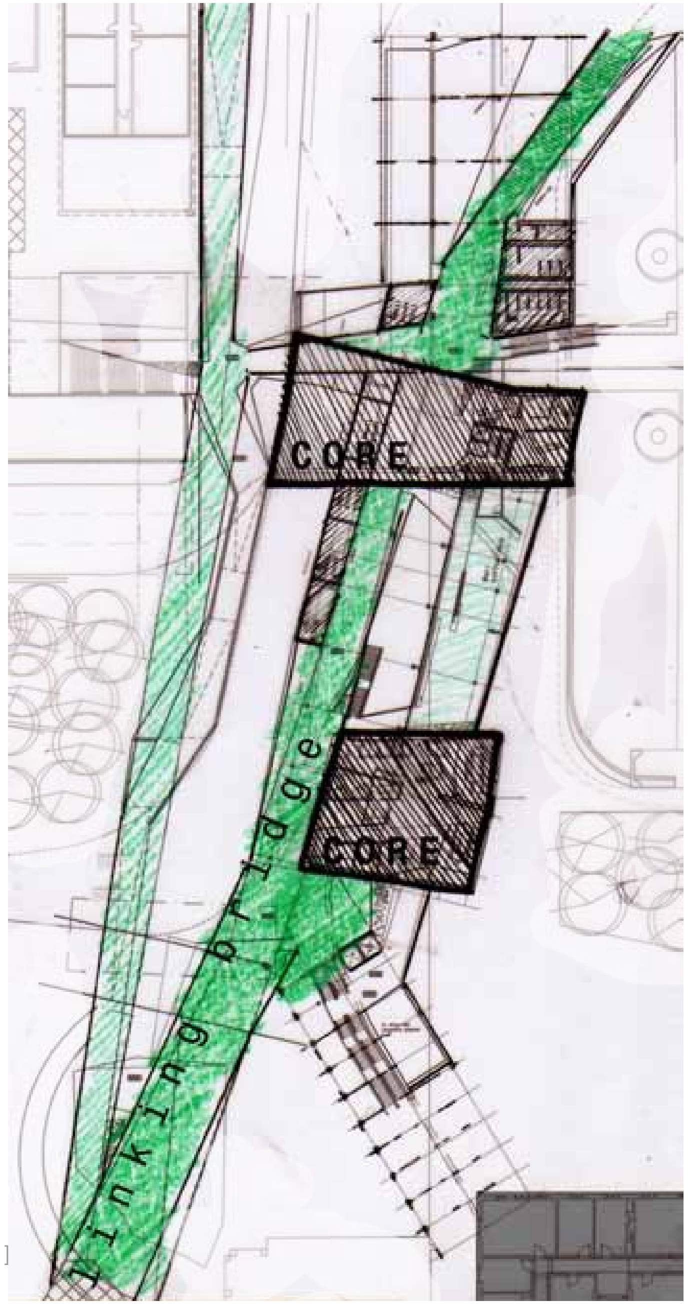


Figure 7-24: Design development 15: Design developed #4 -model and roof [Source: Author]





16- BRT control centre moved to the central entrance structure in aims to condense and simplify the design.

The approach of a more organic roof was investigated – it was discarded as being overly complex for a design that aims to minimise on material use.

Opted to use a single flat roof to link the whole structure.

Figure 7-25: Design development 16: Skin: wrapping -ROOF/WALL/SITE [Source: Author]

Figure 7-26: Design development 16: Linking bridge and core[Source: Author]

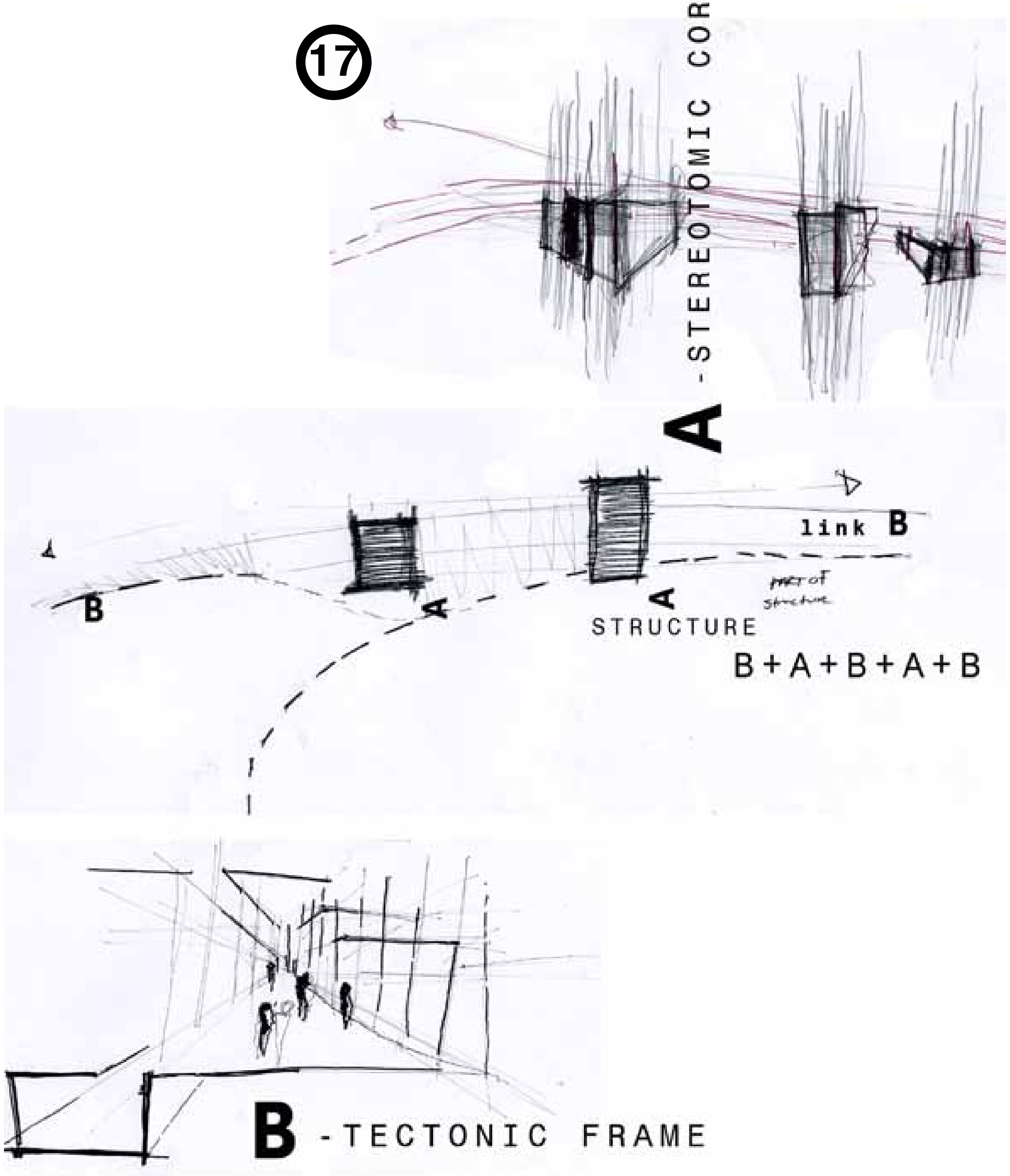


Figure 7-27: Design development 17:
Structural system & tectonic approach.
[Source: Author]

17- The use of structural systems and a tectonic approach was investigated – two systems were chosen one being a framed tectonic system – referring to the landscape as a lifted skin.
The second system is a solid stereotomic system derived from the solid facade of the Pretoria Main Station.

After consulting the structural engineer it was decided to change the stereotomical structure to a framed structure with concrete blocks as infill material. This was done to ensure simplicity of the design and its future adaptability.

18- Design simplified and densified to use less materials, and allow for an easier construction process. All office functions were restricted into two defined points in the whole. This allows for a less imposing structure on the station building and a more direct bridge connection.

The site lines to the Pretoria Main Station was also cleared and the intervention were moved back.

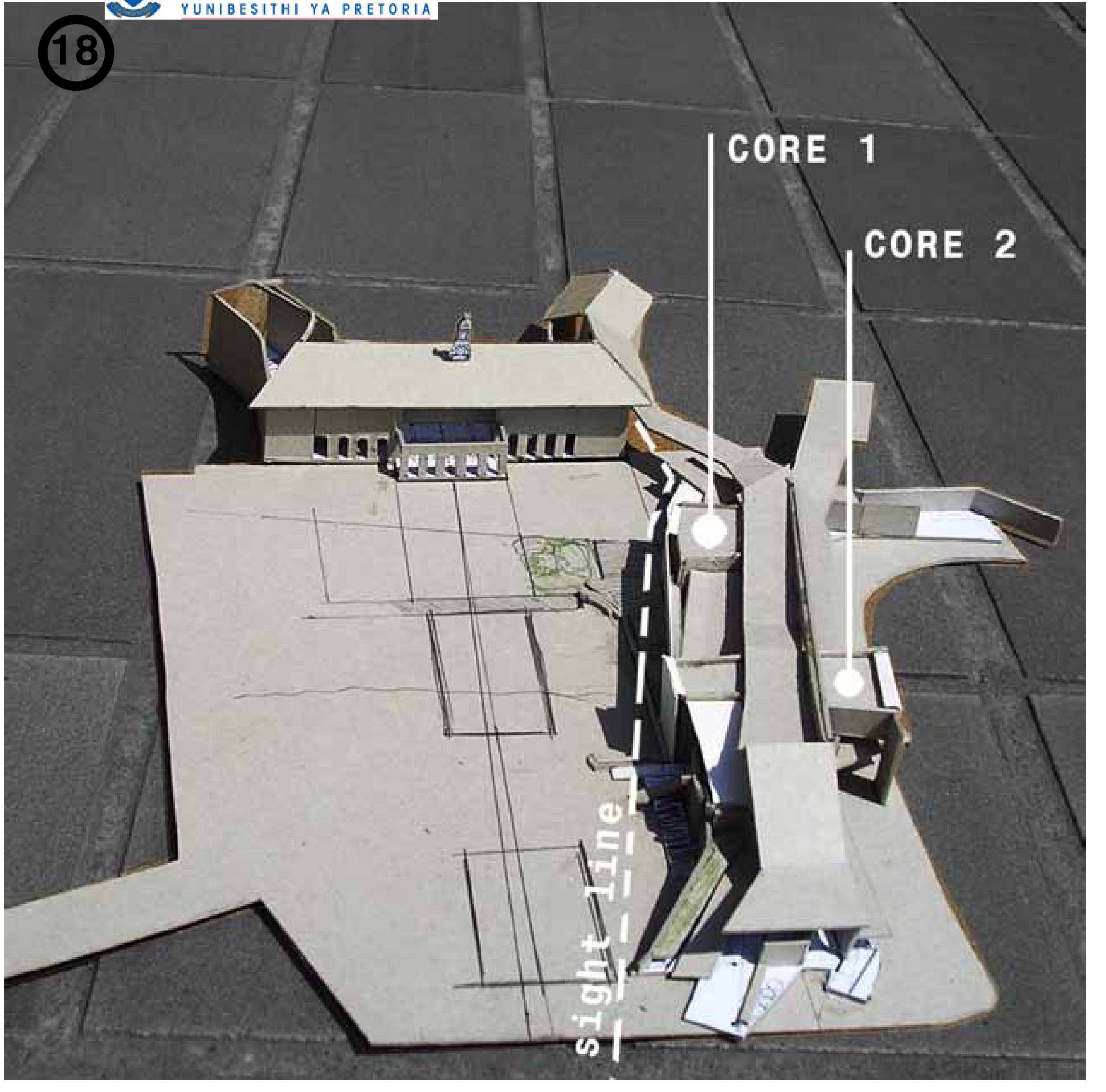


Figure 7-28: Design development 18: Simplifying the design[Source: Author]

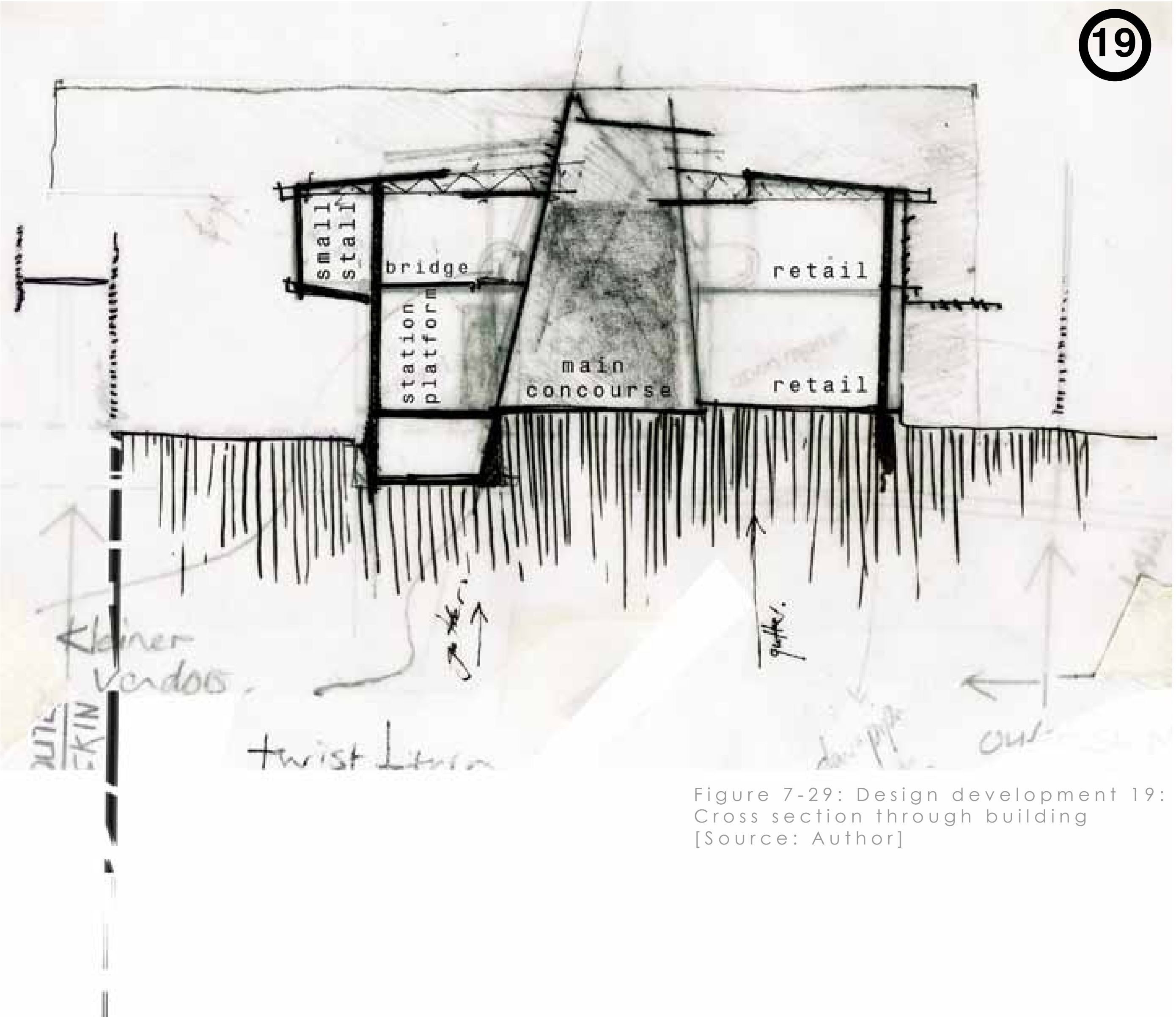
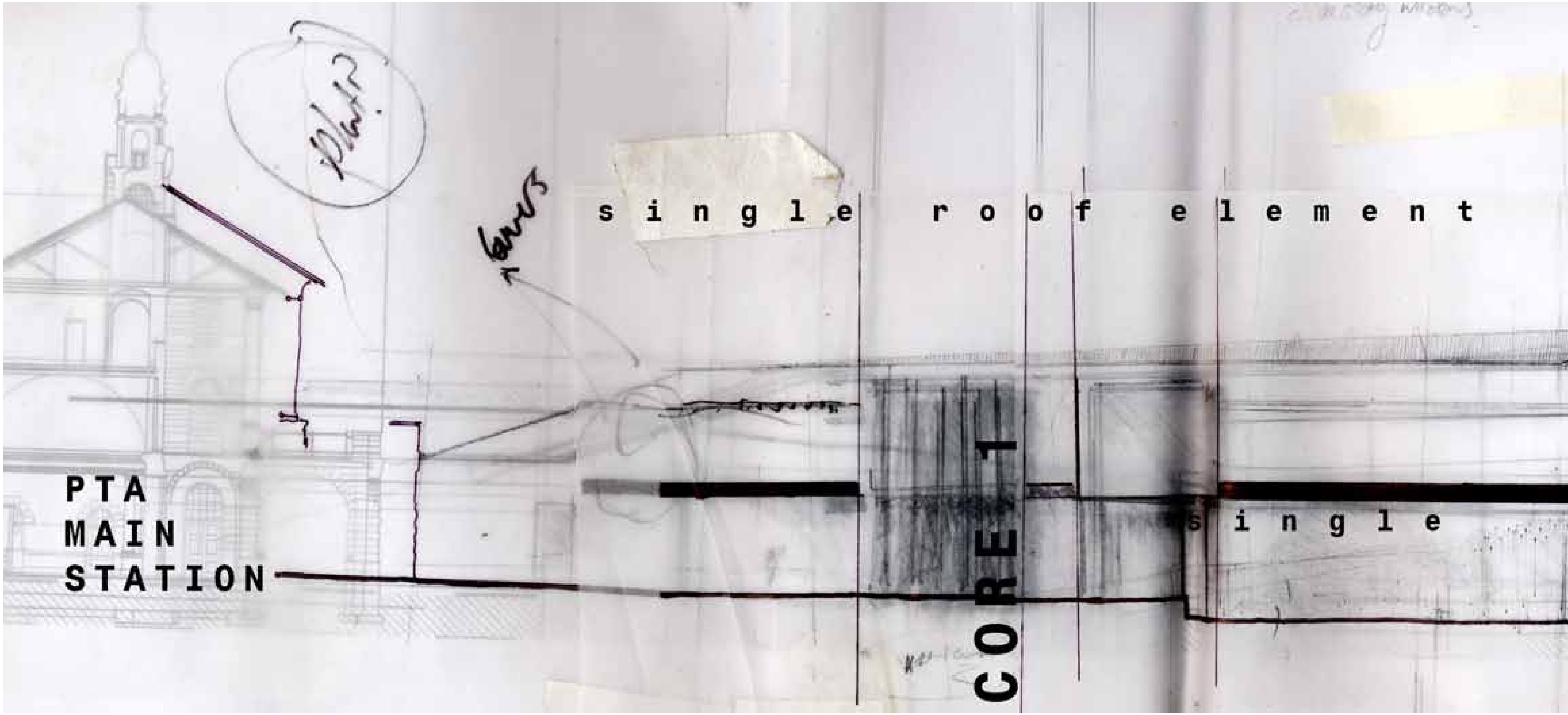


Figure 7-29: Design development 19: Cross section through building [Source: Author]

19- Roof structure was as a series of low roofs, and a steel and glass skin structure that folds over the whole. This allowed for a more economical use of material and systems. Ensuring that the floor planes are carried by the same roof structure.

The floor slabs are carried on a column structure, this also allows for a more versatile ground floor.


single roof element
PTA
MAIN
STATION
CORE 1
single

20- Elevation: A single "linking" roof investigated to cover whole intervention.

The floor slab articulated to reflect horisontality of Pretoria Main Station facade.

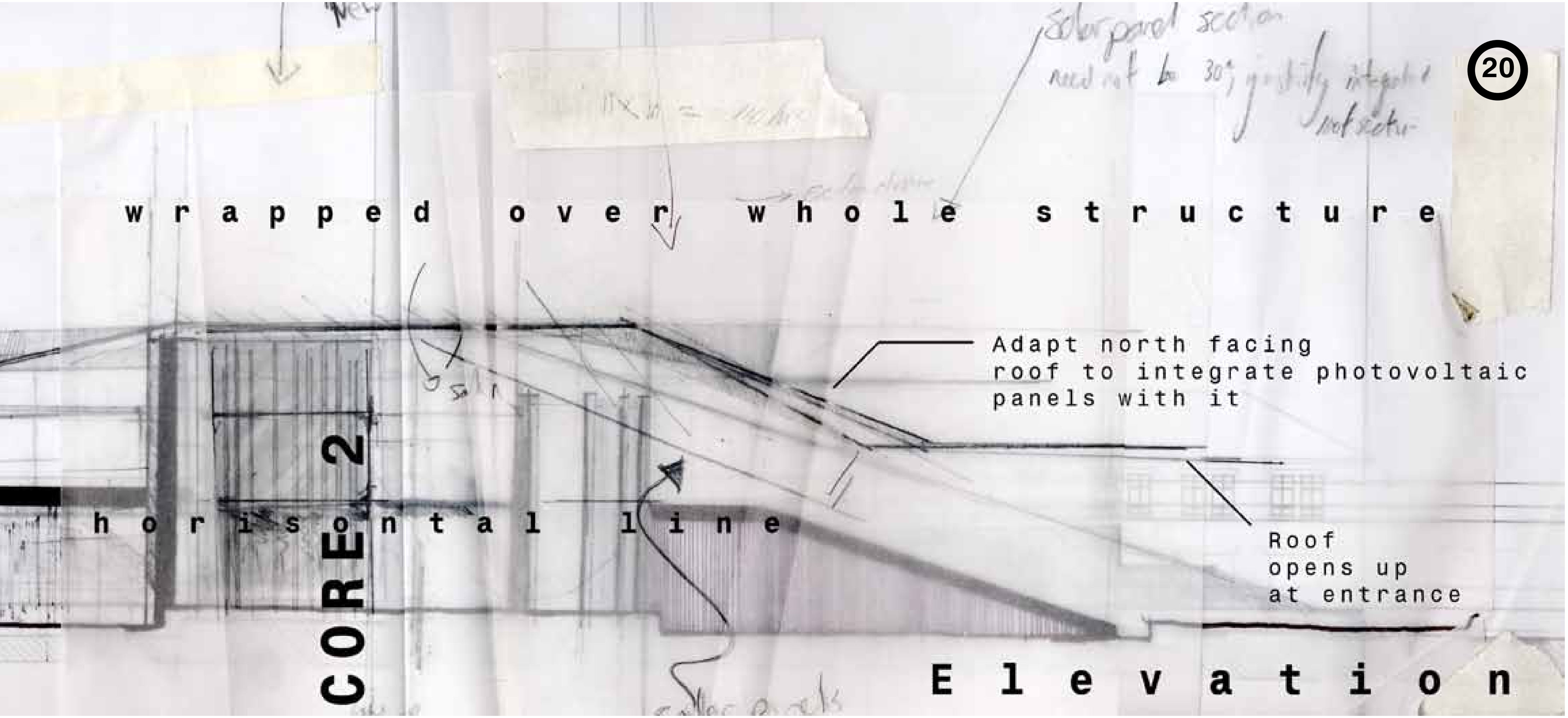


Figure 7-30: Design development 20: Facade study [Source: Author]

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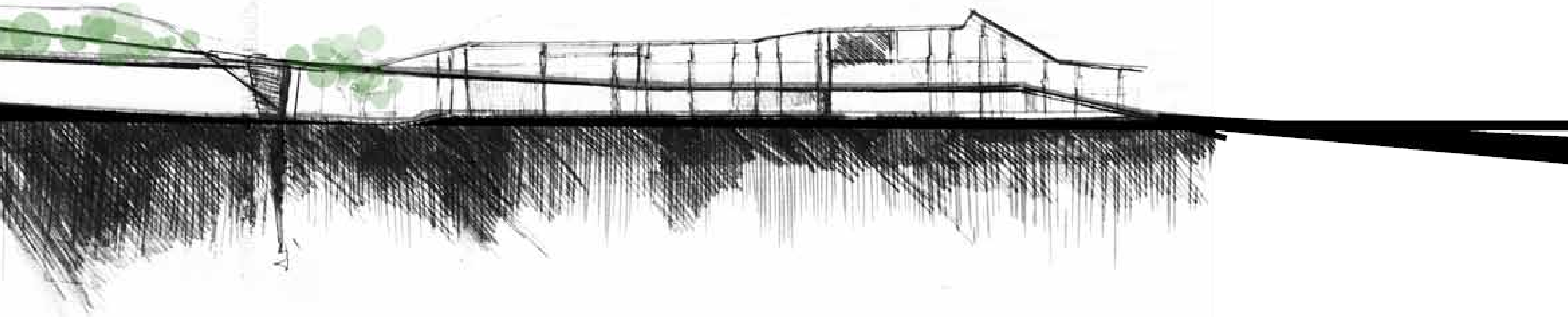
DESIGN SOLUTION

"Ecological design is a design of place, the place of the users, the climate, the topography and the local culture"

[Guy 2002:228]



9.1 The user + site + intervention

The architectural intervention responds to an urban framework that proposes the sustainable redevelopement of Salvokop and Transport precinct. **The design acts as a linking structure that bridges the gap, between the isolated Salvokop precinct and the city.** This will allow for a safe user friendly bridge used by the local inhabitants promoting sustainable movement practices such as walking and cycling.

Along this sky bridge a series of commercial and civic functions are proposed integrated with a vegetated park. This will ensure that the "bridge structure" becomes a multi functional urban space that encourages its use and promotes passive surveillance [Jacobs 1961:195].

The intervention responds to the cultural historical context by **reimagining the Station Square as a linking functional landscape.**

The Pretoria Main Station is addresses by **integrating and reorganizing the varies movement systems on the site** -allowing for easy interchanges between these systems.

This will promote the use of public transport and enable the first time users and tourists to easily navigate between these transport systems.

The design accommodates a series of different retail spaces within the station and along the bridge that will facilitate a wide range of retailers – the shop sizes range from larger retail spaces to smaller kiosk and stalls to retail space for vendors. This will promote social and economic sustainability with in the precinct.

The carbon footprint and embodied energy of the intervention is minimised by using sustainable principles to lower its energy consumption and carbon emissions.

The embodied energy of the structure is minimised by optimising material use through innovative structural systems. Materials were chosen that emit the least amount of carbon dioxide during its manufacturing process.

The building footprint was generated from the movement patterns on site, thus harnessing the economic potential generated by the commuters moving through it.

The functions were identified as a series of skins/edges that respond to speed and its accessibility. Complimentary functions are placed next to each other, with other functions acting as thresholds between them, refer to section 6.1.2.

" Urban mobility infrastructure maximises positive social interactions and minimizes land and energy use"

[Jennings and Newman 2008:239].

A central arcade [deep edge] acts as a link between the BRT platforms on the western edge and the retail and commercial function on the eastern edge.

The western edge is a close edge with controlled access while commuters are allowed to filter through the eastern edge onto the station square.

The intervention slips in between the original station building and newer extension as an effort to link the BRT, Metro Rail and Gautrain transport systems.

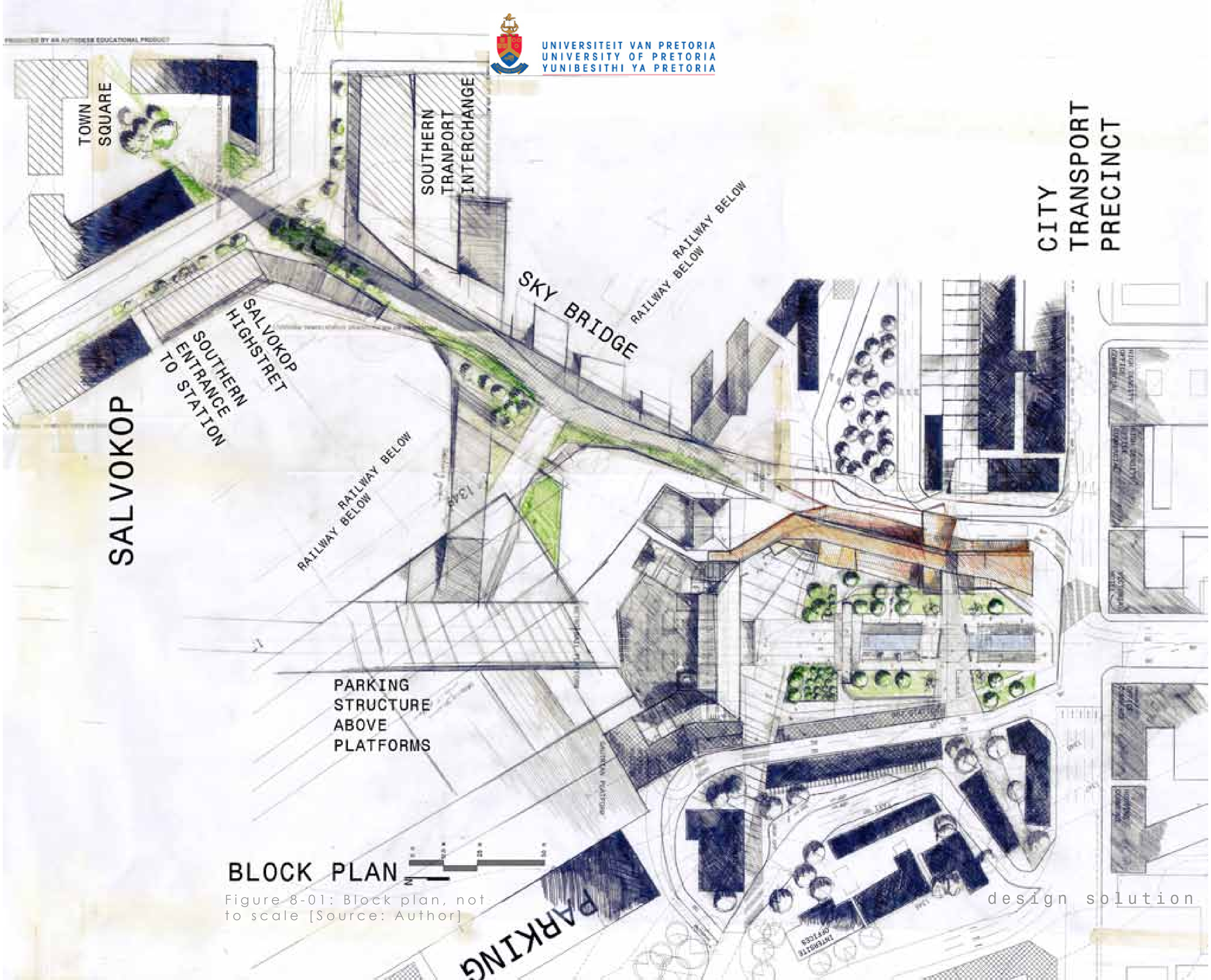


Figure 8-01: Block plan, not to scale [Source: Author]

9.2 Placement of the intervention

The intervention was placed on the western edge of the Station Square in order:

a) To ensure a direct connection to the Salvokop precinct and footbridge
b) Keep the sight lines of the Pretoria Main Station clear to ensure that the the clock tower and porte cochere of the Station are visible while moving up with Paul Kruger street.
c) The design integrates the landscape with the new intervention, placing functions on the Station Square to ensure the usage of the square.
d) Most existing buildings will be retained to minimise the carbon footprint and embodied energy the urban design and new terminal building.
e) The intervention links up with the station building to ensure that the transport systems are integrated to allow easy transfers.

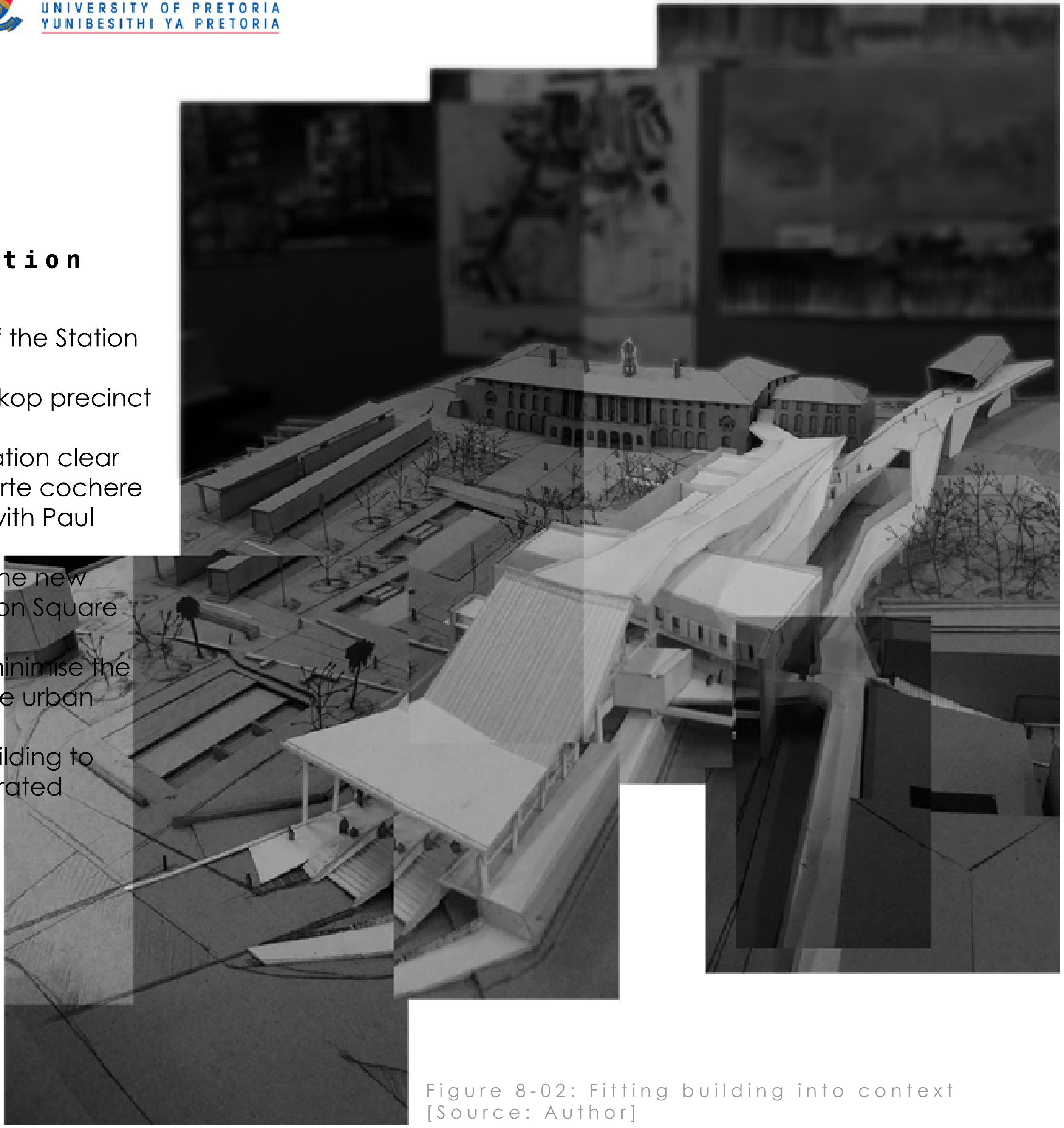


Figure 8-02: Fitting building into context
[Source: Author]

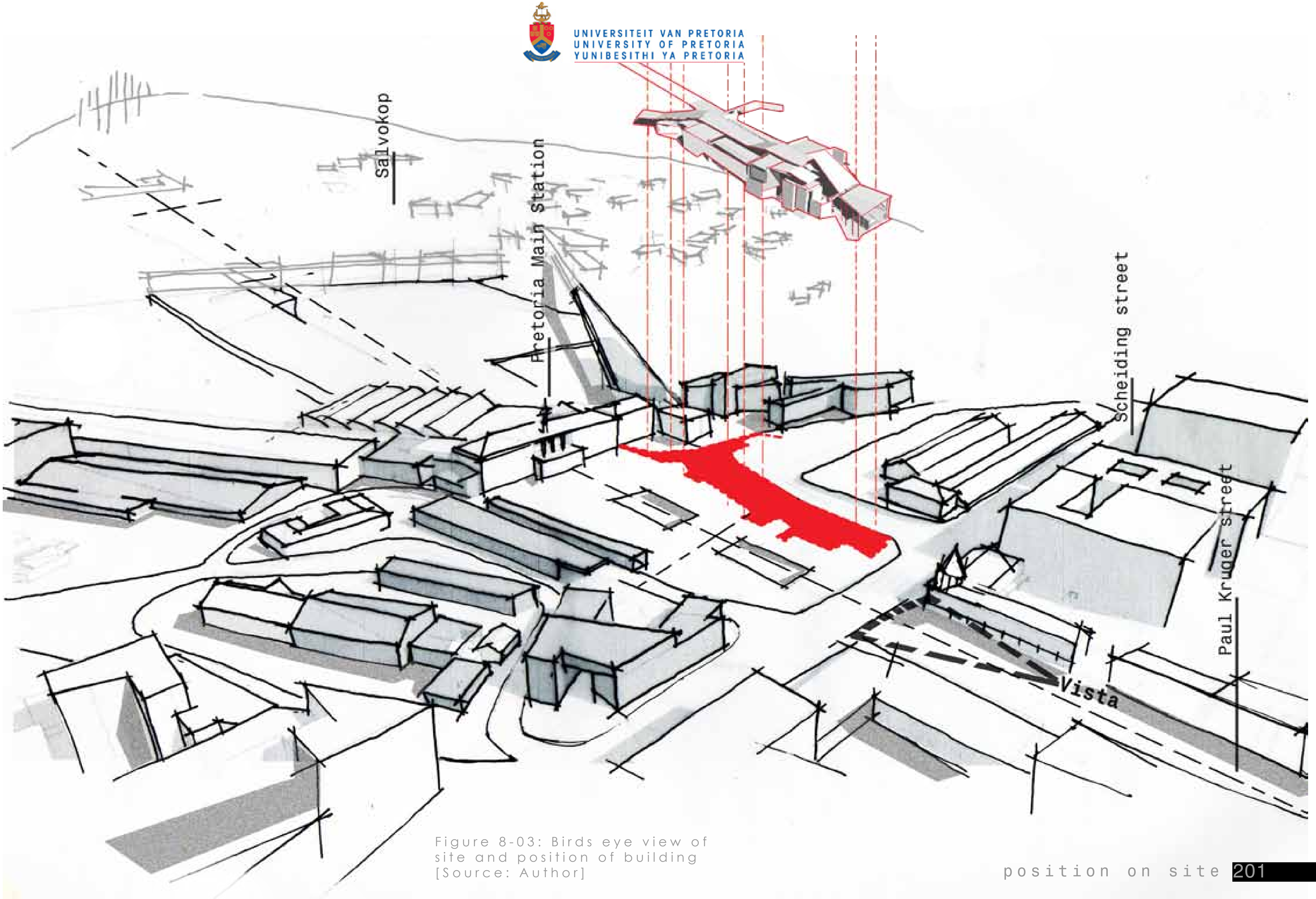


Figure 8-03: Birds eye view of site and position of building [Source: Author]

9.3 Design of the Station Square

The Station Square is reinterpreted as an important urban layer in the transport precinct of Pretoria. **The block layout ensures pedestrian access to the station using the square as a linking layer for the whole site**.

The Station Square is divided into three zones:

a) The Threshold

The paved space in front of the Main Station building acts as an approach that provides a threshold between the building and the landscape. The Station floor finish extends into the landscape providing a new link that enforces the main axis of the building and square. Two bosques are placed on the edge of this space to frame the space in a neo–classical manner.

The new BRT Terminal links with the formal space with a second entrance lining up with the edge of the formal space - creating vista into the new building from the Main Station entrance

b)The Reimagined Memorial.

The existing World War I & II memorial is reinterpreted and moved to open up the central axis and allow commuters to move through the memorial. This is integrated with a new memorial that commemorates heroes of the city of Tswhane. These engraved tiles are fixed in the patterned floor material of the walkway.

c)The Statue Plinth/Meeting Point

The Statue plinth is reinterpreted as new meeting point on the Station Square. Benches and seating are places around the space to allow for commuters to linger and vendors to sell their wares. From the new meeting point the user has the best view of the station building.

The sunken gardens are redesigned as reflective ponds. This will enforce the linear Neo-Classical quality of the Station Square. Extending the formal nature of the Pretoria Main Station into the landscape affirming the importance of the building on the site.

The existing stone walls will be kept while new seating and lingering spaces will be placed next to the ponds.

The main entrance of the BRT terminal is positioned perpendicularly to the meeting point and steps into the landscape in the same manner as the Pretoria Main Station's porte cochere. The new meeting points lines up and links with the entrance .

The eastern edge of the BRT Terminal building opens to the square providing functional spaces on the edge of the square where commuters can linger.

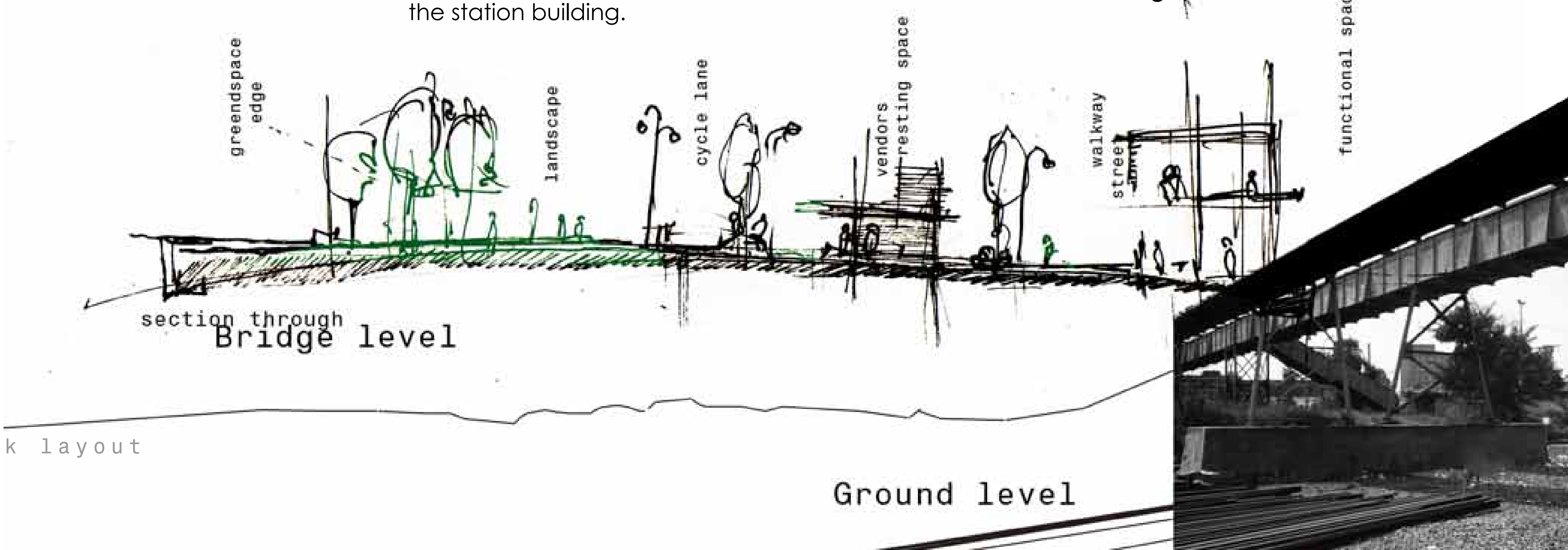


Figure 8-04: Proposed bridge design accommodating all users [Source: Author]

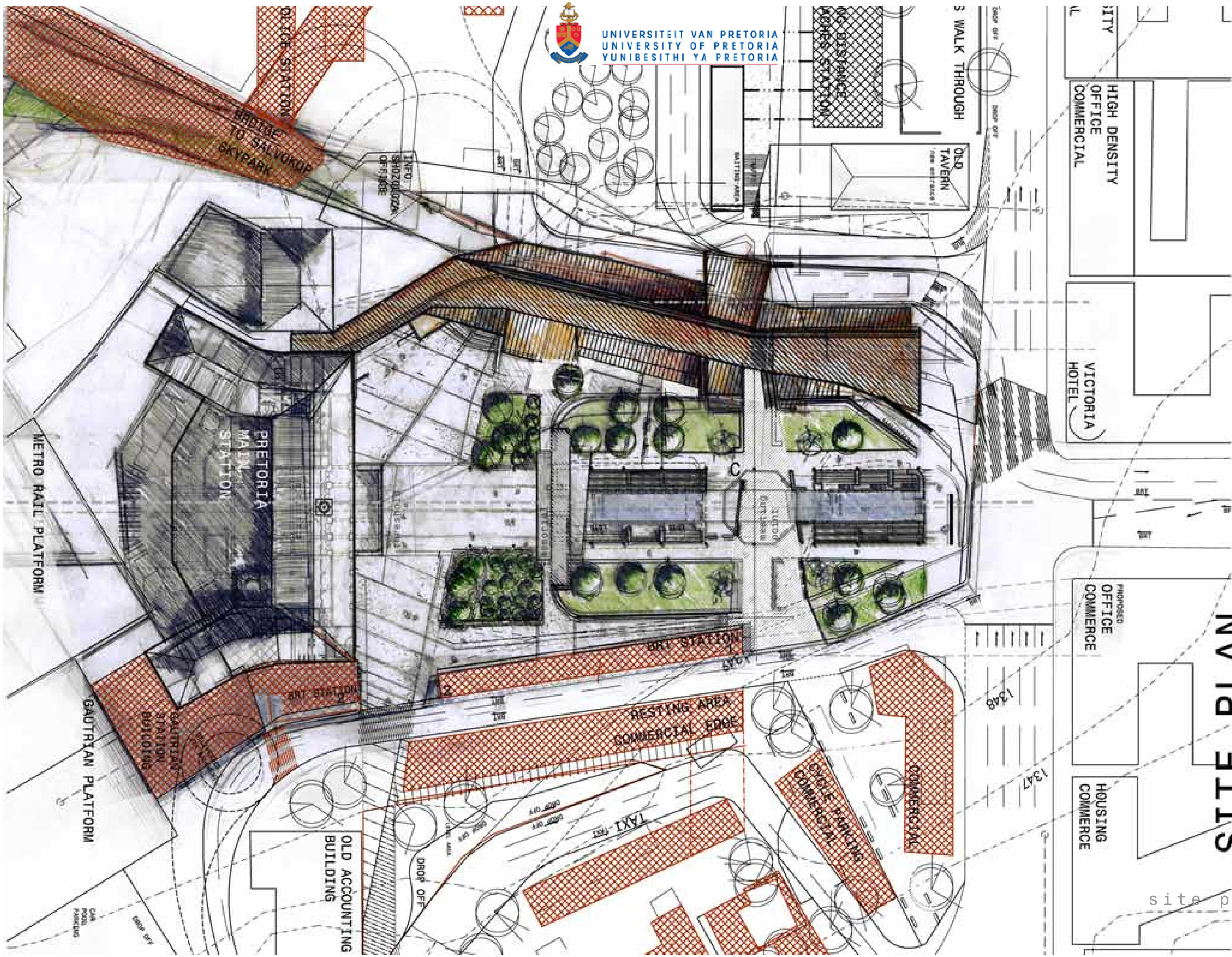


Figure 8-05: Site plan, not to scale [Source: Author]

9.4 Ground floor

The main concourse acts as a central arcade with the BRT platform on the western edge and retail functions on the eastern edge. The retail spaces on ground floor are designed to be adaptable to accommodate future changes

As one moves through the main concourse one is aware of the changes/movement outside the intervention through as series of transparent glass screens/skins. This enforces the experience of change and movement.

The station entrances are integrated with the landscape adapting to the vistas created by the new movement layer on the Station Square. These entrances are articulated as stereotomic structures, while the main entrance responds perpendicularly to the new "meeting point" within the landscape, mimicking the porte cochere of the Main Station building.

main circulation
brt platform
brt control
retail
kiosk
office
servicing
ablution

 ground floor plan

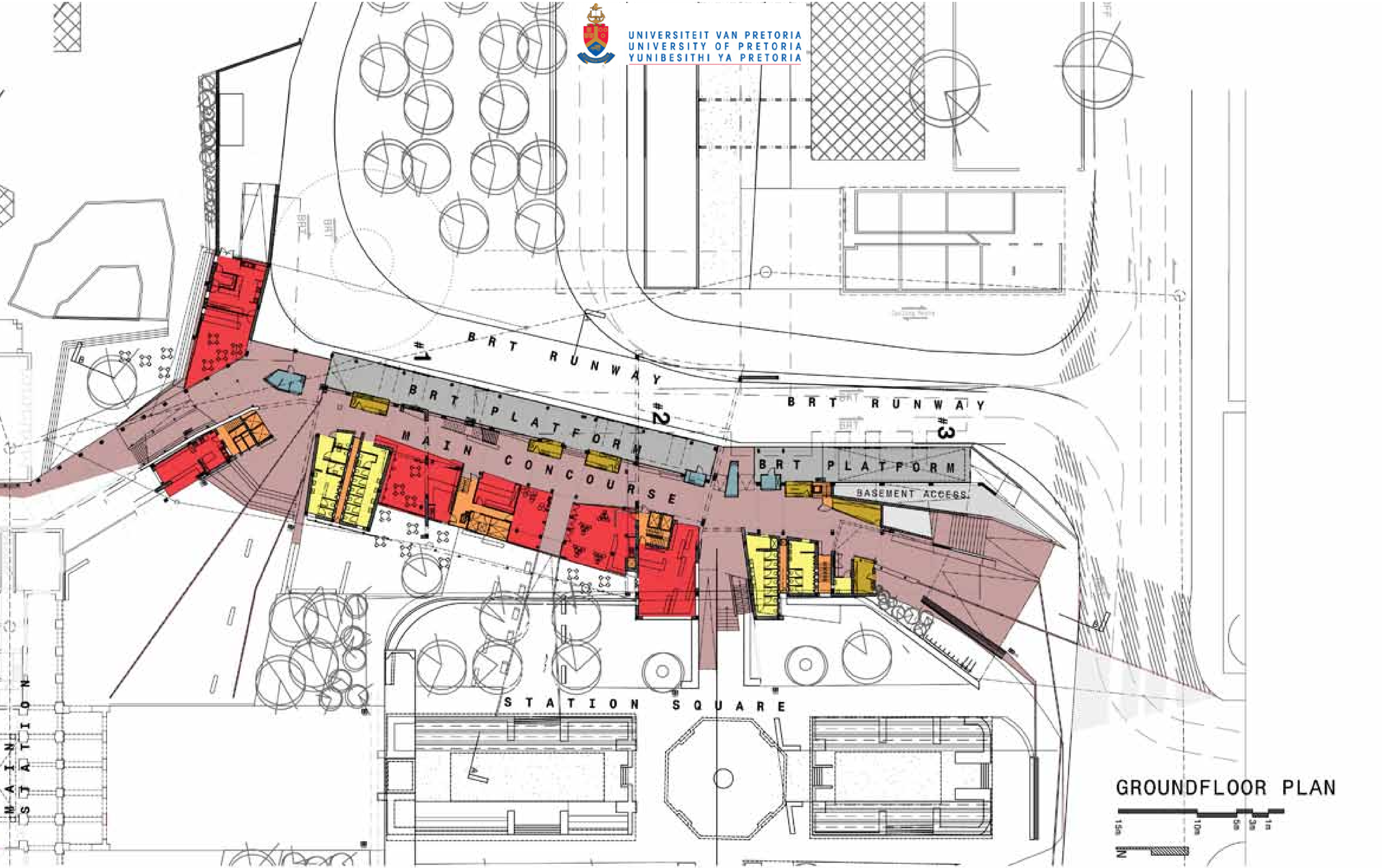
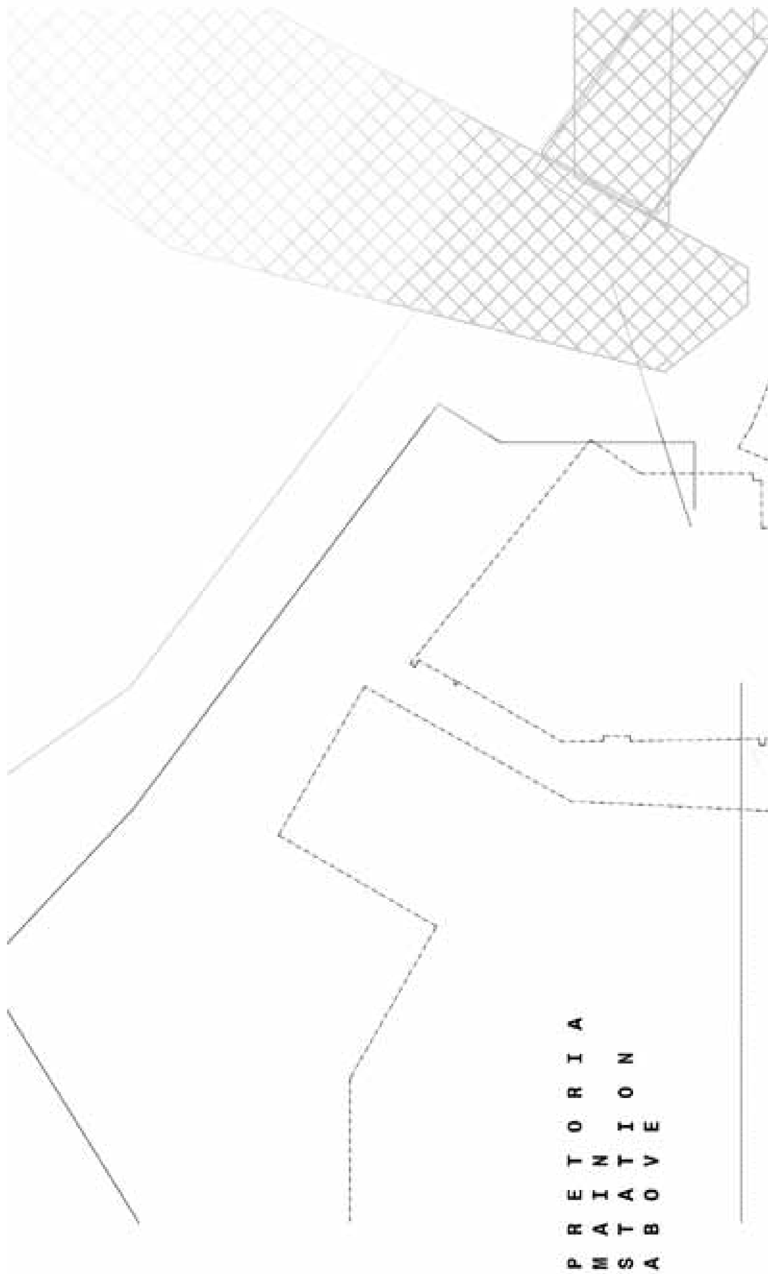


Figure 8-06: Ground floor plan, not to scale [Source: Author]

9.5 Semi-basememt

A semi-basement is constructed under the BRT platform to ensure access for services to the retail spaces as well as providing underground storage Cycling parking and shower facilities are constructed under the arcade, promoting the use of bicycles as transport medium.

- main circulation
- brt platform
- brt control
- retail
- kiosk
- office
- servicing
- ablution



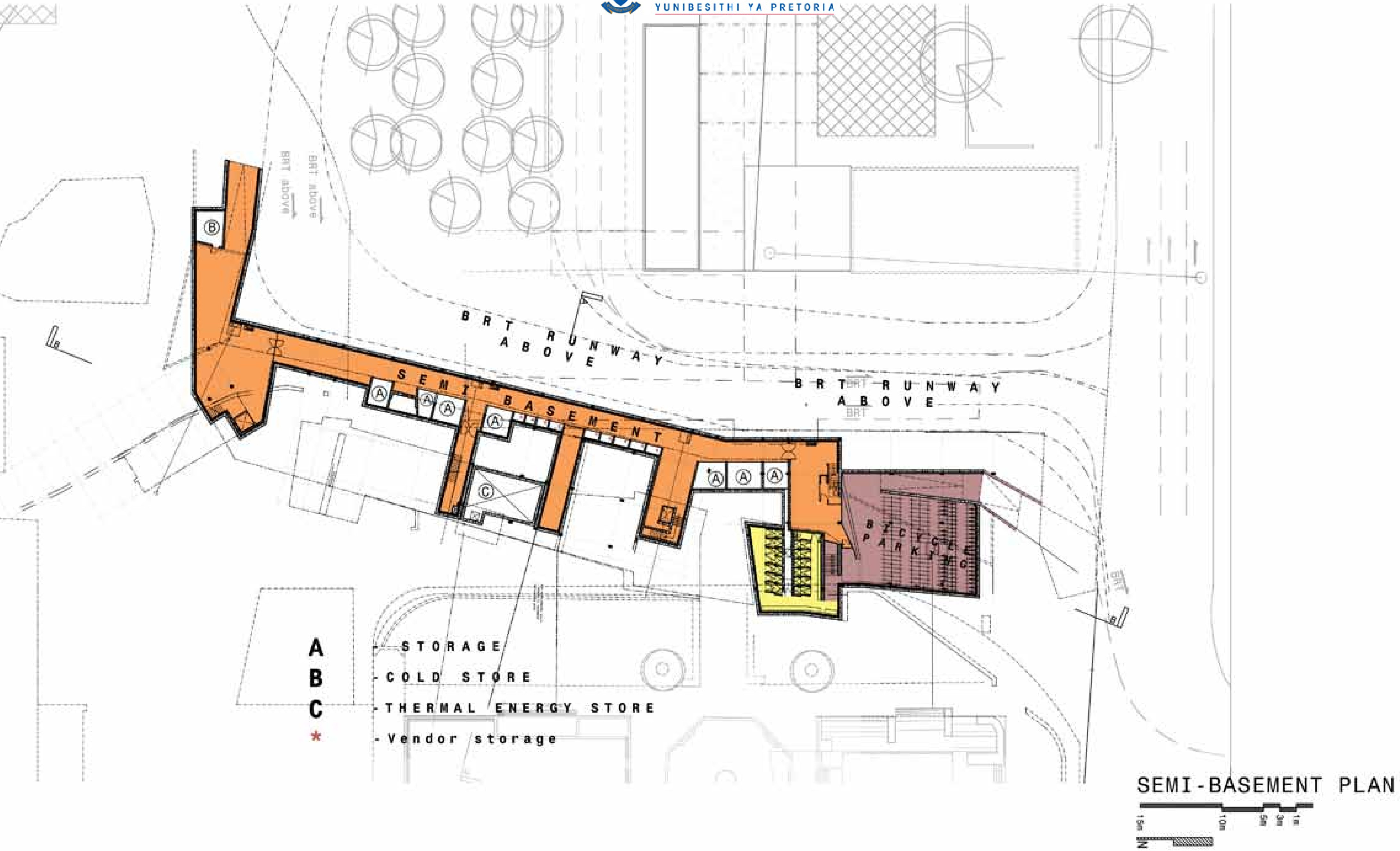


Figure 8-07: Semi basement plan, not to scale [Source: Author]

9.6 First floor

This level connects directly with Salvokop and becomes a combination between a bridge structure and a roof for the BRT station below.

A series of small shops and spaces for vendors are placed along this bridge to provide passive surveillance and harness the economic potential generated by the station and movement of people.

At the northern termination of the bridge a roof covers the walkway, merging the public bridge with the station building. Security offices and a police deck are place at one of the entrances to the station.

Office functions were identified as private den-like spaces in the conceptual investigation [refer to section 6.2.1.]To ensure privacy the office functions [Hotdesking, rentable boardroom and Management offices] are placed on the first floor to with a series of thresholds between these spaces and the the public realm.

main circulation
brt platform
brt control
retail
kiosk
office
servicing
ablution

 first floor plan

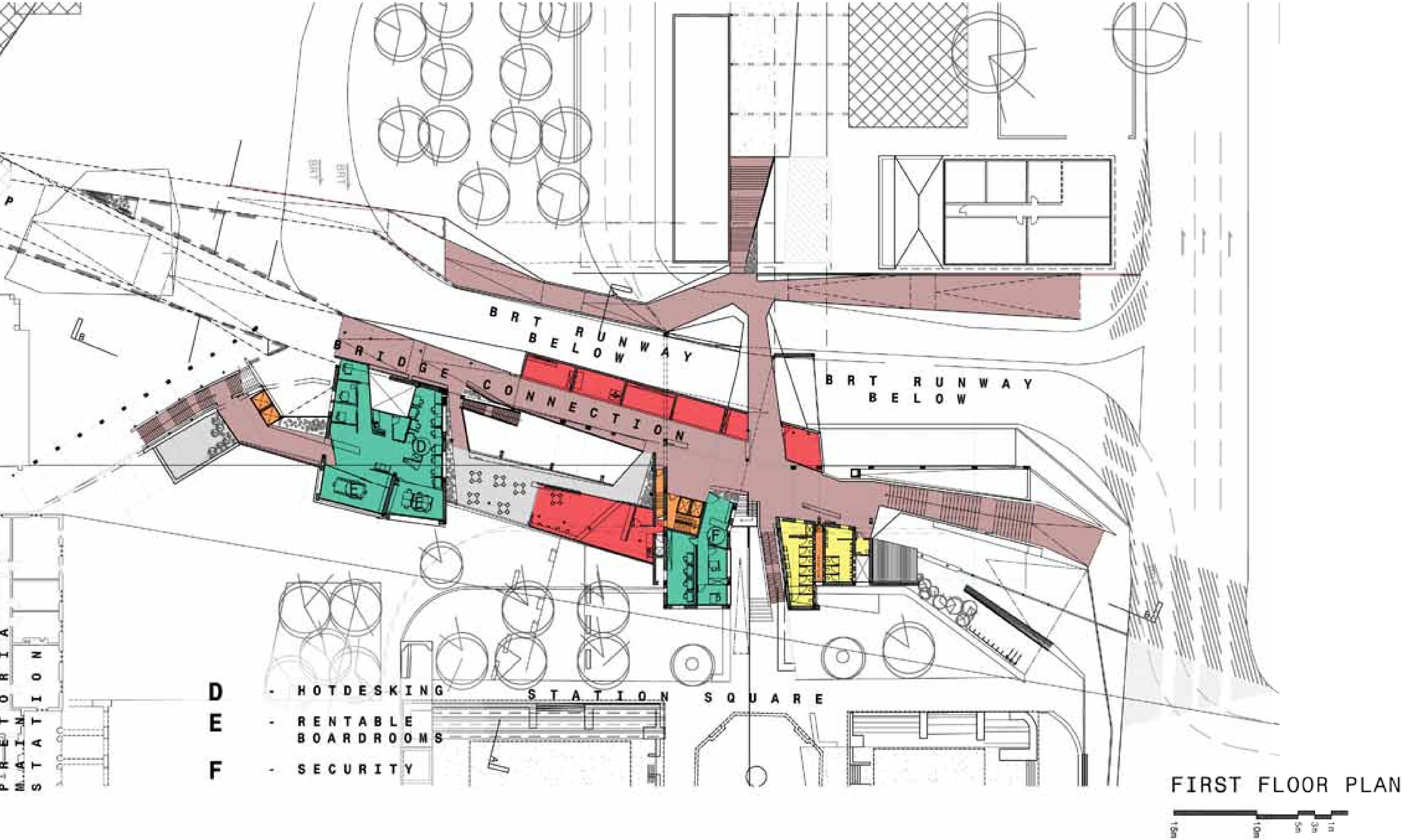


Figure 8-08: First floor plan, not to scale [Source: Author]

9.7 Second floor

The BRT control office is positioned within the stereotomic core. This signifies the importance of the function within the BRT systems as well as a ensuring more private and secure space.

It is accessed with a separate staircase that acts as a threshold for the private space. One of the lifts also directly link the office with the basement and other floors.

The office layout is designed around the manipulation of objects in space to control and guide movement through the space. These objects are articulated as a series of skins that wrap around the space.

The office consists out of two open plan office spaces where the different BRT lines [future lines 1-6] is monitored. A seperate superviser's office and boardroom allows for privacy for its users. While a series lounges and balconies allow for enough leisure spaces for the office workers.

The kitchen and boardroom are positioned close to each other ensuring that the boardroom can also be used for staff lunches.

main circulation
brt platform
brt control
retail
kiosk
office
servicing
ablution

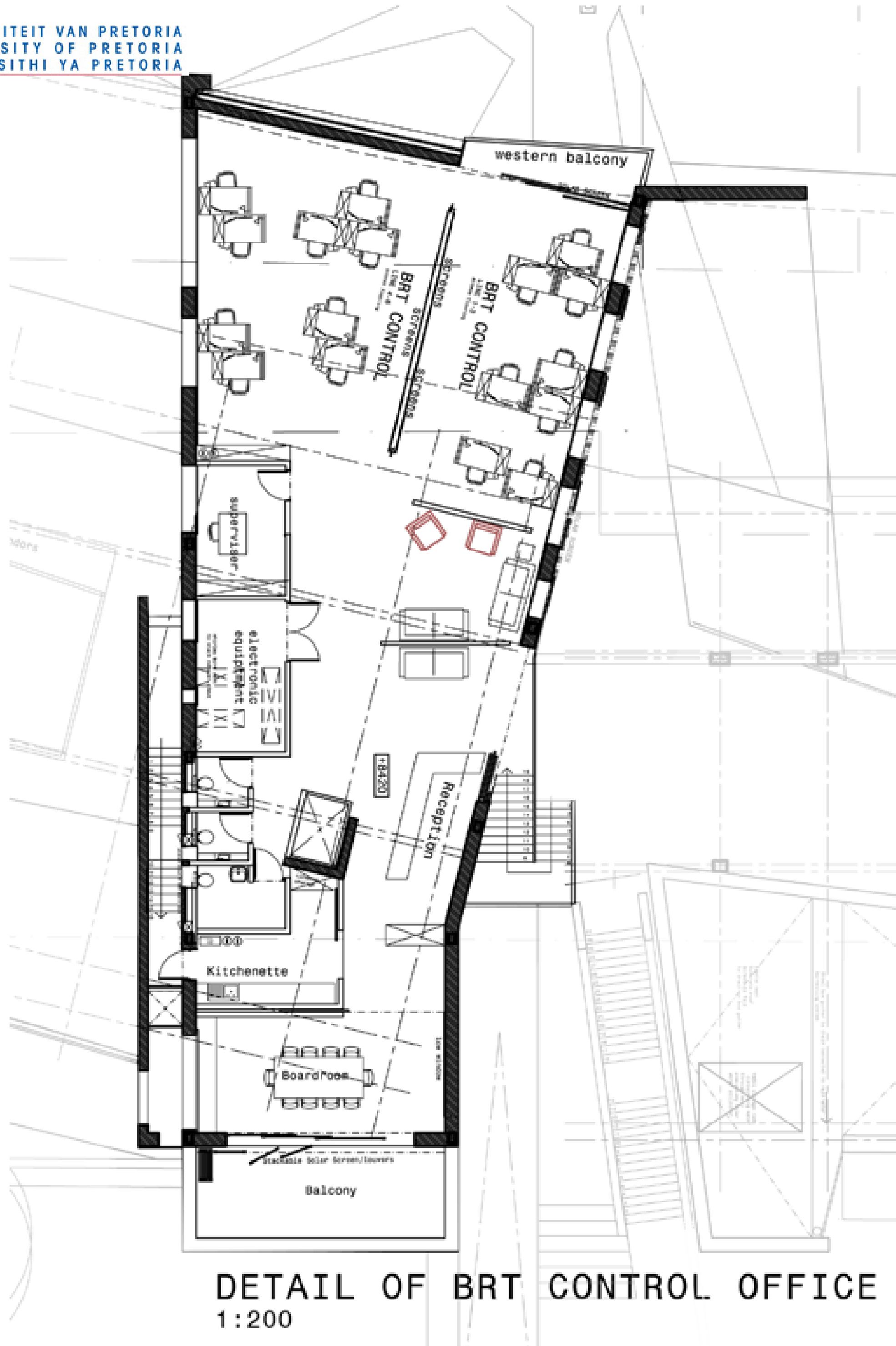
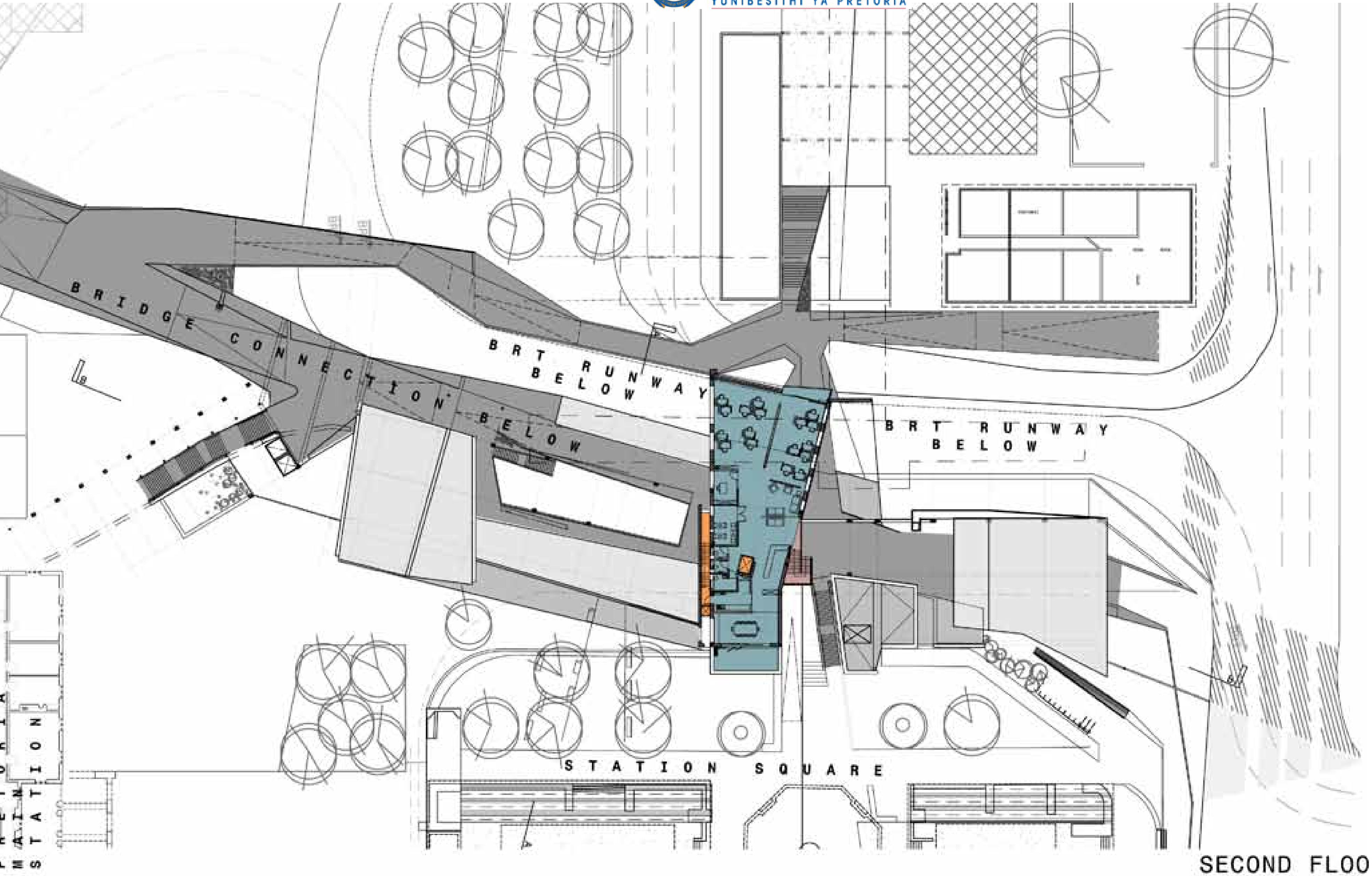


Figure 8-09: Detail plan of BRT control office [Source: Author]



SECOND FLOOR + BRIDGE

15m 10m 5m 3m 1m

Figure 8-10: Second floor and bridge plan, not to scale [Source: Author]

9.2 Western skin/edge

The western edge of the intervention is design as a controlled edge that will only allow commuters access to the BRT busses. It is enclosed with a series of glass screens that houses the BRT platforms.

Theses spaces are visually connected to the commuters in the main concourse and the space beyond, to ensure public safety and allow the commuters to see when busses are approaching.

Kiosks are placed within this transparent skin edge that service both the commuters on the BRT platform and the commuters moving through the arcade.

Existing buildings, new trees and bicycle bridge to the west of the station serve as external skins to the station to provide solar screening.

Small stores will also provide glare control to the central concourse to ensure a comfortable internal space.

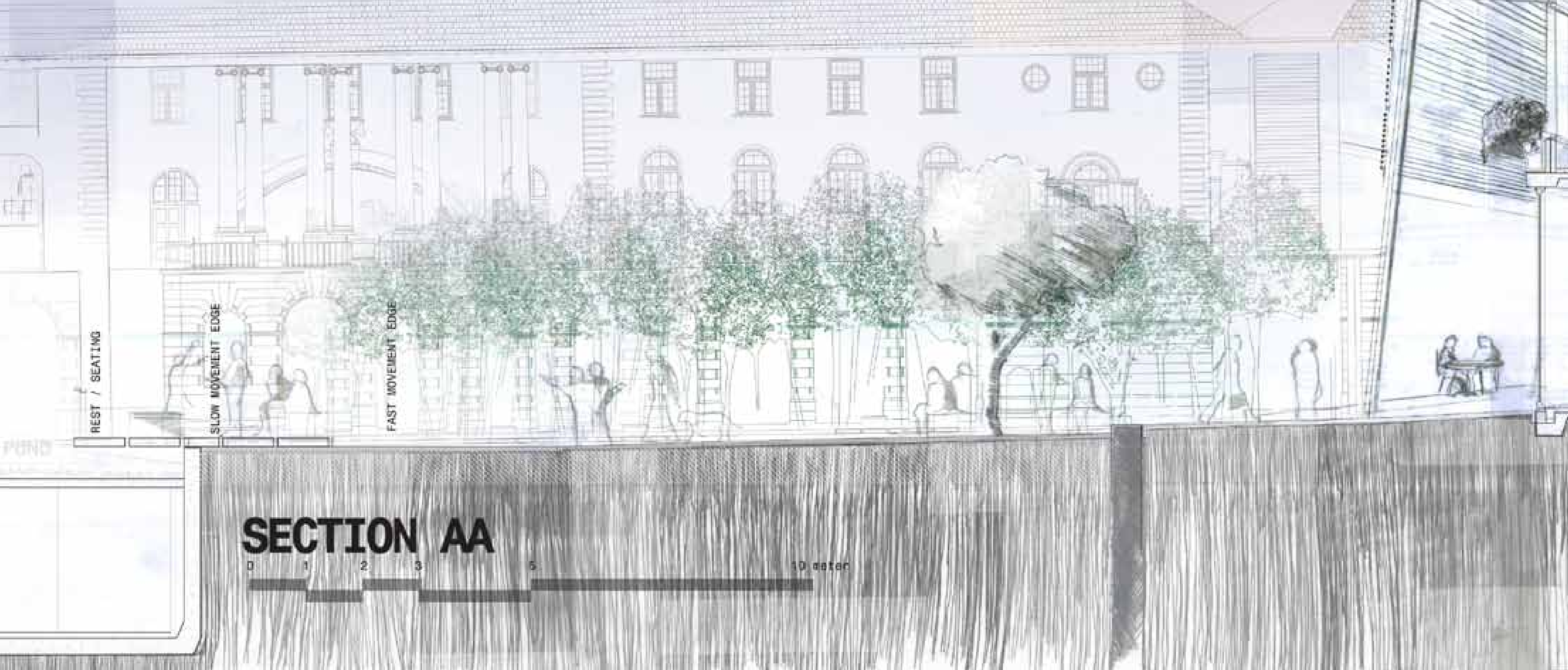
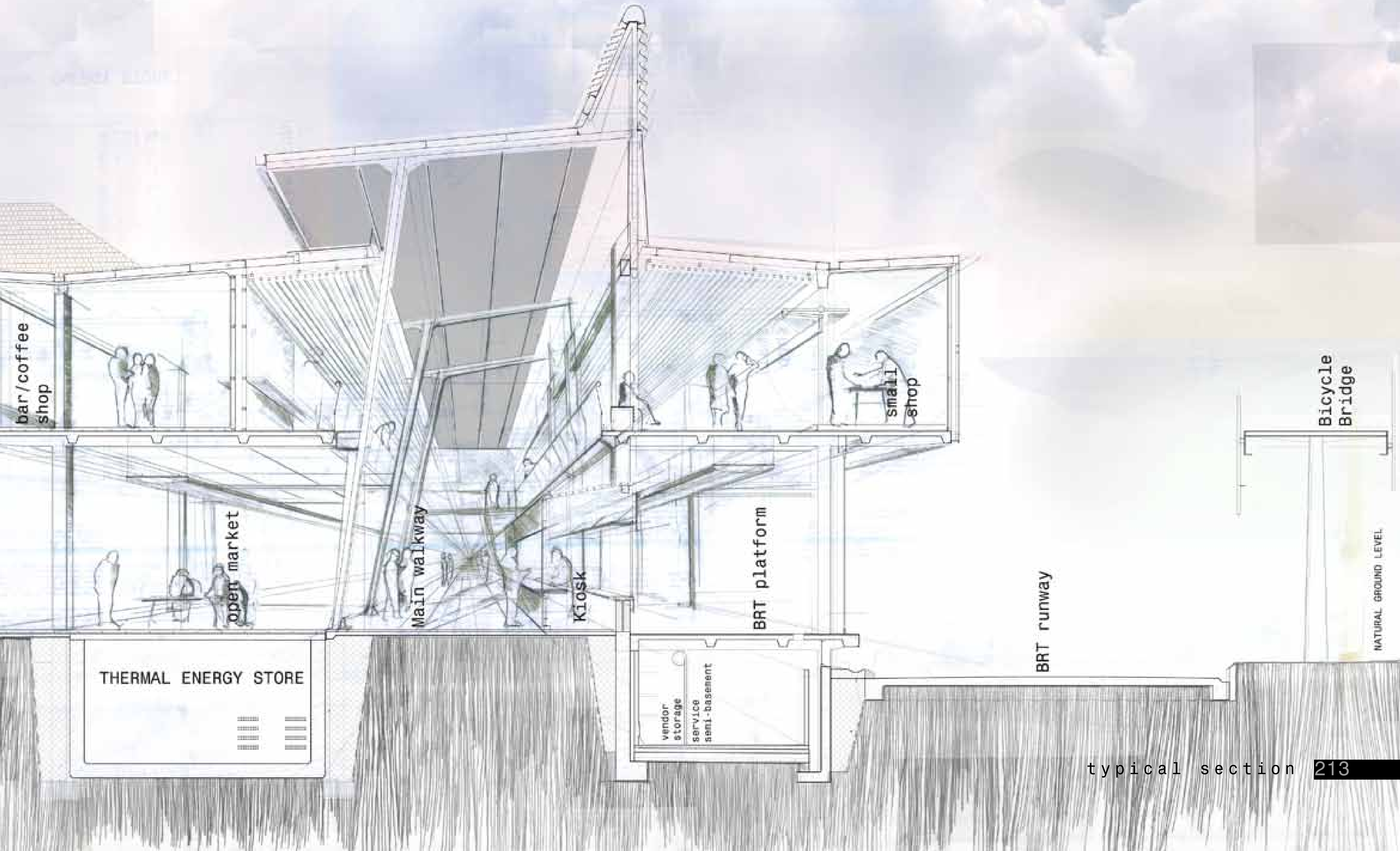


Figure 8-11: Section AA, not to scale [Source: Author]


bar/coffee shop
small shop
Bicycle Bridge
open market
Main walkway
Kiosk
BRT platform
BRT runway
NATURAL GROUND LEVEL
THERMAL ENERGY STORE
vendor storage
service semi-basement

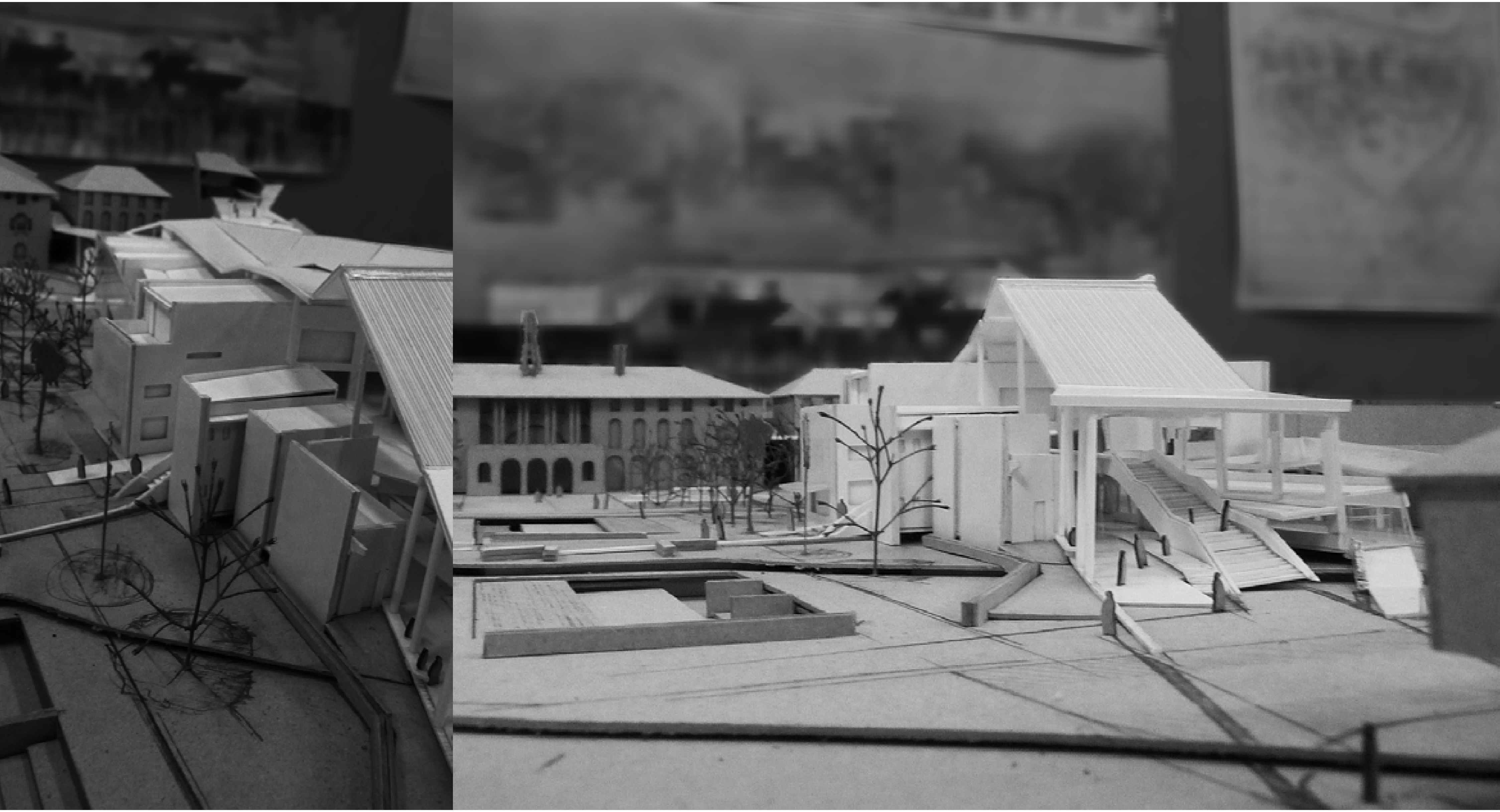


Figure 8-12: Building framing Station Square [Source: Author]

Figure 8-13: View of entrance
[Source: Author]

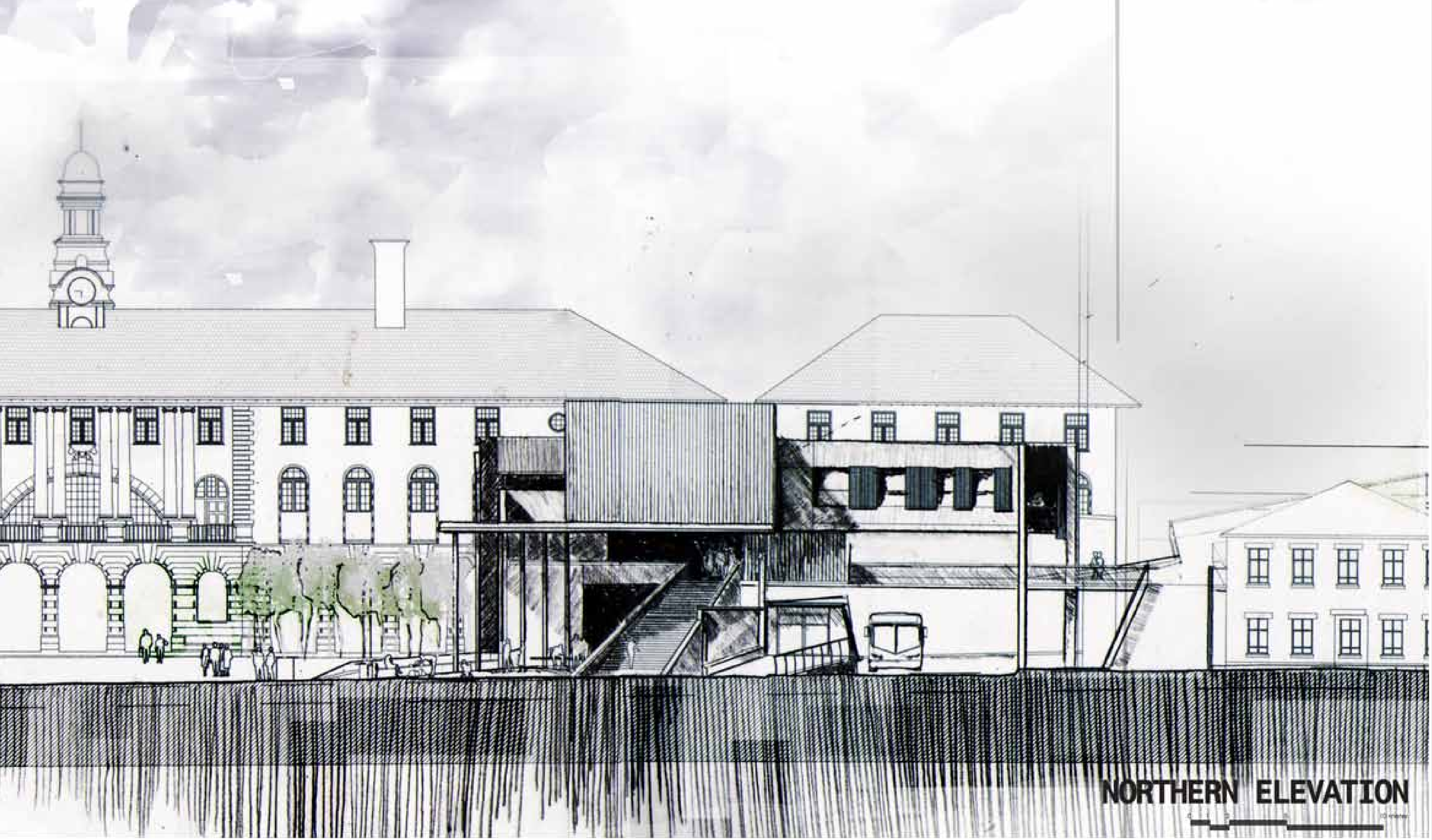
9.8. Scheiding street entrance

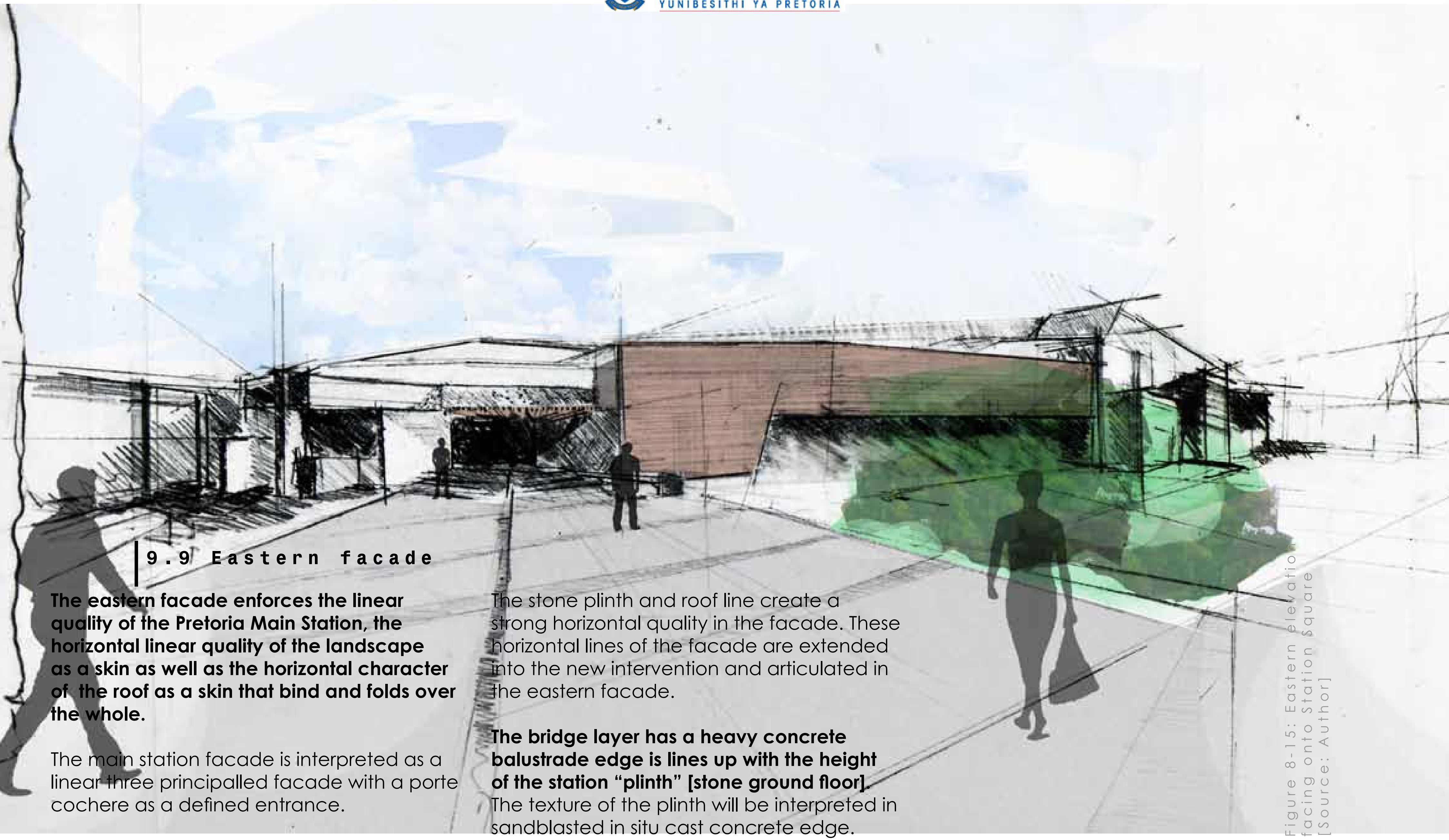
The intervention opens up to Scheiding street and functions as an entrance to the bridge and the station building. The tiled floor finish of the arcade is continued as a new layer onto the sidewalk to **overlap, merge and extend the threshold between the building and the city.** As the commuter enters the building the use of a ramp up to the station level provides a slow transition between the two spaces. The staircase to the Salvokop bridge rises like a monolithic skin from the sidewalk linking Salvokop with the city.

The main roof is articulated as an inviting open structure that draws the commuter into the building. By lifting the roof above the functional spaces the intervention retains its quality as an open hollow structure.

The roof lines up with the Old Tavern next door in an effort to unify street edge and building heights.

Figure 8-14: Northern elevation, not to scale [Source: Author]


NORTHERN ELEVATION



9.9 Eastern facade

The eastern facade enforces the linear quality of the Pretoria Main Station, the horizontal linear quality of the landscape as a skin as well as the horizontal character of the roof as a skin that bind and folds over the whole.

The main station facade is interpreted as a linear three principalled facade with a porte cochere as a defined entrance.

The stone plinth and roof line create a strong horizontal quality in the facade. These horizontal lines of the facade are extended into the new intervention and articulated in the eastern facade.

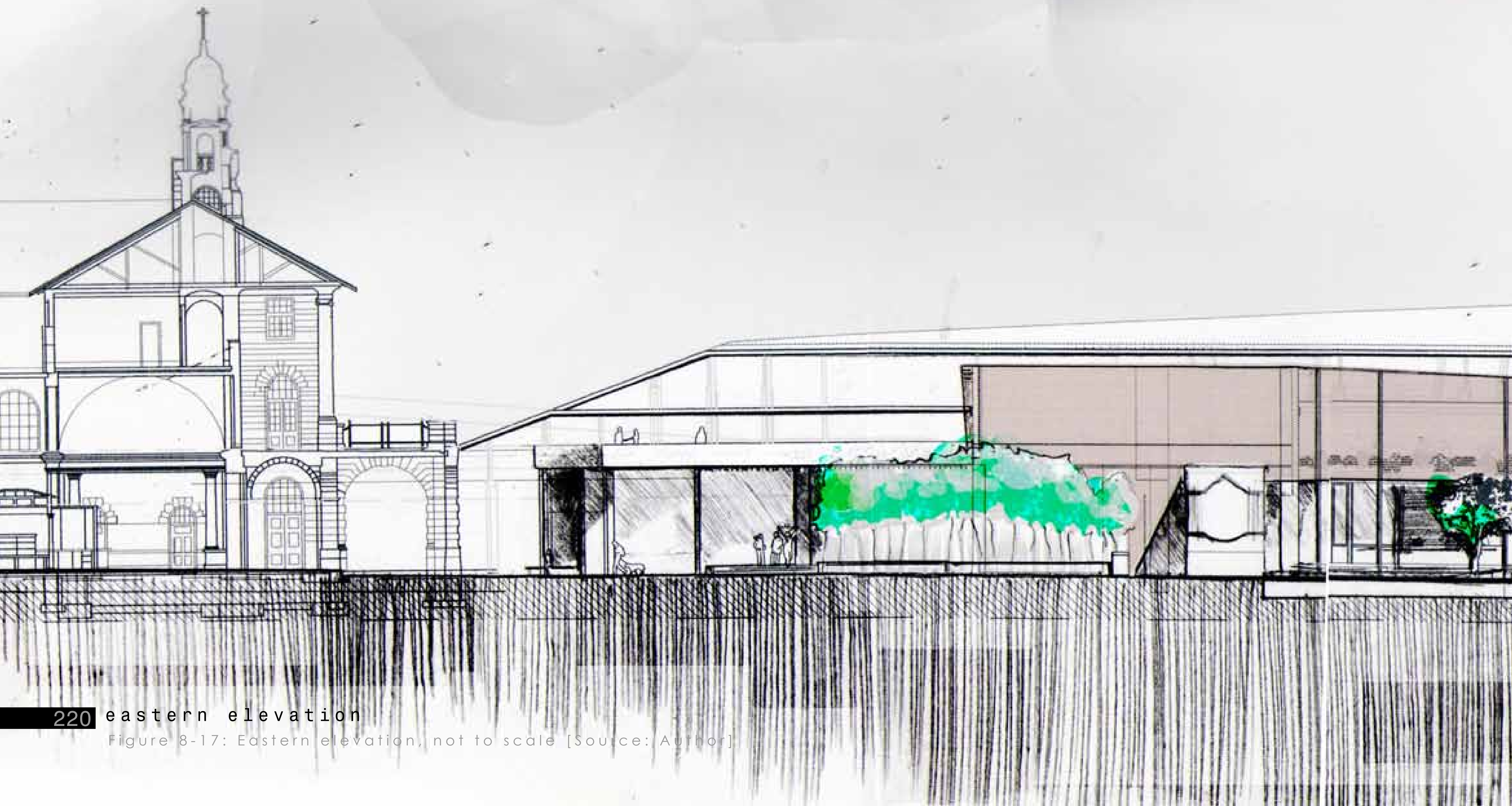
The bridge layer has a heavy concrete balustrade edge is lines up with the height of the station "plinth" [stone ground floor]. The texture of the plinth will be interpreted in sandblasted in situ cast concrete edge.

Figure 8-15: Eastern elevatio
facing onto Station Square
[Source: Author]

Figure 8-16: Main entrance into station [Source: Author]

Timber and steel screens wraps around, through and behind the entire facade, binding the building together and framing the Station Square. Horizontal lines are articulated throughout the screen. The screen provides a comfortable slow transition between the internal and external spaces. The screen also provides glare control creating a comfortable indoor environment.

The roofs enforce the horizontality of the intervention unifying the whole. The roof membrane folds over the stereotomic cores, on the southern edge it slips in between the main station and the newer station addition, while at the northern edge it opens up to the street.

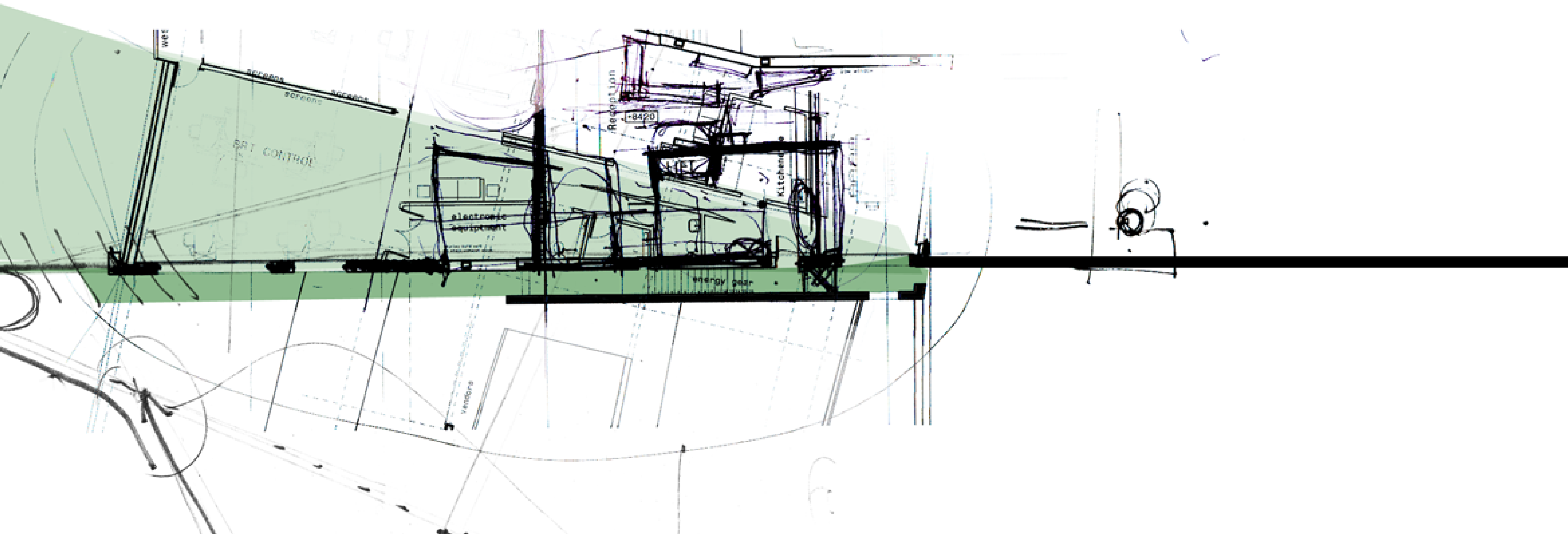


 eastern elevation

Figure 8-17: Eastern elevation, not to scale [Source: Author]

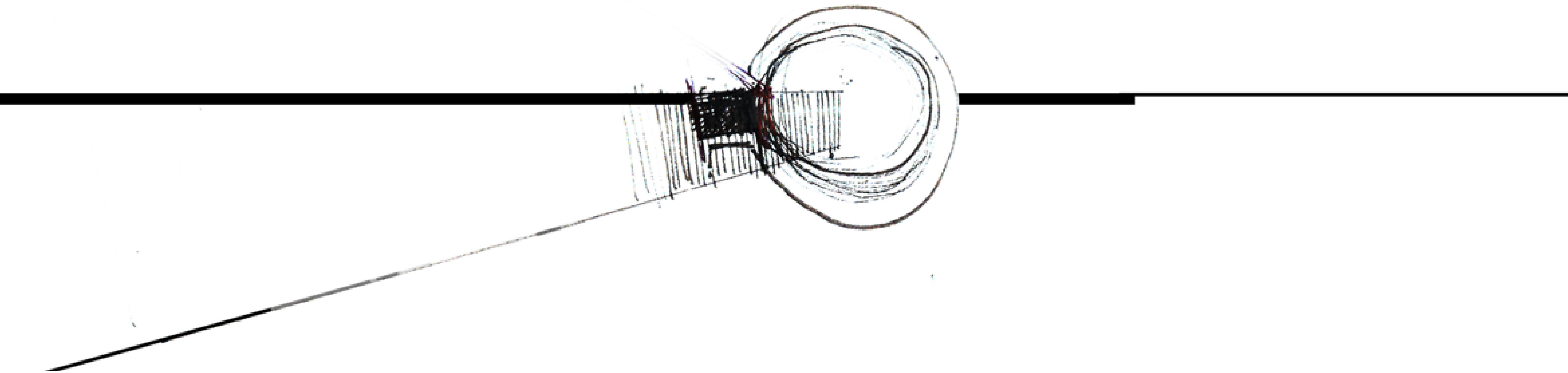
EASTERN ELEVATION

Figure 8-18: Section BB, not to scale [Source: Author]


screens
screens
screens
BRT CONTROL
Reception
+8420
electronic
equipment
Kitchen
energy gear
vendors

10

TECHNICAL INVESTIGATION

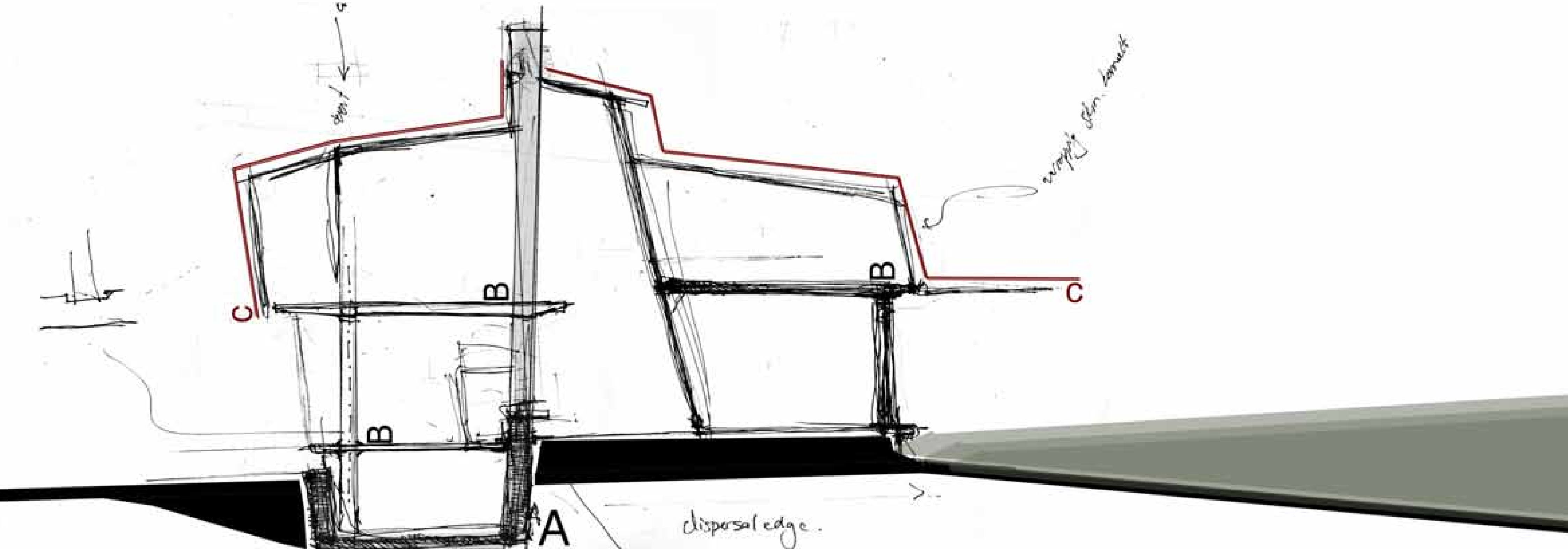


A sustainable approach requires a clear understanding of the whole - the goals for the project, the user and their needs and the context. The focus during the technical investigation phase of the study were the following:

a) Passive design approaches and systems was investigated and developed to ensure that the transport interchange is energy efficient.
b) The embodied energy of the structure is minimised by optimising material use, using efficient structural systems and dematerialising building components through multi use and minimisation [GBSCA 2008:231].
c) Material use was ascertained through embodied energy calculations as well as the efficiency of structural systems.
d) Materials and structural systems was chosen to ensure more a robust, climate change sensitive structure.
e) The existing historical context informed the material use and structural system.
f) Future adaptability of the structural system.

10.1 STRUCTURAL SYSTEMS

The BRT terminal building consists out of three structural systems/components, as indicated in Figure 9-01.



A _ vertical skin - building -sterotomic
B _ lifting skin - landscape -tectonic - horizontal
c _ wrapping skin - the cover - adaptable - control

TYPICAL SECTION

Figure 9-01: Conceptual approach to structural system [Source: Author]

10.1.1 System A [vertical stereotomic layers] "THE BUILDING"

Two solid stereotomic structures mark the entrances into the terminal building.These are positioned on important points identified during conceptual stage. The stereotomic structures refer to the solid facade of the Pretoria Main Station, and the layered and extended threshold into the station building. These structures respond in the same manner to the new movement layers/system superimposed on the Station Square and extend the threshold into the building.

The core points are reinforced concrete framed structures with concrete block infill. The depth and thickness of the concrete block infill will be articulated by fixing the doors or windows to the inside face of the walls.

This will become a series of solid vertical skins that are referred to as "the BUILDING" of the structure. The horizontal articulation of the Pretoria Main Station porte cochere is extended into the new intervention. These horizontal lines is articulated on the east facing screens of the intervention.

The north facing office functions will be housed within these solid structures, by using the thermal mass and correct orientation a comfortable indoor environment will be achieved [Holm 1996:71; SANS 204-2:33].

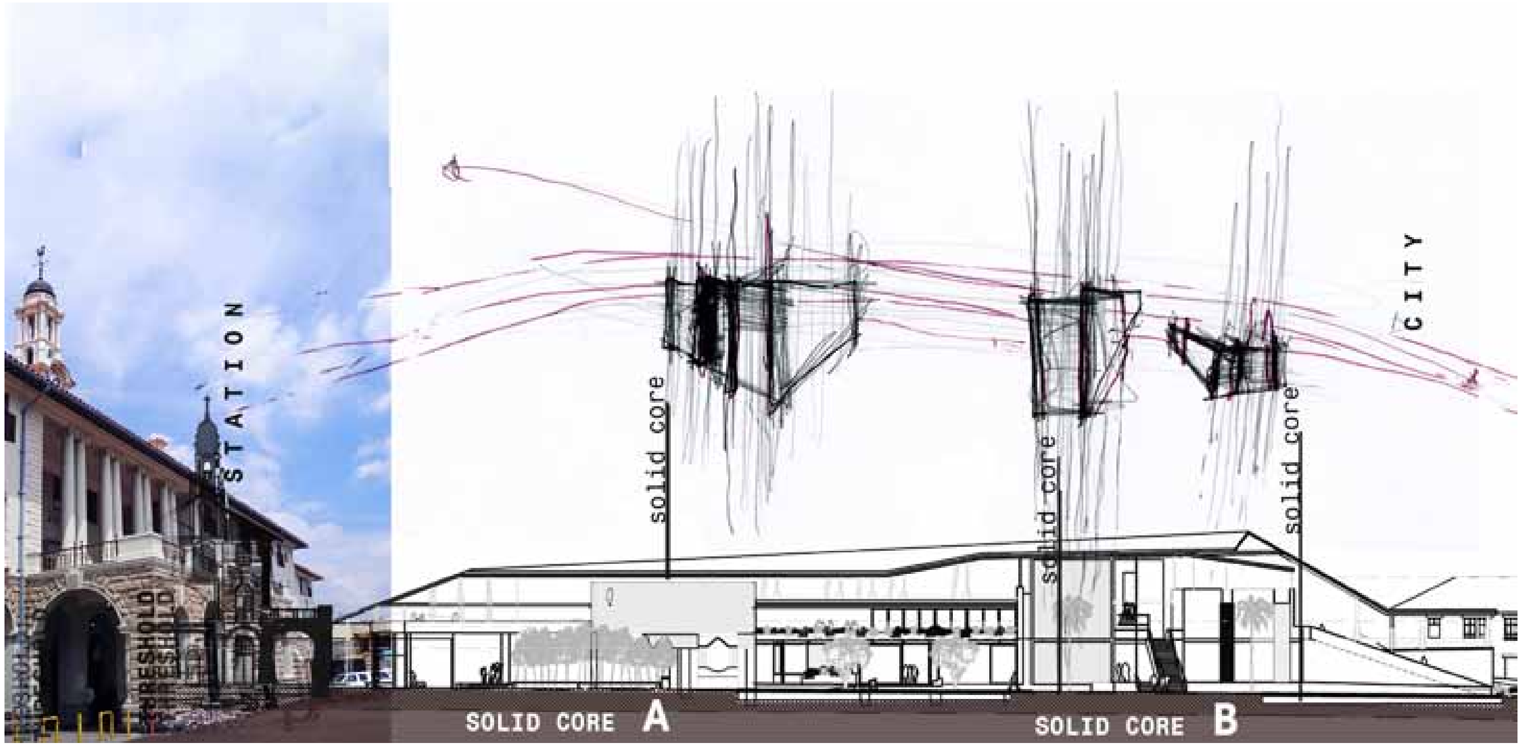


Figure 9-02: Solid cores referring to the port cochere entrance of the station [Source: Author].

10.1.2 System B [horizontal tectonic layers] "THE LANDSCAPE"

The second structural system is seen as a series of adaptable, linking skins that connect Salvokop with the city and the BRT terminal building with the rest of the station functions. The proposed bridge extends from the edge of Salvokop and terminates on the edge of the Station Square – creating a new park over the railway lines. These linear structures will respond to the horizontal lines of the Pretoria Main Station's facade.

The structural system is a concrete column, beam and slab system – that articulates the horizontality of the structure. These structures fixed between the corepoints and existing station are an adaptable open "LANDSCAPE" of structural skins.

The structural system also refers to the open "hollow" foyer space of the Pretoria Main Station building. It creates open adaptable spaces along a central arcade, which accommodate movement through the building. The arcade allows the user to experience the changes of movement on the edges of the structure. The framed structure ensures adaptability as infill material can easily be fixed between these column structures.

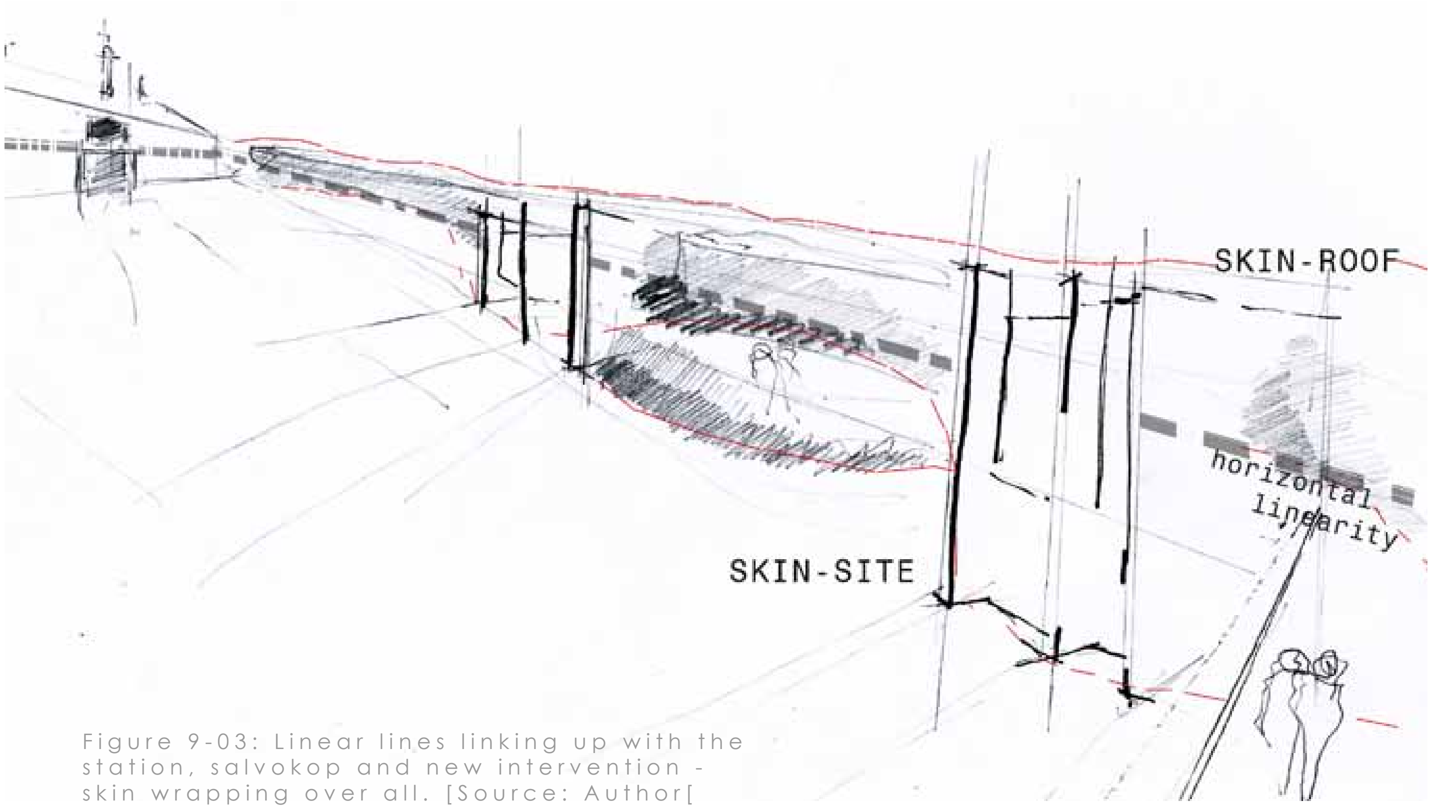


Figure 9-03: Linear lines linking up with the station, salvokop and new intervention - skin wrapping over all. [Source: Author[

10.1.3 System C
[wrapping tectonic structure]
"THE SKIN"

"THE SKIN", is a light tectonic structure that wraps over the different spaces and binding the intervention together. This is articulated as a series of skins that adapt and change to provide the following services:

a) Shade and shelter.
b) Open and close to prevailing winds.
c) Extract, contain and transmit heat.
d) Generate energy and harness heat.
e) Acts as a medium to integrate the landscape with the building.

The skin structure will be a composite system – steel, timber, composite timber and resin slats, glass and polycarbonate sheeting.

The skin will frame the Station Square to reinforce the building as an edge to the square.

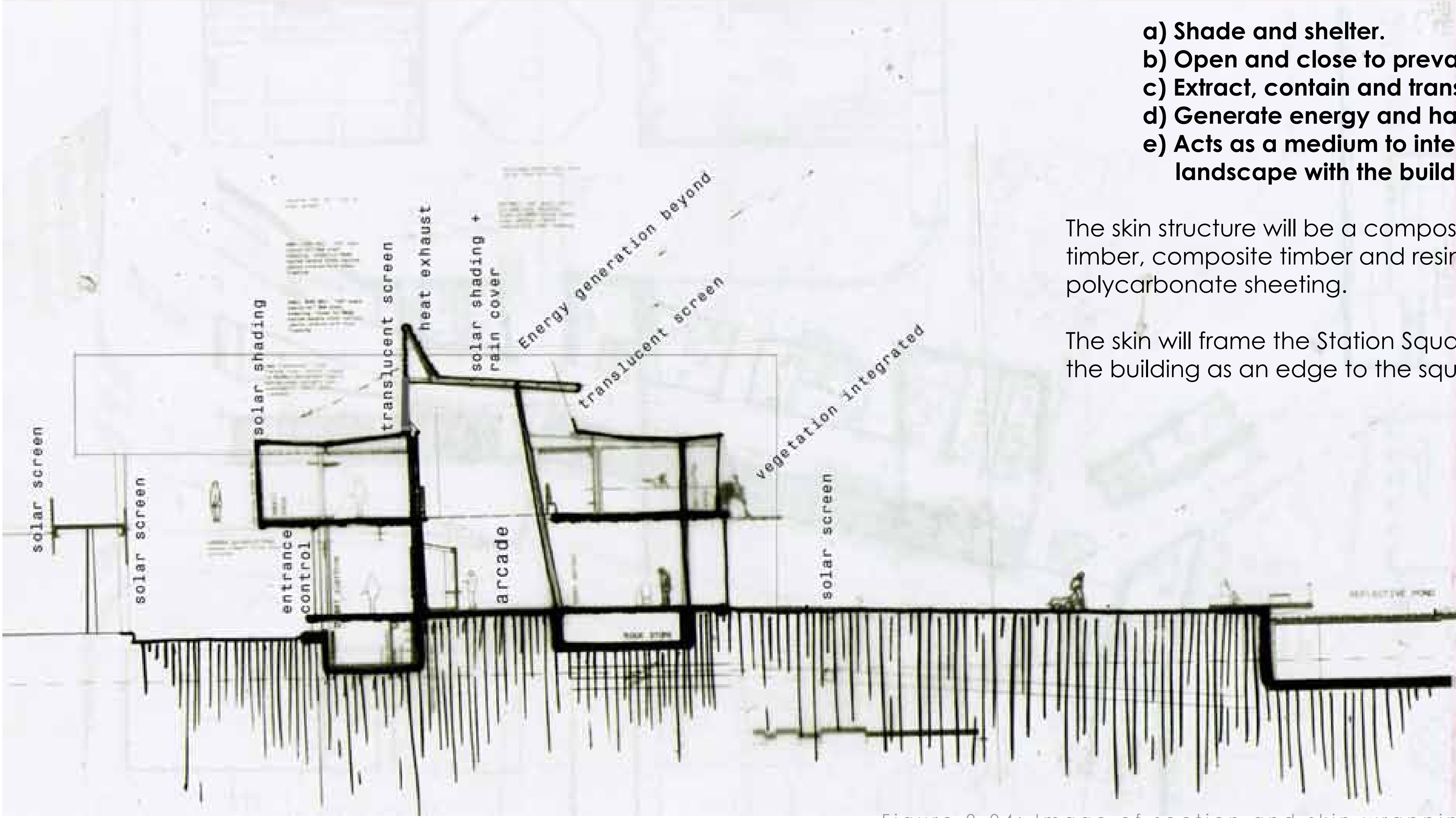


Figure 9-04: Image of section and skin wrapping [Source Author].

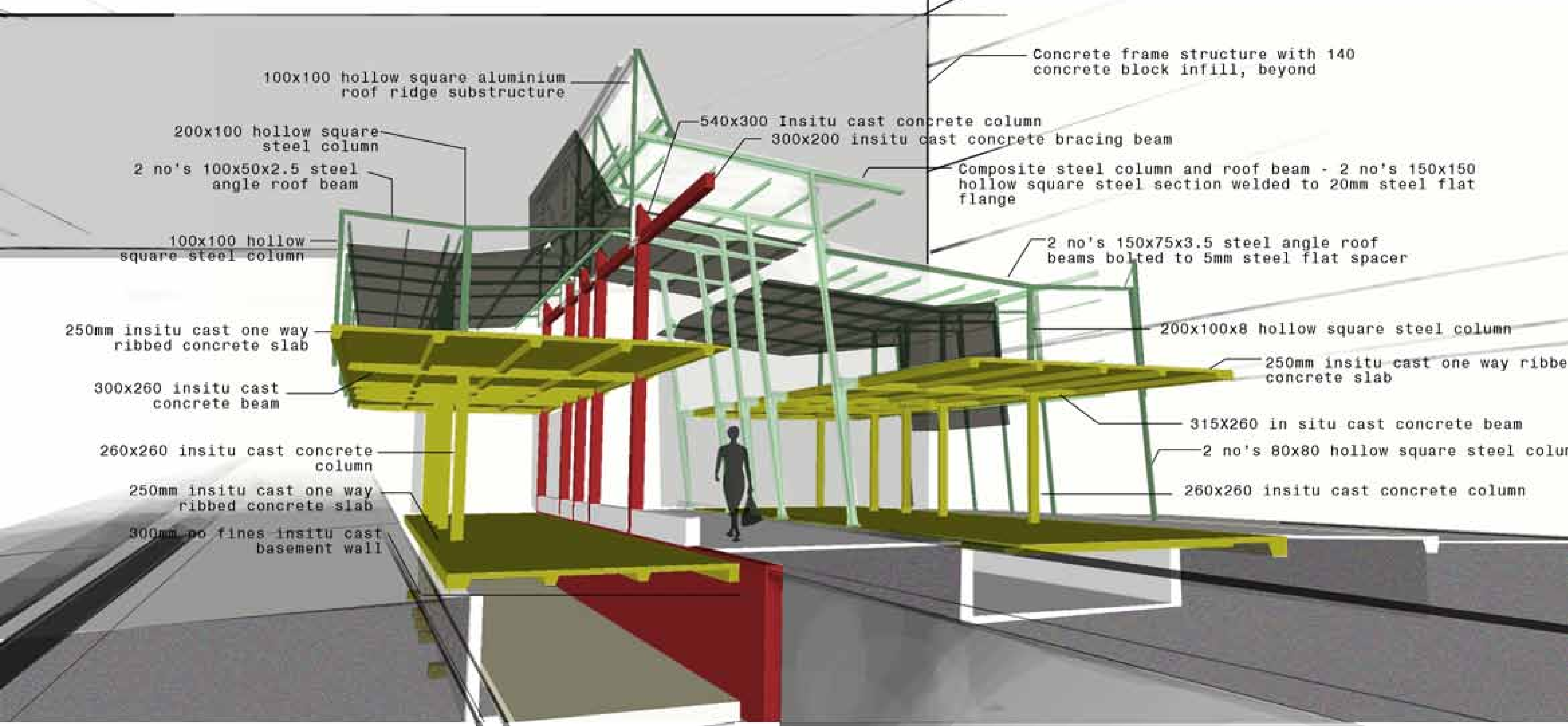


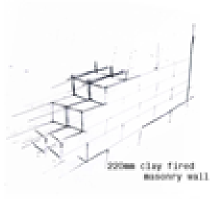
Figure 9-05: Structural components and system [Source Author].

10.2 MATERIAL CHOICE AND FINISH

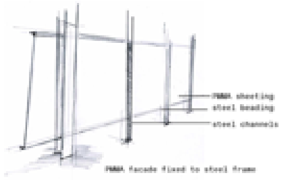
The material choice for the BRT terminal building was determined by:

- **a) Embodied energy and carbon footprint.**
- **b) Robust nature and durability.**
- **c) Suitability to respond to the historic context.**

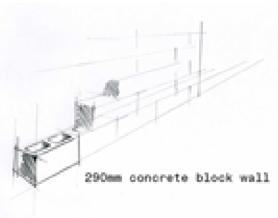
wall



Facebrick
1282 MJ/m²
95 kg CO_2/m²



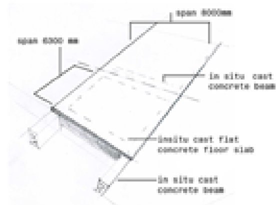
PMMA & Steel
694 MJ/m²
32 kg CO_2/m²



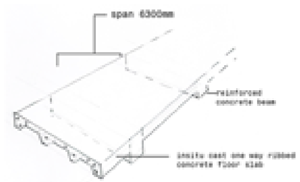
Concrete block
336 MJ/m²
41 kg CO_2/m²

floor slab

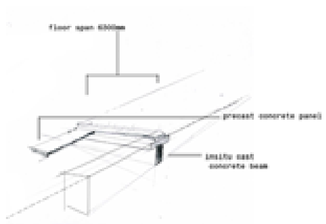
span 6.3 meters



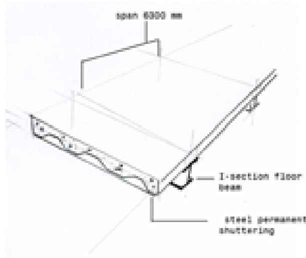
Flat concrete slab
685 MJ/m²
72 kg CO_2/m²



Ribbed concrete slab
585 MJ/m²
62 kg CO_2/m²

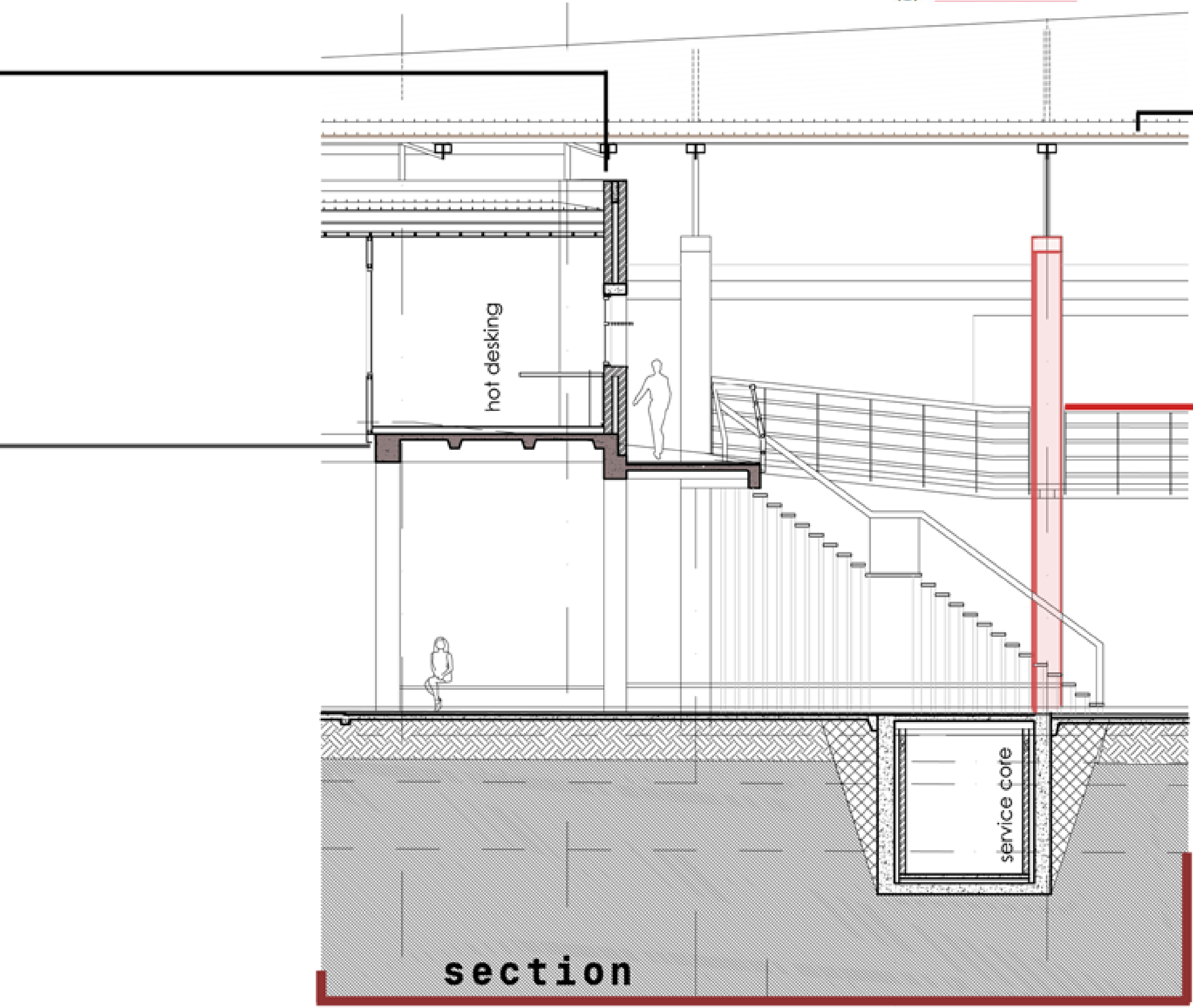


Precast concrete panels
775 MJ/m²
82 kg CO_2/m²



Permanent steel shuttering "QC slabs"
1695 MJ/m²
143 kg CO_2/m²

Figure 9-06: Calculating the embodied energy and carbon footprint of different building components [Source: Author]



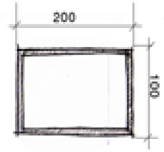
roof

Steel sheeting
264 MJ/m²
19 kg CO_2/m²

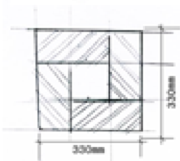
PMMA sheeting
455 MJ/m²
14 kg CO_2/m²

column

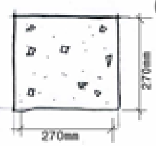
height 4 meters



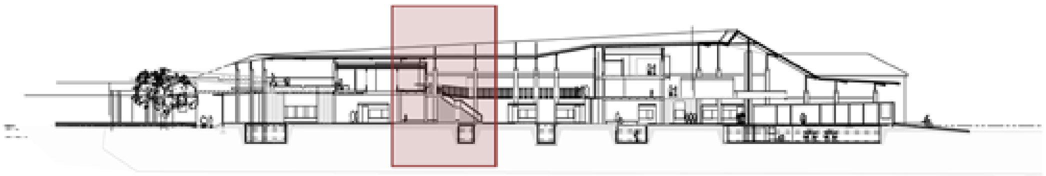
Steel
471 MJ/m
35 kg CO_2/m

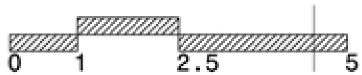


Masonry
613 MJ/m
45 kg CO_2/m



Concrete
392 MJ/m
41 kg CO_2/m





10.2.1 "Building" [A]

Insitu cast concrete frame structure
After analysing different column and floor systems it was concluded that in situ cast steel reinforced concrete column, beam and floor structure has the lowest embodied energy and carbon footprint. Refer to tables 13-04 to 13-09, pg 282-285.

It was also concluded that one way ribbed concrete slab will be the most efficient system. The floor span is 6,3 m with a 250mm deep concrete floor slab. The main concrete columns along the arcade are 540x300mm [1/18 slenderness ratio].

The in situ cast concrete columns and beams are sandblasted to ensure a rough texture – referring to the sand stone plinth of the station.

Concrete block infill
Concrete blocks are used, creating heavy vertical layers. These are cavity walls that are 390mm thick, using 140x190x190 blocks. This ensures that the wall has a high thermal mass, while the cavity will contribute significantly to the insulative value of the wall [Joubert 2010:37].

After analysing different wall systems, it was concluded that concrete block walls will be the most energy efficient to use. A 290 concrete block wall saves up to 75% carbon when compared to 220 facebrick wall. Refer to table 13-05, pg 283.

The concrete block wall will have raked joints to ensure that the masonry units are still visible after plastering and painting the walls. The texture and masonry units refers to the manner by which the station building is articulated.

Thermal resistance of a concrete block wall with a cavity

$R = 1/h_o + d_x/k_x + 1/h_c + d_y/k_y + 1/h_i$

$R = 1/28 + 0.14/1.5 + 1/5.3 + 0.14/1.5 + 1/20$
$= 0.46\ m^2k/w$
$U = 2.17\ w/m^2k$

Thermal resistance of a concrete block wall without a cavity

$R = 1/h_o + d_x/k_x + 1/h_c + d_y/k_y + 1/h_i$

$R = 1/28 + 0.28/1.5 + 1/20$
$= 0.27\ m^2k/w$
$U = 3.7\ w/m^2k$

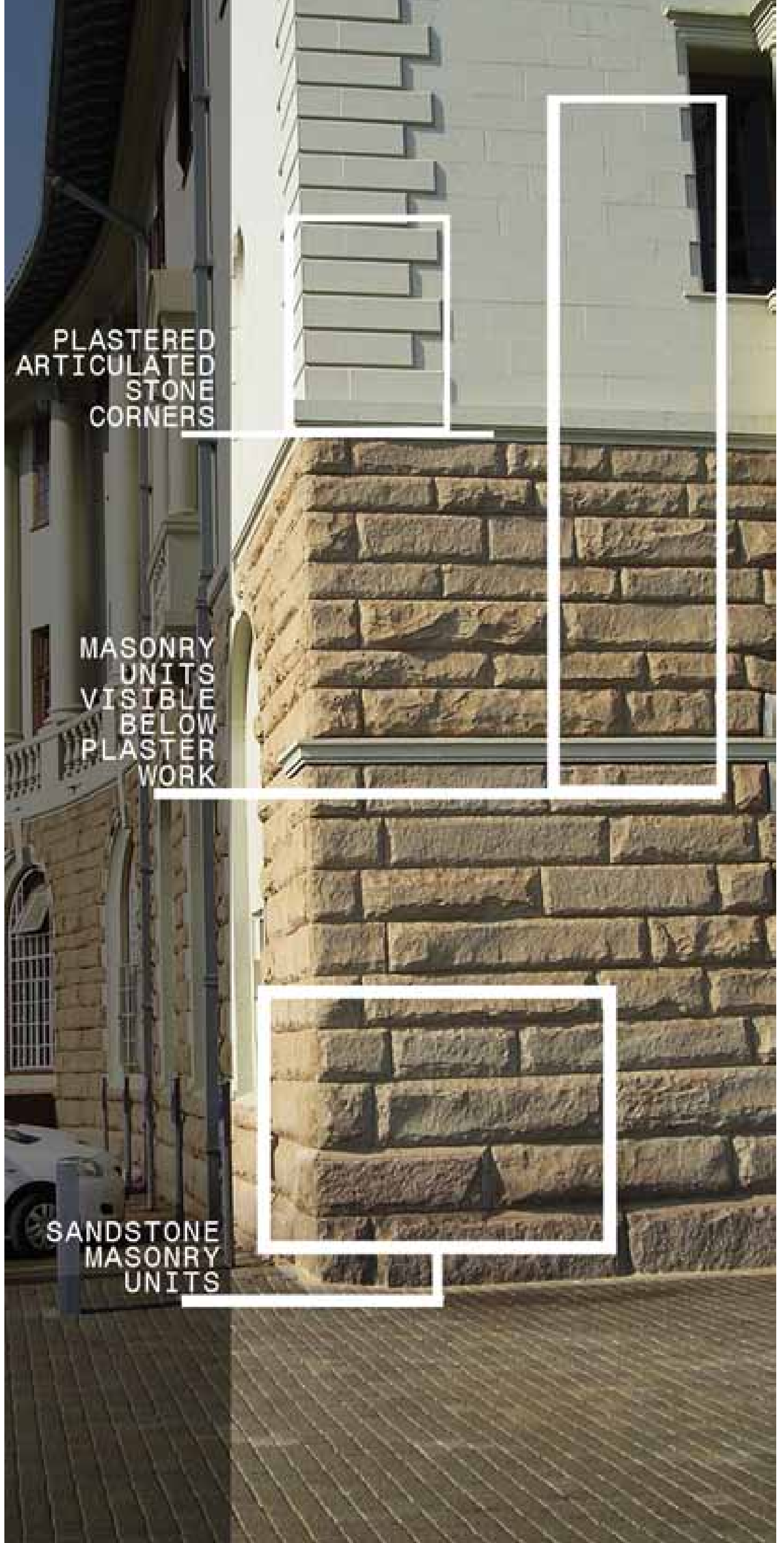


Figure 9-07: Materiality of the Pretoria Main Station wall [Source: Author].

Figure 9-08: Floor finish in Pretoria Main station [Source Author].

Figure 9-09: Natural colours of Salvokop[Source Author].

10.2.2 "Landscape" [B]

Insitu cast concrete frame structure
The structural system is off-shutter in situ cast concrete columns with 250mm deep one way ribbed floor slabs and with 315x260mm floor beams. The columns on this section will be 260x260mm [slenderness ratio1/18].

The floor beams are cantilevered on each side in an effort to use less material [Birsch 2002:252]

The concrete columns and beams is cast in smooth steel formwork panels, which are reusable.

Floor finish.
The main concourse floor finish is ceramic tiles, referring to the tiled floor finish in the main station. **The floor finish extends into the new terminal building, linking the two structures and merging the boundaries.**

The floor finish of the bridging structure will be a 40 mm pigmented cement screed in shades of colours referring to the natural ground colour in Salvokop [Figure 9-09]. This will articulate the different movement routes [walking & cycling] as well as spaces on the bridge.

10.2.3 "Skin" [C]

The skin utilises different materials and finishes to respond specifically to its function, neighbouring buildings and the requirements of the internal environments.

Structural steel
Structural steel sections will be used as substructure for the wrapping "skin". Primary columns will be brought to site in sections and welded together and hand painted on site. Rafter beams and steel columns used higher up in the building will be galvanised and bolt fixed together on site. Highly exposed steel sections , the ridge ventilator, will be black anodised aluminium.

Roof material
Steel roof sheeting was chosen for its efficiency in material use. Refer to Table 4-01, page 130. **Brown Built roof profile sheeting is used, can be fixed at a very low pitch [min 1:60] and allows for a very efficient use of rafters, fixed at 1500 mm centres apart [Brownbuilt 2010].** The 0.58mm ISQ 300 steel sheets have interlocking profiles that uses a clip-fixing system and can be prepainted [Globalcoat^{tm}] [Brownbuilt 2010].

Clear sheeting

Clear polycarbonate sheeting is used to allow as much natural light in as possible into the main concourse. 10mm Translucent fluted "Lexan Thermon clear" sheeting will be used, it has very high weather resistance while transmitting 82% of visible light [Complex plastics 2010].The sheeting will clampfixed to galvanised steel subframes.

Solar screening

A solar screening device is used to create a defined edge on the western edge of the Station Square. **Composite recycled wood and resin slats are fixed to a handpainted steel substructure [Envirodeck].** The slats are composed of recycled 65% wood fibres and 35% high density polyethelyne [Envirodeck 2010:02]. It does not require extensive maintenance and will not fade in sunlight and is UV resistant [Enviro deck 2010:01&04].

Solid clip decking slats is cut to size and used as louvers. The colour will be "Kalahari Sandy Brown" [Environdeck 2010] referring to the stone plinth of the Pretoria Main Station.

Figure 9-10: Brownbuilt roof sheeting fixed at a very high level. [Source: Author].

Figure 9-11: Collage of material finishes, colour and rhythm of the solar screen . [Source:www.dezeen.com; Author; www.archdaily.com]

10.3 SUSTAINABLE ACTIVE/PASSIVE SYSTEMS

10.3.1 Natural lighting

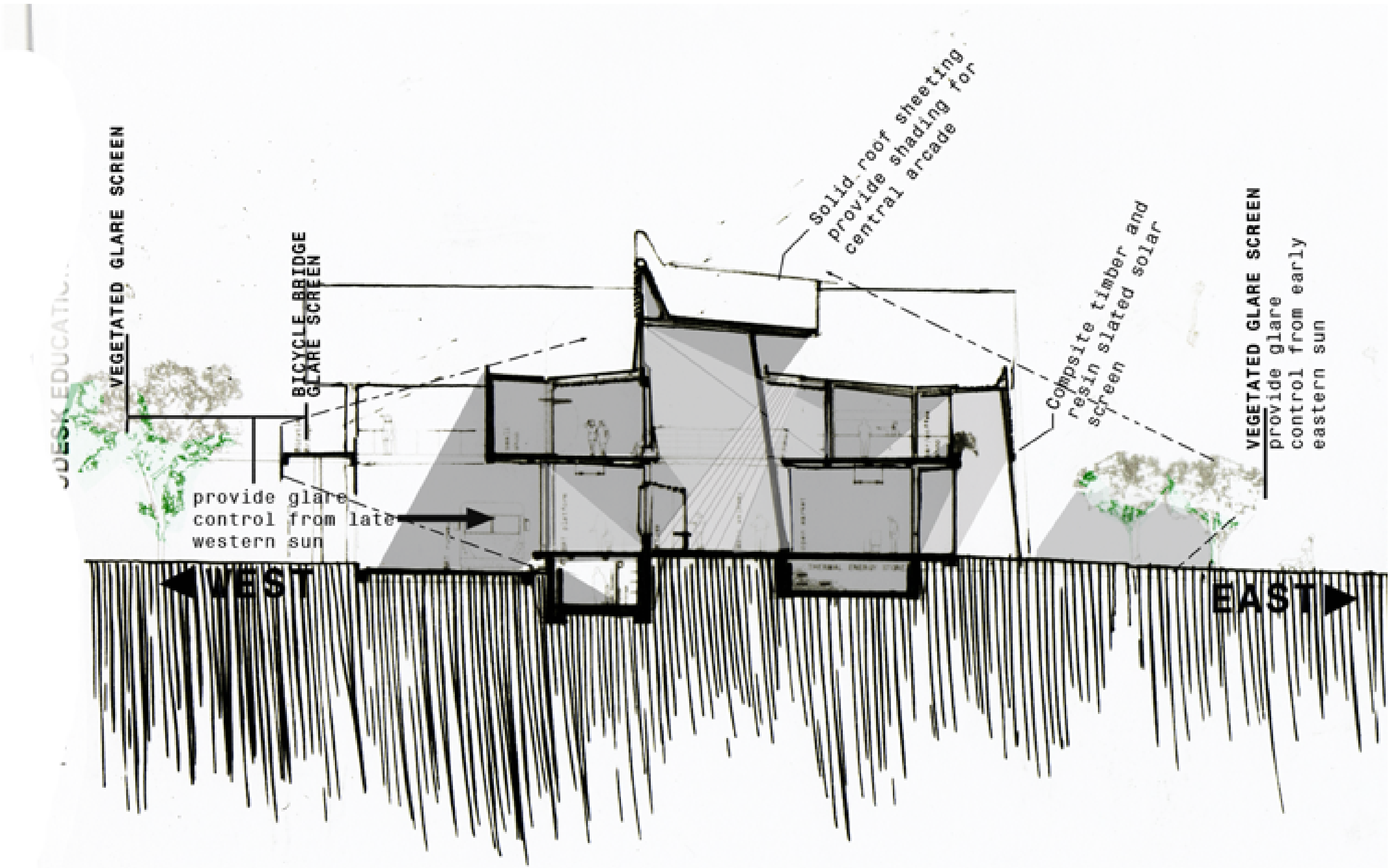


Figure 9-12: Solar screening system of building [Source: Author]

The central roof provides shading for the central arcade, large gaps between the roofs allow diffused sunlight into the central spaces of the structure. This ensures that less artificial lighting is used during the day .

The office functions make use of large south facing windows for good quality diffused daylight. Northern windows will be screened to provide glare protection from direct sunlight on the work levels.

The eastern and western edges of the building has glass envelopes - to ensure visibility and natural light into the building.

Trees are planted on the eastern and western edge of the building to block the direct sun from the retail and BRT stations. The landscape/ site will be adapted to act as an external covering skin to the intervention.

On the western edge the cycling bridge will provide solar screening for the BRT station platforms. The handrails are proposed to act as both barriers and solar screens.

Boardrooms facing east uses of composite wood and resin solar screens to control the sunlight entering the spaces early in the morning. This allows a visual link to the Station Square while ensuring a comfortable interior.

A solar glare screen is utilised to act a glare control for the retail spaces from early summer morning sunlight, while creating more defined spaces for the users on ground level. This frames the Station Square and unify the building's eastern facade.

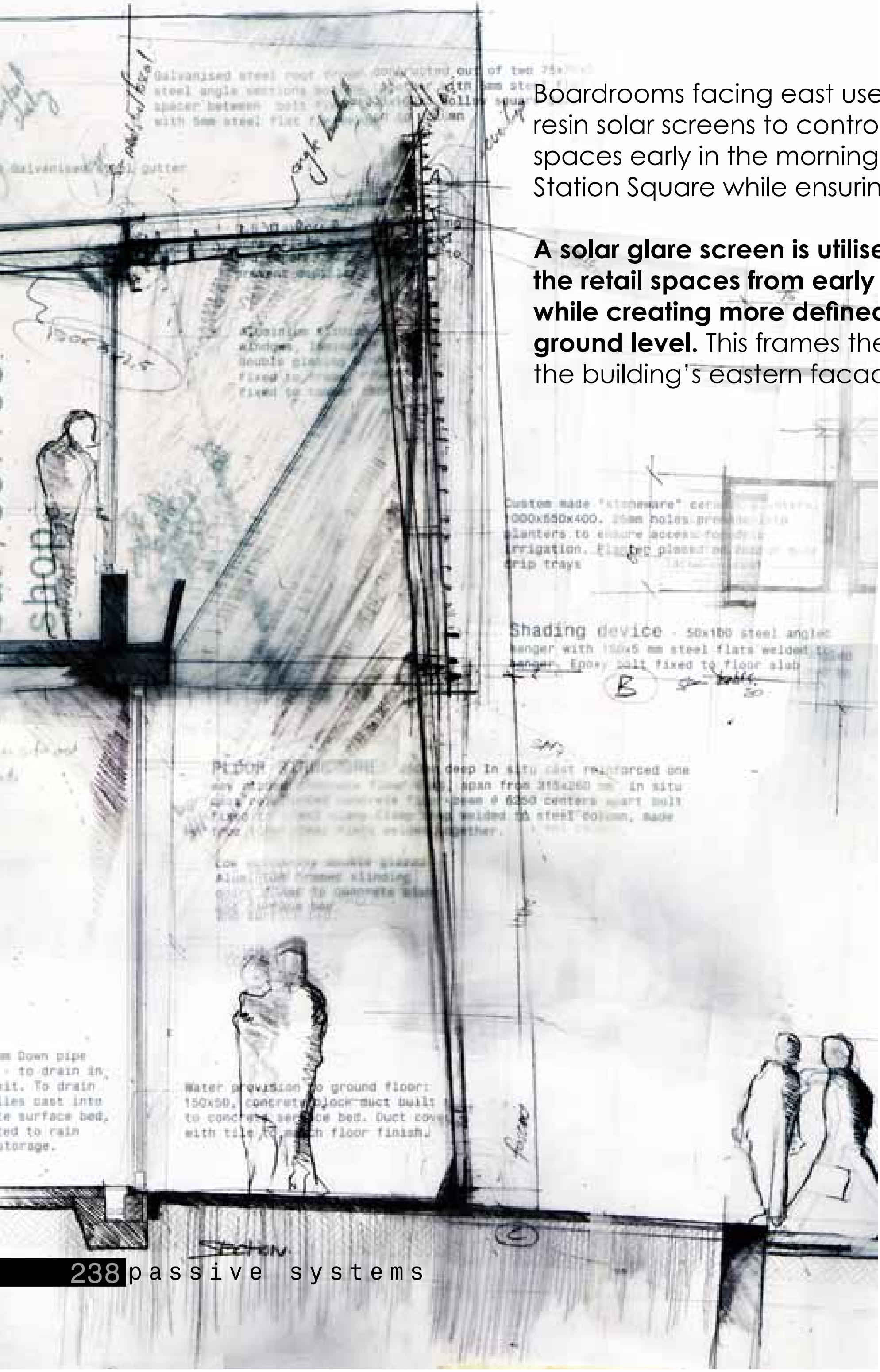


Figure 9-13: Section developing [Source: Author]

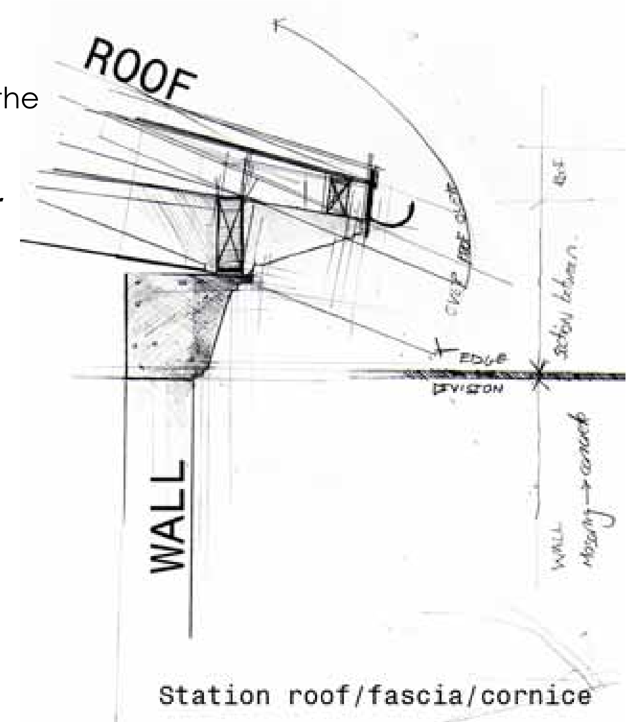


Figure 9-14: Detail development: Referring to the station roof [Source: Author]

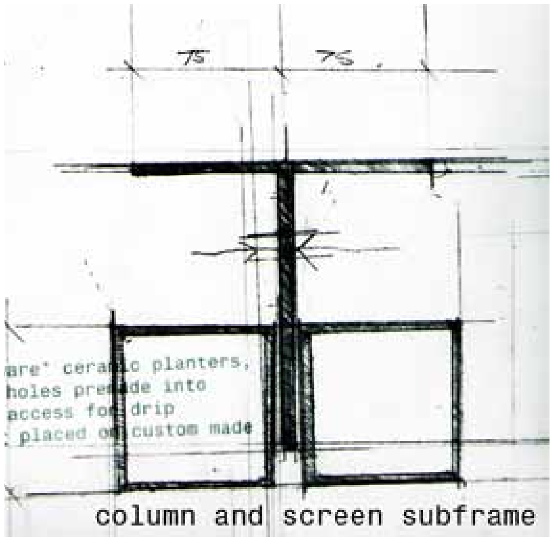


Figure 9-15: Steel Column of solar screen [Source: Author]

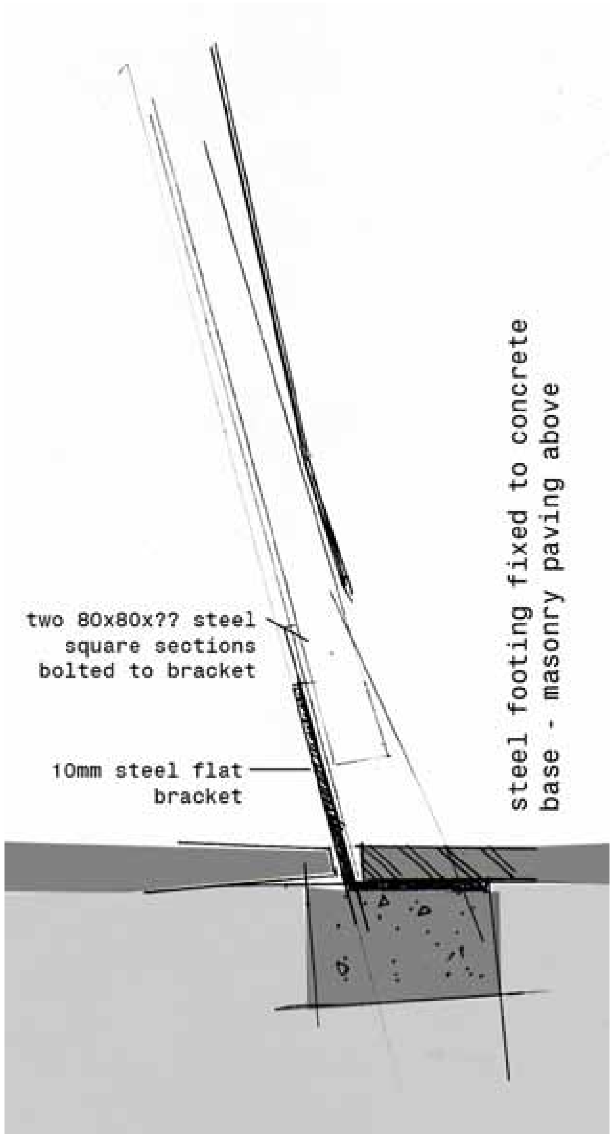


Figure 9-16: Column footing
[Source: Author]

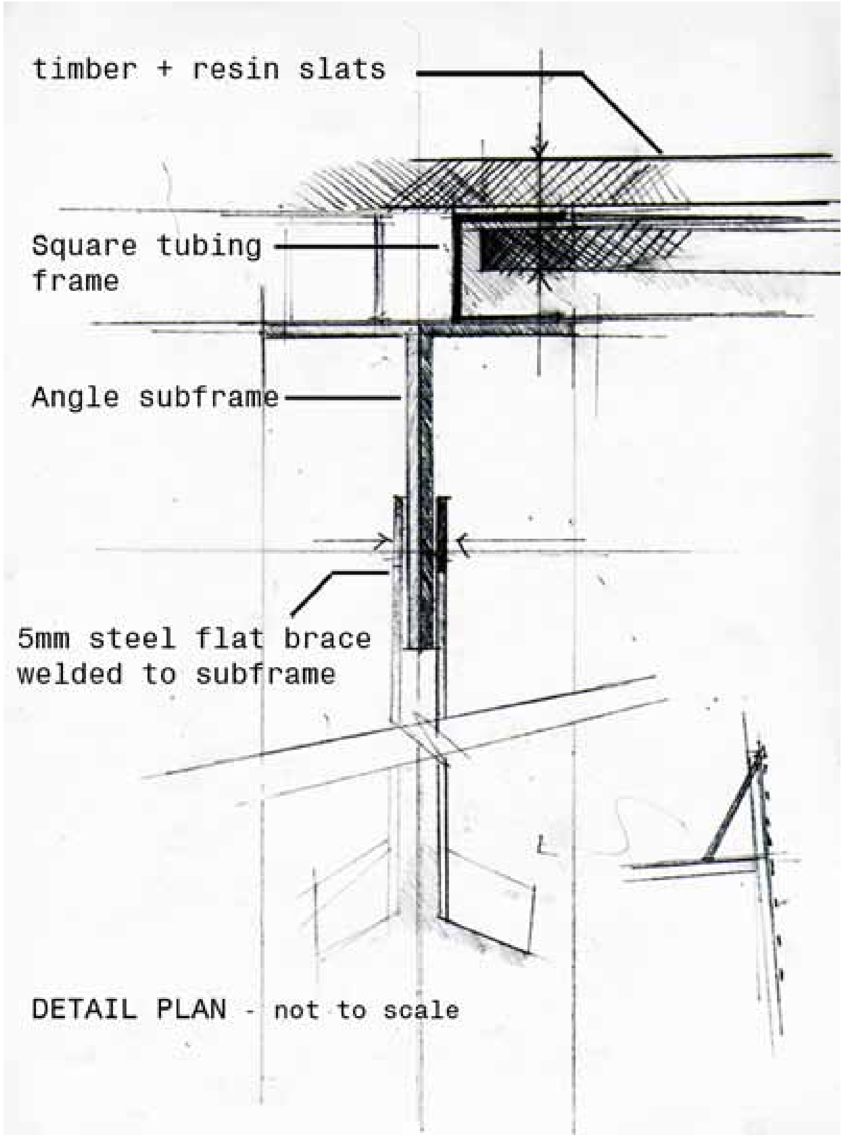


Figure 9-17: Steel Bracing connection
[Source: Author]

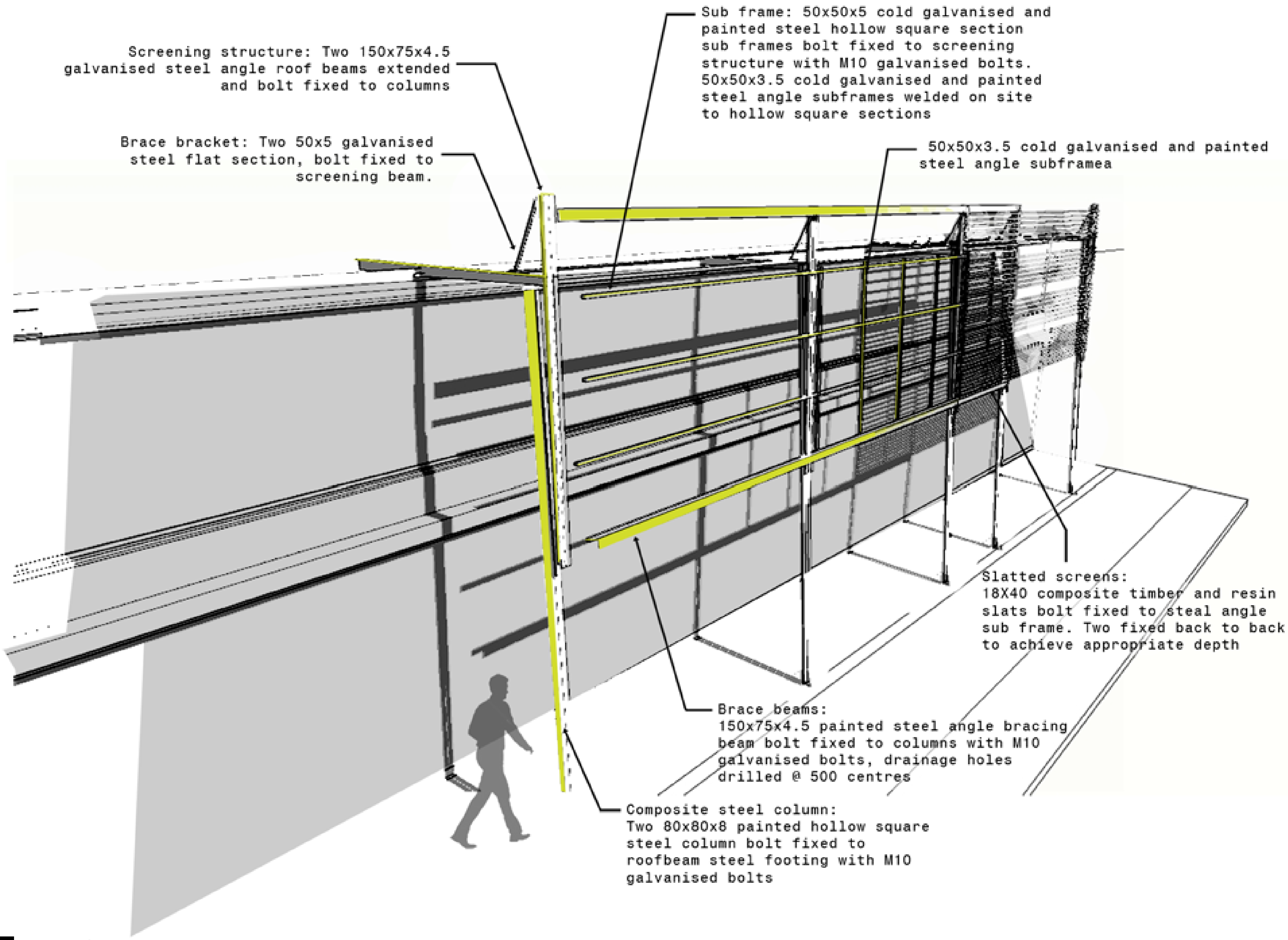


Figure 9-18: Perspective of screen detail components [Source: Author]

10.3.2 Ventilation and heating/cooling

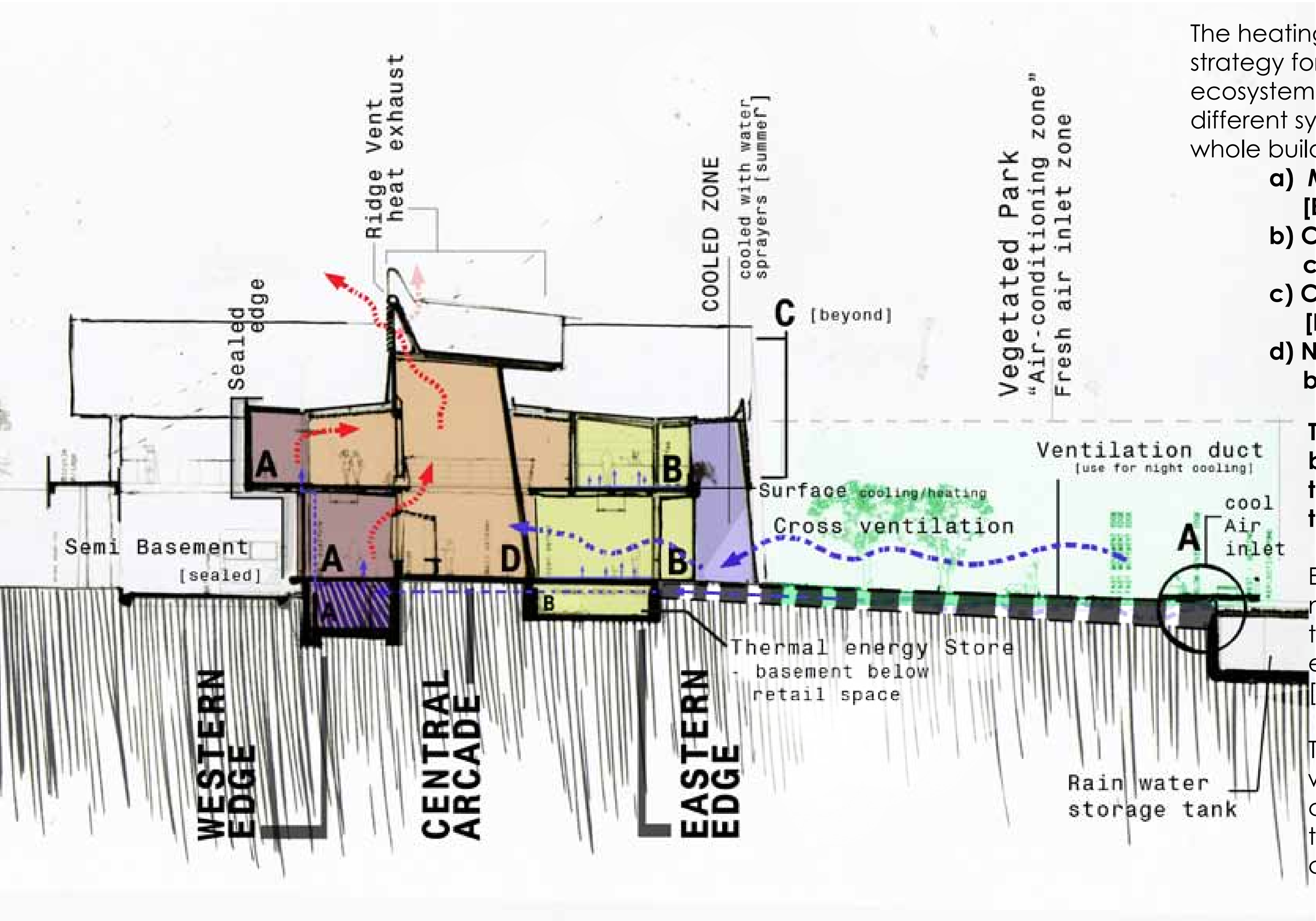


Figure 9-19: Ventilation systems and zoning within the building [Source: Author]

The heating and cooling as well as ventilation strategy for the building is developed out of an ecosystemic approach, integrating a series of different systems. As indicated in Figure 9-19 the whole building is divided into four zones:

- **a) Mechnically ventilated western zone – [BRT platforms and Small stores]**
- **b) Cross ventilated, surface heated and cooled eastern zone - [Retail shops]**
- **c) Cross ventilated office zones [BRT control offices and Offices]**
- **d) Naturally ventilated main concourse and bridge**

The strategy aims to shade the whole building to prevent heat build up, using the main concourse as an exhaust for the different zones.

Exposed materials with high thermal mass are integrated with this strategy to passively cool or heat to the indoor environment
[refer to precedent 4, pg 150].

The temperature within these zones will not differ greatly, yet provide a comfortable indoor environment where the transition between the spaces are comfortable as well.

ZONE A

Zone A is situated on the western edge of the building and houses the BRT platforms and small shops above. There will be high amounts of commuters moving through the platforms daily [at peak hour > 2000 people per hour] [Advanced Logistics Group 2008:115]. It is clear from Graph 13-02 [pg 302] and climate change predictions [Engelbrecht 2010] that cooling will be the main focus within this zone. The maximum cooling load is 69 kW which is in February.

The zone is mechanically ventilated to prevent air from the BRT runway filtering into the station. Air is collected from above the reflective ponds in the Station Square and cooled through evaporative cooling using a concrete ventilation duct with water sprayers. This will ensure that clean air is drawn through the system.

Inside the duct a series of water sprayers will be installed, to cool the air as it is drawn through the duct [Holm 1996:12]. To prevent legionella disease the water flow is controlled to ensure all moisture evaporates before touching the surface of the ventilation duct. The air duct will also be accessible to ensure that it is cleaned regularly.

An air handler unit is installed in the sealed semi-basement. The semi-basement is used as a duct to reticulated the air and introduce it into the station through ventilation panels cast into the floor.

The principle of displacement ventilation is used in the system. By introducing pressurised cold air at a low level into a space and allowing hot air to exit through the displacement by air pressure differences, 50% energy can be saved as less cold air is needed to ensure a comfortable indoor environment [Carew 2009:06].

ZONE B

Zone B houses the eastern retail edge, **these spaces are designed to ensure good cross ventilation**, the minimum floor to ceiling height was calculated using the following principle: Room Width < 5 Height [through ventilation]
Room width< 2 Height [one sided ventilation]
[Halliday 2008:258].

Planting within the Station Square, and integrated into the building will cool the micro climate ensuring that the air is cooled and cleaned before entering the building [refer to section 2.5.1]. The building is orientated in such a manner to allow prevailing wind from the Station Square into the interior spaces.

During the extremely hot periods the air will be precooled in the "cooled zone" , refer to Figure 9-19, with through an evaporative cooling method using mist sprayers.

As the building is 940mm above ground level to ensure easy access for disabled commuters onto the platforms, the opportunity to use the infill space as a thermal energy store was utilised.

The indoor environments in zone B are surface cooled and heated by incorporating high mass floors with water radiator pipes [in a closed circuit] and a 105 m³ thermal energy store.

The thermal energy store below zone B will be filled with water [Specific Heat coefficient of 4180 J/kgK] [Dincer 2001:378; Joubert 2010:5]. Integrating this system with water as a phase change material and a solar water heater a 6 months cycle system is developed [Dincer 2001:380]. The system effectively displaces thermal energy by removing heat from the structure in the summer and transferring it back into the building in the winter [Hollmuller *et al* 2006:01].

Water will be circulated in a closed loop with series 20mm copper pipes.

To additionally cool or heat the thermal store water will be ciruclated through a flat bed solar water heater collector. This will be used during the day to add heat into the system [Dincer 2001:380] and at night to remove heat from the system through radiation.

Zone C.

Zone C is naturally ventilated and makes use of the thermal mass of the building material to ensure a comfortable indoor environment is created.

The floor to ceiling height is 2.6 meters to ensure that the width of the office building is never more than 5 times the floor to ceiling height [Halliday 2008:258].

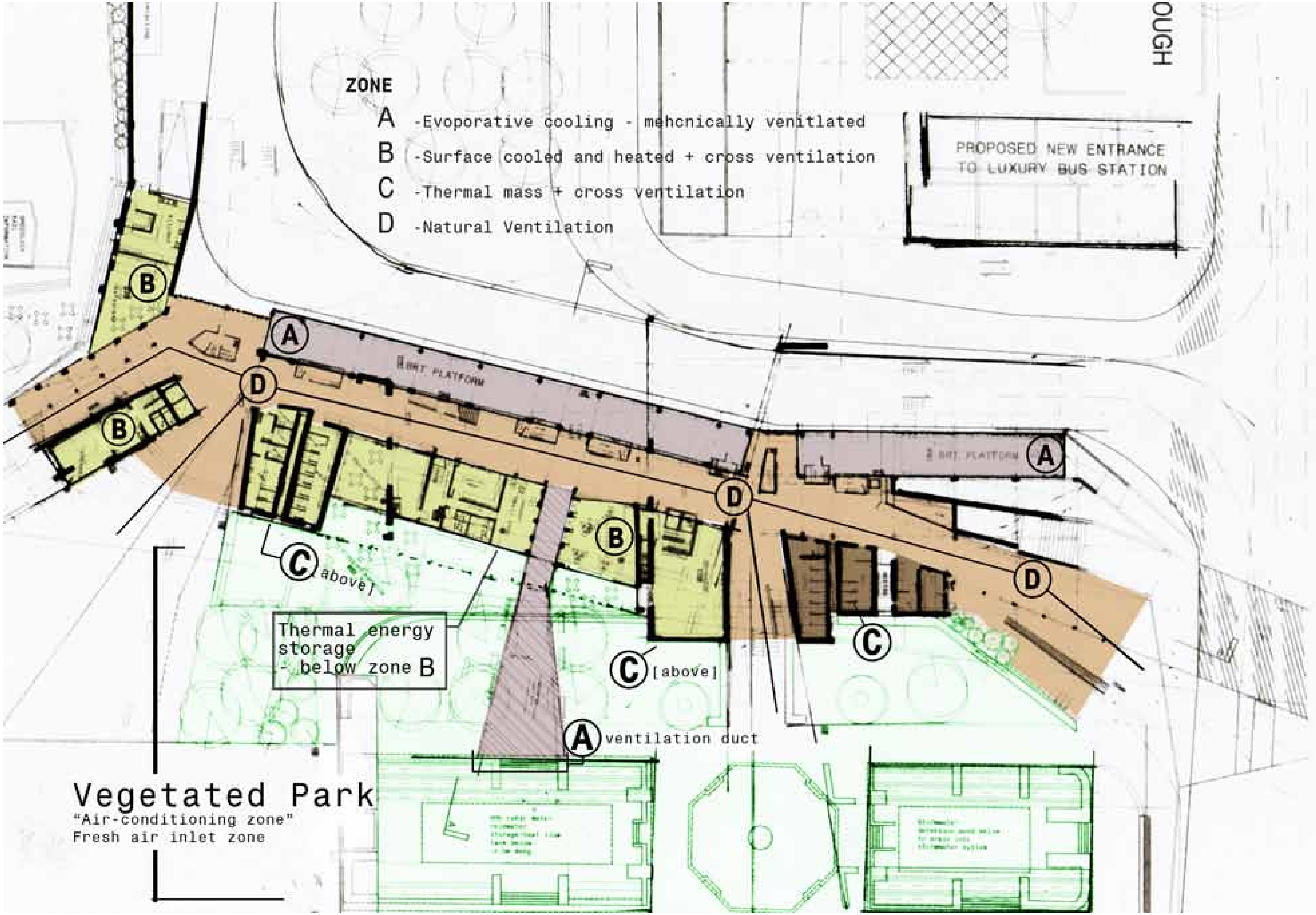


Figure 9-20: Zoning of indoor spaces [Source: Author]

ZONE D - Main Concourse

The main concourse and bridge are defined as naturally ventilated low pressure zones. By utilising the stack effect this zone will act as an exhaust to draw air through zones A, B and C.

The stack effect forces air into the building at a low level, while driving warm air out at the top and is effective for up to five times the distance from the inlet to the exhaust [Halliday 2008:270]. This is achieved by the density difference between the warmer air inside the building and the cooler air outside [Halliday 2008:258].

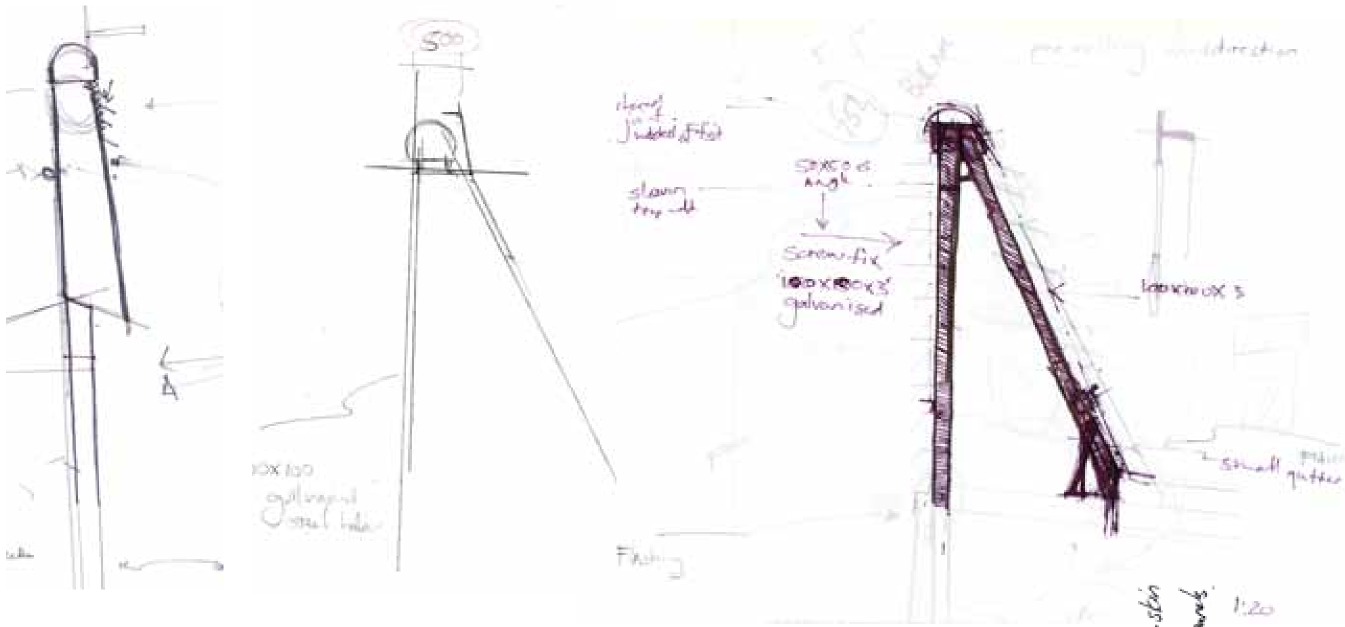
A ridge ventilator is fixed to the top of the roof and to act as a chimney to remove excess heat from the building. A high air temperatures will be achieved by the following;

a) Heat generated from the commuters walking through the space.

b) The ridge vent will be black anodised aluminium that will heat up quickly during the day. As solar gain can be used to enhance the stack effect, this can be particularly effective in Pretoria with its clear skies [Halliday 2008:258].

c) The prevailing wind on the site comes from the south easterly direction and will create a negative pressure on the

leeward side of the roof, this will improve the stack effect and pull air from the main concourse [Holm & Viljoen 1996:16; DETR 1998:9].



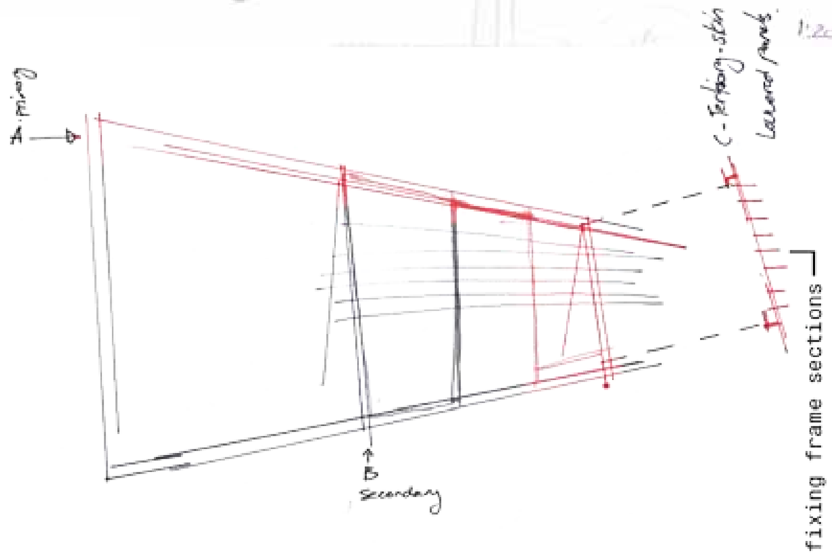


Figure 9-21: Development of Ridge ventilator [Source: Author]

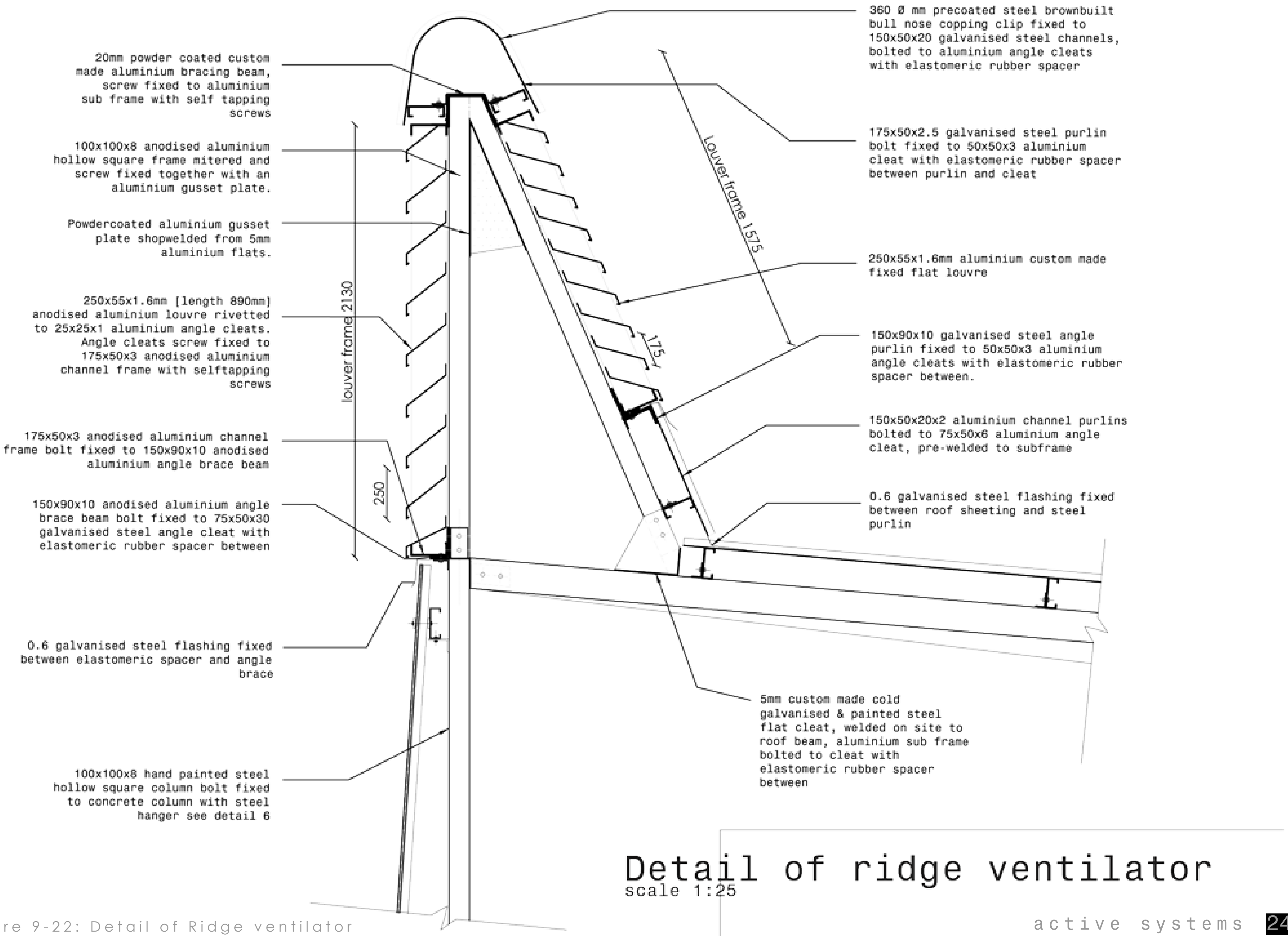


Figure 9-22: Detail of Ridge ventilator
[Source: Author]

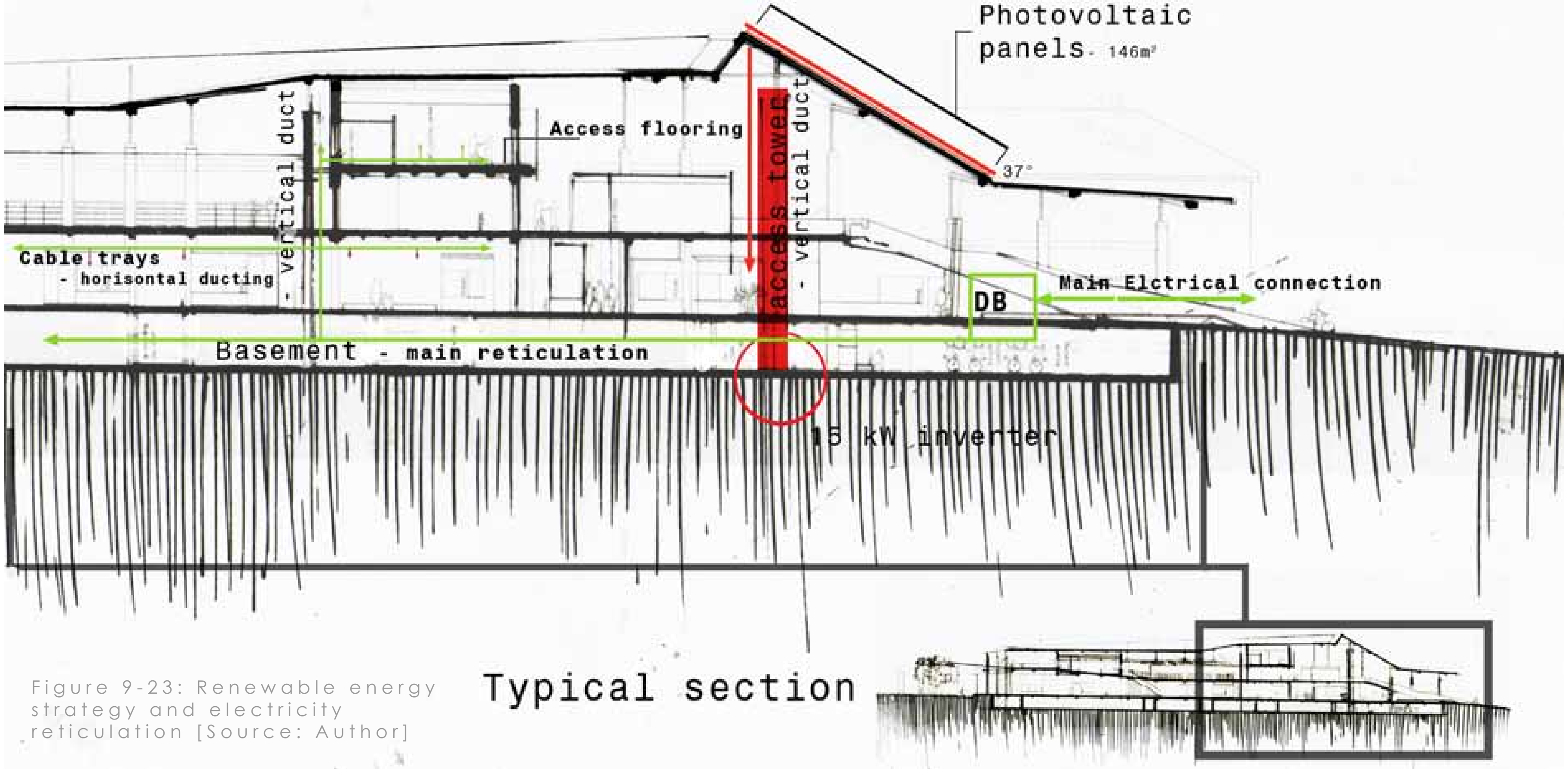


Figure 9-23: Renewable energy strategy and electricity reticulation [Source: Author]

10.3.3. Generating electricity.

Due to the inefficiency of existing renewable energy systems only a portions of the energy consumption will be generated on site [Holm 2010]. The artificial lighting energy consumption as calculated according to the SANS 204-08 minimum illuminance/lighting levels. The total energy required per day is 81 kWh , refer to table 13-17, pg 290.

The photovoltaic panels will be directly connected to the grid to ensure 90% efficiency [storing the energy in batteries normally have 75% efficiency] [Moraal 2010].

Photovoltaic panels can on average generate 0.62 kWh/m^2 per day in Pretoria [Holm 2010], to ensure 81 kWh energy is generated per day a photovoltaic system of 146 m^2 will be needed, refer to Table 13-19, pg 291.

A 15 kW grid tied inverter [Five 3 kW inverters that services portions of the whole system] will be used to convert the photovoltaic energy from DC to AC [Wiredirect 2010; Planmypower 2010].

Additional energy will be purchased through a tradable renewable energy certification process, to ensure that renewable energy initiatives is supported and develop in South Africa.

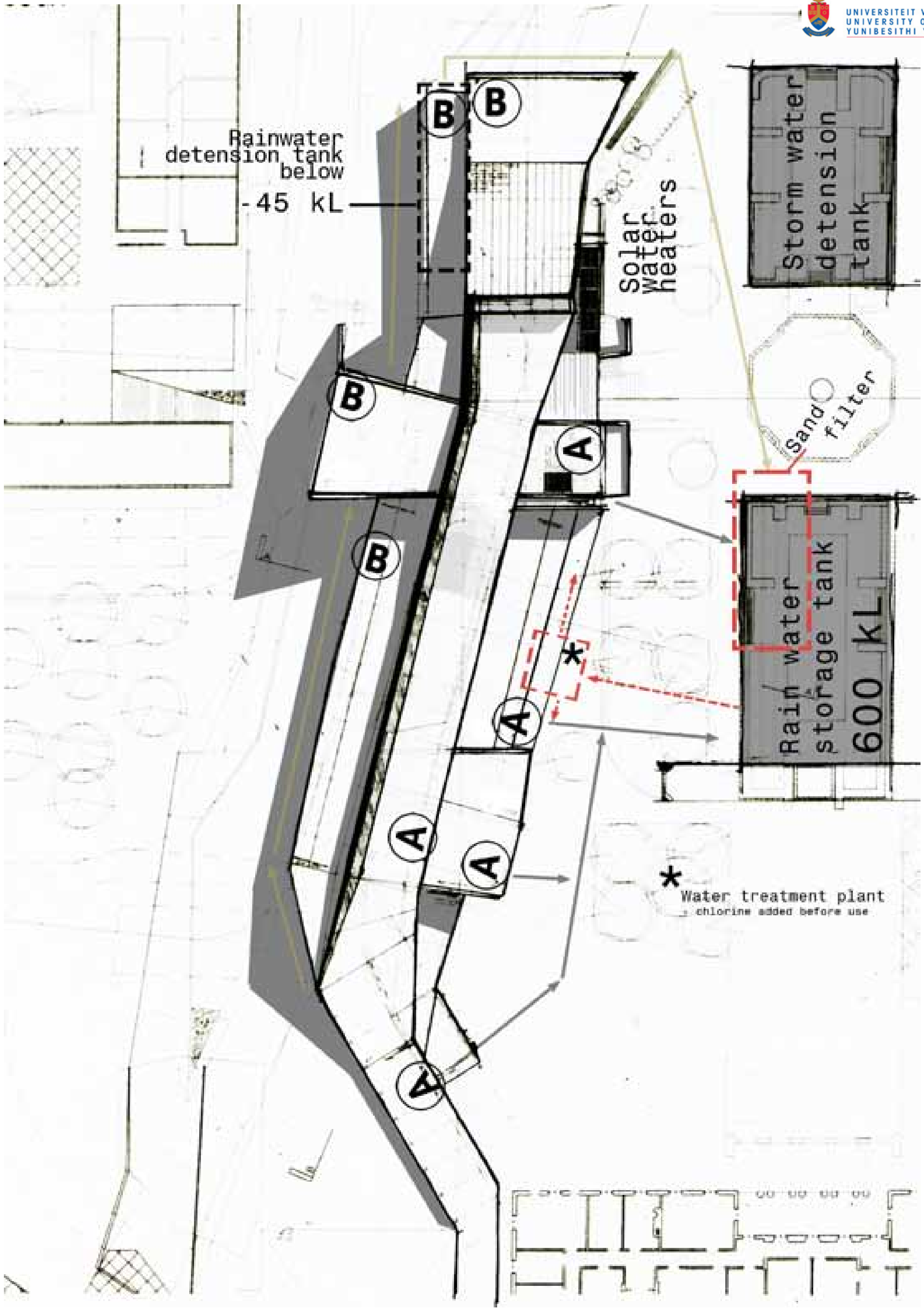


Figure 9-24: Rain water harvesting strategy [Source: Author]

10.3.4. Solar water heater for showers.

Solar water heaters in combination with electrical geysers are used to heat the water for the cyclists' shower facilities. Eight glass heat evacuating solar water collectors are proposed to be installed above the ablution core and service a 1400 liter tank [Apricus 2010]. Water consumption of the shower facilities are controlled by only allowing a five minute shower with controlled water valves and limiting the flow rate [10 liters per minute] [Gibbert 2009:131]. Refer to Table 13-20, pg 292 for water calculations.

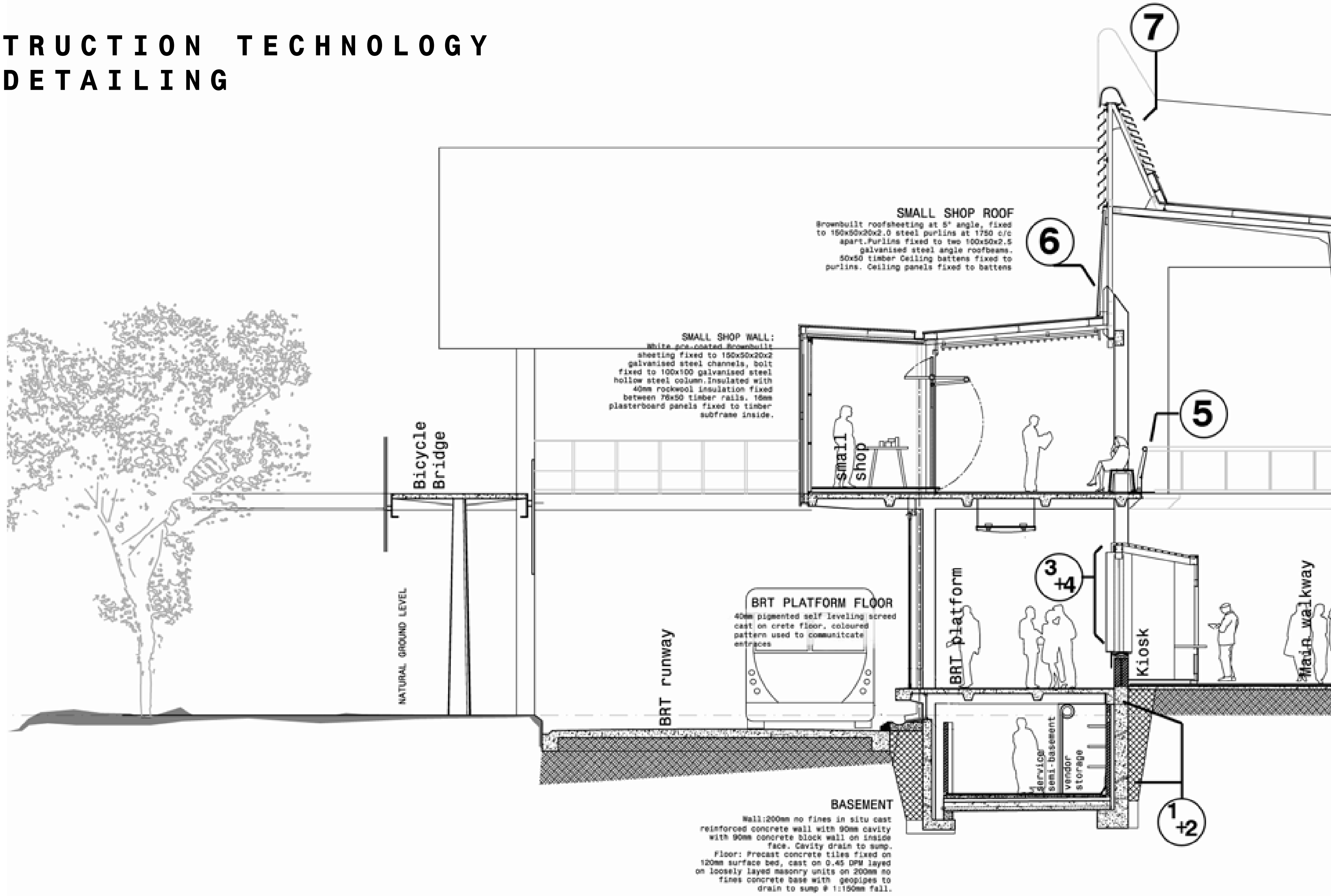
10.3.5. Harvesting rain water

Rainwater is collected from the roofs to service the public toilets.

The total roof area is 2050m^2 , yet only 90% of the total rain water can be harvested[Gibbert 2009:125]. A storage tank of 600 kL will store the rainwater and ensure that the public toilets can be serviced for 11 months of the year, refer to Table13-21, pg 292.
A Rainwater storage tank is positioned below the reflective pond in the Station Square, with a 24m^3 sand filter that pre filters the water before storing it – this ensure that the water is not contaminated [GIBBERT 2009:133][Refer to Table 13-22, pg 292].

An 18 kL holding tank will pre-store the water to guarantee that it passes through the filter at a slow rate [1liter/1 m^2/min] ensuring that it is adequately cleaned before storing it [Van Lengen 2008:619].

10.4 CONSTRUCTION TECHNOLOGY AND DETAILING



SECTION AA- construction technology

0 1 2.5 5 10 meter

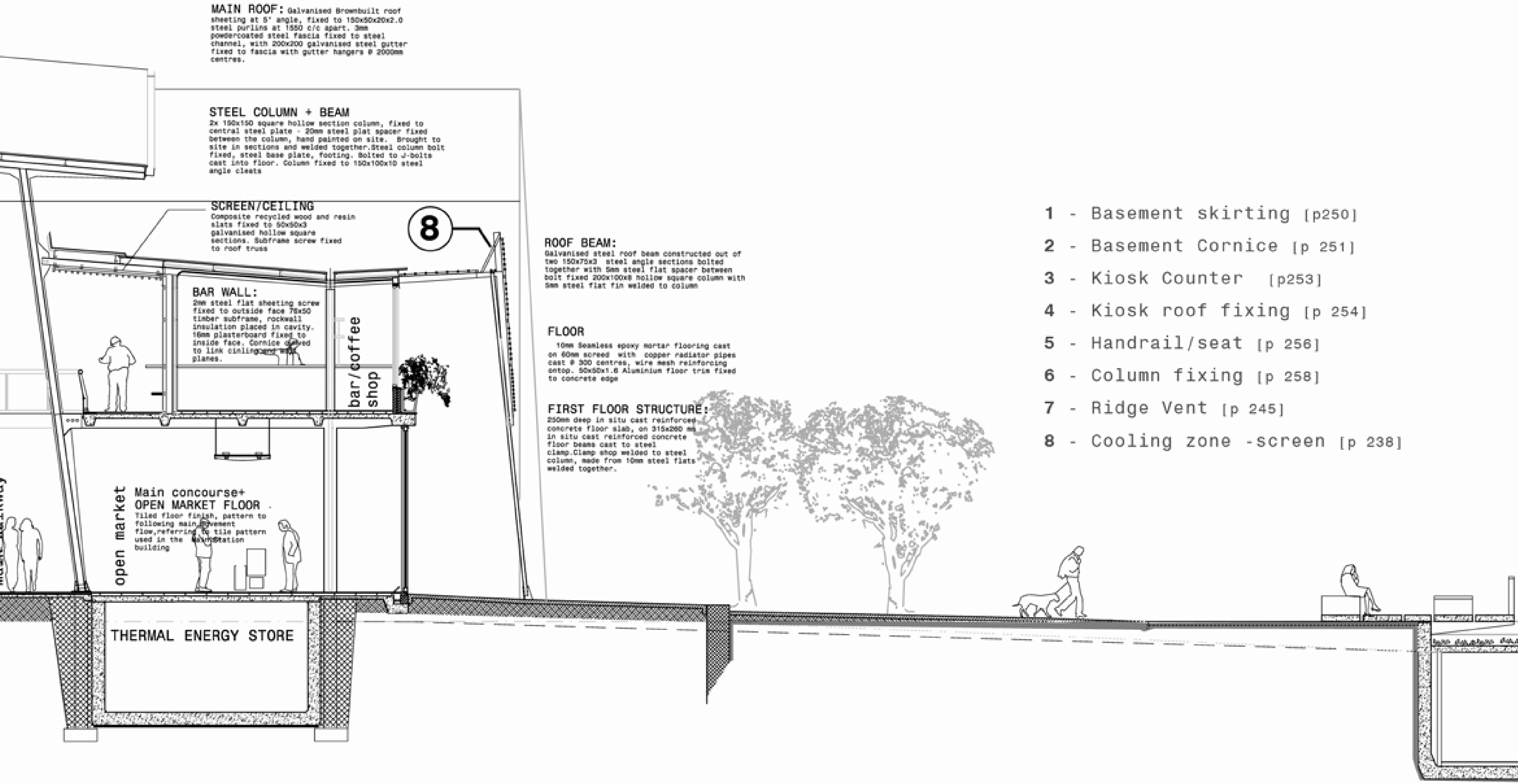


Figure 9-25: Detail section through structure [Source: Author]

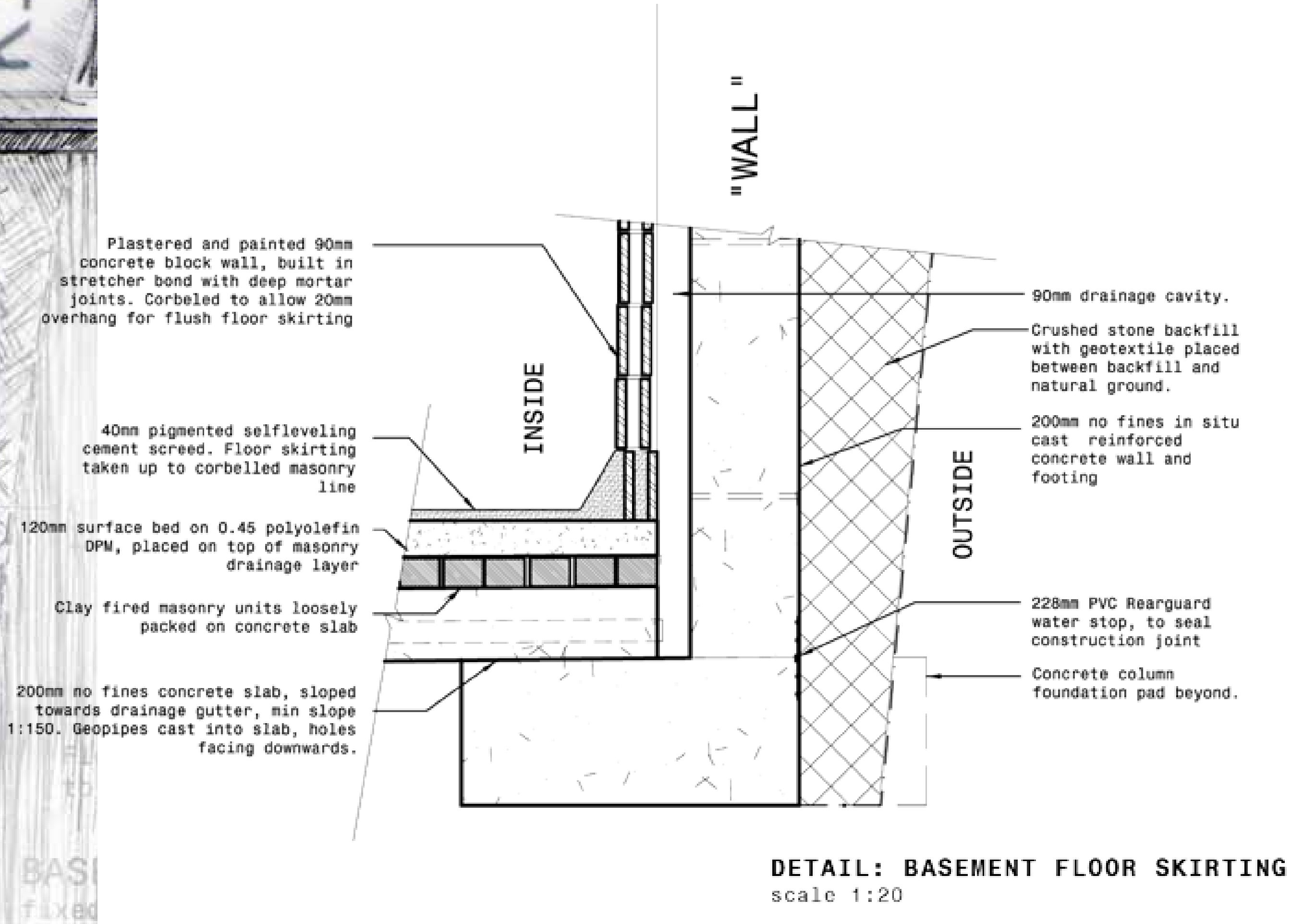


Figure 9-26: Developement of detail [Source: Author]

Figure 9-27: Detail of basement skirting [Source: Author]

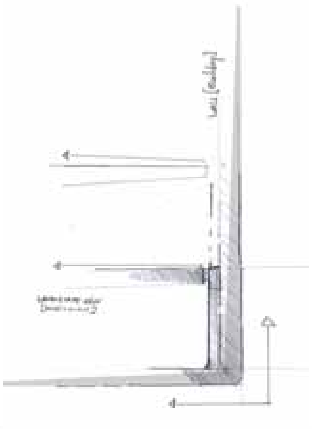
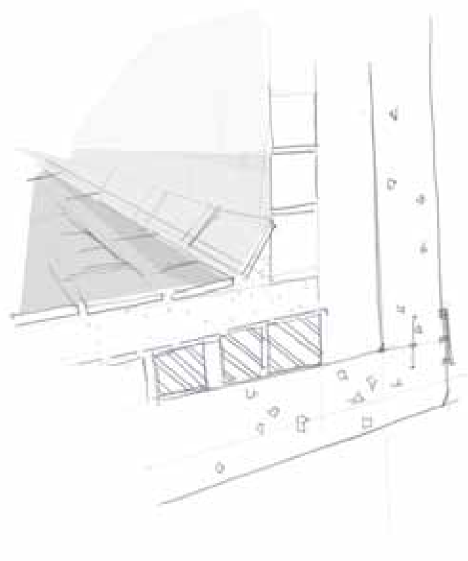


Figure 9-28: Conceptual approach to basement [Source: Author]



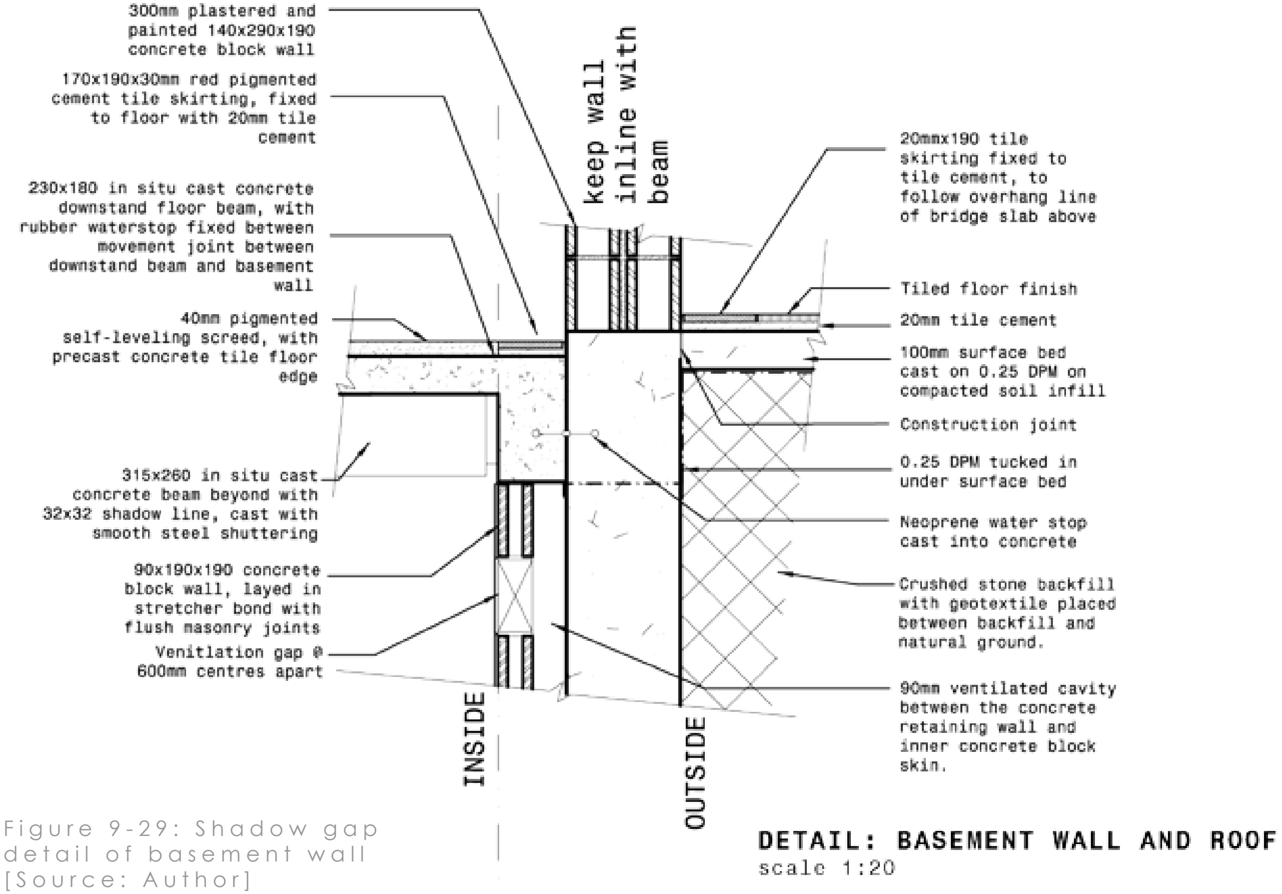


Figure 9-29: Shadow gap detail of basement wall [Source: Author]

Figure 9-30: Skirting in basement[Source: Author]

Figure 9-31: Detail of basement ceiling shadow gap [Source: Author]

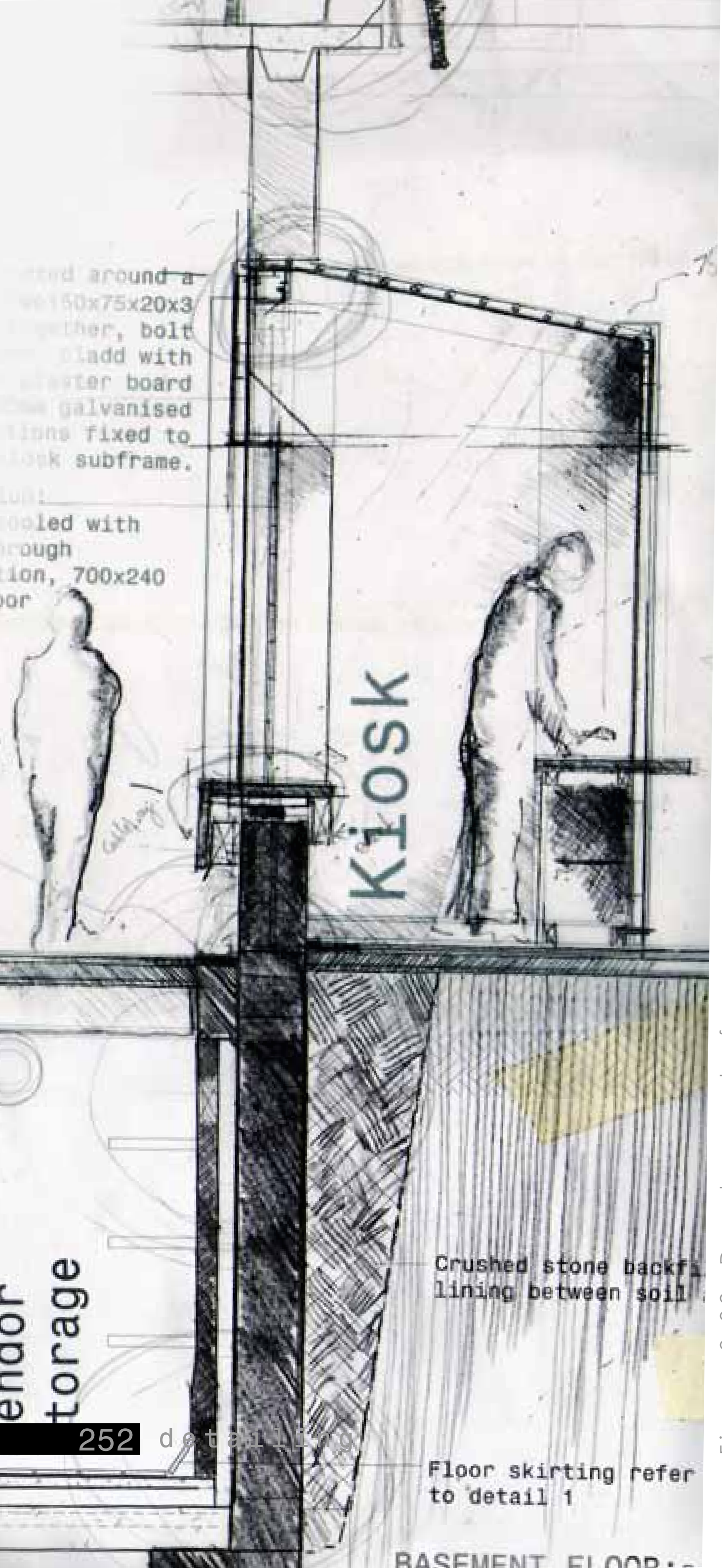


Figure 9-32: Development of Kiosk detail [Source: Author]

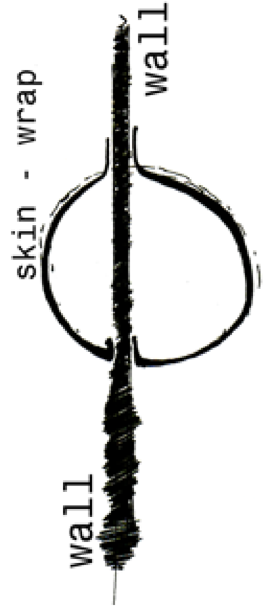


Figure 9-33: Conceptual approach to kiosk detail [Source: Author]

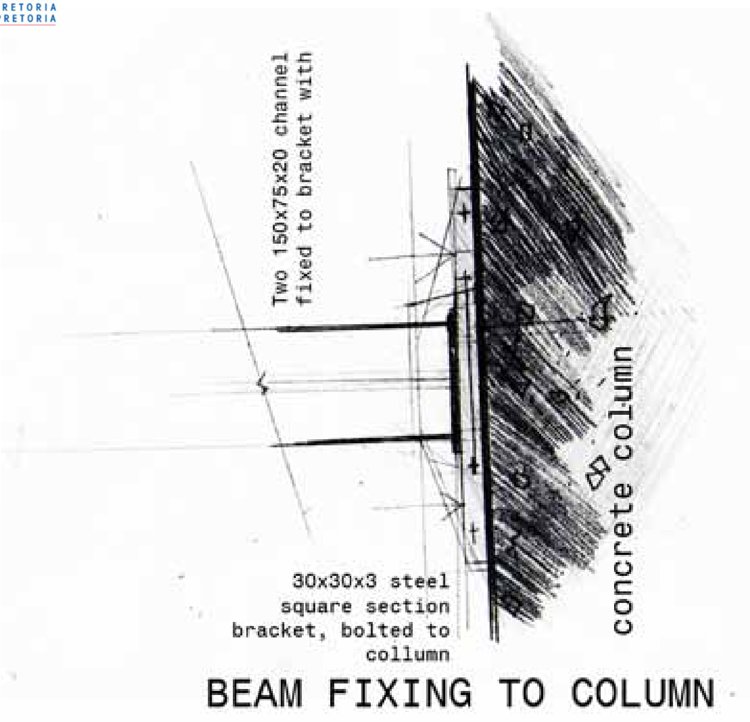


Figure 9-34: Steel beam fixing to column [Source: Author]

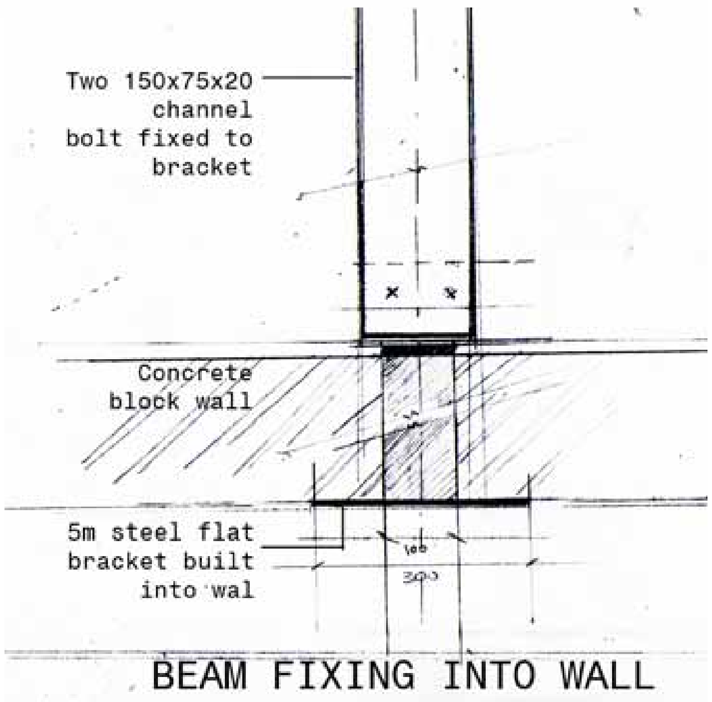


Figure 9-35: Steel column fixing to subwall [Source: Author]

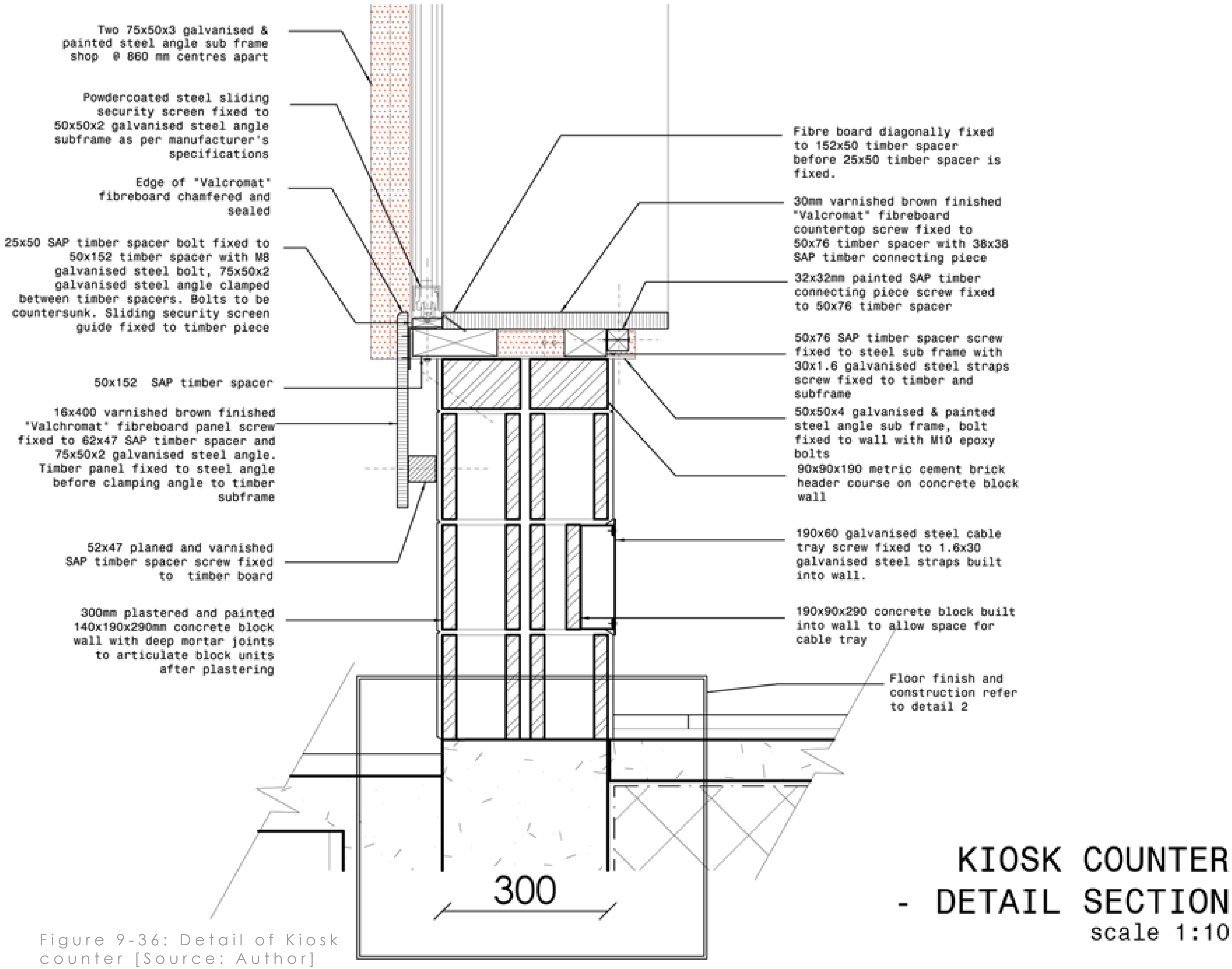


Figure 9-36: Detail of Kiosk counter [Source: Author]

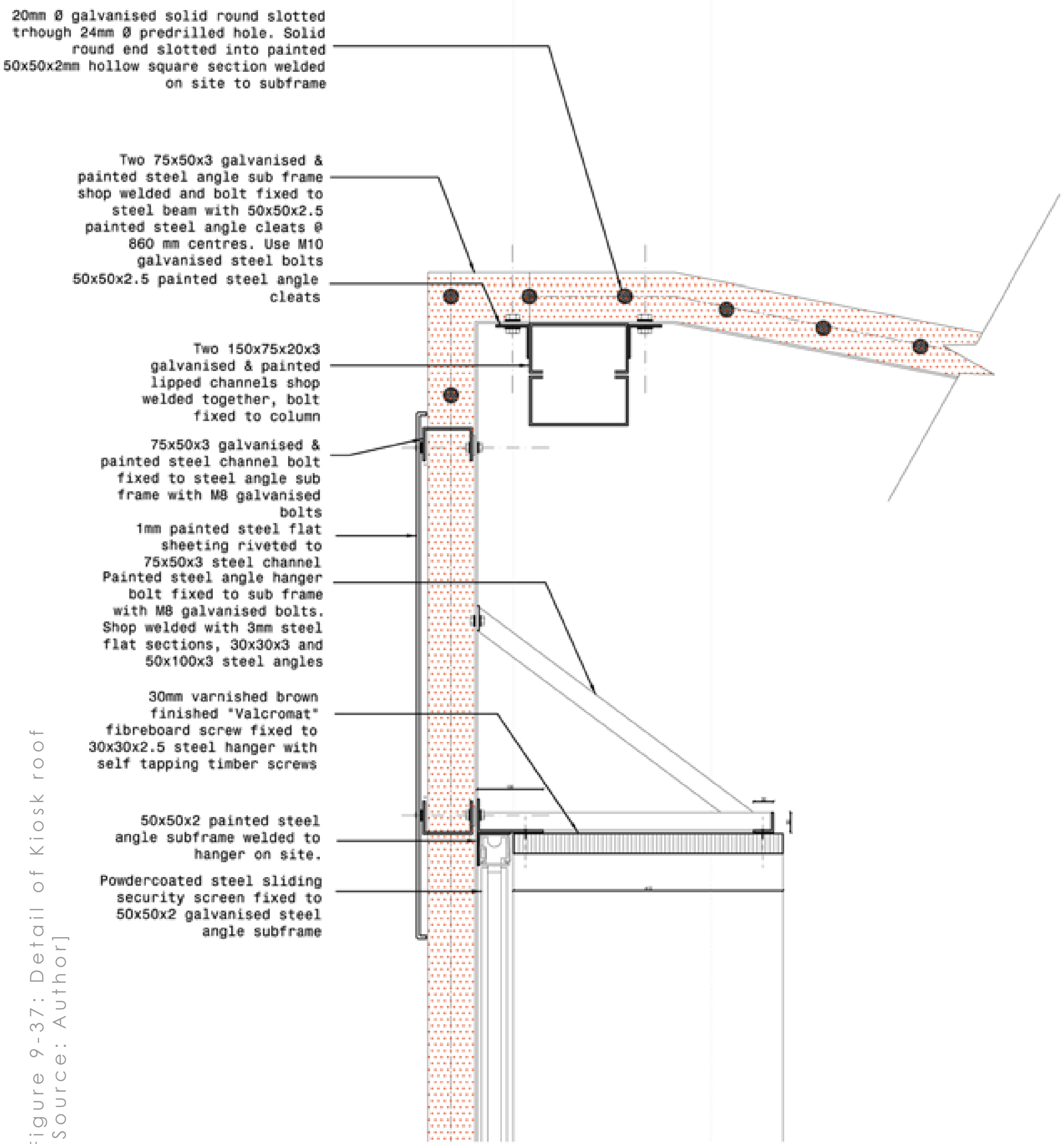
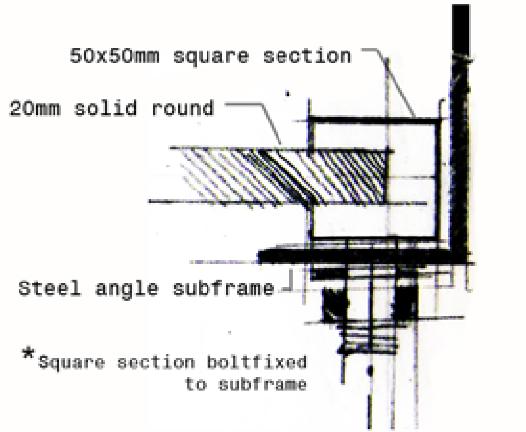


Figure 9-37: Detail of Kiosk roof [Source: Author]



End fixing of solid round sections

Figure 9-38: End fixing of solid rounds [Source: Author]

KIOSK SUBFRAME - DETAIL SECTION
scale 1:10

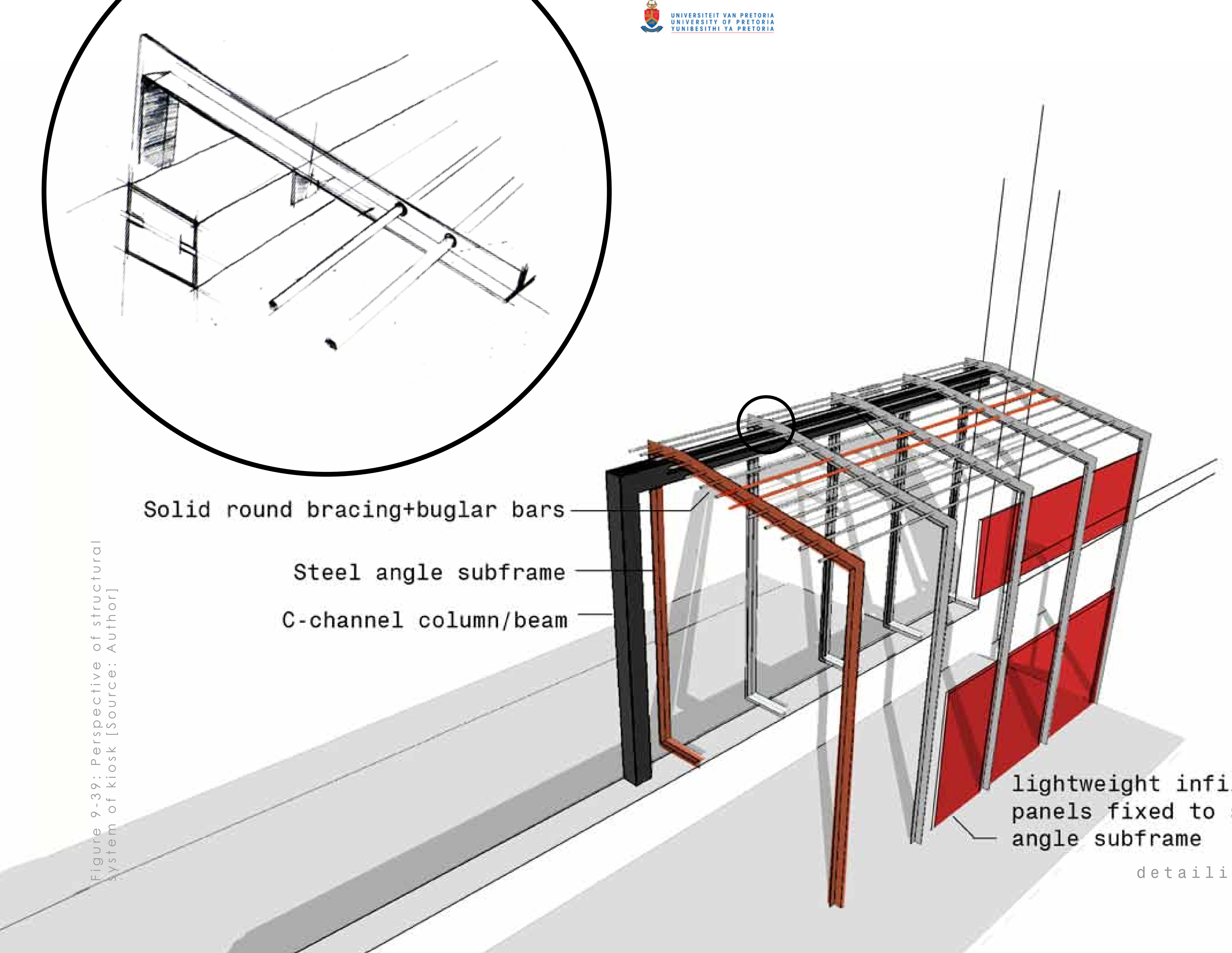
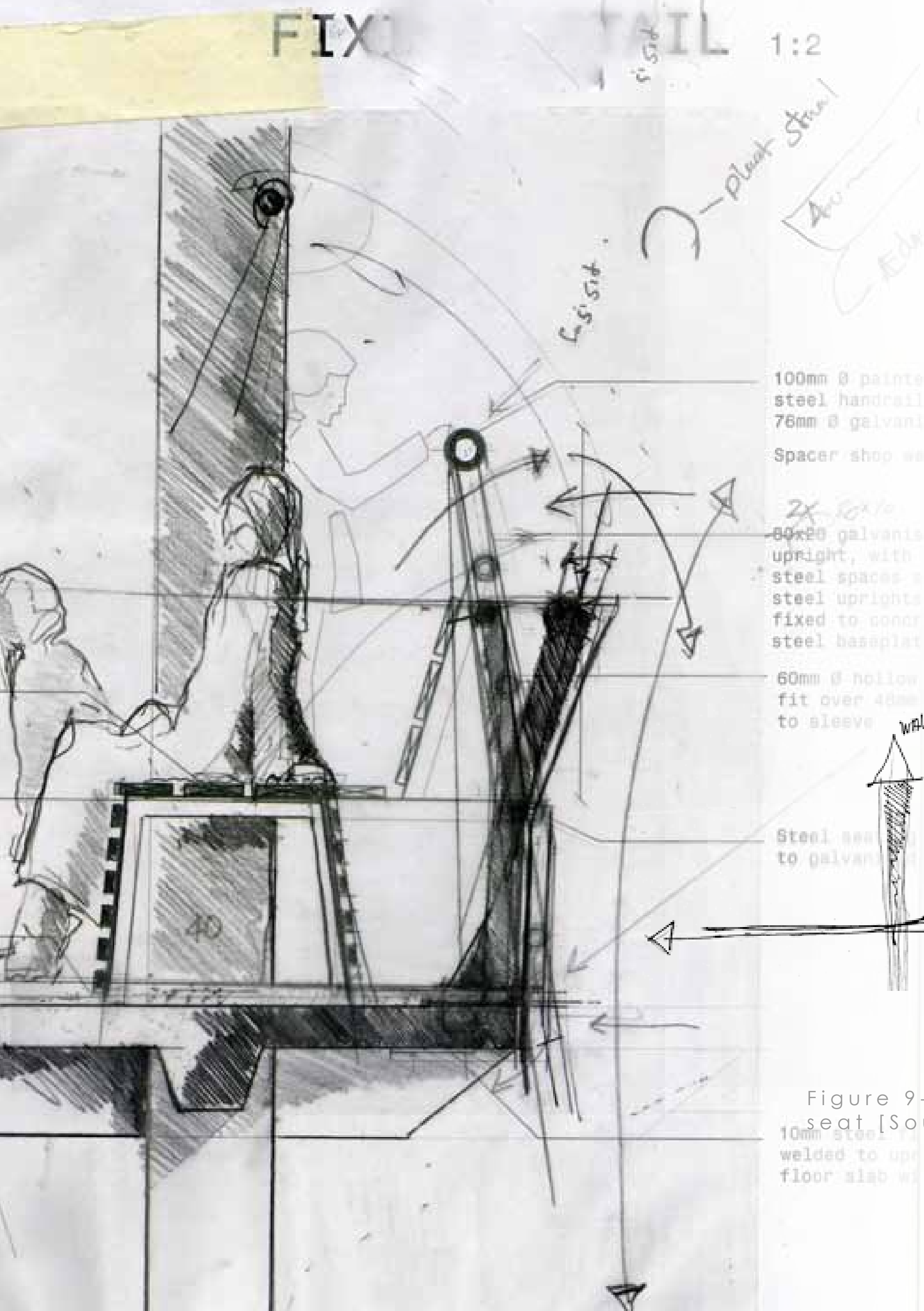


Figure 9-39: Perspective of structural system of kiosk [Source: Author]



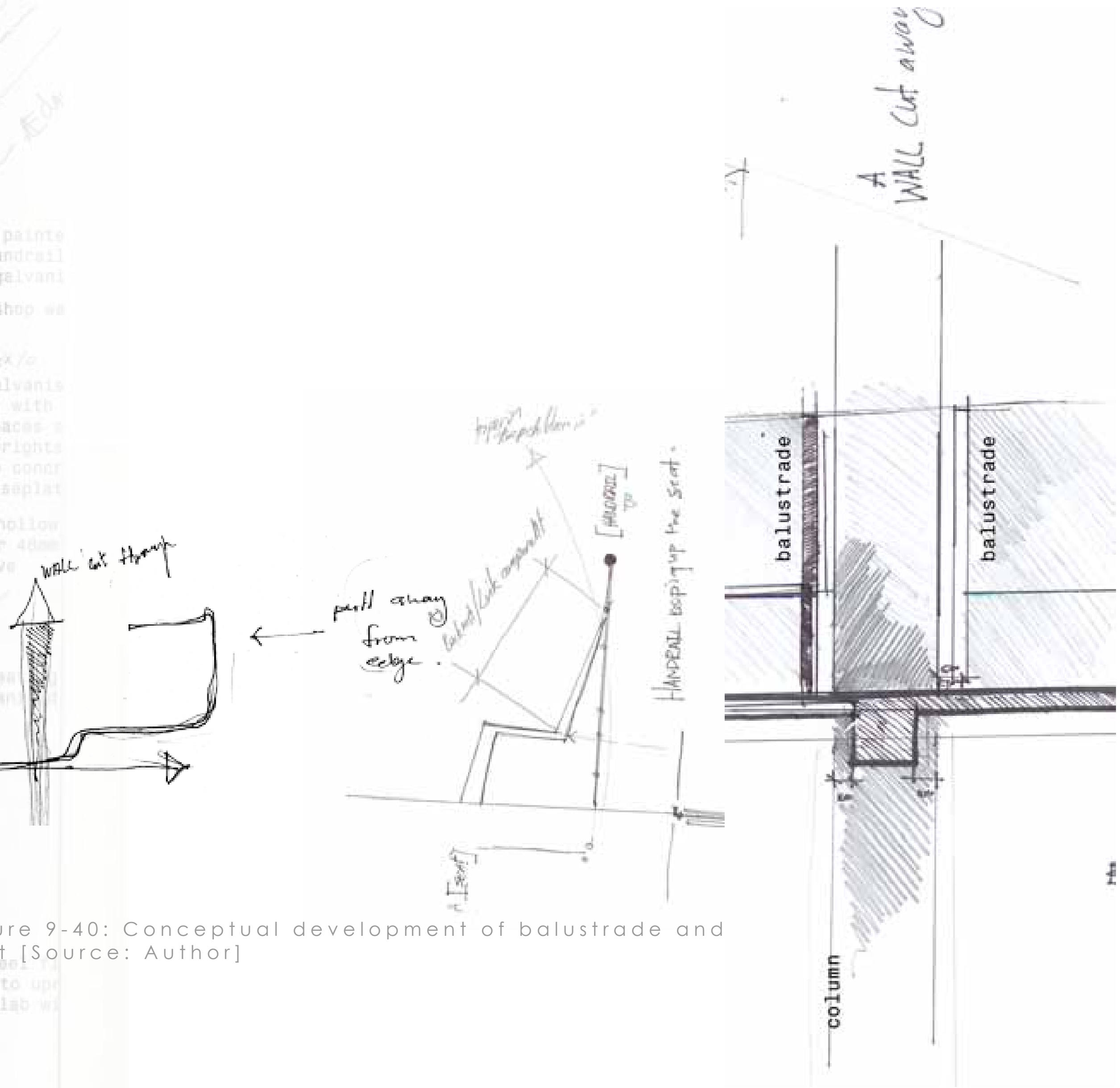
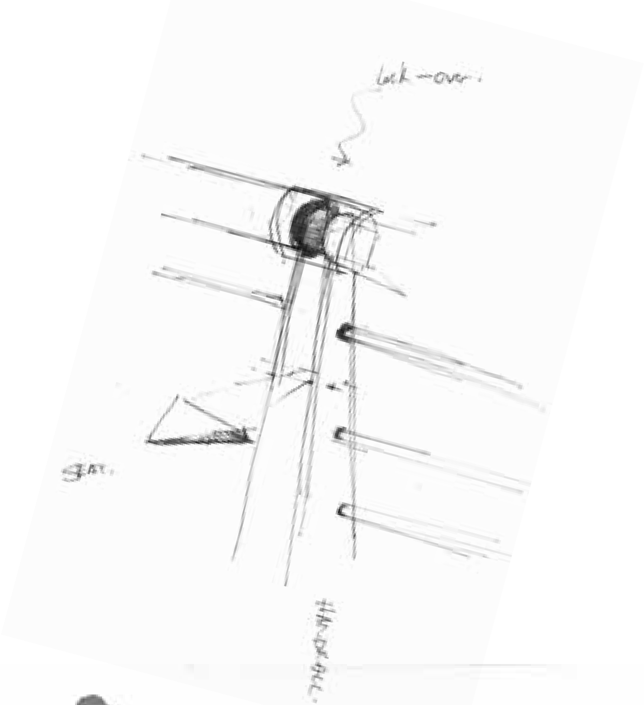
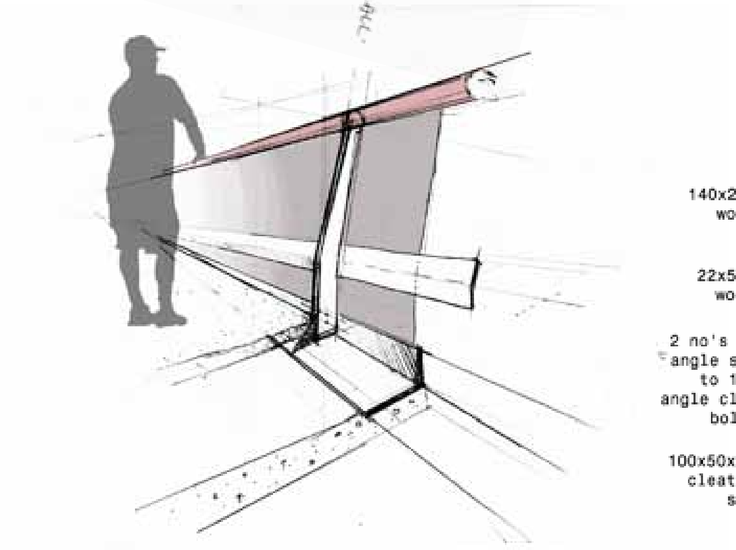
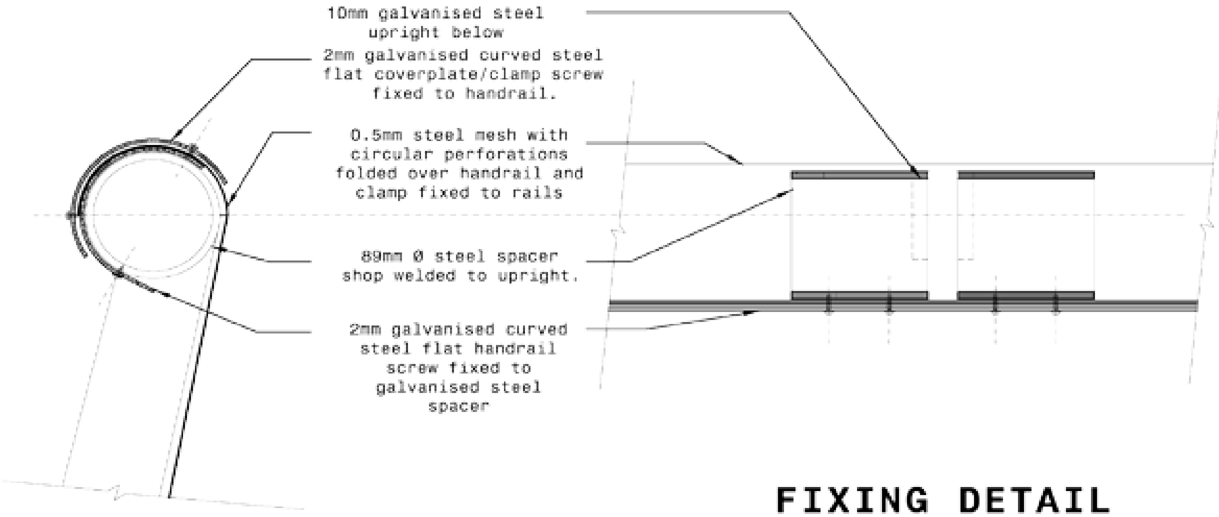


Figure 9-40: Conceptual development of balustrade and seat [Source: Author]



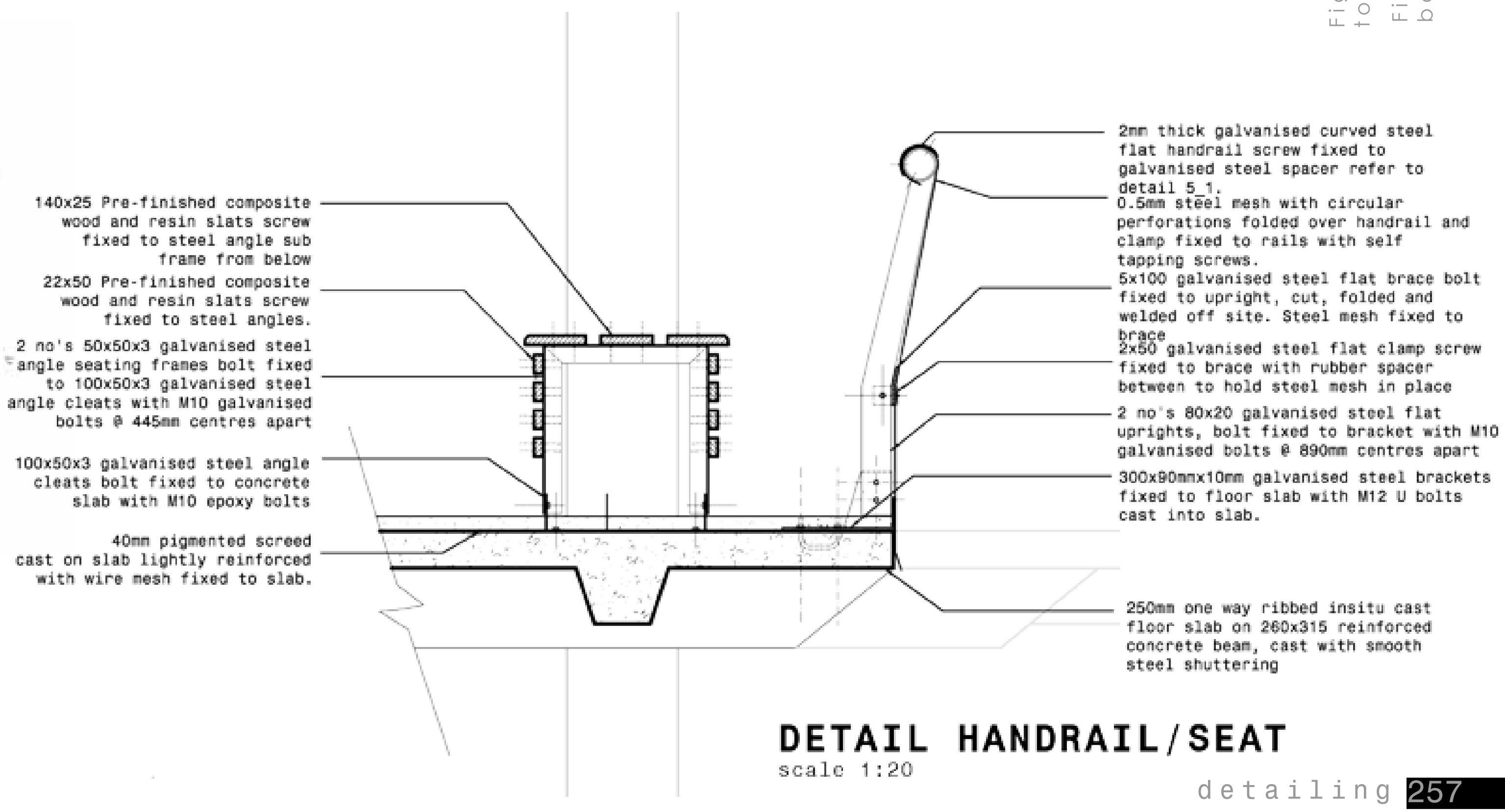




FIXING DETAIL
scale 1:5

Figure 9-41: Detail fixing of handrail to balustrade[Source: Author]

Figure 9-42: Detail section of balustrade/ seat[Source: Author]



DETAIL HANDRAIL/SEAT
scale 1:20

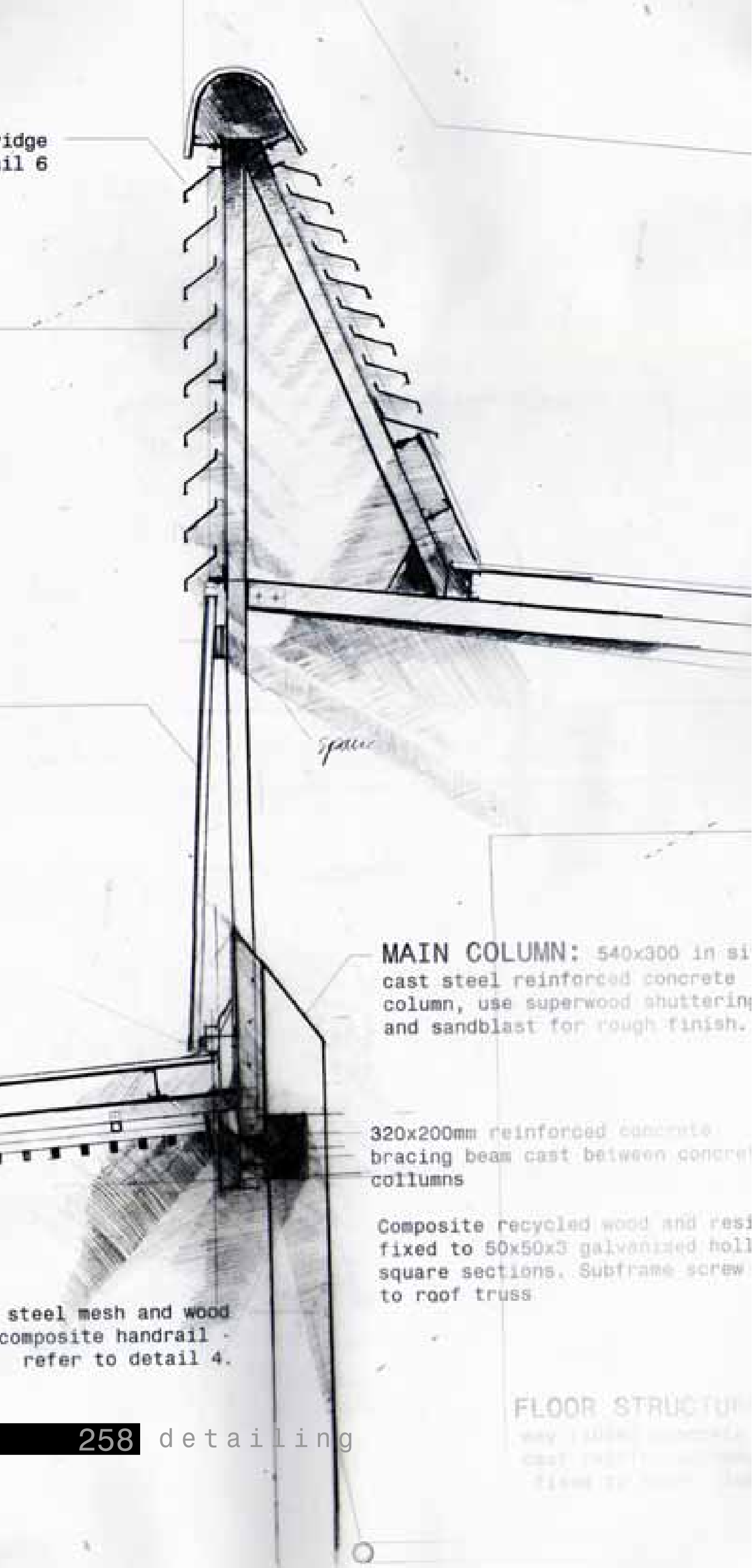


Figure 9-43: Section through steel column bracket and roof ridge [Source: Author]

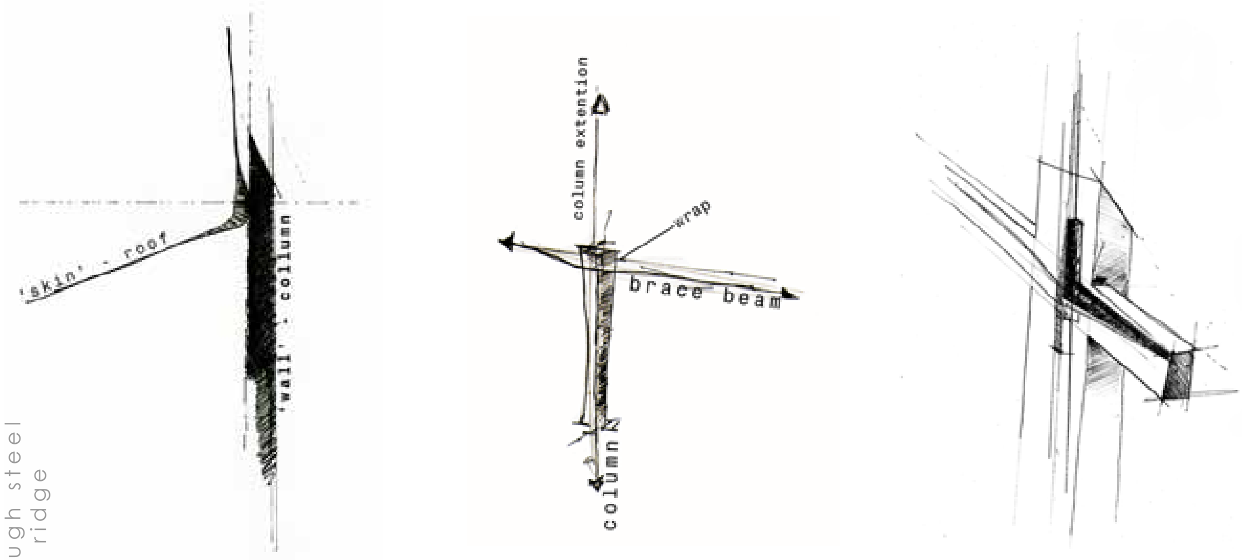
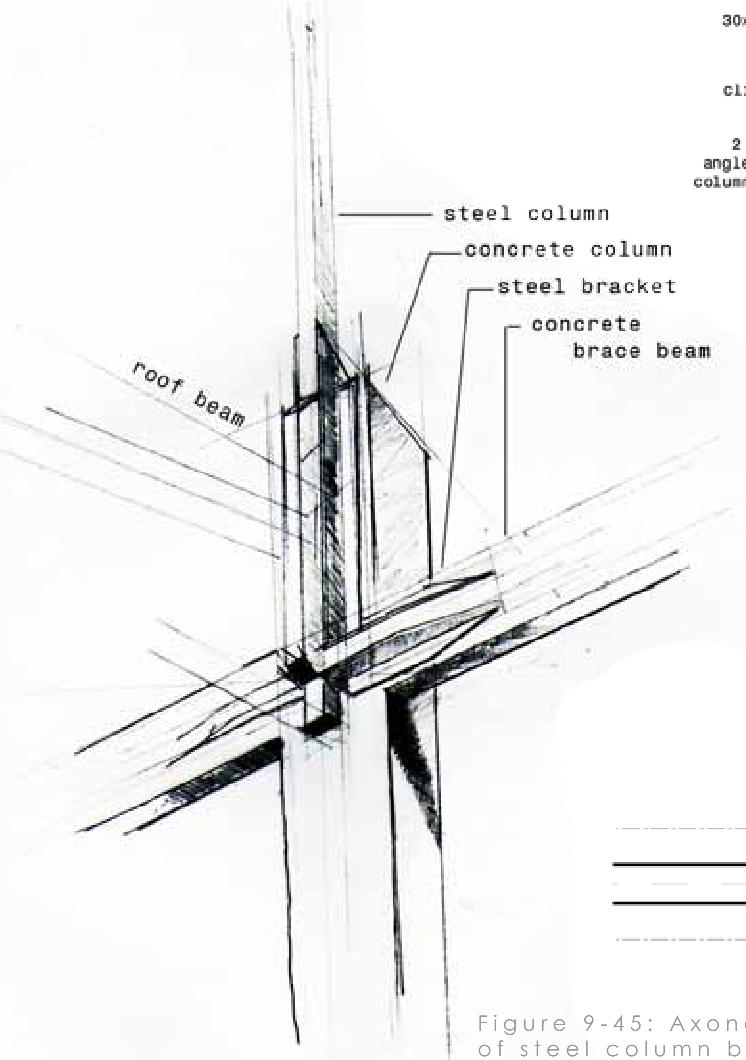
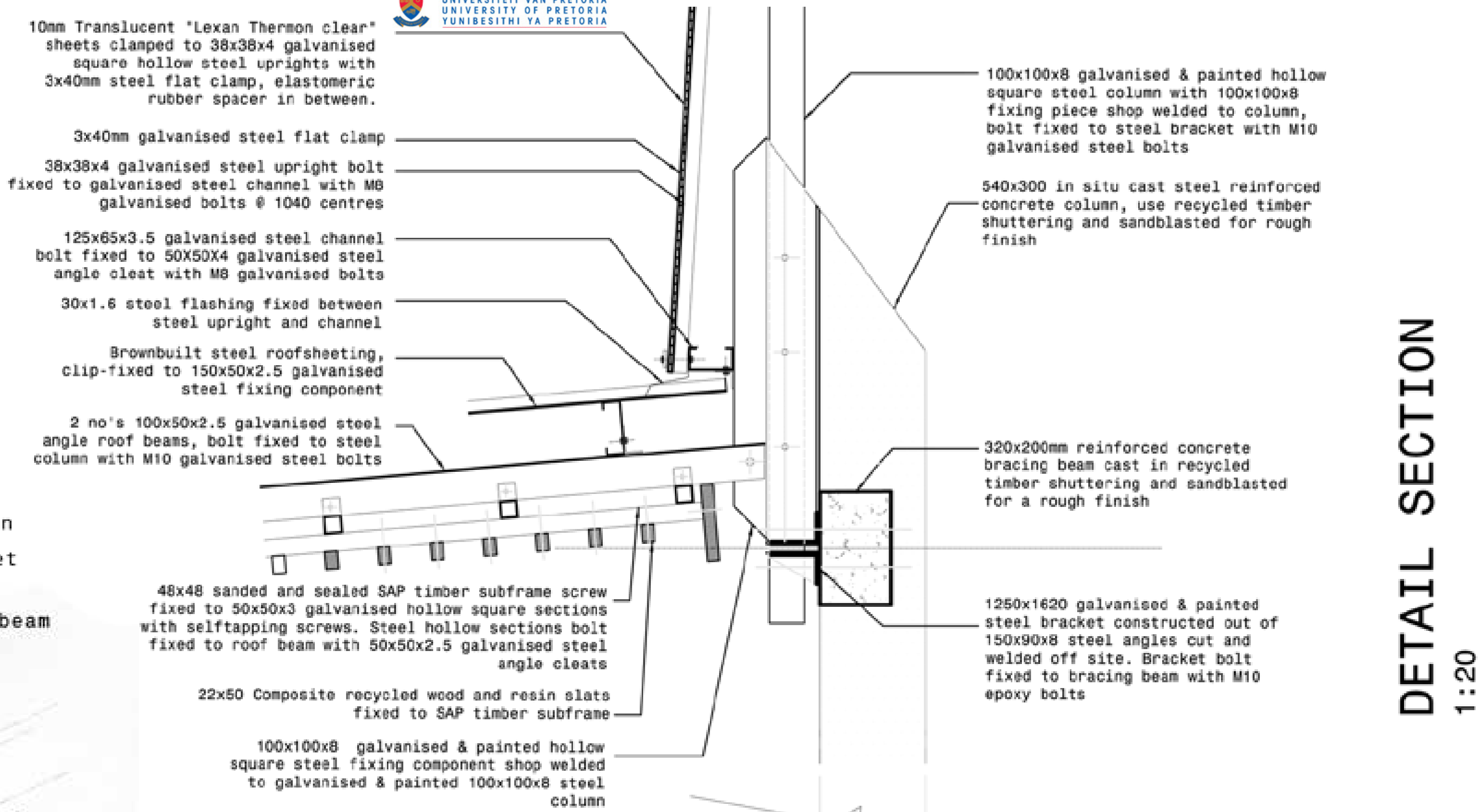


Figure 9-44: Conceptual development of steel column bracket [Source: Author]





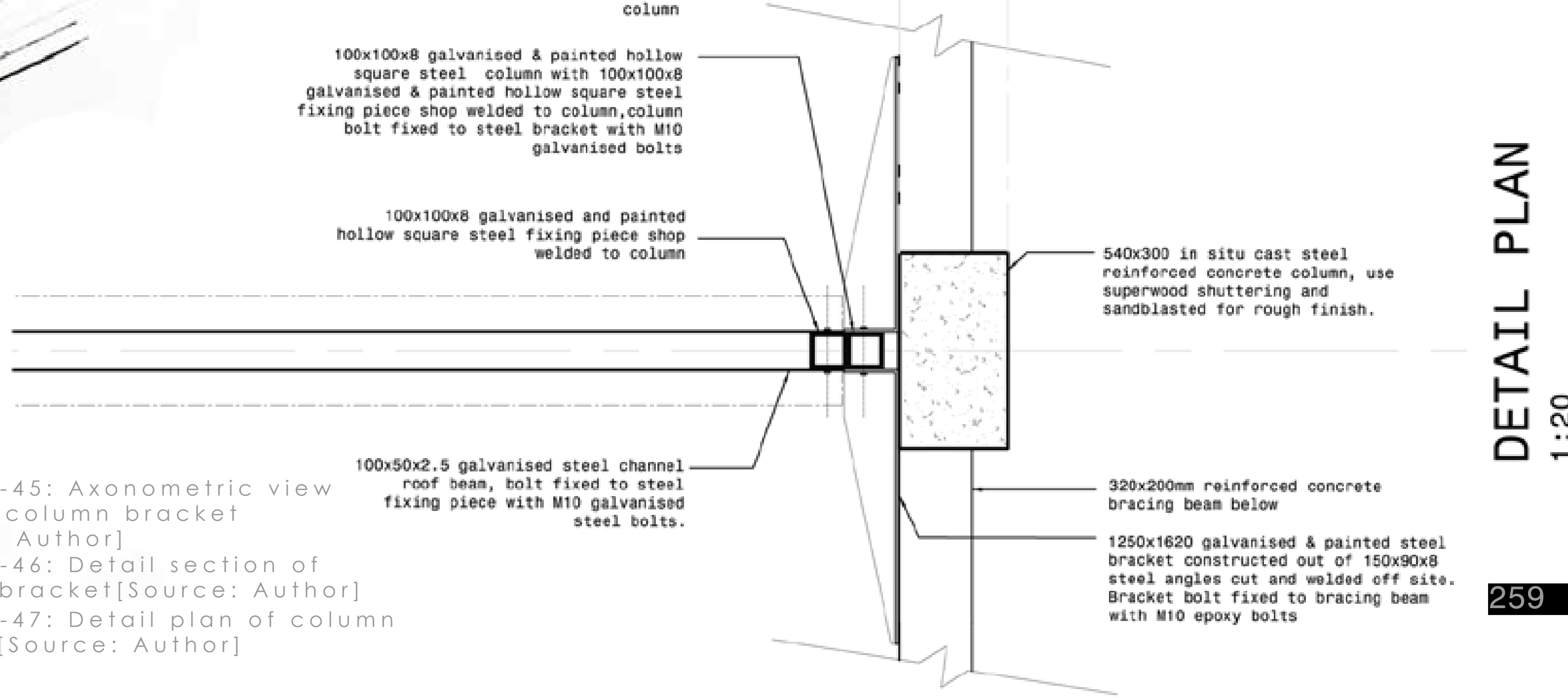


Figure 9-45: Axonometric view of steel column bracket [Source: Author]
Figure 9-46: Detail section of column bracket[Source: Author]
Figure 9-47: Detail plan of column bracket[Source: Author]

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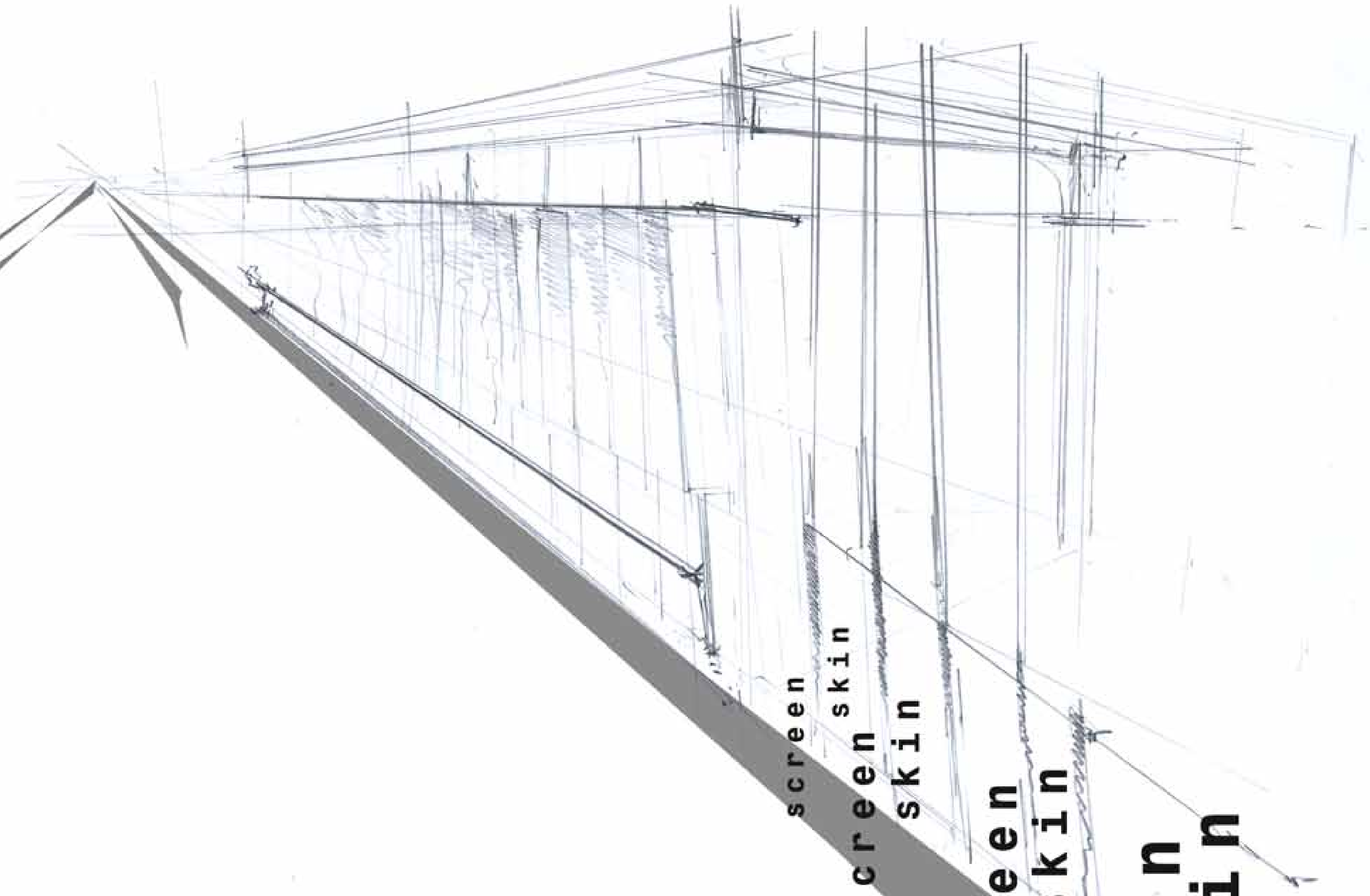
BRT PROTOTYPE_ DESIGN DEVELOPMENT

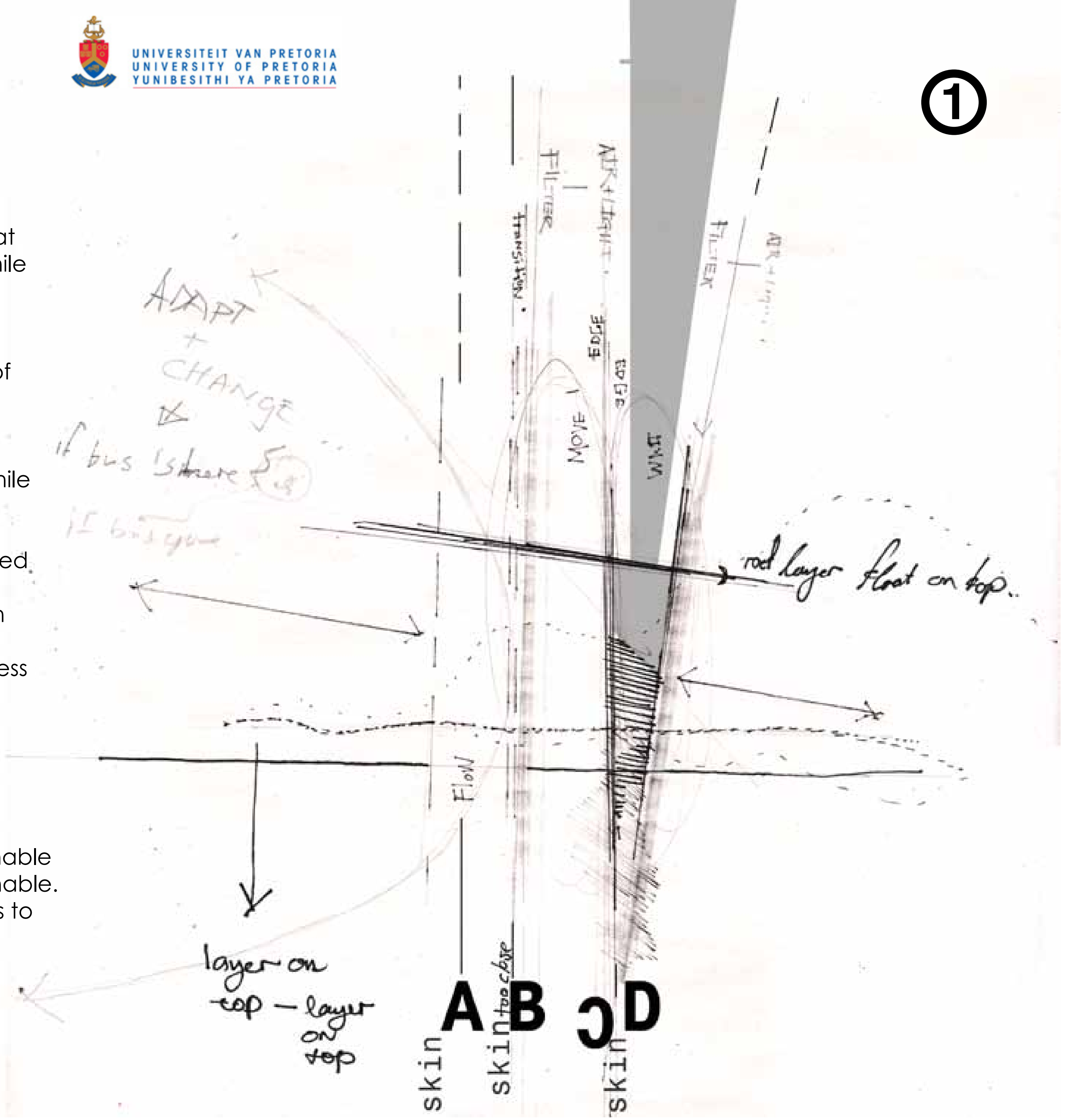


The BRT system in Tshwane needs to have an image that will be easily legible and ensure ease of orientation, while adaptable to the diverse contexts within Tshwane as a city. The station will act as an important nodal point within peri-urban areas, while at the same time be a low 'subdued" structure within the denser urban core of Tshwane

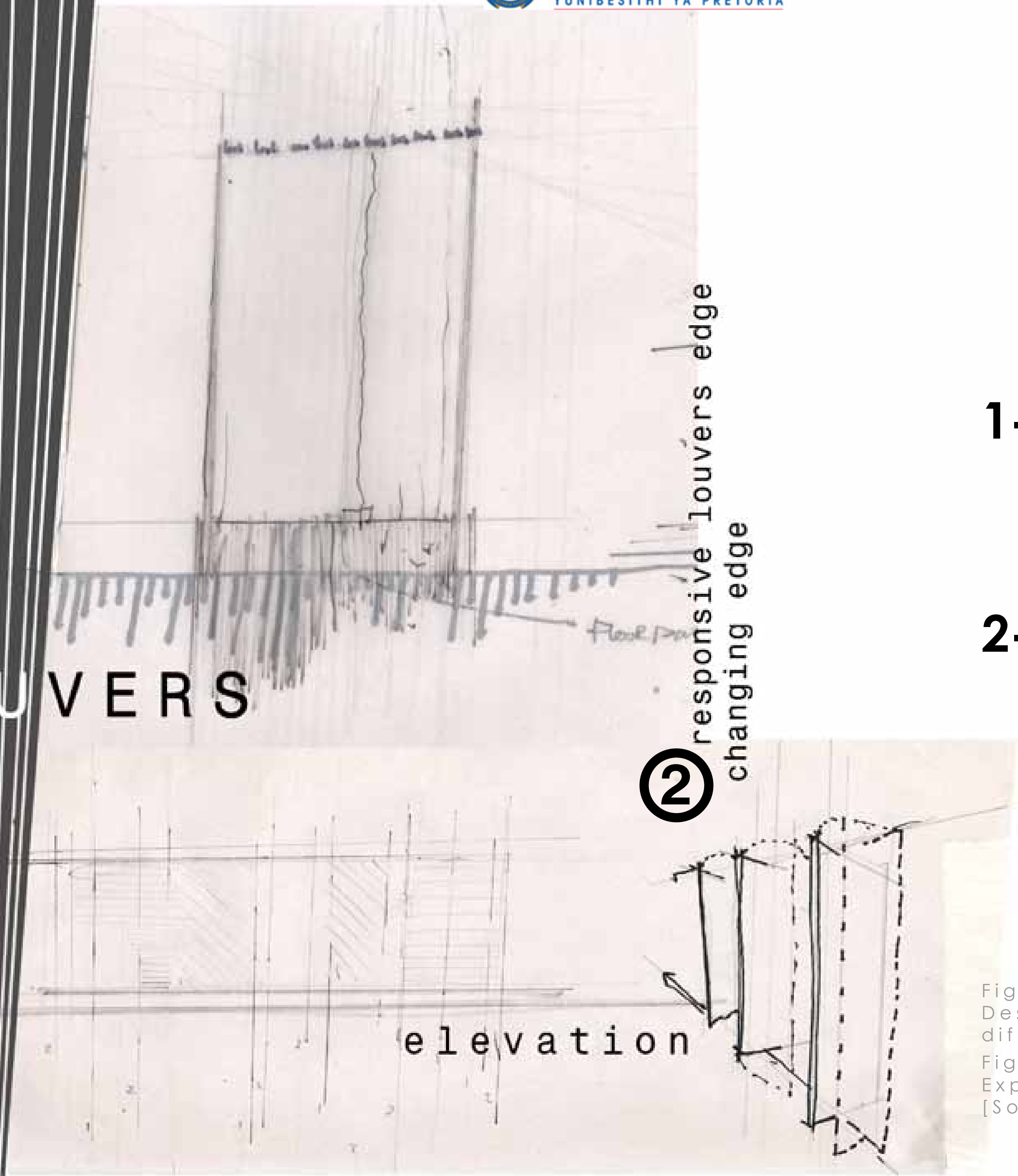
In a changing climate it will need to respond to the increasingly changing climate of the urban climate, while also mitigating it. The prototype will respond in the following manner:

a) Have a low embodied energy through selected material use.
b) Ensure the components of the BRT station can be manufactured easily and efficiently.
c) Make use of sustainable strategies to ensure less energy consumption.
d) Harvesting renewable energy to power the station.
e) Provide enough shading and protection from outdoor climate.

While the structure needs to be environmentally sustainable and responsive, the station must also be socially sustainable. The design needs to ensure that it is safe for commuters to use any time of the day.



LOUVERS



1- The initial design approach developed out of the concept of linking skins. A series of skins were identified – all responding differently to its specific edge condition.

2- The idea of a station covered with responsive louvers were explored- **Louvers closing during the day** / opening at night / **allowing air in**/ keeping rain out.

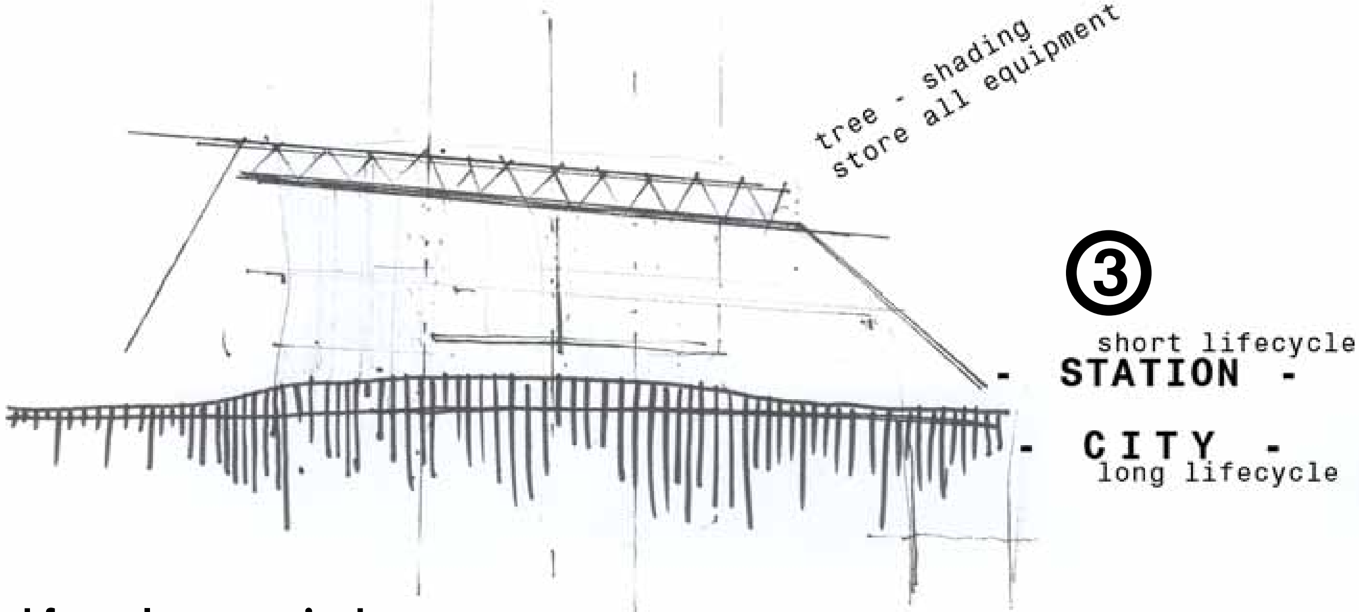
It was discarded as not being robust enough for an public building with high usage.

Figure 10-01: [Previous page] Design development 1: Identifying different skins[Source: Author]

Figure 10-02: Design development 2: Exploring louvers and systems [Source: Author]

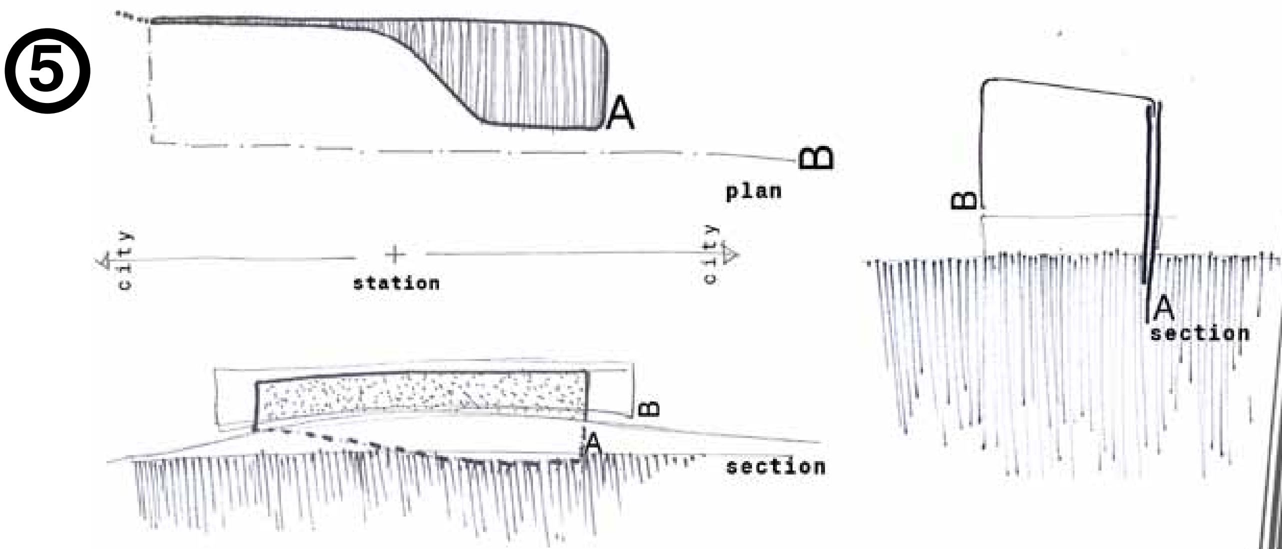
3- The idea of placing all services in the roofspace was explored
– a station city over the city _layer on top of layer.

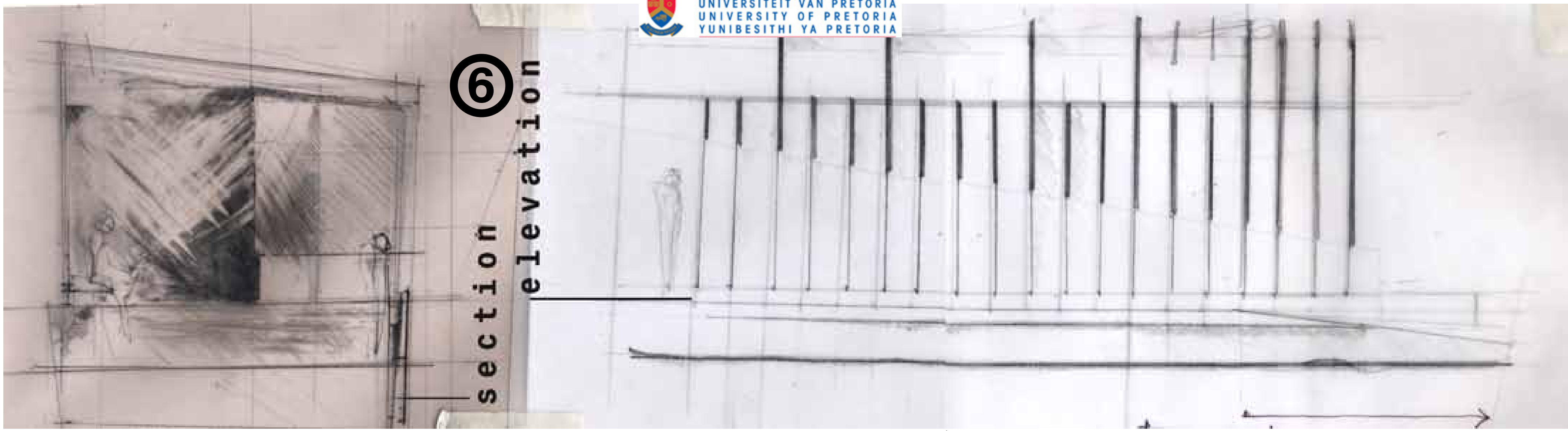
It was discarded as too much energy is invested in the station platform to not use it. Keeping the technical equipment in the platform kept the equipment safe and secure.



4- Design process stopped for a long period – to finalise terminal building design

5- Having worked on the Terminal building for a few months. The approach to the Prototype changed.
a) Two types of skins identified.
b) Utilising the kiosk as an object to direct movement.
Skin A links with the ground and city.
Skin B links with the movement of the BRT and people; floating above the ground .





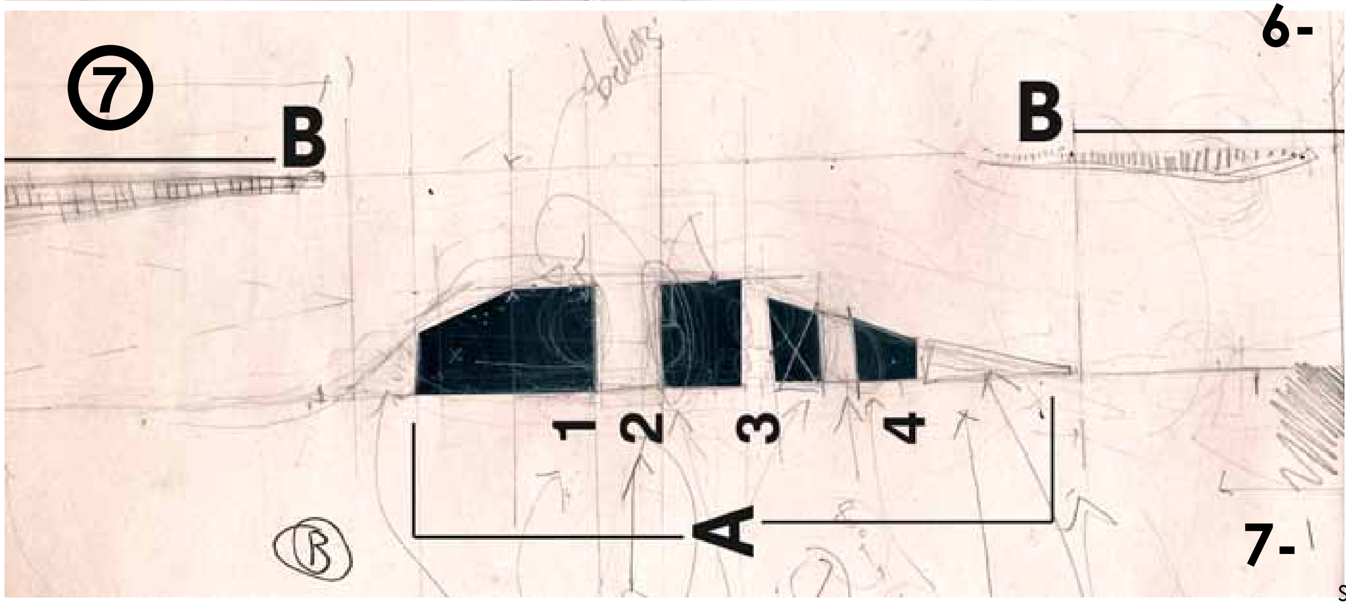


Figure 10-03: [previous design] Design development 3: Station over city [Source: Author]

Figure 10-04: [previous design] Design development 5: New approach: Skin A and B [Source: Author]

Figure 10-05: Design development 6: Solar screening skins [Source: Author]

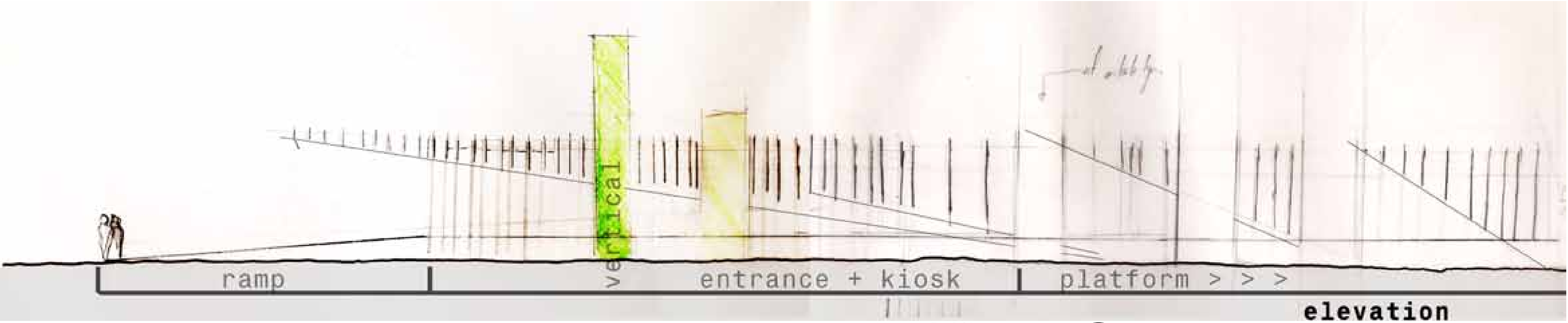
Figure 10-06: Design development 7:Kiosk components [Source: Author]

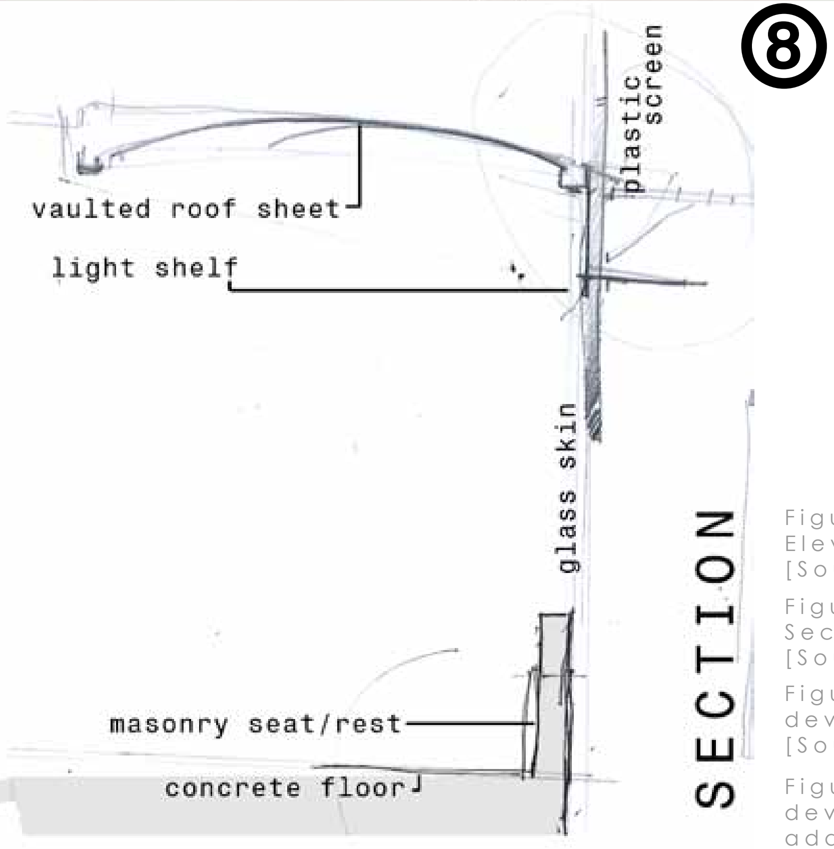
6- The architectural language was determined, it needs to respond to its immediate context, the city and the terminal building. It was decided to develop a lower scale structure that blends into the urban context – while still allowing for a nodal attachment to be added to the structure once it is being built in peri-urban spaces.

It was decided that the prototype will be developed for the first BRT line – linking Mabopane with the city. Having investigated the effect of the natural energies on the BRT station , vertical slatted screens were added to deal with solar glare – in most cases the station faces east-west.

7- The Kiosk is split into 4 sections – each housing a specific function – each section designed to be pre-manufactured independently.

This approach was discarded - for a more energy efficient construction process being concrete block construction.





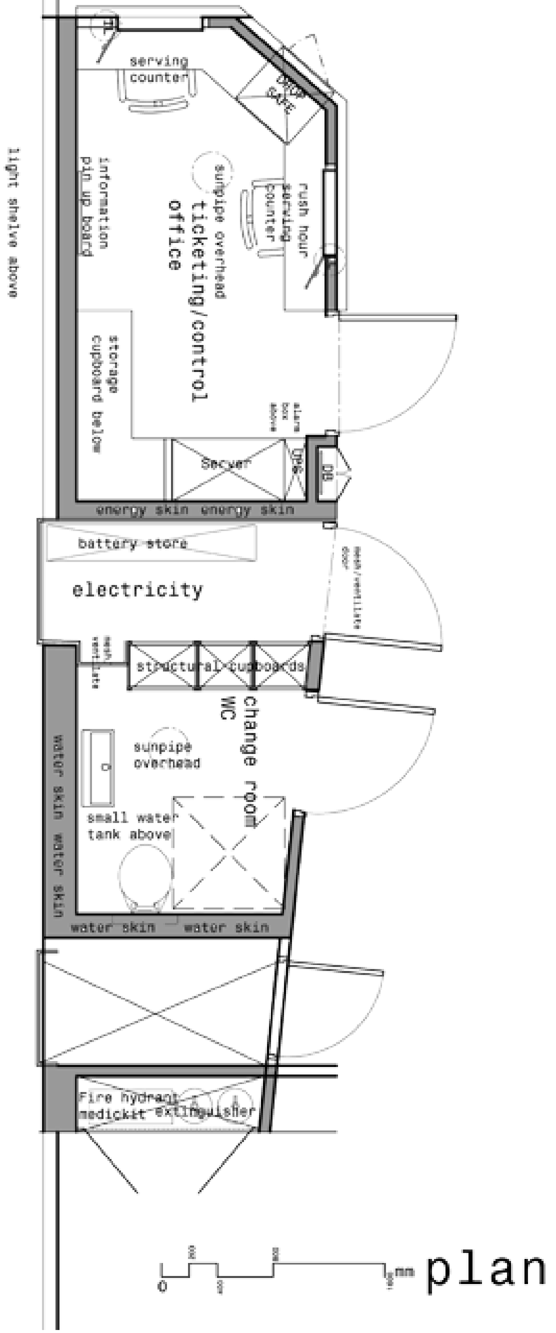
8- Section was adapted – adding a light shelf and vaulted roof.
Vertical elements added to ensure legibility of the BRT station and making it a reference point. Diagonal lines created with the vertical screens aiming to communicate a sense of speed and change.

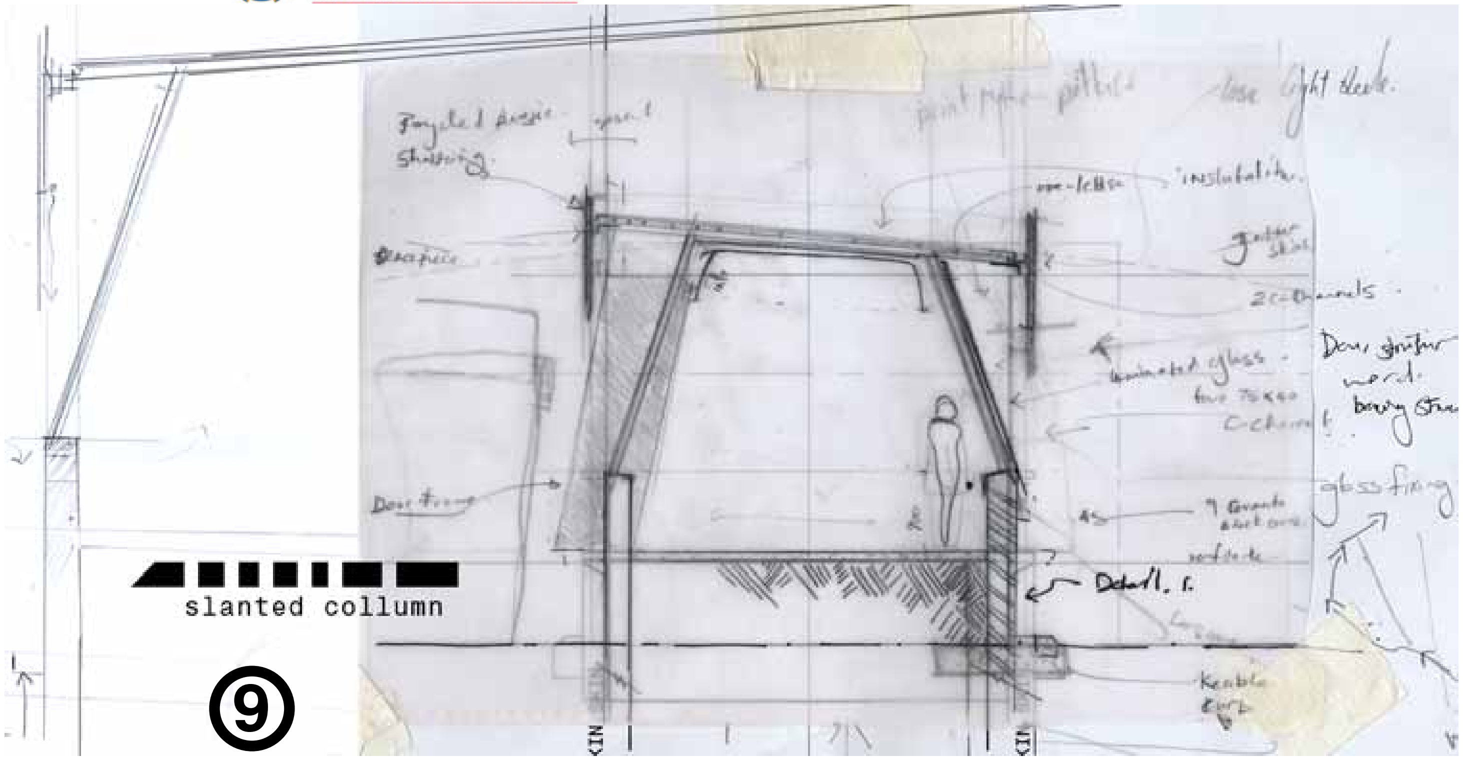
Figure 10-07: Design development 8: Elevation exploration [Source: Author]

Figure 10-08: Design development 8: Section exploration [Source: Author]

Figure 10-09: [Next page]Design development 9: Kiosk design [Source: Author]

Figure 10-10: [Next page]Design development 9: Section: Columns adapted [Source: Author]





9- Techniques of dematerialisation and material efficiency were investigated. **Columns were slanted to save 17% in steel use** _ Single gutter used to save on material. Glass fixed to column and slanted – to provide more protection from sun light.

Concrete block masonry units and ground filled concrete floor used- to lower carbon footprint and embodied energy.
Concrete block masonry adds to thermal mass of station – while reducing the use of stainless steel.

Water tank to be installed below to make station self sufficient. **The Kiosk layout developed to reduce space requirement and increase functional efficiency.**

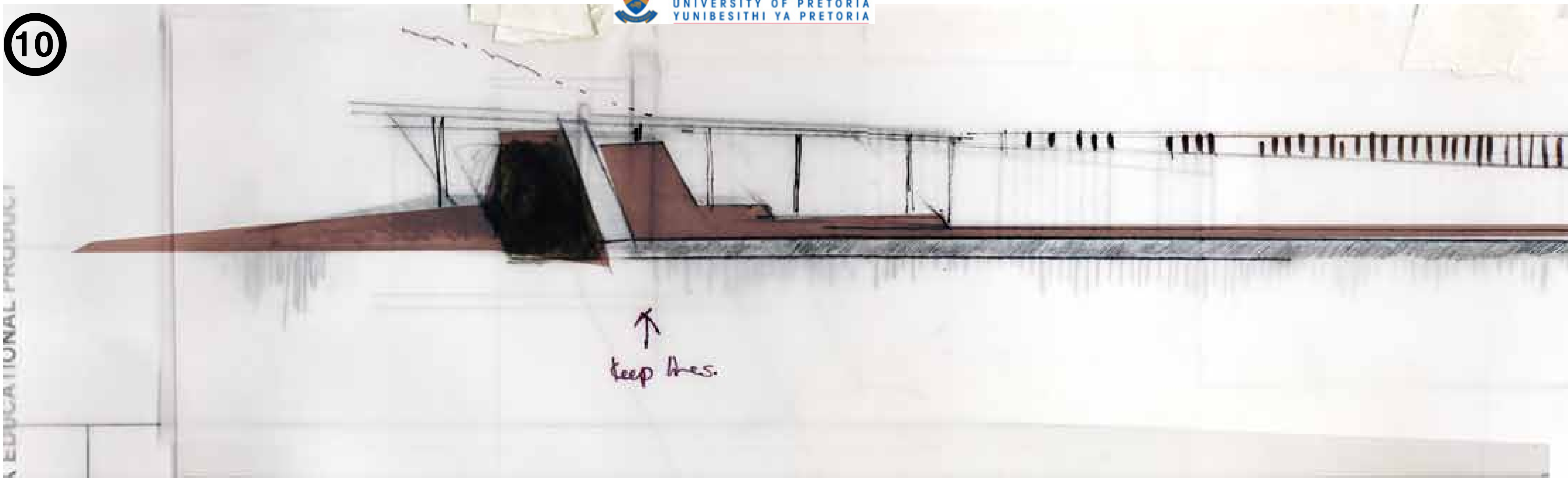
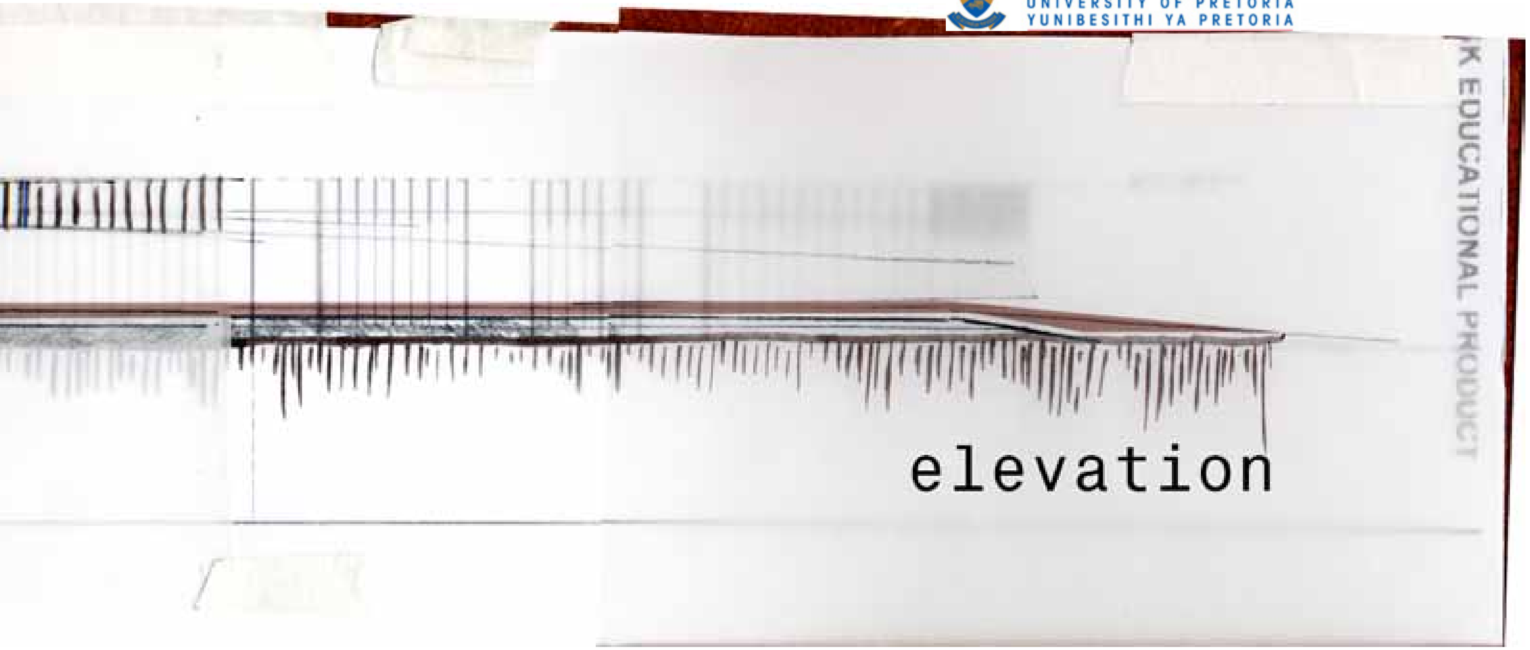
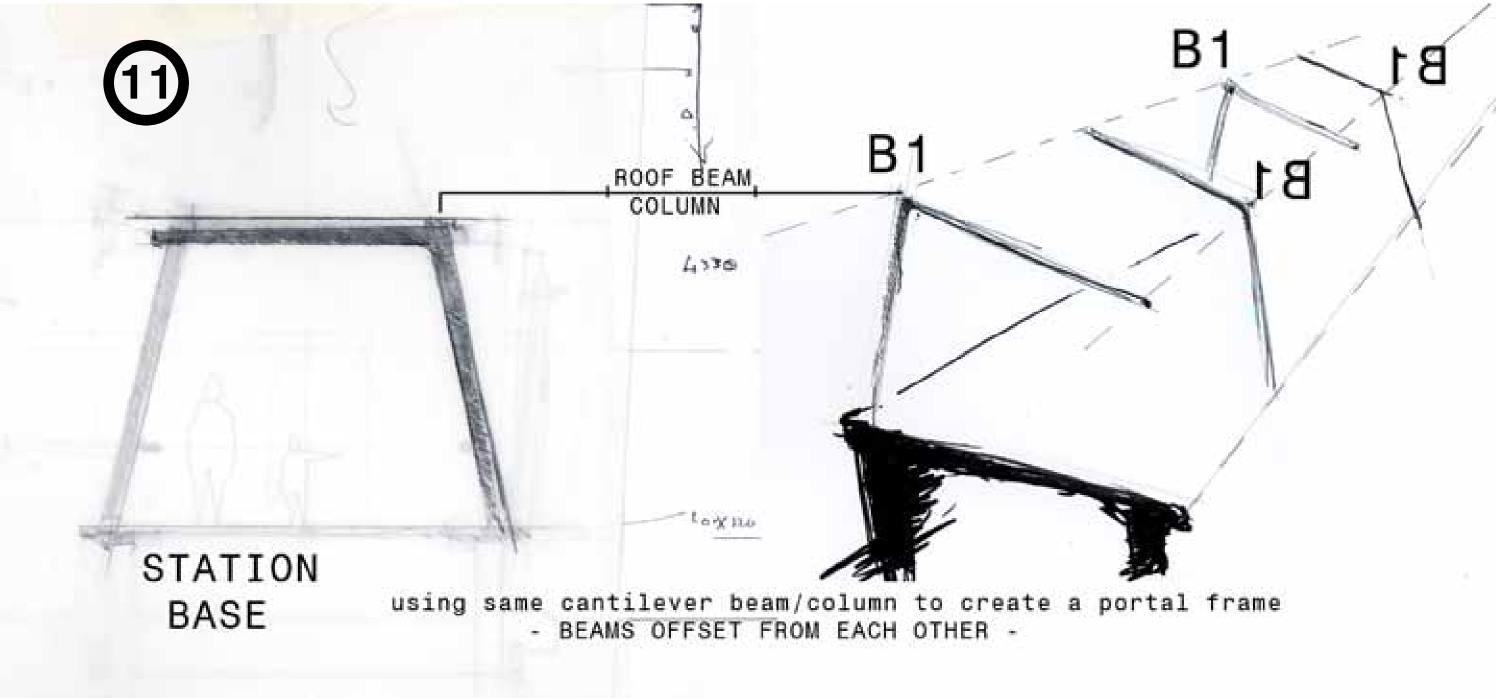


Figure 10-11: Design development 10: Facade investigation.[Source: Author]

10- Kiosk designed to be constructed with concrete blocks, station edge/plinth cast out of reinforced concrete and concrete block infill.

Diagonal lines kept to induce a sense of speed and movement on the facade





11- Cantilever roof beam and column structural system was developed. These cantilever steel sections allow for two different grid systems on each station edge.

The same roof beam/column is pre-manufactured and fixed facing each other to complete portal frame.

Figure 10-12: Design development 11: New portal frame system
[Source: Author]

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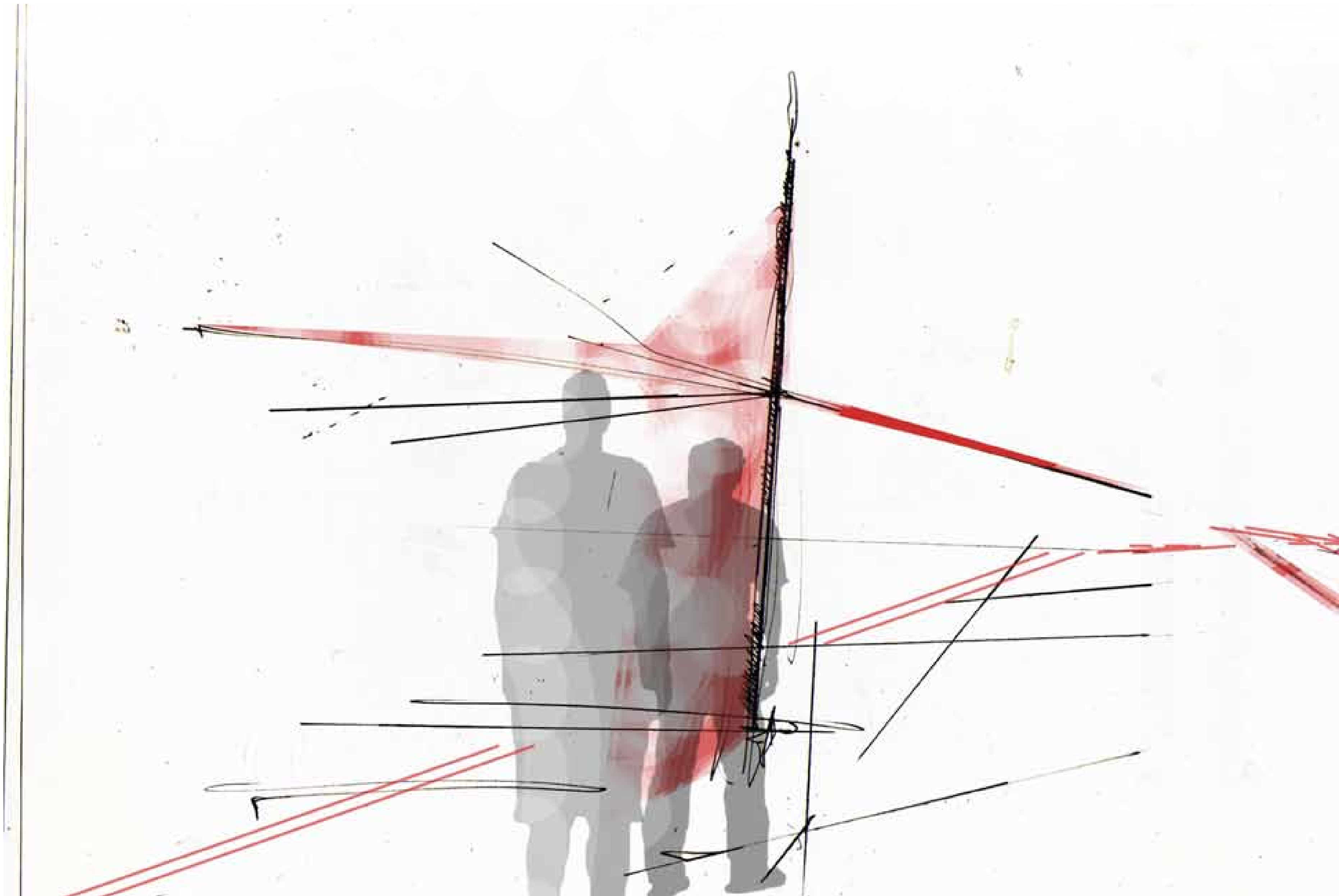
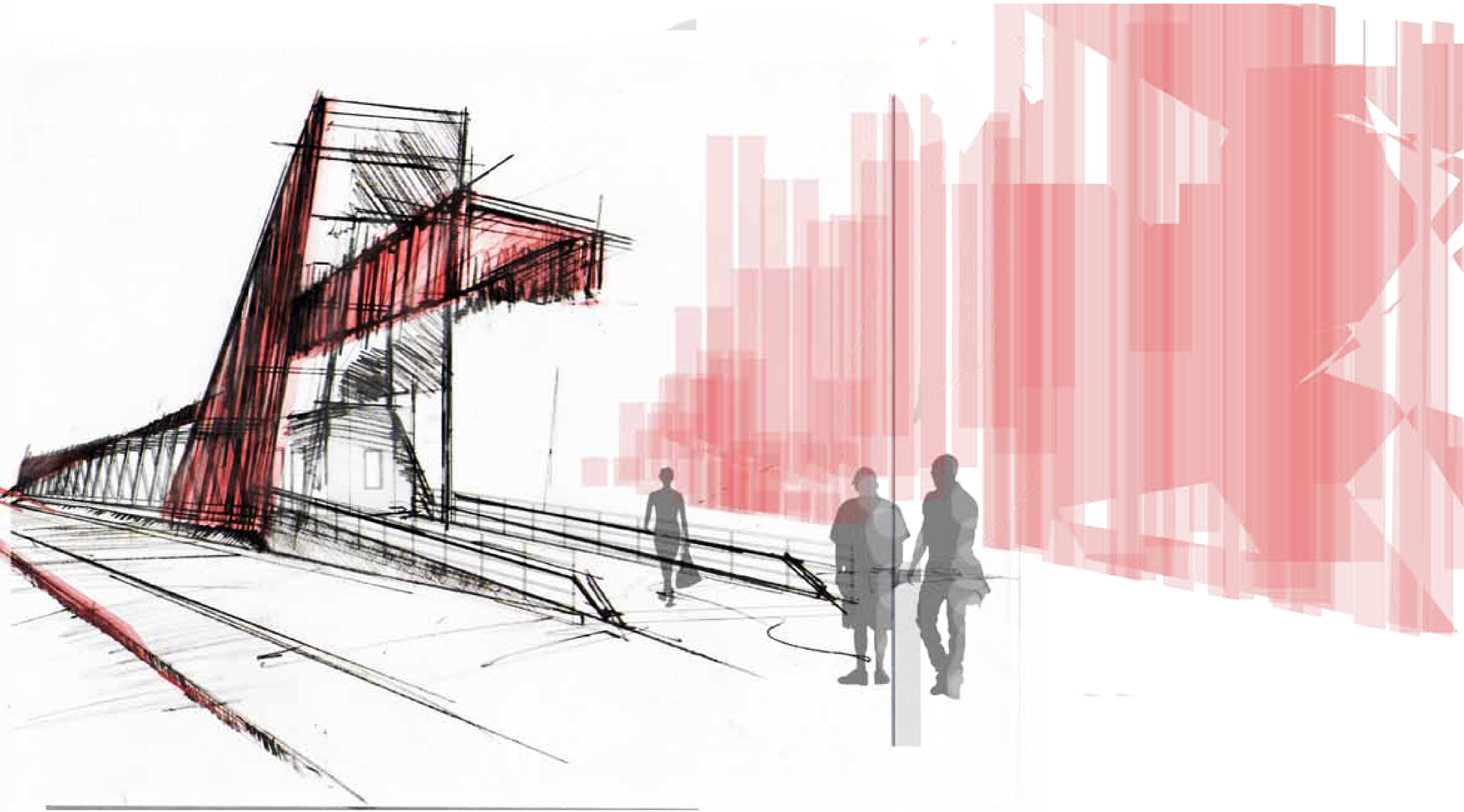


_ 11
BRT PROTOTYPE DESIGN



The BRT prototype developed out of the theoretical research and the conceptual development of the BRT terminal building.
The prototype is designed more specifically for the first stage of the BRT system in Tshwane
– the Line 1 connecting the northern suburbs with the city centre.

The architectural language developed out of the conceptual investigation for the BRT terminal building as well as the need to respond to its immediate context and the city. It was decided to develop a lower scale structure that blends into the urban context – while the entrance is articulated with a steep sloping roof. The use of diagonal lines refer to the experience of speed and movement. **The high entrance becomes a recognisable node within the urban context**

The design of the prototypical station will continue into the next semester and culminate in a finalised design.

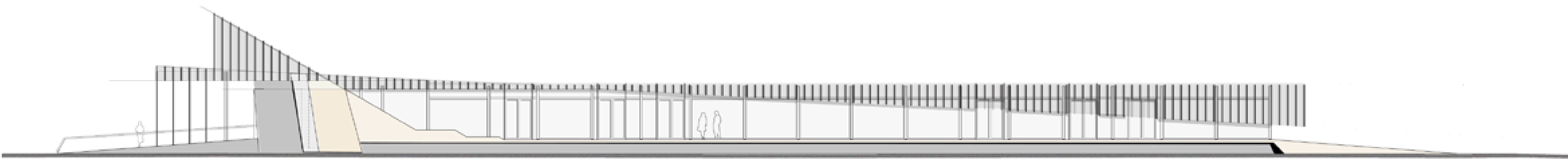
TWO SKINS LINKING THE STATION - ADAPTING TO MOVEMENT FUNCION TIME WEATHER

A -HOUSES FUNCTIONS, PROTECTS USERS, MORE STATIC - SOLID/HEAVY/STEREOTOMIC

B -OPENS AND CLOSES, ADAPT TO MOVEMENT , SCREEN,ROOF - LIGHT/TECHTONIC/PREMANUFACTURED

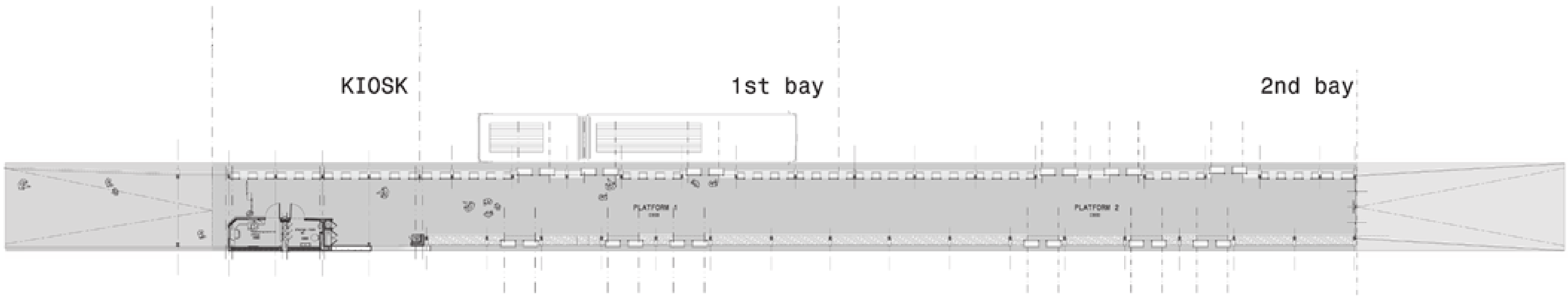
Figure 11-01: Conceptual approach to the design of the BRT station [Source: Author]

11.1 PROTOYPE DESIGN



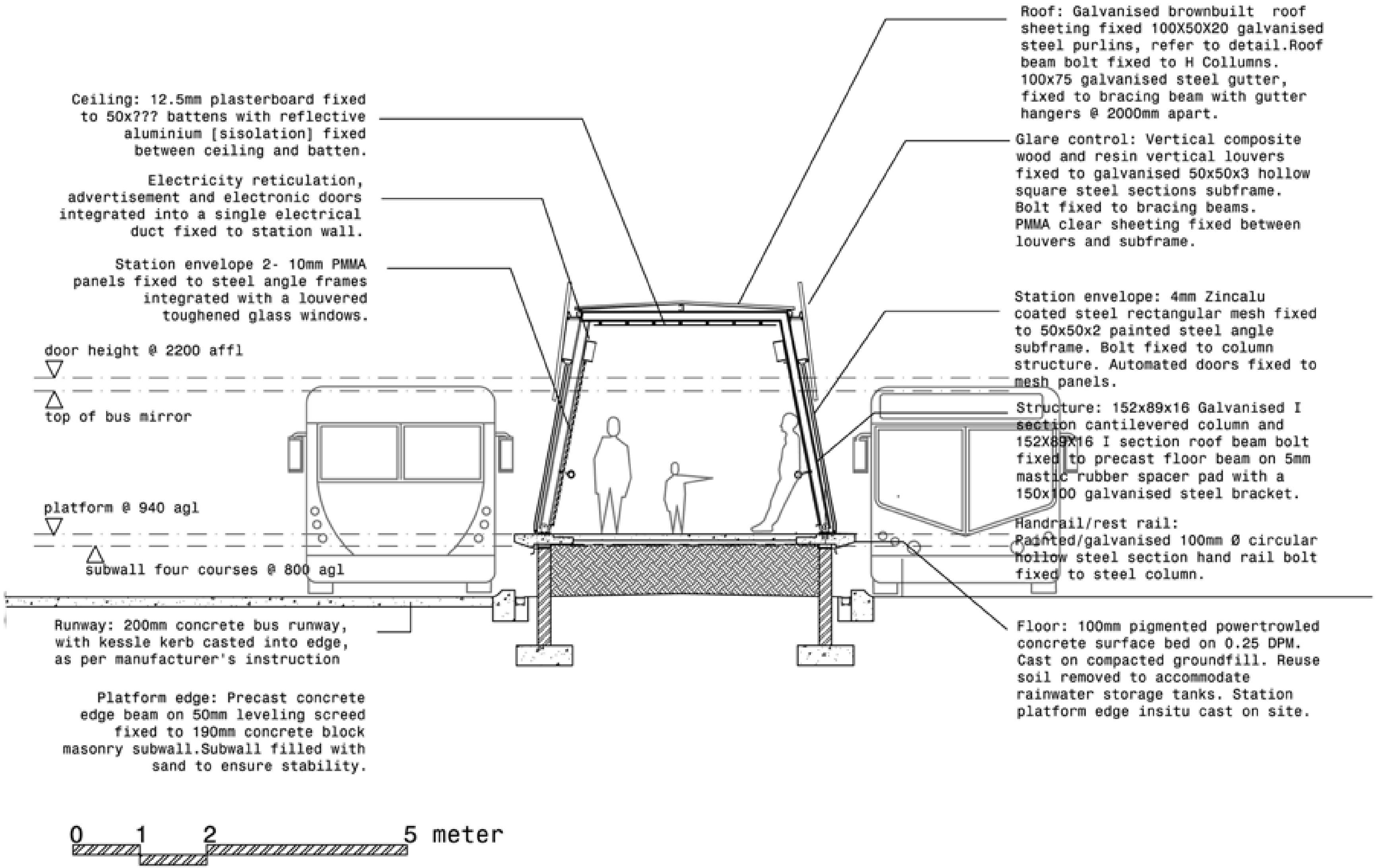
ELEVATION 1

Figure 11-02: Elevation [A] of the BRT station [Source: Author]



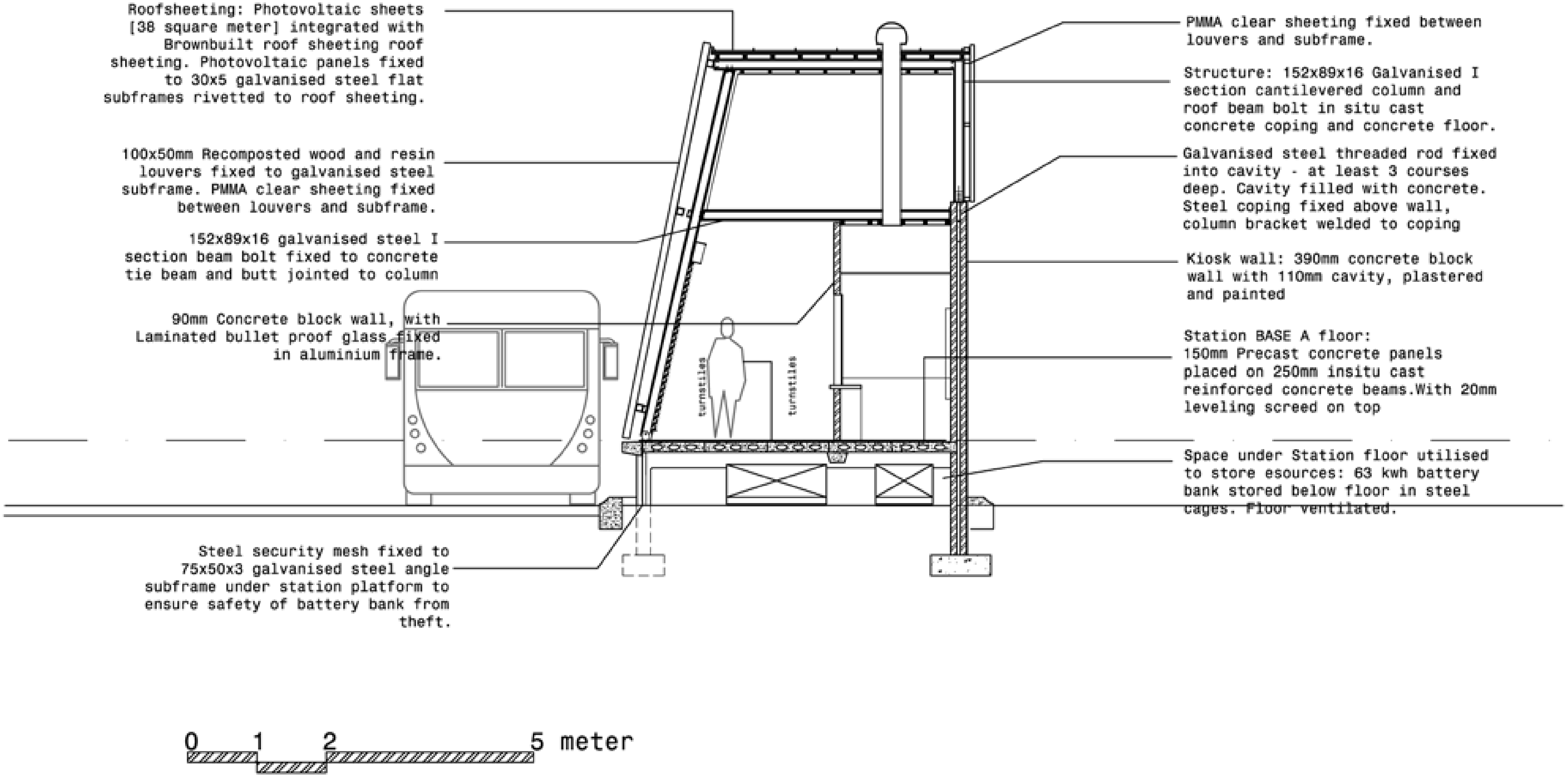
PLAN

Figure 11-03: Plan of the BRT station [Source: Author]



SECTION AA
- typical section through station

Figure 11-04: Typical section AA of the BRT station [Source: Author]



SECTION BB
- typical section through kiosk

Figure 11-05: Typical section BB of the BRT station [Source: Author]

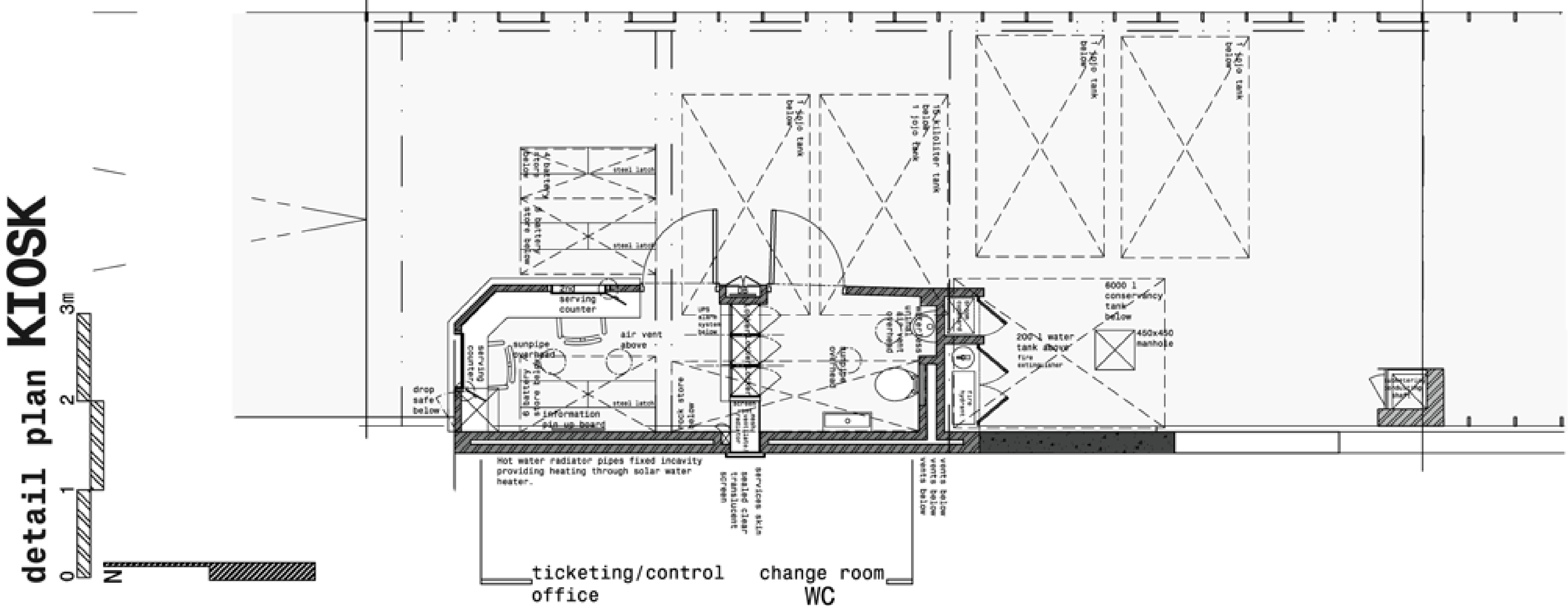


Figure 11-06: Detail plan of Kiosk [Source: Author]

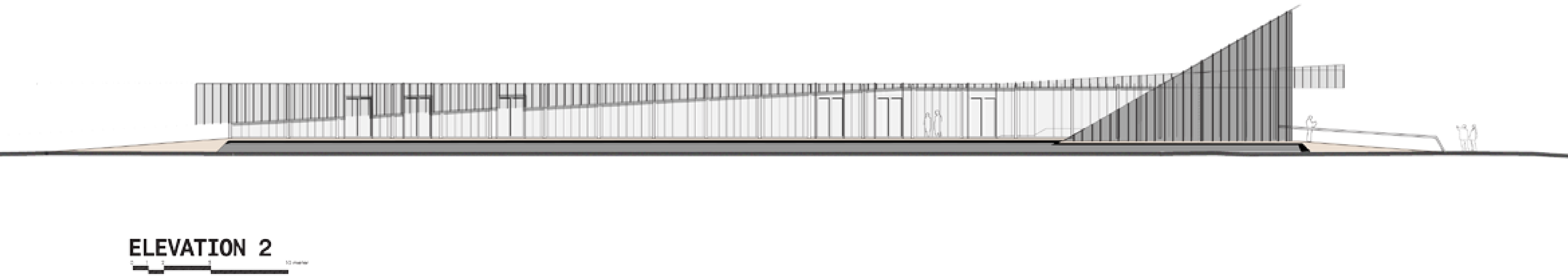
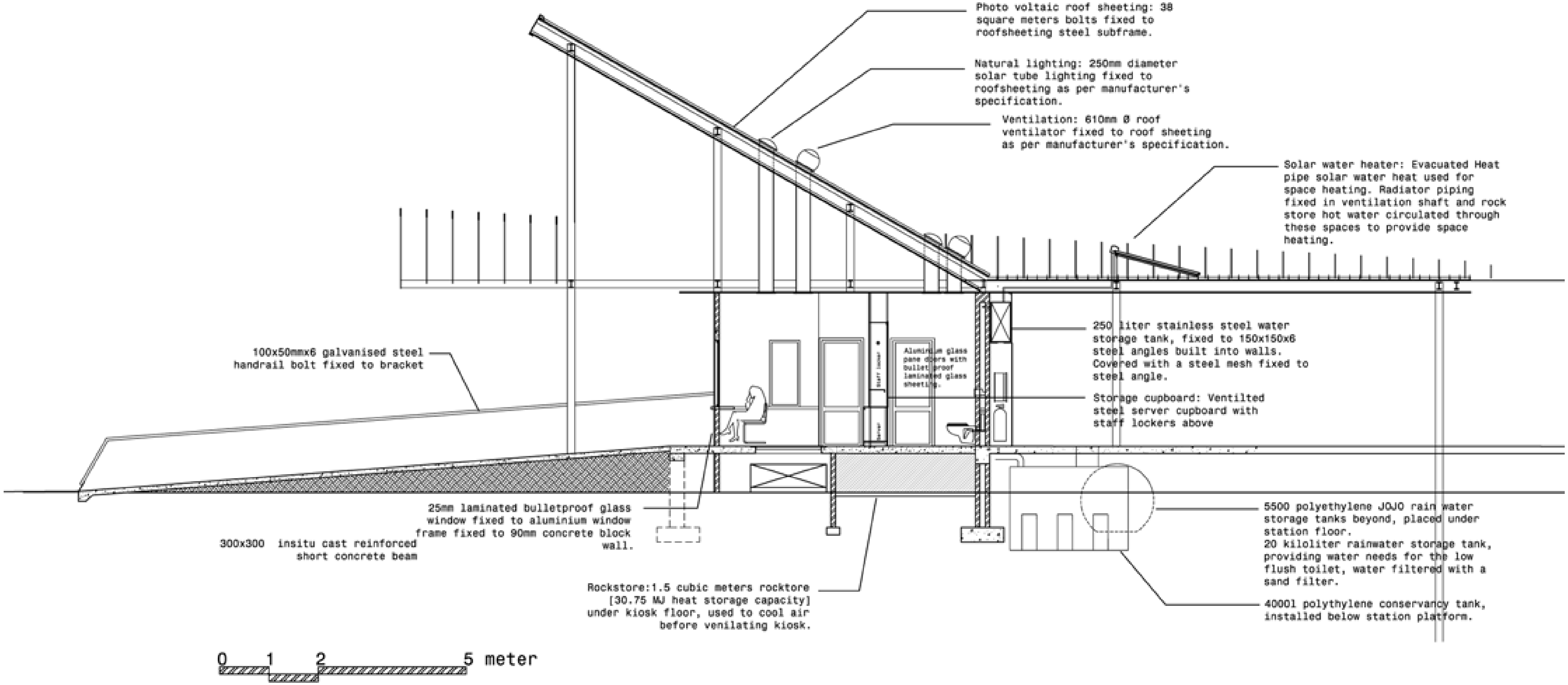


Figure 11-07: Elevation [B] of the BRT station [Source: Author]



SECTION CC
- section through station entrance

Figure 11-08: Detail section CC of entrance [Source: Author]

11.2 STRUCTURE AND SYSTEMS

The structural systems and service systems used in the BRT station were developed along with the terminal building and are elaborated on in the chapter 10. The following aspects regarding the prototype will be discussed:

a) Structural system and material use
b) Energy used and harvesting
c) Ventilation system
d) Water harvesting.

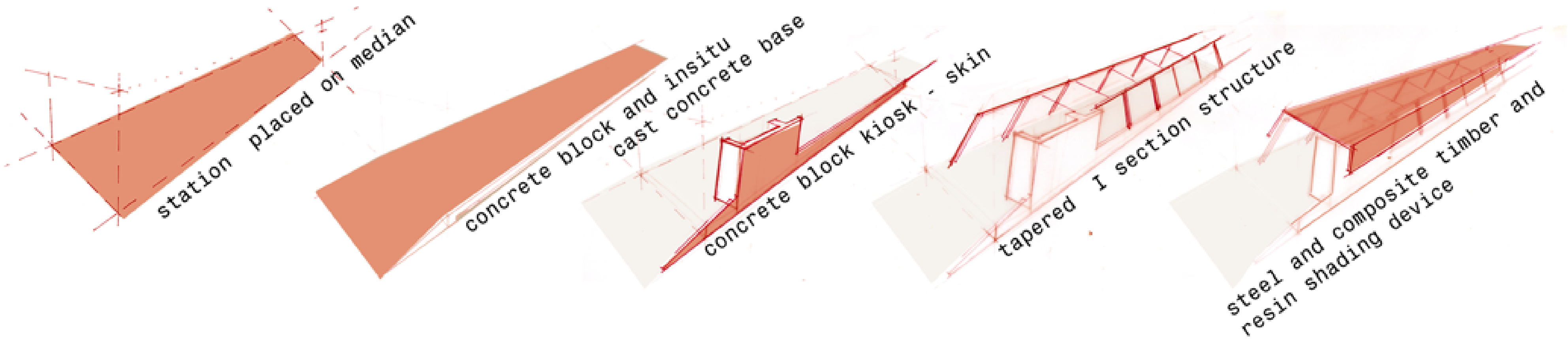


Figure 11-09: Structural components of the BRT station [Source: Author]

11.2.1 Structural system and material choice.

The structural system and material choice for the BRT station focuses on minimizing the embodied energy and carbon footprint of the station. The materials were also chosen according to the framework established [refer to section 4.4] and focused on materials that are robust enough to withstand the high usage of the station.

The station base is a100 mm power trowled concrete surface bed cast on soil infill and 190mm concrete block subwalls. The station edge is an insitu cast reinforced concrete edge. This approach will contain 46% less embodied energy than casting the whole station base in concrete, refer to Table 13-12, pg 287. Local labour will be used for the construction that will contribute to social and economical sustainability.

The ticket office will be constructed from concrete blocks. A plastered 240mm cavity walls has the lowest embodied energy, refer to Table 13-05, pg 283, as well as a high thermal mass.

The roof and envelope structure is a dry construction process. The galvanized steel structure is constructed out of 152x89x16kg/m I-beam column and beam structures.

By tapering the structure 17% steel will be saved – lowering the embodied energy of the structure [refer to Tables 13-16, pg 289].

Only one side of the station is enclosed with PMMA sheeting protecting for the commuters from driving rain and wind. This materialhas a high embodied energy but will be strong enough to withstand vandalism.

11.2.2 Heating and ventilation system

The station waiting area will be naturally ventilated. As the commuters will only wait 5 minutes on average for the next bus it will not be energy efficient to cool/heat the waiting areas.

The ticket office will need to be heated during the winter, refer to Graph 13-03, pg 296. **Heat evacuated tubes [Apricus 2010] are fixed to the roof from which very hot water is circulated through the rock store and concrete wall to provide space heating.** The water circulates in 20mm copper pipes.

610mm Ø roof ventilators is fixed in the roof of the office to draw air through the 1.5 m^3 rockstore into the office [Turbovent 2010]. One ventilator has a exchange rate of 6150 m3 /hr will mean that the office will have an air change rate of 0.5 per hour [Turbovent 2010].

11.2.3 Energy use and harvesting

The daily energy consumption of the station has been calculated as 22kWh per day, refer to Tables 13-24+25 , pg 293-4. **A photovoltaic system, 35m^2, is integrated with the roof sheeting [at 37° north facing] to provide renewable carbon free energy.**

The energy will be stored in a 63.9 kWh battery bank, this will be store in the base of the station under the floor, refer to Table 13-26, pg 294.

250mm Ø solar tubes are installed in the roofs of the ticket office and change room [solartube 2010]. A single solar tube provides adequate day lighting for 22 m^2 and will ensure that less artificial lighting is used during the day within the office [Solartube 2010].

11.2.4 Rain water harvesting

Water will be collected from the station roof, for the toilet. Four 5500l water storage tanks [JOJO tanks 2010] is positioned under the station floor to store 20 kiloliters, refer to Table 13-28, pg 295. This will provide enough water for the toilet, while a waterless urinal will be installed to minimise water consumption.

11.2.5 Carbon footprint & Environmental Rating

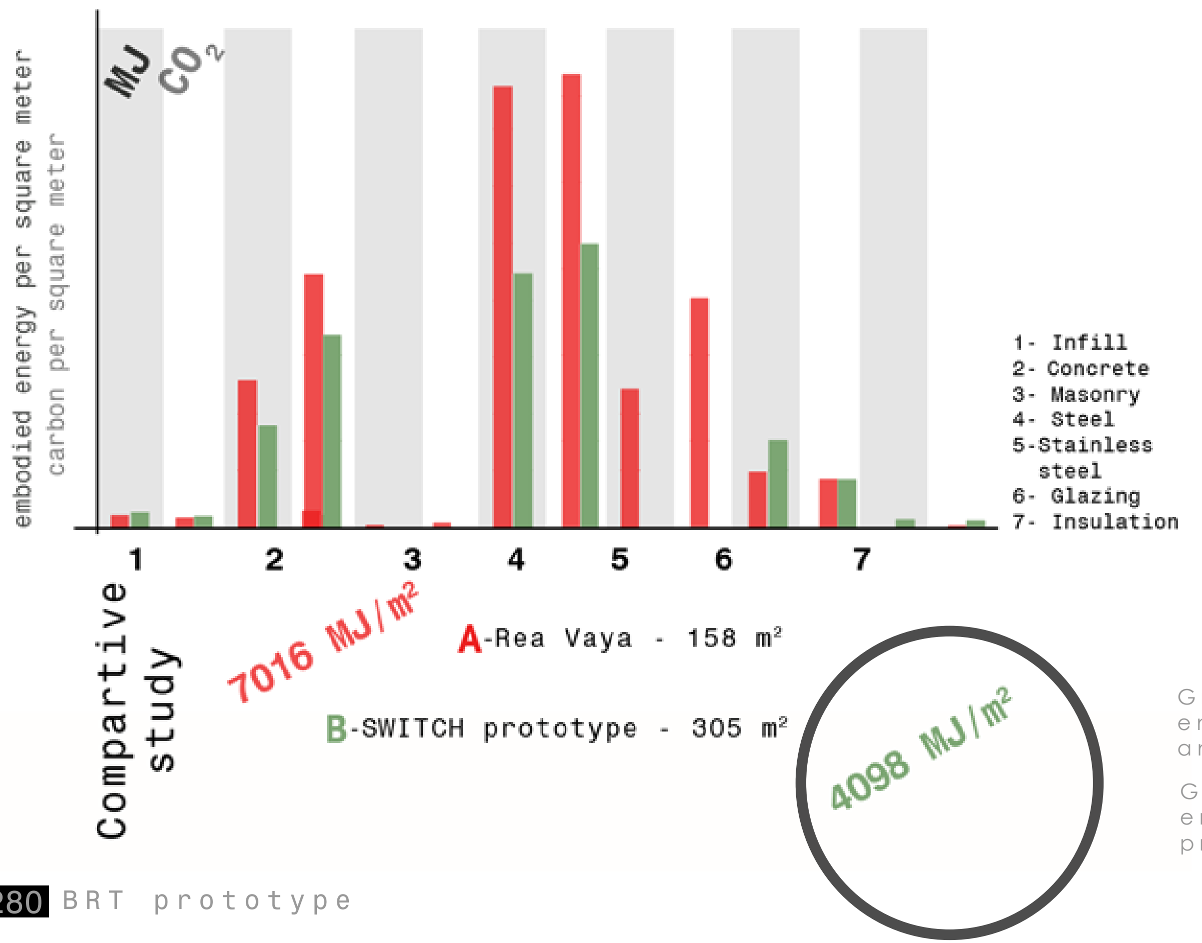
The carbon footprint and embodied energy of the prototypical station structure has been calculated and compared to a Rea Vaya BRT station in Johannesburg.

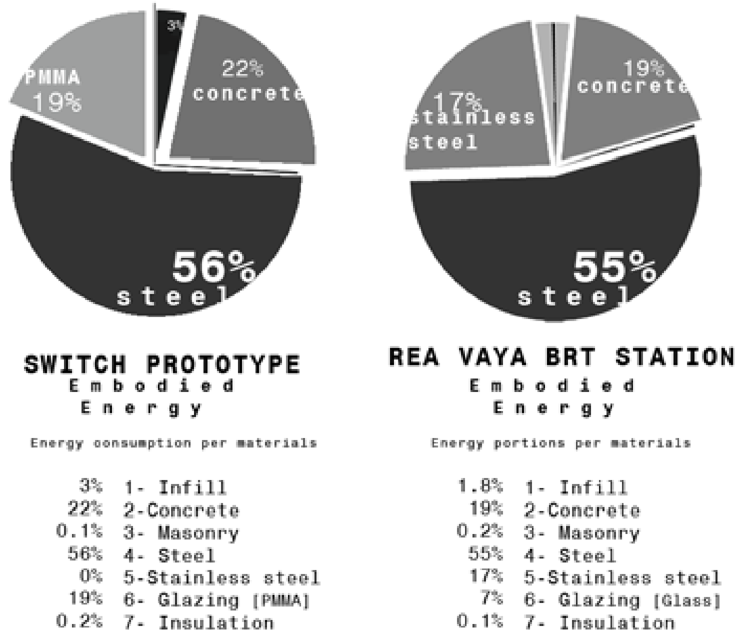
Figures used in the calculations were taken from the material analysis in section 4.4, pg 124.

The "Switch" prototype has a 42 % lower embodied energy and carbon footprint per square meter than the Rea Vaya BRT station.

The total embodied energy of the Switch prototype is 1 249 956 MJ [Table 11-01] while the Rea Vaya station has a total of 1 108 540 MJ [Table 4-02].

This can be attributed to the size difference of the two stations [158 m² - Rea Vaya; 305 m² - Switch], as the Switch prototypical station needs to be bigger to accommodate the high number of commuters from the northern suburbs in Tshwane that will be using the system.





Graph 11-01: Comparative study of the embodied energy and carbon footprint of the Switch prototype and Rea Vaya Station [Source Author]

Graph 11-02: Comparative study of the embodied energy of material use compared to the whole[Switch prototype and Rea Vaya Station] [Source Author]

EMBODIED ENERGY _ SWITCH PROTOTYPE

Material	Component	Size m3	kg/m^3	Weight kg	MJ/kg	kg CO_2/kg	Embodied energy MJ	Carbon Footprint KG
Infill aggregate	Infill base 780mm deep	202.7	2000	405 400	0.1	0.005	40540	2027
Concrete	Ramp	5.4	2400	12 960	2.42	0.256	31363.2	3317.76
	Ramp surface bed	10.8	1900	20 520	1.39	0.209	28522.8	4288.68
	low column [kiosk]	0.15	2400	360	2.42	0.256	871.2	92.16
	floor beam [kiosk]	0.828	2400	1 987	2.42	0.256	4809.024	508.7232
	Precast floor[kiosk]	8.55	2400	20 520	3.7	0.39	75924	8002.8
	skuins muur [east elevation]	3.9	2400	9 360	2.42	0.256	22651.2	2396.16
	Floor 100mm [power trowled]	27.7	1900	52 630	1.39	0.209	73155.7	10999.67
Concrete block	Low wall - retain	16	1900	30 400	0.81	0.098	24624	2979.2
Concrete block	Kiosk wall	8.17	1900	15 523	0.81	0.098	12573.63	1521.254
concrete floor	Ramp Paving	0	1900	0	1.39	0.209	0	0
Masonry	Ramp Paving	0	1900	0	0.81	0.098	0	0
Alumium	Doors frame							
Steel	Steel "vastrap"@ bus entrance	0	8000	0	29.44	2.22	0	0
	I-beam Collums	0.44	8000	3 520	29.44	2.22	103628.8	7814.4
	Roof beam	0	8000	0	29.44	2.22	0	0
	Purlins @ 700 centres	0	8000	0	29.44	2.22	0	0
	Bracing member C channels	0.15	8000	1 200	29.44	2.22	35328	2664
	Footings	0.0007	8000	6	29.44	2.22	164.864	12.432
	I-beam Collums [Kiosk]	0.15	8000	1 200	29.44	2.22	35328	2664
	Bracing member [kiosk]	0.026	8000	208	29.44	2.22	6123.52	461.76
	Footings	0.0001	8000	1	29.44	2.22	23.552	1.776
	Corrugate roof	0.0.09	8000	8 000	39	2.82	312000	22560
	Corrugate roof [kiosk]	0.22	8000	1 760	39	2.82	68640	4963.2
	Corrugated Ceiling	0	8000	0	31.5	0.256	0	0
	Steel facia board	0.0012	8000	10	29.44	2.22	282.624	21.312
	Steel door frames	0	8000	0	29.44	2.22	0	0
	Steel gate	0	8000	0	29.44	2.22	0	0
	Steel handrail	0.2	8000	1 600	29.44	2.22	47104	3552
	Steel handrail [ramp]	0.053	8000	424	29.44	2.22	12482.56	941.28
	Window structural frame	0.248	8000	1 984	29.44	2.22	58408.96	4404.48
	Louver frame	0.0078	8000	62	29.44	2.22	1837.056	138.528
	Window bead	0	8000	0	29.44	2.22	0	0
Stainless Steel	Handrail	0	7500	0	56.41	6.15	0	0
	Seat -rest	0	7500	0	56.41	6.15	0	0
	Stainless steel office	0	7500	0	56.41	6.15	0	0
	Bus entrance handrail	0	7500	0	56.41	6.15	0	0
Glass	Glass elevation	0	2400	0	35	2	0	0
MESH*	elevation [west] [136m^2]	136	5.92	805	56.41	2.53	45416.8192	2036.9536
PMMA	elevation [east]	1.6	940	1 504	80.5	2.53	121072	3805.12
PMMA	elevation [rain cover]	0.6	940	564	80.5	2.53	45402	1426.92
	Glass door BRT door	0.09	2400	216	35	2	7560	432
	Glass panel @ kiosk (bullet proof)	0.1	2400	240	35	2	8400	480
	Emergency exit	0.037	2400	89	35	2	3108	177.6
	Plastic louvers #	0.11	940	103	19	1	1964.6	103.4
	Ceiling	3.4	900	3 060	6.75	0.38	20655	1162.8
Insulation	Ceiling	0	11	0	28	1.35	0	0
						TOTAL	1249965.109	95957.3688
						Area	305	305
						per meter	4 098.25	314.61

used particle board figure - doubled the figure to use 35 MJ/kg
* used stainless steel embodied energy - will have to be analysed
calculated according to weigth per square meter - as per manufacturer's specification.

Table 11-01: Embodied energy and carbon footprint analysis of Switch prototypical BRT station [Source: Author]

An Environmental rating assessment has been done for the Switch prototype. The Green Star Office Rating Tool was used and adapted to rate applicable aspects of the design.

Aspects assessed by the tool that were deemed not applicable were removed from the assessment process in an effort to give a fair rating.

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Rating of Switch BRT prototype

Summary of Sustainability rating of Prototype*

* Green Star SA - Office Design V1 adapted and used.

		SCORE AVAILABLE	TOTAL ACHIEVED	%	WEIGHTING	WEIGHTED SCORE
Management						
	None of the credits were applicable to the design process.					
Indoor Environment Quality						
IEQ-1	Ventilation Rates	3	3			
IEQ-2	Air Change Effectiveness	2	2			
IEQ-3	Carbon Dioxide Monitoring & Control	1	0			
IEQ-4	Daylight	3	3			
IEQ-5	Daylight Glare Control	1	1			
IEQ-7	Electric Lighting Levels	1	1			
IEQ-8	External Views	2	2			
IEQ-9	Thermal Comfort	2	0			
IEQ-10	Individual Comfort Control	2	2			
IEQ-11	Hazardous Materials	1	0			
IEQ-12	Internal Noise Levels	2	0			
IEQ-13	Volatile Organic Compounds	2	0			
IEQ-14	Formaldehyde Minimisation	1	0			
IEQ-15	Mould Prevention	1	1			
IEQ-16	Tenant Exhaust Riser	1	0			
IEQ-17	Environmental Tobacco Smoke Avoidance	1	1			
	TOTAL	**26**	**16**	**61.53846**	**0.15**	**9.230769231**
Energy						
ENE-1	Greenhouse Gas Emissions	20	20			
ENE-2	Energy Sub-metering	2	2			
ENE-3	Lighting Power Density	4	3			
ENE-4	Lighting Zoning	2	0			
ENE-5	Peak Energy Demand Reduction	2	2			
	TOTAL	**30**	**27**	**90**	**0.25**	**22.5**
Transport						
TRA-3	Cycle Facilities	3	0			
TRA-4	Commuting Mass Transport	5	3			
TRA-5	Local Connectivity	2	2			
	TOTAL	**10**	**5**	**50**	**0.09**	**4.5**

		SCORE AVAILABLE	TOTAL ACHIEVED	%	WEIGHTING	WEIGHTED SCORE
Water						
WAT-1	Occupant Amenity Water	5	5			
WAT-2	Water Meters	2	0			
WAT-4	Heat Rejection Water	4	4			
WAT-5	Fire System Water Consumption	1	0			
TOTAL		**12**	**9**	**75**	**0.14**	**10.5**
Materials						
MAT-1	Recycling Waste Storage	2	0			
MAT-3	Reused Materials	1	0			
MAT-4	Concrete	3	1			
MAT-7	PVC Mininisation	1	0			
MAT-9	Design for disassembly	1	1			
Mat-10	Dematerialisation	1	1			
Mat- 11	Local Sourcing	2	1			
TOTAL		**11**	**4**	**36.36364**	**0.13**	**4.727272727**
Land Use & Ecology						
ECO_2	Reuse of Land	2	2			
ECO-4	Change in ecological value	4	0			
TOTAL		**6**	**2**	**33.33333**	**0.07**	**2.333333333**
Emmissions						
EMI-1	Refrigerant/Gaseous ODP	1	1			
EMI-2	Refrigerant GWP	2	2			
EMI-4	Insulant ODP	1	0			
EMI-5	Watercourse Pollution	3	0			
EMI-6	Discharge to Sewer	5	0			
EMI-7	Light Pollution	1	1			
EMI-8	Legionella	1	1			
TOTAL		**14**	**5**	**35.71429**	**0.08**	**2.857142857**
	TOTAL SCORE					56.64851815
	WEIGHTED SCORE	exluding Management credits				**62%**
	RATING	**FIVE STAR RATING**				

Table 11-02: Environmental assessment summary [Source: Author - based on the Green Star SA - Office V1 rating tool]

This assessment does give one a fair idea of the performance of the Switch prototypical station, though one must keep in mind that this tool focusses on office buildings and does not necessarily assess the appropriate design aspects.

The BRT prototype performs very well in terms of energy consumption, indoor environment, water conservation and public transport accessibility.

The design process focussed on the minimisation of material use - which has led to a low carbon footprint and embodied energy [refer to Graph 11-01]. This is not necessarily reflected in the rating assessment, which shows that a sustainable intervention has many more aspects to focus on.

Yet the fact that the BRT prototype scores a five star rating shows that the Green Star SA rating tools do focus to mitigating climate change as well.

C O N C L U S I O N

The thesis investigation has indicated that a low carbon intervention can be designed to provide a flexible urban and architectural framework to facilitate a more sustainably conscious society in future.

The proposed BRT terminal building at the Pretoria Main Station acts as a bridging structure that links the isolated Salvokop precinct to the city. Through the integration of the different transport systems on the site and reimagining the Station Square as a new functional green space the intervention acts as a catalyst between the two precincts contributing to its economic and social sustainability as well as ensuring this area regain its importance as a gateway into Tshwane,

The intervention responds to the urban context by adding complimentary functions to the existing that provide economic opportunity, while combating social problems caused by the isolation of these precincts. To mitigate climate change the design integrates the transport systems around the station promoting sustainable movement patterns within Tshwane. By developing a low carbon terminal building and prototypical BRT station the project also addresses the carbon footprint and embodied energy of public transport infrastructure within the city.

The Station Square is redeveloped as an urban green space which merges with the terminal building in an effort to provide a functional safe park that mitigates the heat island effect within the urban environment. The landscape also acts as an external skin to the building preventing unwanted glare inside.

Using sustainable principles, the design was generated through an analysis and response to the socio-cultural and historic context. It uses and enhances the existing character of the site while adding to its diversity with a new flexible intervention serving both the inhabitants of Salvokop and commuters alike.

Its impact on the environment during its construction phase is kept to the minimum by analysing the embodied energy and carbon footprint of construction materials and building technologies. This minimises the initial energy input for the structure.

Sustainable principles together with passive and active systems were utilised to lower the intervention's energy consumption during its functional phase. The terminal building is designed to allow high amounts of natural light into the building, while the vegetation around the building and screening devices are used to protect the interior spaces from direct sunlight and prevent heat build up. Natural ventilation is integrated with efficient mechanical ventilation systems to ensure a comfortable indoor environment. Available resources on site are harvested such as rainwater, solar thermal energy and photovoltaic energy.

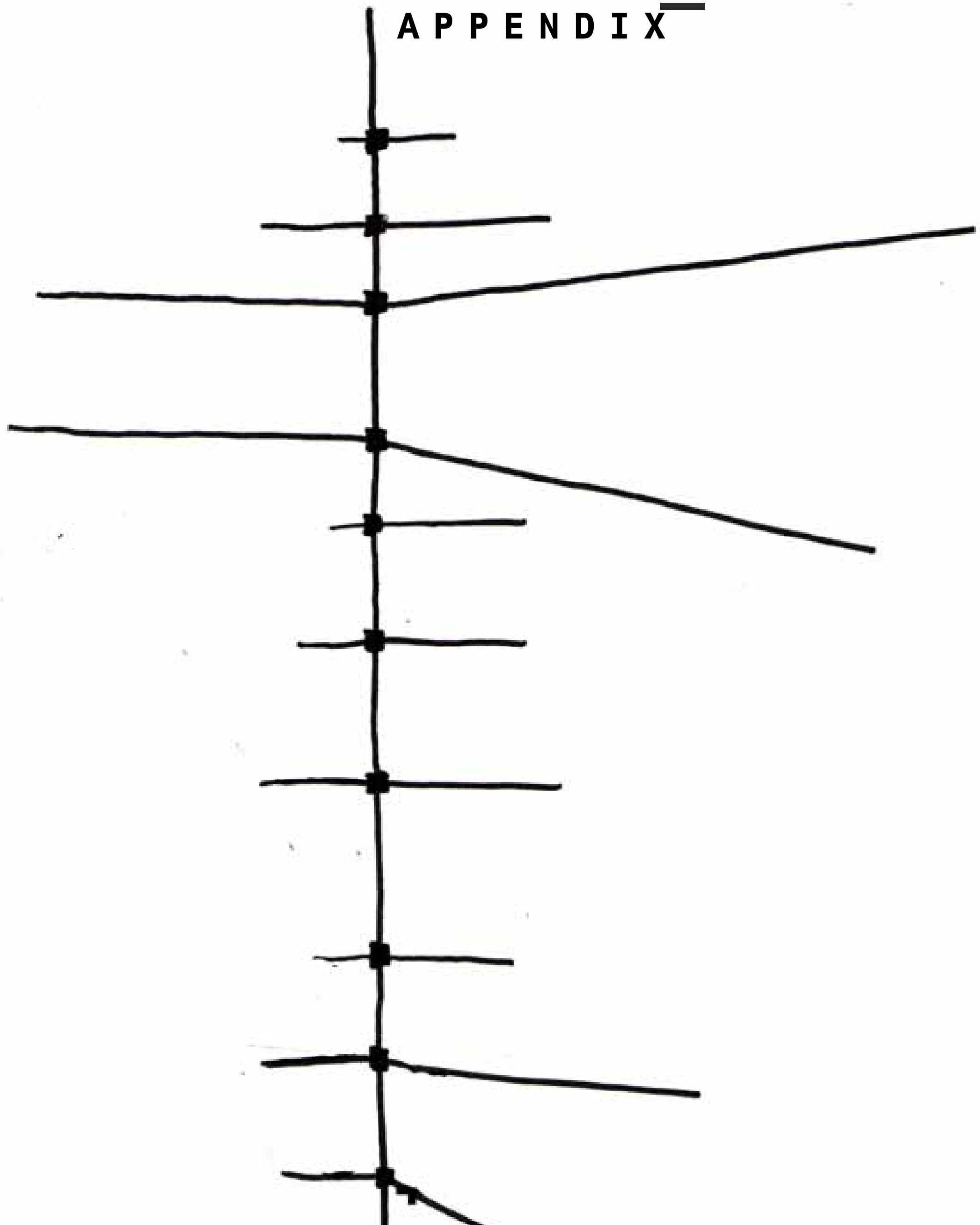
Finally the following two significant points can be deduced:

To develop a sustainable built environment the building industry must collectively undertake a paradigm shift to have real and quantifiable effects. Isolated projects and interventions are too dependent on existing inefficient systems and processes leaving these projects stranded. Interaction between the different professions and disciplines is vital to achieve this.

The most effective immediate action that can be taken is to minimise built interventions and their effects, while increasing their efficiency in terms of material use, systems and functions. This should not be seen as a restrictive approach but rather a shift in our understanding of the role of new architectural solutions in our society.

13

APPENDIX



13.1. ORIGINAL RESEARCH PROPOSAL

10.1.1 UNDP/GEF STUDENT GRANT PROJECT PROPOSAL

1. The Research Objectives

The objective is to design, with recognition of the GEF BRT Climate change requirements, a low Carbon Bus Rapid station and Auxiliary Building/s. The Site chosen is that of the existing Pretoria Main station. This station serves as an interchange not only for BRT System but also forms an integral transportation hub for other modes of transport.

The second objective of the study is to design some of the components of the Low Carbon BRT Station and Auxiliary building/s in such a way that some of the modules could be used as a prototype and/or model for other such nodal and modal interchanges.

The third objective that such a design as described above should respect the cultural and historical setting of the Pretoria Main Station and hence be sensitive to and respond to its context.

The Fourth objective is that the study should incorporate aspects of LEED [or other green building rating systems] and then also components of a design approach and normative position regarding the cradle-to grave definition of materials and their production, a low carbon footprint study, embodied energy and life-cycle performance and management of these aspects within the architectural research and design resolution.

A fifth aim is that the student and the study promoters attend a South African Green Building Council GreenStar course.

2. The anticipated approach to the research and methodology to be applied

The study will commence with a literature study and the gathering of data relevant to the design of Climate Change Sensitive low Carbon BRT station and Auxiliary building/s.

After the literature study the student will engage with the design of these structures. The design will be refined within an iterative process. The final design of the structures will be measured with a green building rating system. A set developed detail technical drawings will be provided to support the design. The designed structures are academic investigations and will culminate in a mini dissertation and two publications to be submitted for peer reviewed publication in Architecture SA.

3. Expected interim and final deliverables and the timeframe thereof

Interim deliverables for 2010 and the first semester of 2011 are the following:

1.At the end of the first term of the University of Pretoria calendar the student should have proofed investigation including data capturing and literature study into the complexities of the following:

a. Climate change as it pertains to the urban environment and in particular Tshwane.
b. BRT systems in Tshwane.
c. BRT systems of Pretoria Main station.
d. Low carbon construction technologies.
e. The LEED or other ration systems.
f. The Cultural and historical heritage of the site.
g. The above should be presented to the supervisors at the end of the term.

2. At the end of the second term, the student should have proofed investigation and provide evidence of the study in the above as well as into the complexities of the following:

a. Design approach and normative position regarding the cradle-to-grave definition of materials and their productions, low carbon footprint, embodied energy and life cycle performance and management of the aspects.
b. A draft literature study of the work conducted to date and this should include the objectives of the study.
c. A conceptual urban framework for the design should be presented.

3. At the end of the third quarter the student should provide a preliminary design o the project that acknowledges and responds to the above two quarters and the objectives of the study with the final aim of a low carbon BRT station and auxiliary building/s.

4. The fourth quarter should be concluded with a written mini dissertation that complies with the objectives of this research project and the graduation regulation s of the Department of Architecture.

5. The first and second quarter of 2011 should result in two submitted publications [for peer review] to the Journal architecture SA based on the research conducted by the student in 2010. The student is responsible for the writing and submission of this research paper.

4. Conclusion

We trust that this research proposal will meet the requirements of the UNDP and GED for this project. The Department of Architecture is known for its stature to promote and educate students in sustainable and green architecture. The Department is thus most grateful for this opportunity to partner with the GEF and UNDP to further this integral goal and to build more capacity in the department and students that graduate from our Professional Masters programme

13.2 EMBODIED ENERGY OF MATERIALS

13.2.1 Embodied energy tables

Embodied Energy Table: Europe

Material	Weight [kg/m³]	Durability	Loss factor [21%]	Years left as reserves	Primary energy consumption [MJ/kg]	
					North Europe	Central Europe
Aluminium [50% recycled]	2700	High	21	220	58	184
Steel [100% recycled]	8000	High	-	-	6	10
Steel [galvanised from ore]	7500	High	21	21	12	25
Stainless steel from ore	7800	High	21	21	12	25
Concrete structural	2400	High	16	-	0.6	1
Concrete Aerate prefab units	500	Medium	5	-	-	4
Concrete Lightweight prefab units	750	Medium	6	-	2	4
Lime Mortar	1700	Medium	10	-	1	1
Glass	2400	High	3	-	7	8
Fired clay Bricks	1800	Very High	10	-	2	3
Expanded Polystyrene XPS	23	Meduim	11	40	72	72
Expanded Polustyrene [PUR]	35	Low/medium	11	40	98	110
Timber	550	Meduim/High	20	Renewable	3	3
Laminated timber	550	Medium/High	-	390	4	4
Cellulose fibre insulation [100 % recycled and boric salts]	60	Medium	1	295	19	21

Table 13-01: Table indicating the different embodied energy quantities of construction materials in Europe [Source:Berge 2006: p20]

Embodied Energy Table: International

	EMBODIED ENERGY	
MATERIAL	**MJ/KG**	**MJ/M³**
Aggregate	0.1	150
Straw bale	0.24	91
Soil-cement	0.42	819
Stone [Local]	0.79	2 030
Concrete block	0.94	2 950
Concrete [30mpa]	1.3	3 180
Concrete Precast	2.0	2 780
Lumber	2.5	1 380
Brick	2.5	5 170
Cellulose insulation	3.3	112
Gypsum wallboard	6.1	5 890
Particle Board	8.0	4 400
Aluminium[recycled	8.1	21 870
Steel [recycled]	8.9	37 210
Shingles [asphalt]	9.0	4 990
Plywood	10.4	5 720
Mineral Wool insulation	14.6	139
Glass	15.9	37 550
Fibreglass insulation	90.3	970
Steel	32.0	251 200
Zinc	51.0	371 200
Brass	62.0	519 580
PVC	70.0	93 620
Copper	70.6	631 164
Paint	93.3	117 500
Linoleum	116	150 930
Polystyrene insulation	117	3770
Carpet [synthetic]	148	84 900
Aluminium	227	515 700
Note: Embodied energy is only international amounts		

Embodied Energy Table: Australia

Material	Embodied energy MJ/kg	Material	Embodied energy MJ/Kg	Material	Embodied Energy MJ/Kg
Kiln dried softwood	3.4	Stabilised Earth	0.7	Aluminium	170
Kiln dried hardwood	2.0	Imported dimension granite	13.9	Copper	100
Air dried hardwood	0.5	Local Dimension granite	5.9	Galvanised steel	38
Hardboard	24.2	Gypsum plaster	2.9	Glass	12.7
Particle board	8	Plaster board	4.4	Plastic	90
MDF	11.3	Fibre Cement	4.8	PVC	80
Plywood	10.4	Cement	5.6	Acrylic Paint	61.5
Laminated Timber	11	Insitu concrete	1.9	Synthetic Rubber	110
Glass	12.7	Precasat steam-cured concrete	2.0	Clay bricks	2.5
		Precast tilt-up concrete	1.9	Concrete blocks	1.5

Table 13-02: Embodied energy for Australian materials, list compiled in 1996 [Source: Milne & Reardon s.a. :p4]

Table 13-03: Table indicating the different embodied energy quantities of construction materials [Source: Astrup 2004 p104]

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13.2.2 Carbon footprints and embodied energy of different Construction technologies

The embodied energy and carbon footprint of different construction systems and technologies were investigated and used to guide the design process and material choice. Calculation based on figures established by life cycle assessment framework [section 4.4]. The calculations were made for the cradle to gate cycle - excluding transportation energy

Calculations for Terminal building

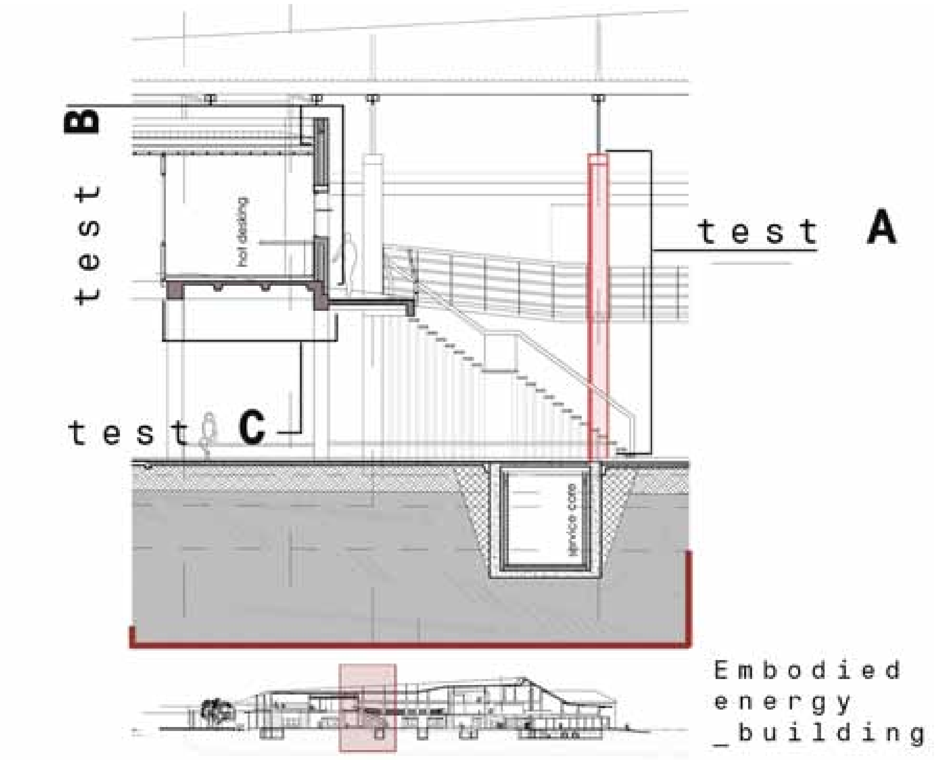


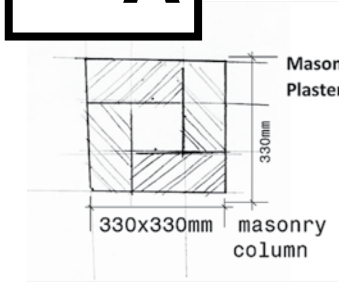
Figure 13-01: Components of the terminal building tested during technical investigation [Source: Author]

test A

COLUMN - height 4 meter

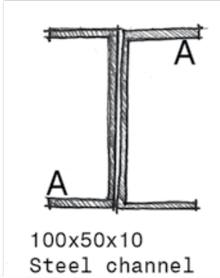
Tests were done of different construction methods, calculating the embodied energy and carbon footprint of each system

The analysis wwere done for generic systems and calculated to per collumn



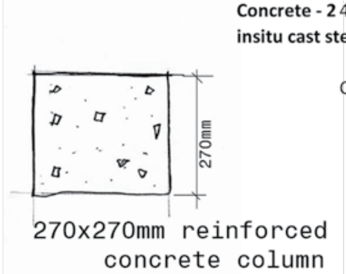
Masonry
Plastered and painted

Masonry	330x330	0.43	m^3	x	1900	kg/m^3	=	**817**	kg
		817	kg	x	3	MJ/kg	=	**2451**	MJ
		817	kg	x	0.22	kg CO_2/kg	=	**179.74**	kg CO_2
						TOTAL		**2451**	MJ
								179.74	kg CO_2



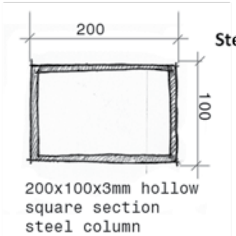
Steel column - Hot rolled channels
2 maal 100*50*11 channels welded together

steel	88	kg	x	4.8	m	=	**422.4**	kg
	422.4	kg	x	29.44	MJ/kg	=	**12435**	MJ
	422.4	kg	x	2.22	kg CO_2/kg	=	**937.73**	kg CO_2
					TOTAL		**12435**	MJ
							937.73	kg CO_2



Concrete - 2 4 meter
insitu cast steel reinforced

Collumn	270*270	0.27	m^3	x	2400	kg/m^3	=	**648**	kg
		648	kg	x	2.42	MJ/kg	=	**1568.2**	MJ
		648	kg	x	0.256	kg CO_2/kg	=	**165.89**	kg CO_2
						TOTAL		**1568.2**	MJ
								165.89	kg CO_2



Steel column _ Cold Formed hollow square section

200x100x3	0.008	m^3	x	8000	kg/m^3	=	**64**	kg
	64	kg	x	29.44	MJ/kg	=	**1884.2**	MJ
	64	kg	x	2.22	kg CO_2/kg	=	**142.08**	kg CO_2
					TOTAL		**1884.2**	MJ
							142.08	kg CO_2

Table 13-04: Test A- Calculating Embodied energy and carbon footprint of columns [Source: Author]

test B

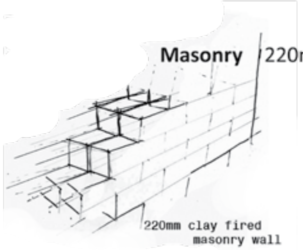
WALL

Tests were done of different construction methods, calculating the embodied energy and carbon footprint of each system

The analysis wwere done for generic systems and calculated to per square meter

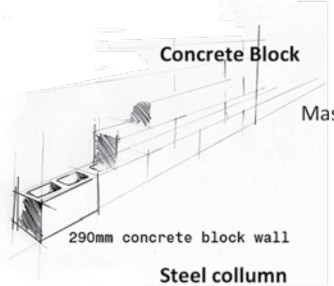
Wall - 5x2.4[h]

Masonry /220mm



Masonry	220 mm wall	12	m^2	x	1282.2	MJ/m^2 =	15386	MJ
		12	m^2	x	95.86	CO_2/m^2 =	1150.3	kg CO_2
TOTAL							15386	MJ
							1150.3	kg CO_2

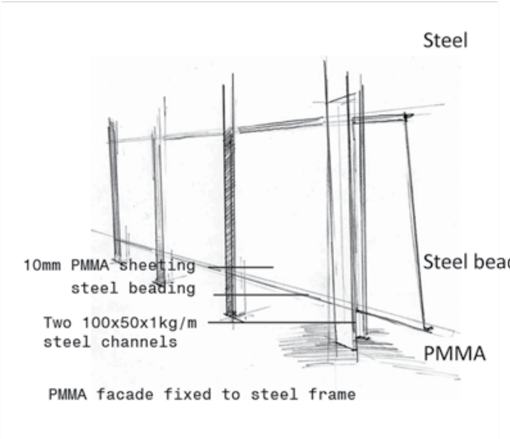
Concrete Block



Masonrry	290 mm wall	12	m^2	x	336	MJ/m^2 =	4032	MJ
		12	m^2	x	41.14	CO_2/m^2 =	493.68	kg CO_2
TOTAL							4032	MJ
							493.68	kg CO_2

Steel collumn

2 [100x50x11kg/m] channels welded together



Steel	2 collumns used	11	kg	x	4.8	m =	52.8	kg
		52.8	kg	x	29.44	MJ/kg =	1554.4	MJ
		52.8	kg	x	2.22	kg CO_2/kg =	117.22	kg CO_2
TOTAL							3108.9	MJ
							234.43	kg CO_2
Steel beading		0.02	m^3	x	29.44	MJ/m^3 =	0.5888	MJ
		0.02	m^3	x	2.22	CO_2/m^3 =	0.0444	kg CO_2
PMMA	10 mm wall	11.5	m^2	x	454	MJ/m^2 =	5221	MJ
		11.5	m^2	x	14	CO_2/m^2 =	161	kg CO_2
TOTAL							8330.5	MJ
							395.48	kg CO_2

Table 13-05: Test B- Calculating Embodied energy and carbon footprint of walls [Source: Author]

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test C

REINFORCED CONCRETE SLABS- medium span

Tests were done of different construction methods, calculating the embodied energy and carbon footprint of each system

The analysis wwere done for generic systems and calculated to square meters

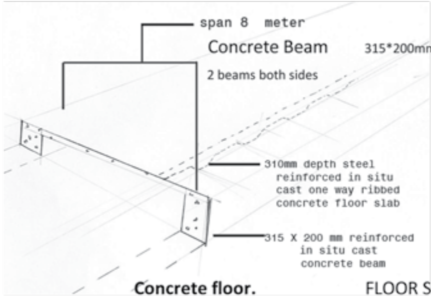
FLOOR SYSTEMS -8 meter span length 6.3 meter

Floor area 51.2m^2

Concrete floor.

Reinforced one way ribbed floor

Concrete	310mm depth	5.5	m^3	x	2400	kg/m^3 =	13200	kg
		13200	kg	x	2.42	MJ/kg =	31944	MJ
		13200	kg	x	0.256	kg CO_2/kg =	3379.2	kg CO_2
Concrete Beam (2 beams both sides)	315*200mm depth	0.8	m^3	x	2400	kg/m^3 =	1920	kg
		1920	kg	x	2.42	MJ/kg =	4646.4	MJ
		1920	kg	x	0.256	kg CO_2/kg =	491.52	kg CO_2
TOTAL							36590	MJ
							3870.7	kg CO_2



Concrete floor. FLOOR SYSTEMS -6.3 meter span length 8

Reinforced one way ribbed floor

Concrete	250mm depth	4.5	m^3	x	2400	kg/m^3 =	10800	kg
		10800	kg	x	2.42	MJ/kg =	26136	MJ
		10800	kg	x	0.256	kg CO_2/kg =	2764.8	kg CO_2
Concrete Beam (share 2 beams only quantity 1)	400mm*200 beam	0.64	m^3	x	2400	kg/m^3 =	1536	kg
		1536	kg	x	2.42	MJ/kg =	3717.1	MJ
		1536	kg	x	0.256	kg CO_2/kg =	393.22	kg CO_2
TOTAL							29853	MJ
							3158	kg CO_2

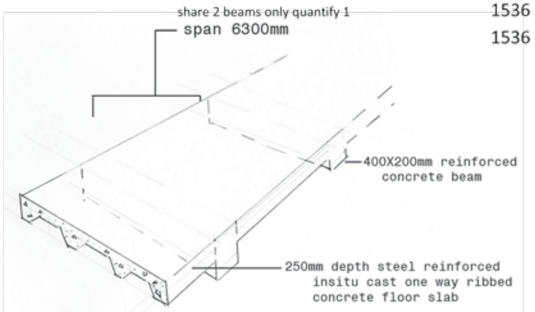
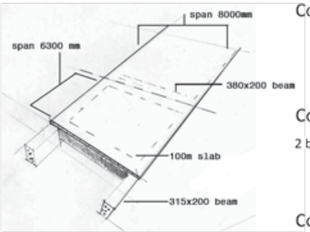


Table 13-06: Test C- Calculating Embodied energy and carbon footprint of concrete slab [Source: Author]

test C

Concrete floor. FLOOR SYSTEMS -6.3 meter span length 8

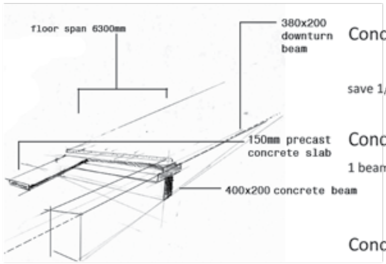
Flat cast floor beams both ways



Concrete	100mm depth	4.56	m^3	x	2400	kg/m^3	=	**10944**	kg
		10944	kg	x	2.42	MJ/kg	=	**26484**	MJ
		10944	kg	x	0.256	kg CO_2/kg	=	**2801.7**	kg CO_2
Concrete Beam1	315*200mm depth	0.78	m^3	x	2400	kg/m^3	=	**1872**	kg
2 beams both sides		1872	kg	x	2.42	MJ/kg	=	**4530.2**	MJ
		1872	kg	x	0.256	kg CO_2/kg	=	**479.23**	kg CO_2
Concrete Beam 2	380mm*200 beam	0.67	m^3	x	2400	kg/m^3	=	**1608**	kg
3 cross beams/2		1608	kg	x	2.42	MJ/kg	=	**3891.4**	MJ
		1608	kg	x	0.256	kg CO_2/kg	=	**411.65**	kg CO_2
						TOTAL		**34906**	MJ
								3692.5	kg CO_2

Concrete floor. FLOOR SYSTEMS -6.3 meter span length 8

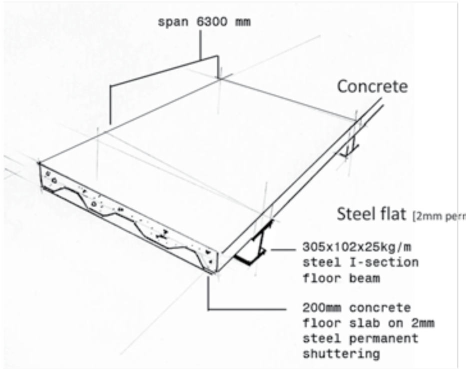
precast panel on in situ cast beams and down turn beam



Concrete	150mm depth	5.4	m^3	x	2400	kg/m^3	=	**12960**	kg
	standard depth	12960	kg	x	2.42	MJ/kg	=	**31363**	MJ
save 1/3 in concrete		12960	kg	x	0.256	kg CO_2/kg	=	**3317.8**	kg CO_2
Concrete Beam1	400*200mm depth	0.64	m^3	x	2400	kg/m^3	=	**1536**	kg
1 beams both sides		1536	kg	x	2.42	MJ/kg	=	**3717.1**	MJ
		1536	kg	x	0.256	kg CO_2/kg	=	**393.22**	kg CO_2
Concrete Beam 2	380mm*200 beam	1.152	m^3	x	2400	kg/m^3	=	**2764.8**	kg
3 cross beams/2	avarage of 200x900	2765	kg	x	2.42	MJ/kg	=	**6690.8**	MJ
		2765	kg	x	0.256	kg CO_2/kg	=	**707.79**	kg CO_2
						TOTAL		**41771**	MJ
								4418.8	kg CO_2
Concrete	150mm depth	0.768	m^3	x	2400	kg/m^3	=	**1843.2**	kg
	standard depth	1843	kg	x	2.42	MJ/kg	=	**4460.5**	MJ
save 1/3 in concrete		1843	kg	x	0.256	kg CO_2/kg	=	**471.86**	kg CO_2
						TOTAL		**39541**	MJ
								4182.8	kg CO_2

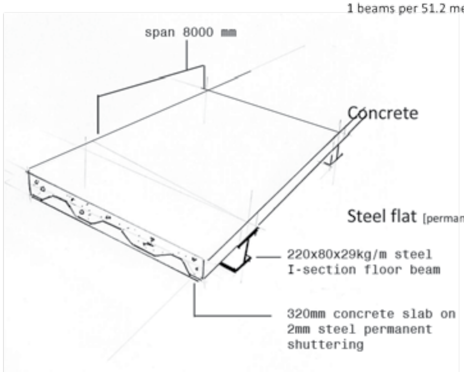
Table 13-07: Test C- Calculating Embodied energy and carbon footprint of concrete slabs [Source: Author]

Steel floor composit floor - span 8 meter



Steel beam	220*80*29kg/m]								
2 beams		353.8	kg	x	7.2		=	**2547.4**	kg
		2547	kg	x	29.44	MJ/kg	=	**74994**	MJ
		2547	kg	x	2.22	kg CO_2/kg	=	**5655.1**	kg CO_2
Concrete	320mm depth	6.4	m^3	x	1900	kg/m^3	=	**12160**	kg
		12160	kg	x	1.39	MJ/kg	=	**16902**	MJ
		12160	kg	x	0.209	kg CO_2/kg	=	**2541.4**	kg CO_2
Steel flat [2mm permanent shuttering]		0.1	m^3	x	8000	kg/m^3	=	**800**	kg
		800	kg	x	29.44	MJ/kg	=	**23552**	MJ
		800	kg	x	2.22	kg CO_2/kg	=	**1776**	kg CO_2
						TOTAL		**115449**	MJ
								9972.6	kg CO_2

Steel floor composit floor - span 6.4 meter

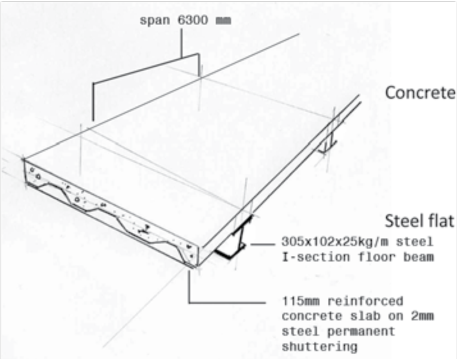


Steel beam	[305x102x25kg/m] 1.2 beams per 10 meter								
1 beams per 51.2 meter square		200	kg	x	7.2		=	**1440**	kg
		1440	kg	x	29.44	MJ/kg	=	**42394**	MJ
		1440	kg	x	2.22	kg CO_2/kg	=	**3196.8**	kg CO_2
Concrete	210mm depth	4.3	m^3	x	2400	kg/m^3	=	**10320**	kg
		10320	kg	x	2.42	MJ/kg	=	**24974**	MJ
		10320	kg	x	0.256	kg CO_2/kg	=	**2641.9**	kg CO_2
Steel flat [permanent shuttering]		0.081	m^3	x	8000	kg/m^3	=	**648**	kg
		648	kg	x	29.44	MJ/kg	=	**19077**	MJ
		648	kg	x	2.22	kg CO_2/kg	=	**1438.6**	kg CO_2
						TOTAL		**86445**	MJ
								7277.3	kg CO_2

Table 13-08: Test C- Calculating Embodied energy and carbon footprint of concrete slabs [Source: Author]

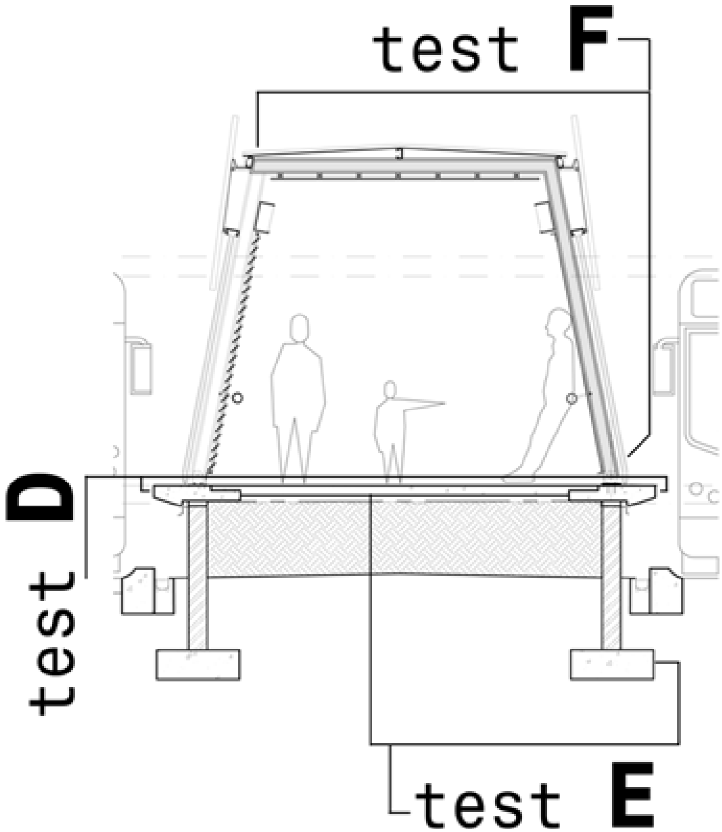
test C

Steel floor composit floor - span 6.4 meter - reinforced span 1/70



Steel beam	[305x102x25kg/m]								
1 beams per 51.2 meter square		200	kg	x	7.2		=	1440	kg
		1440	kg	x	29.44	MJ/kg	=	42394	MJ
		1440	kg	x	2.22	kg CO_2/kg	=	3196.8	kg CO_2
Concrete	115mm depth	5.8	m^3	x	2400	kg/m^3	=	13920	kg
		13920	kg	x	2.42	MJ/kg	=	33686	MJ
		13920	kg	x	0.256	kg CO_2/kg	=	3563.5	kg CO_2
Steel flat	[permanent shuttering]	0.06	m^3	x	8000	kg/m^3	=	480	kg
		480	kg	x	29.44	MJ/kg	=	14131	MJ
		480	kg	x	2.22	kg CO_2/kg	=	1065.6	kg CO_2
					TOTAL			90211	MJ
								7825.9	kg CO_2

Table 13-09: Test C- Calculating Embodied energy and carbon footprint of concrete slabs [Source: Author]



Embodied energy - PROTOTYPE

Figure 13-02: Different components tested during technical investigation [Source Author]

test D FLOOR SYSTEM

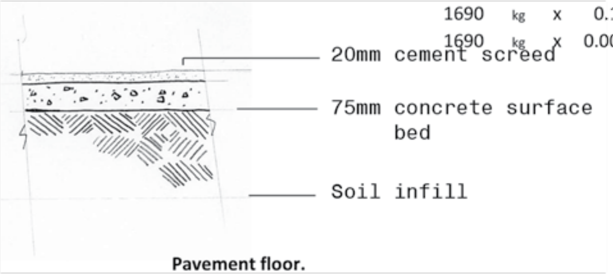
Tests were done of different construction methods, calculating the embodied energy and carbon footprint of each system

The analysis wwere done for generic systems and calculated to square meters

Floor systems worked out for 1 square meter

Concrete floor.

Screed	0.02	m^3	x	1900	kg/m^3	=	38	kg
	38	kg	x	0.6	MJ/kg	=	22.8	MJ
	38	kg	x	0.61	kg CO_2/kg	=	23.18	kg CO_2
Surface bed	0.075	m^3	x	2400	kg/m^3	=	180	kg
	180	kg	x	1.39	MJ/kg	=	250.2	MJ
	180	kg	x	0.209	kg CO_2/kg	=	37.62	kg CO_2
Infill	0.845	m^3	x	2000	kg/m^3	=	1690	kg
	1690	kg	x	0.1	MJ/kg	=	169	MJ
	1690	kg	x	0.005	kg CO_2/kg	=	8.45	kg CO_2
				TOTAL			442	MJ
							69.25	kg CO_2



Pavement floor.

Masonry	0.08	m^3	x	1900	kg/m^3	=	152	kg
	152	kg	x	3	MJ/kg	=	456	MJ
	152	kg	x	0.22	kg CO_2/kg	=	33.44	kg CO_2
Infill	0.86	m^3	x	2000	kg/m^3	=	1720	kg
	1720	kg	x	0.1	MJ/kg	=	172	MJ
	1720	kg	x	0.005	kg CO_2/kg	=	8.6	kg CO_2
				TOTAL			628	MJ
							42.04	kg CO_2

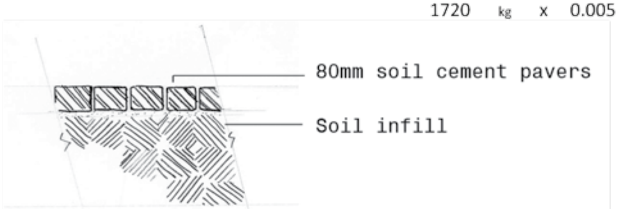
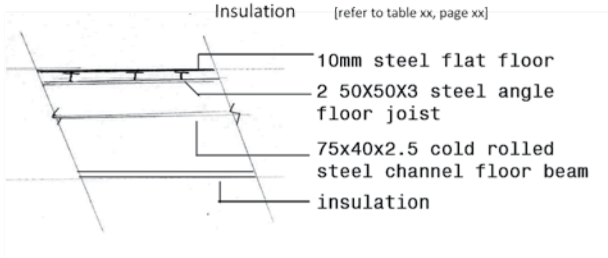


Table 13-10: Test D- Calculating Embodied energy and carbon footprint of floor systems for the BRT [Source: Author]

test D

Steel floor

Steel beam	[75x40x2.5]	two beams per 3 meter							
		2.5	kg	x	0.667		=	1.6675	kg
		1.668	kg	x	29.44	MJ/kg	=	49.091	MJ
		1.668	kg	x	2.22	kg CO_2/kg	=	3.7019	kg CO_2
Steel angle	[50x50x3]	0.00063	m^3	x	8000	kg/m^3	=	5.04	kg
		5.04	kg	x	29.44	MJ/kg	=	148.38	MJ
		5.04	kg	x	2.22	kg CO_2/kg	=	11.189	kg CO_2
Steel flat		0.01	m^3	x	8000	kg/m^3	=	80	kg
		80	kg	x	29.44	MJ/kg	=	2355.2	MJ
		80	kg	x	2.22	kg CO_2/kg	=	177.6	kg CO_2
Insulation	[refer to table xx, page xx]							70.88	MJ
								2	kg CO_2
						TOTAL		2623.5	MJ
								194.49	kg CO_2



Reinforced concrete floor. 1 meter cantilever on edge

Concrete	0.083	m^3	x	2400	kg/m^3	=	199.2	kg
	199.2	kg	x	2.42	MJ/kg	=	482.06	MJ
	199.2	kg	x	0.256	kg CO_2/kg	=	50.995	kg CO_2
Screed	0.02	m^3	x	1900	kg/m^3	=	38	kg
	38	kg	x	0.6	MJ/kg	=	22.8	MJ
	38	kg	x	0.61	kg CO_2/kg	=	23.18	kg CO_2
				TOTAL			504.86	MJ
							74.175	kg CO_2

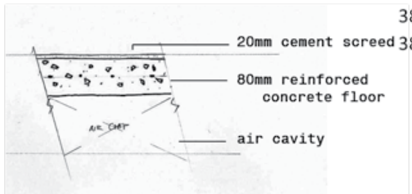


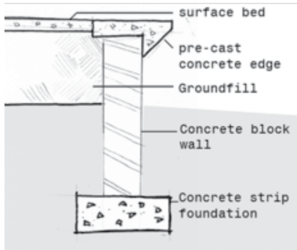
Table 13-11: Test D- Calculating Embodied energy and carbon footprint of floor systems for the BRT [Source: Author]

test E

Floor systems

Including foundation and a 300mm subsurface foundation wall
All floor calculated at 940mm above groundlevel height
Floor calculated over 8m length and 4.5 meter width
Foundation taken to be 300mm below ground level
If floor is not cast on site an added precast BRT edge is added [0.8 m^3 precast concrete]

Concrete Block wall with 100mm surface bed and ground infill



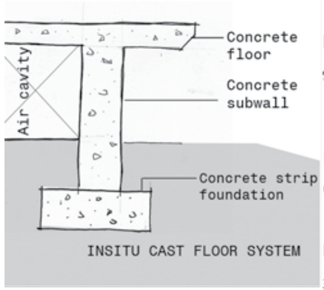
Item		cubic meter	kg/m^3	mass	Result
Foundation -concrete (720x300mm)		3.4	1900	6460 kg	
Embodied energy	1.39 J/kg				8979.4 J
Carbon footprint	0.209 kgCo/kg				1350.14 kg CO_2
Concrete block wall (280mm)		2.4	1900	4560 kg	
Embodied energy	0.81 J/kg				3693.6 J
Carbon footprint	0.098 kgCo/kg				446.88 kg CO_2
Ground fill (840mm)		41	2000	82000 kg	
Embodied energy	0.1 J/kg				8200 J
Carbon footprint	0.005 kgCo/kg				410 kg CO_2
Concrete Surface bed (100mm)		3.5	1900	6650 kg	
Embodied energy	1.39 J/kg				9243.5 J
Carbon footprint	0.209 kgCo/kg				1389.85 kg CO_2
Precast station edge (special)		0.8	2400	1920 kg	
Embodied energy	3.7 J/kg				7104 J
Carbon footprint	0.39 kgCo/kg				748.8 kg CO_2
TOTAL					37220.5 J 4345.67 kg CO_2
TOTAL/M^2					**1034 J** **120.7 kg CO_2**

Table 13-12: Test E- Calculating Embodied energy and carbon footprint BRT Platform construction systems[Source: Author]

test E

Reinforced concrete floor

floor with 1 meter cantilever



Item		cubic meter	kg/m^3	mass	Result
Foundation -concrete (900x300mm)		4.32	1900	8208	
Embodied energy	1.39 J/kg				11409.12 J
Carbon footprint	0.209 kgCo/kg				1715.47 kg CO_2
Reinforced concrete subwall (300mm)		5.4	2400	12960	
Embodied energy	2.42 J/kg				31363.2 J
Carbon footprint	0.256 kgCo/kg				3317.76 kg CO_2
Reinforced concrete floor (90mm; add station edge 0.8m3)		4.04	2400	9696	
Embodied energy	2.42 J/kg				23464.32 J
Carbon footprint	0.256 kgCo/kg				2482.17 kg CO_2
Concrete screed (20mm)		0.72	1900	1368	
Embodied energy	1.39 J/kg				1901.52 J
Carbon footprint	0.209 kgCo/kg				285.91 kg CO_2
TOTAL					68138.16 J 7801.32 kg CO_2
TOTAL/M^2					**1893 J** **217 kg CO_2**

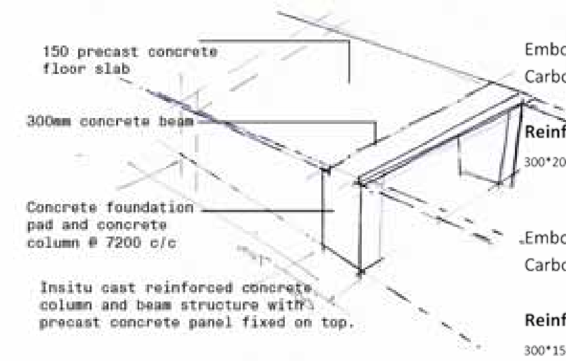
Table 13-13: Test E- Calculating Embodied energy and carbon footprint BRT Platform construction systems[Source: Author]

test E

Precast Reinforced concrete floor

floor with 500mm cantilever

floor rib every 7,2 meters



Foundation pad -concrete

900x600mm	cubic meter	kg/m^3	mass
	0.324	2400	777.6

Embodied energy	2.42 J/kg	1881.79 J	
Carbon footprint	0.256 kgCo/kg	199.06 kg CO_2	

Reinforced concrete subwall

300*200mm	cubic meter	kg/m^3	mass
	0.11	2400	264

Embodied energy	2.42 J/kg	638.88 J
Carbon footprint	0.256 kgCo/kg	67.58 kg CO_2

Reinforced concrete beam

300*150mm	cubic meter	kg/m^3	mass
	0.2	2400	480

Embodied energy	2.42 J/kg	1161.6 J
Carbon footprint	0.256 kgCo/kg	122.88 kg CO_2

Precast Reinforced concrete floor

150mm	cubic meter	kg/m^3	mass
add station edge 0.8m3	6.2	2400	14880

Embodied energy	3.7 J/kg	55056 J
Carbon footprint	0.39 kgCo/kg	5803.2 kg CO_2

Concrete screed

20mm	cubic meter	kg/m^3	mass
	0.72	1900	1368

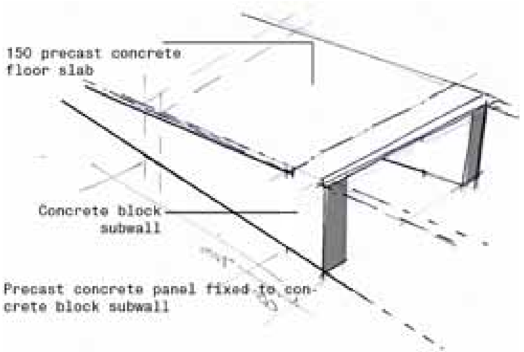
Embodied energy	1.39 J/kg	1901.52 J
Carbon footprint	0.209 kgCo/kg	285.91 kg CO_2

TOTAL	60639.79 J 6478.64 kg CO_2
TOTAL/M^2	**1685 J** **180 kg CO_2**

Table 13-14: Test E- Calculating Embodied energy and carbon footprint BRT Platform construction systems [Source: Author]

test E

Concrete Block wall with 150mm precast concrete floor



Foundation -concrete

720x300mm	cubic meter	kg/m^3	mass
	3.4	1900	6460 kg

Embodied energy	1.39 J/kg	8979.4 J
Carbon footprint	0.209 kgCo/kg	1350.14 kg CO_2

Concrete block wall

280mm	cubic meter	kg/m^3	mass
	2.4	1900	4560 kg

Embodied energy	0.81 J/kg	3693.6 J
Carbon footprint	0.098 kgCo/kg	446.88 kg CO_2

Ground fill

840mm	cubic meter	kg/m^3	mass
	41	2000	82000 kg

Embodied energy	0.1 J/kg	8200 J
Carbon footprint	0.005 kgCo/kg	410 kg CO_2

Precast concrete floor

150mm	cubic meter	kg/m^3	mass
add station edge 0.8m3	6.2	2400	14880 kg

Embodied energy	3.7 J/kg	55056 J
Carbon footprint	0.39 kgCo/kg	5803.2 kg CO_2

TOTAL	75929 J 8010.22 kg CO_2
TOTAL/M^2	**2109 J** **223 kg CO_2**

Table 13-15: Test E- Calculating Embodied energy and carbon footprint BRT Platform construction systems[Source: Author]

test **F**

BRT station

TESTING DIFFERENT STRUCTURAL SYSTEMS

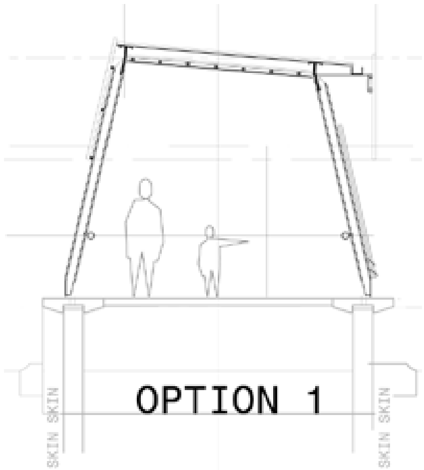
Tests were done of different construction methods, calculating the embodied energy and carbon footprint of each system

The analysis wwere done for generic systems and calculated to per square meter

Section calculated over a single BRT bay

STEEL COLUMN, BEAM AND ROOF PURLIN STRUCTURE

OPTION 1 PORTAL FRAME



Column 152x152x23 (length 3.28 m)

3.28	m	x	16		=	52.48	kg
52.48	kg	x	29.44	MJ/kg	=	1545.01	MJ
52.48	kg	x	2.22	kg CO_2/kg	=	116.5	kg CO_2
use 14 column			14			21630.15	MJ
						1631.07	kg CO_2

bracing roof beam (length 23.8)

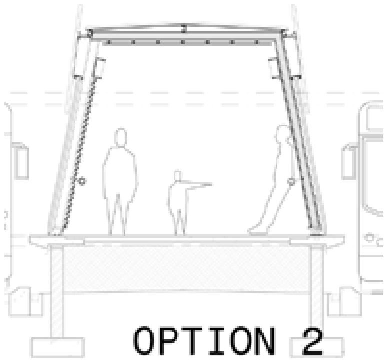
0.17	m^3	x	8000	kg/m^3	=	1360	kg
1360	kg	x	29.44	MJ/kg	=	40038.4	MJ
1360	kg	x	2.22	kg CO_2/kg	=	3019.2	kg CO_2

Roof brace

0.006	m^3	x	8000	kg/m^3	=	48	kg
48	kg	x	29.44	MJ/kg	=	1413.12	MJ
48	kg	x	2.22	kg CO_2/kg	=	106.56	kg CO_2

TOTAL	63081.67	MJ
	4756.83	kg CO_2

Option 2 Tapered structure with inveerted cantilever structure



Column and roof beam (length 6.3)

use 152x89x16 I section beam

6.3	m	x	16		=	100.8	kg
100.8	kg	x	29.44	MJ/kg	=	2967.55	MJ
100.8	kg	x	2.22	kg CO_2/kg	=	223.77	kg CO_2
use 16 columns			16			47480.83	MJ
						3580.41	kg CO_2

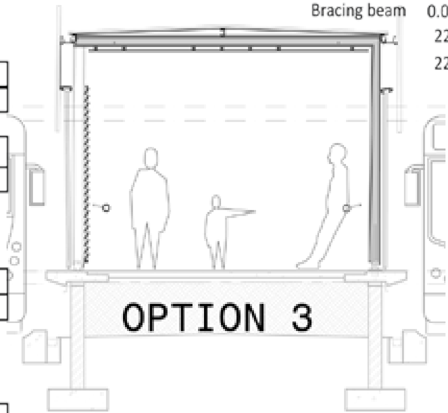
Bracing beam

4.35	kg/m	x	47.6	m	=	207.06	kg
207.06	kg	x	29.44	MJ/kg	=	6095.84	MJ
207.06	kg	x	2.22	kg CO_2/kg	=	459.67	kg CO_2

total	53577	MJ
	4040	kg CO_2

test **F**

Option 3 Rectangular structure, inverted cantilever



Column and roof beam (length 6.5)

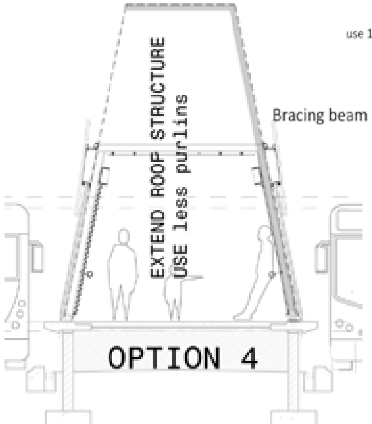
7.7	m	x	23		=	177.1	kg
177.1	kg	x	29.44	MJ/kg	=	5213.82	MJ
177.1	kg	x	2.22	kg CO_2/kg	=	393.16	kg CO_2
use 16 columns			16			83421.18	MJ
						6290.59	kg CO_2

Bracing beam

0.028	m^3	x	8000	kg/m^3	=	224	kg
224	kg	x	29.44	MJ/kg	=	6594.56	MJ
224	kg	x	2.22	kg CO_2/kg	=	497.28	kg CO_2

total	90015.74	MJ
	6787.87	kg CO_2

Option 4 -Extra high roof



Column and roof beam (length 6.1)

7.1	m	x	23		=	163.3	kg
163.3	kg	x	29.44	MJ/kg	=	4807.55	MJ
163.3	kg	x	2.22	kg CO_2/kg	=	362.52	kg CO_2
use 16 columns			16			76920.83	MJ
						5800.41	kg CO_2

Bracing beam

4.84	kg/m	x	47.6	m	=	230.38	kg
230.384	kg	x	29.44	MJ/kg	=	6782.50	MJ
230.384	kg	x	2.22	kg CO_2/kg	=	511.45	kg CO_2

total	83 704	MJ
	6 312	kg CO_2

Table 13-16: Test F - Calculating Embodied energy and carbon footprint BRT structural systems [Source: Author]

13.3 BUILDING SYSTEM ANALYSES

BRT TERMINAL BUILDING
ENERGY CONSUMPTION OF LIGHTING

Lighting levels in accordance with Sans 204-08

FLOOR	AREA TYPE	AREA			ZONE		WATT	TIME USE		TOTAL DAILY		TOTAL MONTHLY
			LUX	Lumens	Lighting type	quantity						
BASEMENT												
	Ablution	64 m²	200	12800 L	CFL 11&14 watt	20	11 w	2	hours	440 Wh	30	13200 Wh
	Movement	562 m²	50	28100 L	CFL14 watt	35	14 w	17	hours	8330 Wh	30	249900 Wh
	Storage	104 m²	150	15600 L	CFL14 watt	18	14 w	2	hours	504 Wh	30	15120 Wh
	Cycle parking	165 m²	100	16500 L	CFL 18 watt	15	18 w	11 only half in day	hours	2970 Wh	30	89100 Wh
GROUNDFLOOR				L								
	Station platform	326 m²	100	32600 L	CFL 11 watt	52	11 w	7 daylighting	hours	4004 Wh	30	120120 Wh
	Movement	908 m²	50	45400 L	CFL14 watt	55	14 w	7 daylighting	hours	5390 Wh	30	161700 Wh
	Kiosk and tickets	73 m²	400	29200 L	CFL 18 watt	25	18 w	7 daylighting	hours	3150 Wh	30	94500 Wh
	Retail and catering	445 m²	250	111250 L	CFL 18 Watt	100	18 w	8.5 short hours	hours	15300 Wh	30	459000 Wh
	Service areas	65 m²	100	6500 L	CFL 14 Wattt	7	14 w	11.25 good windows	hours	1102.5 Wh	30	33075 Wh
	Ablution	123 m²	200	24600 L	CFL 11 Watt	39	11 w	7	hours	3003 Wh	30	90090 Wh
First floor												
	Movement	75 m²	50	3750 L	CFL 5 watt	18	5 w	12 daylighting	hours	1080 Wh	30	32400 Wh
	Kiosks	112 m²	400	44800 L	CFL 30 watt	23	30 w	7	hours	4830 Wh	30	144900 Wh
	Retail	85 m²	50	4250 L	CFL 7 watt	14	7 w	8.5 daylighting	hours	833 Wh	30	24990 Wh
	Office 9-5	236 m²	400	94400 L	CFL 30 watt	48	30 w	6.5	hours	9360 Wh	30	280800 Wh
	Boardrooms	30 m²	400	12000 L	CFL 18 watt	11	18 w	4	hours	792 Wh	30	23760 Wh
	Service area	23 m²	100	2300 L	CFL 11 watt	4	11 w	12	hours	528 Wh	30	15840 Wh
	Ablution	47 m²	200	9400 L	CFL 11 Watt	15	11 w	7	hours	1155 Wh	30	34650 Wh
Second Floor	BRT Office 5-22	185 m²	400	74000 L	CFL 30 watt	38	30 w	13	hours	14820 Wh	30	444600 Wh
	Boardroom+foyer	60 m²	400	24000 L	CFL 30 watt	13	30 w	7	hours	2730 Wh	30	81900 Wh
	Ablution	33 m²	200	6600 L	CFL 11 Watt	10	11 w	7.5	hours	825 Wh	30	24750 Wh
									TOTAL	81146.5 wh		2434395 wh
										81 kWh		2 430 kWh

Table 13-17: Energy consumption for lighting in terminal building [Source: Author]

TERMINAL BUILDING
- Photovoltaic energy generation

	Total energy generated per day		
		82	kwh
grid tied	efficiency rate [90%]	**0.9**	
	total energy	**90**	kwh
solar panel generation - 0.62 kw/h per m²			
		145.16	m²
		thus need 146m² for solar generation.	

Table 13-18: Terminal building - quantifying photovoltaic panels [Source: Author].

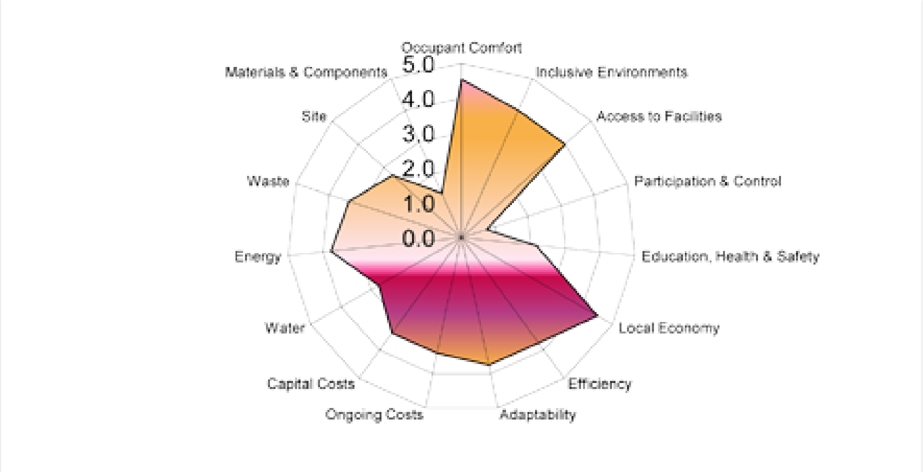
TERMINAL BUILDING
- AC/DC inverter

	82 kwh	per day
	6	sunlight hours
	13.66 kw	
Whole system need a 13 KW inverter		
Product:	SK3000-XXX inverer	
	3 KW	
use 5 inverters		

Table 13-19: Terminal building - quantifying inverter size [Source: Author].

SUSTAINABLE BUILDING ASSESSMENT TOOL (SBAT- P) V1

PROJECT		ASSESSMENT		
Project title:	BRT TERMINAL BUILDING	Date:	29-06-2010	
Location:	Tshwane	Undertaken by:	JM Hugo	
Building type:	BRT stations and terminal building	Company / organisation:		
Internal area (m2):	0	Telephone:	Fax:	
Number of users:	0	Email:		



Social	3.1	Economic	3.8	Environmental	2.8
Overall	3.2	Classification	Average		

Graph 13-01: SBAT assessment of the project [Source: Author].

TERMINAL BUILDING - water consumption

				frequency per day	Users	quantity	Total per day		Total per month
Toilet	6	L	per flush	20		21	2520	30	75600
Shower	40	L	per shower		30		1200	20	24000
Handwash basin	3	L	per wash	20		21	1260	30	37800
Urinal Waterless									
								Total	137400

Table 13-20: Terminal building - Water consumption [Source: Author].

TERMINAL BUILDING - RAIN WATER COLECTION

Roof size 2050m² 10% lost Water use: PUBLIC WC's

Month	DES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV
Rainfall	0.108	0.135	0.076	0.079	0.054	0.013	0.007	0.003	0.005	0.02	0.007	0.01
Water collected kL	194.4	243	136.8	142.2	97.2	23.4	12.6	5.4	9	36	12.6	18
Water used kL	76	76	76	76	76	76	76	76	76	76	76	76
Used	118.4	285.4	346.2	412.4	433.6	381	317.6	247	180	140	76.6	18.6
Surplus Kl	118.4	285.4	346.2	412.4	433.6	381	317.6	247	180	140	76.6	0

Table 13-21: Terminal building - Rain water collection quantified [Source: Author].

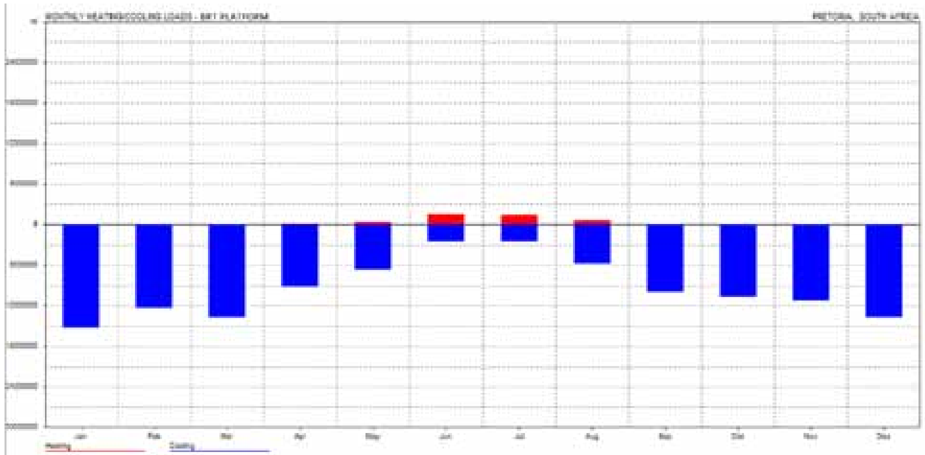
TERMINAL BUILDING -sand filter

according to Bare foot architect

1600l for 2 meters over 600x1000mm

MAX RAINWATER COLLECTED PER MONTH		234.9 kl	per month
15 Rain days per month	15	15.66 kl	per rain shower
	1.6	9.7875	for 2 meters over 0.6x1m
size		10*2*0.6m	size 10x2x1.2m
Filter area		6 m²	
		1min	6 liter
		1 hour	360 liter
		1 day	8640 liter
Filter size	Double	12 m²	
		1min	12 liter
		1min	720 liter
		1 day	17280 liter
	pre-filter rain water holding tank		18000 liter

Table 13-22: Terminal building - Sand filter size [Source: Author].



Graph 13-02: Heating and cooling requirements of the BRT platform [Source: Author].

TERMINAL BUILDING -Thermal energy store

Q=m*c*t

ROCK STORE	Total size	105 m³	
C- Substance specific heat storage	Stone	4180 J/kgK	
M- Mass	Mass	1000 kg/m³	
	mass	105000 kg	over 6months period
	temp difference	50	winter heat added
		5	summer cooled through radiation
THERMAL STORAGE CAPACITY		**21 945 000 000 J**	**winter**
		20.9 GJ	
		2 194 500 000 J	summer
		2 GJ	

Table 13-23: Thermal storage capacity of thermal energy store [Source: Author].

13.4 BRT PROTOTYPICAL ANALYSES

BRT PROTOTYPICAL STATION -Electrical equipment & consumption

ZONE	TYPE	DESCRIPTION	SIZE	physical size	ENERGY USE	QUANTITY	HOURS USED	Energy consumption per day
SALES OFFICE								
	Cash Register			drawer size		2		
	Computer	DESKTOP / Dell	1066 Kwh per year	85[w]x300[h]x330[d]	0.17 kWh	1.3	17 h	3.75 kwh
		Laptop			0.045 kWh	1.3	17 h	1.0 kwh
	Drop Safe			650H x 500W x 500D		1		
	Card Validator			265[w]X285 mm[h]X86 mm [d]	0.015 kWh	2	17 h	0.51 kwh
Technology Hut	DB Board			450[w]x300[h]x85[d]		1		
	UPS	TOTAL ENERGY - 13 kWh		160[w]x200[h]x450[d]		1		
	SERVER	ESG GROUP 12 v ports	too big?			1		3.1 kwh
	Induction Loop			small				
	Internet connection	Is it satelite						
	BATTERIES	3days 72kwh -too heavy in floor 256kg		415[h] x 262[d] x 740[w]		16		
security	CCTV		connect to server					
	RECORDING		connect to server					
	ALARM SYSTEM			300[w]x300[h]x100[d]				
			antenna - length 1 meter					
Water services								
	Waterpump					1		
	Waterfilter	Sand filter	Basement			1		
	UV-Filter	not used - 240 V energy consumption too high				0		
Ventilation								
	Air pump					1		
	Cooling chamber					1		
	Solar water heater		heat evacuating tubes			2		
Energy								
	Photovoltaic panels		Intergrated with roof					
					TOTAL DAILY COSUMPTION			8.36 kwh

Table 13-24: BRT Electrical Equiptment- energy consumption [Source: Author].

BRT PROTOTYPICAL STATION -Lighting energy consumption

Zone	Area	Lux	Lumen	lumen/lamp	effiency rate	product	kWatt	Lamps used	Kw/h	hours/day	DAILY ENERGY CONSUMPTION
Office	13.1 m^2	400	5240								
sales	5.6 m^2	400	2240	380	900	CFL 7 watt	0.007	6	0.042	16	0.672 kwh
toilet	2.6 m^2	300	780	380	470	CFL 7 watt	0.007	2	0.014	2	0.028 kwh
Technology Hub	0 m^2	500	0	0	1560	ST8-SD4-765- LED LAMP	0.0235	0	0	2	0 kwh
											0.7 kwh
Tasklighting	2 unit	500									
waiting area A	149.8 m^2	100	14980	640	590	CFL 11 watt	0.011	24	0.264	8	2.112 kwh
waiting area B	288.3 m^2	100	28830	640	590	CFL 11 watt	0.011	45	0.495	8	3.96 kwh
waiting area C	432.8 m^2	100	43280	640	590	CFL 11 watt	0.011	68	0.748	8	5.984 kwh
										TOTAL A	**2.81 kwh**
										TOTAL B	**4.66 kwh**
										TOTAL C	**6.68 kwh**

ADD TOTAL DAILY CONSUMPTION	8.3 **kwh**
TOTAL	**14.98 kwh**

Table 13-25: BRT station - Lighting energy consumption [Source: Author].

BRT PROTOTYPICAL STATION -Photovoltaic energy generation

To generate **22 kWh per day**

14.9	0.7 efficiency	21.28	21.3 kwh	total generated	
21.3	0.62 per m^2	34.35	35 m^2	needed	all lighting + computers

35m^2 total photovoltaic panels

Battery bank to store energy

	energy	days	total
Store electricity for 3 days	21.3 kwh	3 =	63.9 kwh
Battery store 4.7 kwh	63.9 kwh	4.7	13.59

16 batteries needed

Table 13-26: BRT station - Photovoltaic system and battery bank store [Source: Author].

BRT PROTOTYPICAL STATION -ROCK STORE

Thermal energy storage
Q=m*c*t

Rock store total size :		1.5 m^3		
C- Substance specific heat storage	Stone	1900 J/kgK		
M- Mass	Mass	2700 kg/m^3		
	mass	4050 kg		
			Degrees Celsius	
	temp difference	50	MAX	70
			Min	20
THERMAL STORAGE CAPACITY		385 MJ		

Table 13-27: BRT station - Rock store storage capacity [Source: Author].

BRT PROTOTYPICAL STATION -RAIN WATER HARVESTING

SINGLE

Rain water collection — Roof size 189m² — 170 m^2

Month	DES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV
Rainfall	**0.108**	**0.135**	**0.076**	**0.079**	**0.054**	**0.013**	**0.007**	**0.003**	**0.005**	**0.02**	**0.007**	**0.01**
Water collected kL	**18.36**	**22.95**	**12.92**	**13.43**	**9.18**	**2.21**	**1.19**	**0.51**	**0.85**	**3.4**	**1.19**	**1.7**
Water used kL	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**	**4**
Surplus kL	**14.36**	**33.31**	**42.23**	**51.66**	**56.84**	**55.05**	**52.24**	**48.75**	**45.6**	**45**	**42.19**	**39.89**
	14.36	**20**	**20**	**20**	**20**	**18.21**	**15.4**	**11.91**	**8.76**	**8.16**	**5.35**	**3.05**

DOUBLE

Rain water collection — Roof size 331m² — 298 m^2

Month	DES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV
Rainfall	0.108	0.135	0.076	0.079	0.054	0.013	0.007	0.003	0.005	0.02	0.007	0.01
Water collected kL	32.184	40.23	22.648	23.542	16.092	3.874	2.086	0.894	1.49	5.96	2.086	2.98
Water used kL	4	4	4	4	4	4	4	4	4	4	4	4
Surplus kL	28.184	64.414	83.062	102.604	114.696	114.57	112.656	109.55	107.04	109	107.086	106.066
	10	10	10	10	10	9.8	7.8	4.7	2.26	4.22	3.08	2.06
	15	15	15	15	15	14.8	12.8	9.7	7.26	9.22	8.08	7.06

TRIPLE

Rain water collection — Roof size 472m² — 425 m^2

Month	DES	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV
Rainfall	0.108	0.135	0.076	0.079	0.054	0.013	0.007	0.003	0.005	0.02	0.007	0.01
Water collected kL	45.9	57.375	32.3	33.575	22.95	5.525	2.975	1.275	2.125	8.5	2.975	4.25
Water used kL	4	4	4	4	4	4	4	4	4	4	4	4
Surplus kL	41.9	95.275	123.575	153.15	172.1	173.625	172.6	169.875	168	172.5	171.475	171.725

USE A 20 000 Liter storage tank - to service smallest prototype

WATER CONSUMPTION	3 workers	Twice per shift	2 shifts	1 full flush	1/5 flush	2 handwashes
		Consumption				
	6 persons	**19.5 liters**	**117 liter per day**			
			30 days			
			3510 liter/month			

Table 13-28: BRT station -Rain water harvesting calculations [Source: Author].

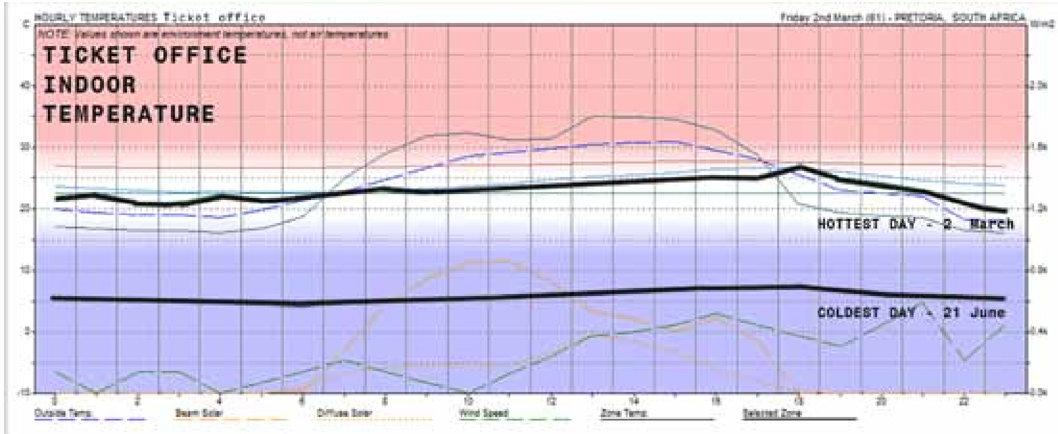
BRT PROTOTYPICAL STATION -SAND FILTER

according to Bare foot architect 1600l — for 2 meters over 600x1000mm

approx amount of water to filter per day				
MAX RAINWATER COLLECTED PER MONTH		57.3 kl	per month	
15 Rain days per month	15	3.82 kl	per rain shower	
	1.6	2.3875	for 2 meters over 600x1000mm	
Sand filter size		2.5*2*0.6	size 2.5x2x1.2m	
		1.5 m^2		
			1min	1.5 liter
			1 hour	90 liter
			1 day	2160 liter
FILTER SIZE	Double	3 m^2	size 2.5x2x1.2m	
			1min	3 liter
			1min	180 liter
			1 day	4320 liter
	pre filter rain water holding tank			4000 liter

Table 13-29: BRT station -Sand filter size calculated [Source: Author].

Graph 13-03: BRT station - Heating and cooling required for Kiosk station [Source: Author].



Graph 13-04: BRT station - Thermal comfort of ticket office [Source: Author].

13.5. BRT SYSTEMS INFORMATION

13.5.1 Frequency and statistics of BRT systems

Item	Line 1	Line 2	Overall Route
Corridor Length	37.3 km	33.2 km	67.6 km
Length of Dedicated Bus lanes	37.3 km	33.2 km	67.6 km
Number of Terminals	2 Terminals	2 Terminals	4 Terminals
Number of Stations	15 Stations	37 Stations	46 Stations
Average Station Separation	2,200 m	870 m	1,380 m
Number of Bays per Station	1, 2 or 3	1	
Station Length	20, 50 or 81 m	20 m	
Station Width	3.0 to 4.5 m	3.0 m	
AM Peak Hour Frequency	40 departures	40 departures	
AM Peak Hour Headway (gap)	90 seconds	90 seconds	
AM Peak Frequency - All Stops Service	12 departures	20 departures	
AM Peak Frequency – Express / Limited Stop Service	28 departures	20 departures	
Operational Speed (Max speed 90kph)	All Stops - 49 kph Limited Stop – 50 kph	All Stops - 26 kph Express - 35 kph	
Estimated System Capacity (passengers per hour)	5,200 – 6,400	5,200 – 6,400	
Estimated Fleet Size – articulated buses	60	99	159

Table 13-30: Overall information regarding the first phase development [Source: ALG, p 9]

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switch:

- a device for making and breaking the connection in an electric circuit
- a transfer, change-over, or deviation
- an exchange