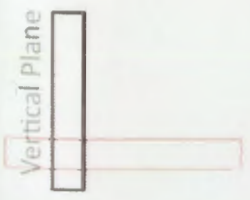


Vertical City Plane

# A Living Tower

using architecture for sustainable future growth

Build Fabric & Nature



Parking

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**The Living Tower – using architecture for sustainable future growth**

Design Research Project APG5058S

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

by

Jacobus Olivier Scott

September 2009

# LIVING TOWER

*To my Heavenly Father &  
parents*

## Abstract

This thesis demonstrates how architectural design can be used to help alleviate the current environmental crisis, using a radical sustainable approach that integrates high density living and farming activities within the context of suburban planning.

In South Africa, population growth and urbanisation have led to low-rise low-density buildings invading bio diversity nodes, valuable arable land, and natural reserves on the periphery of cities. Not only are the infrastructural costs of servicing these low-density suburbs very high, but the pollution caused by daily commuting to and from the workplace has lasting environmental consequences. Continuing deforestation is needed to create new arable land; at the same time, ploughing and shipping within the agricultural sector make a significant contribution to global pollution, while up to 70% of potable water is lost through evaporation during irrigation.

The architectural approach on which this thesis is based, integrates the usually separate components of living and farming, into a single closed high-rise entity, called the Living Tower. Taking a cue from ecosystem dynamics, a Living Tower model was developed to mimic the natural process whereby the waste of one entity becomes the food of another, creating an efficient cyclical flow of resources. In this way, renewable resources comprise the heart of the life-giving and life-sustaining Tower.

Analysis of earlier designs based on similar principles is used to identify key elements of the Living Tower. These include amongst other integrated stacked greenhouses, evaporative coolers, an anaerobic digester, a central atrium design and a living machine (eco restorer).

Living Tower models of differing heights are compared and evaluated in terms of their sustainability and efficiency. A thirty storey Living Tower is shown to provide the optimal solution to the core environmental issues considered, including the renewal of natural resources and the reclaiming of arable land. The corresponding diagrams, calculations and graphs illustrate the potential impact on both nature and society of a thirty storey Living Tower.

This innovative design solution focuses on shaping the landscape with contextual reference in order for the Tower to 'grow' out of the hills and include a variety of mixed used programs in the form of living, working and playing to enhance social interaction. Through the design solutions the Living Tower successfully combines higher living densities and an ecologically friendly lifestyle in a structure that is economically viable, aesthetically pleasing, and therefore using architecture for sustainable future growth.

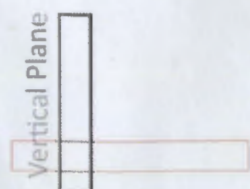
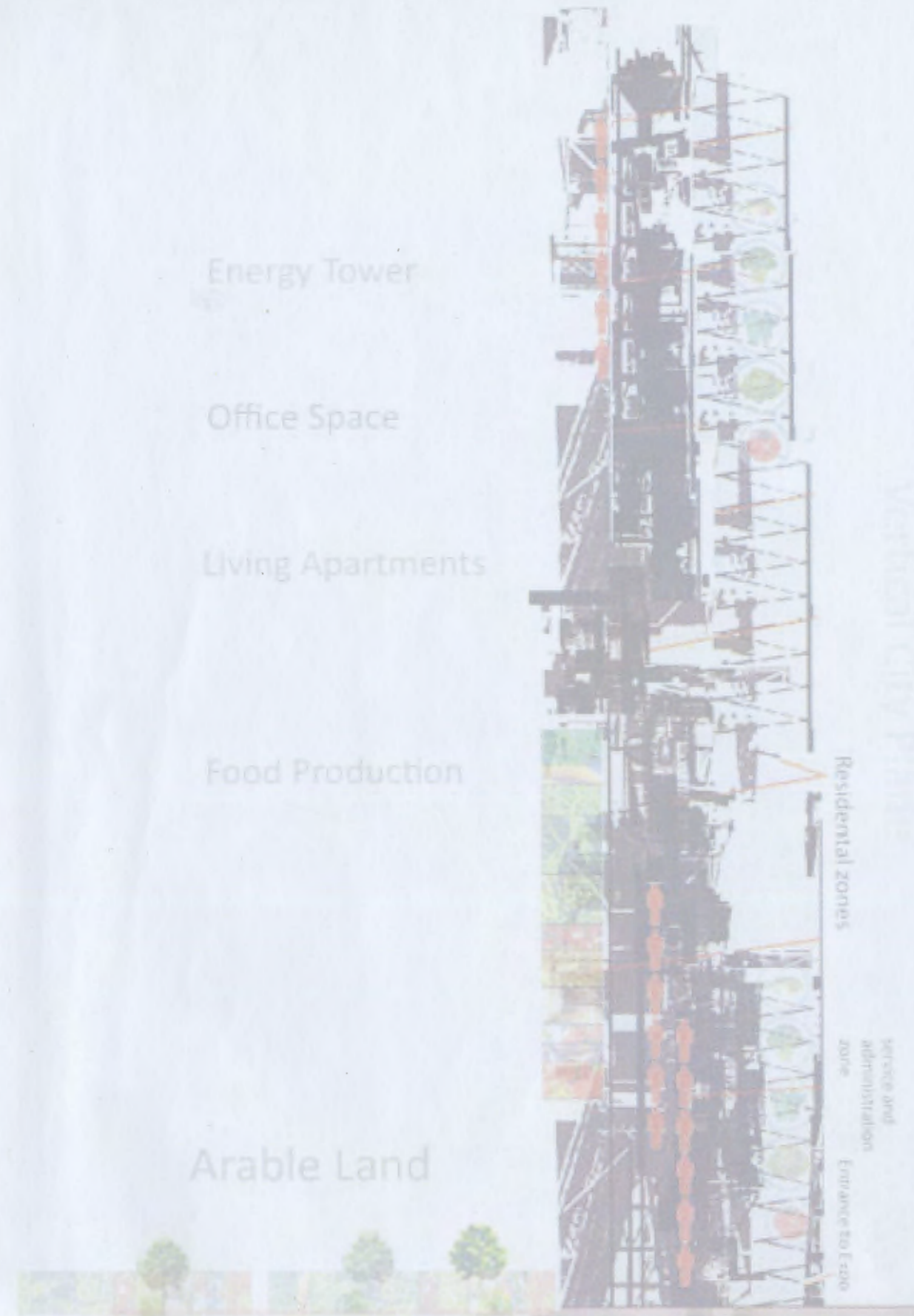
### Notes:

The *Living Tower* is a term the author uses to express his proposition; this term has also been used by French architects SOA Architects to describe their 'Tour Vivante' project in Paris [of which the author was previously unaware].



*"This graphic illustration was created by the author of this thesis to demonstrate the basic concept of a Living Tower."*

# LIVING TOWER



## Cover page

This thesis comprises four different sections merged together to tell the story how the concept of a Living Tower (LT) evolved towards restoring the imbalance between the natural and human environment. The former Theory and Technology Documents were merged because the topic discussed in each document was partly overlapping and by merging them, a more coherent and cohesive entity was established. The last two sections of this thesis naturally developed out of the Technology Document and focus on sustainability and viability, using the research findings from the former document as well as a spatial design exploration component in support of the argument proposed in the previous document.

The four different sections are:

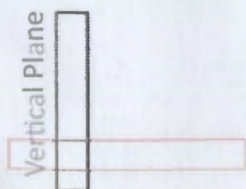
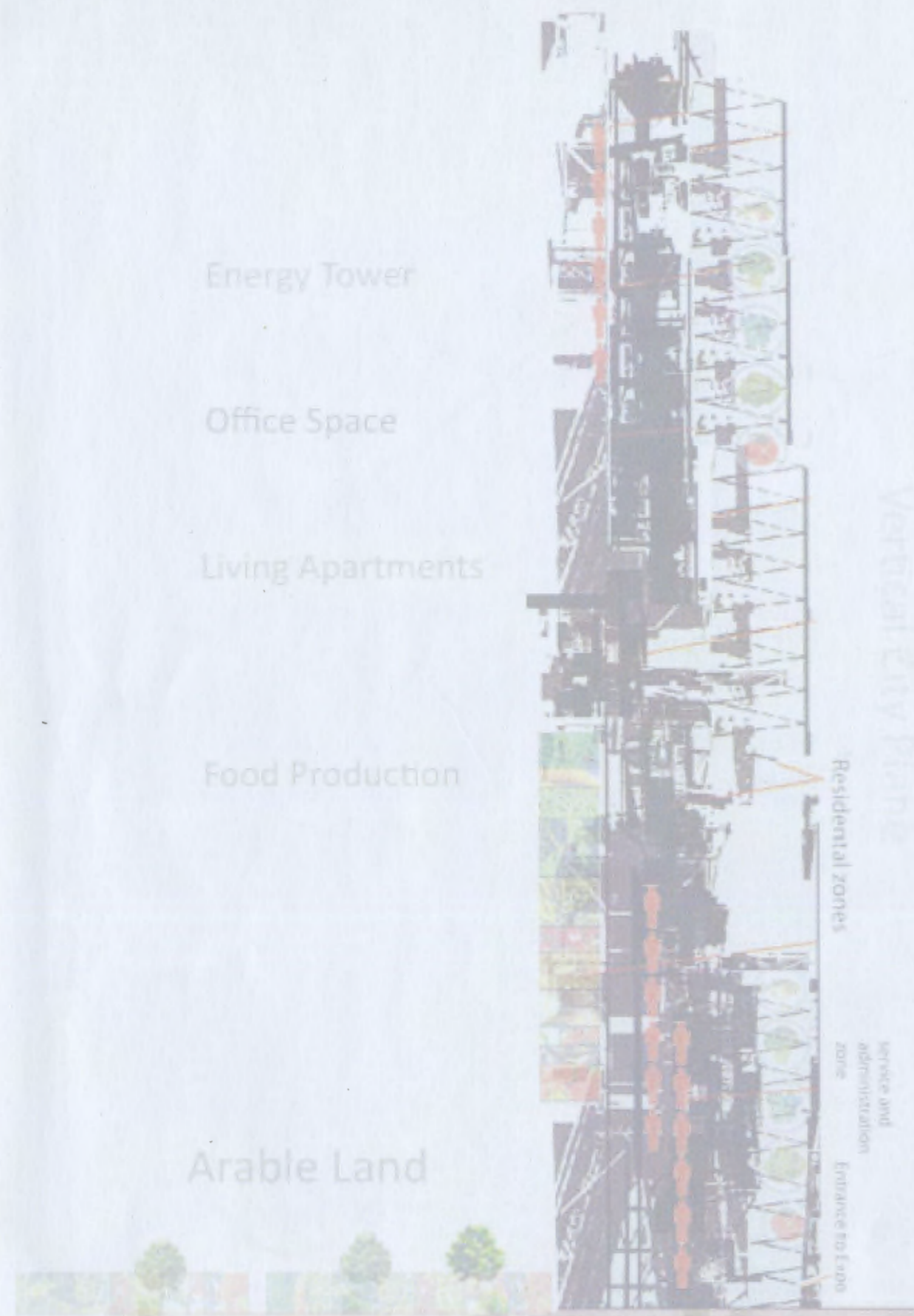
**The first section** of the thesis deals with the understanding of a LT in a broader scale; the roots of the situation, its response to the environmental crisis and essentially the LT as a possible solution to the argument.

**The second section** will investigate the LT as a possible solution by thoroughly analysing and testing its components in a building. The integration of the different systems of the LT will comprise a significant part of this section.

**The third section** of the thesis deals with the sustainability and viability of such a building in our current context. Energy generated in the building with natural renewable resources will be compared to the energy consumed by the greenhouses, the living units and the office spaces. The amount of land that the tower reclaims for green environmental purposes forms the core focus of this section.

All the research findings and information gathered will be applied and explored graphically and spatially in the **fourth and final design section**. The three dimensional shape of the LT responds to the local climatic conditions, the current environmental crisis and aims to restore the imbalances of the human relationship with nature and fostering their holistic integration. The design reflects the local environment by growing out of the landscape imitating the hills in Durbanville, just outside the northern suburbs of Cape Town.

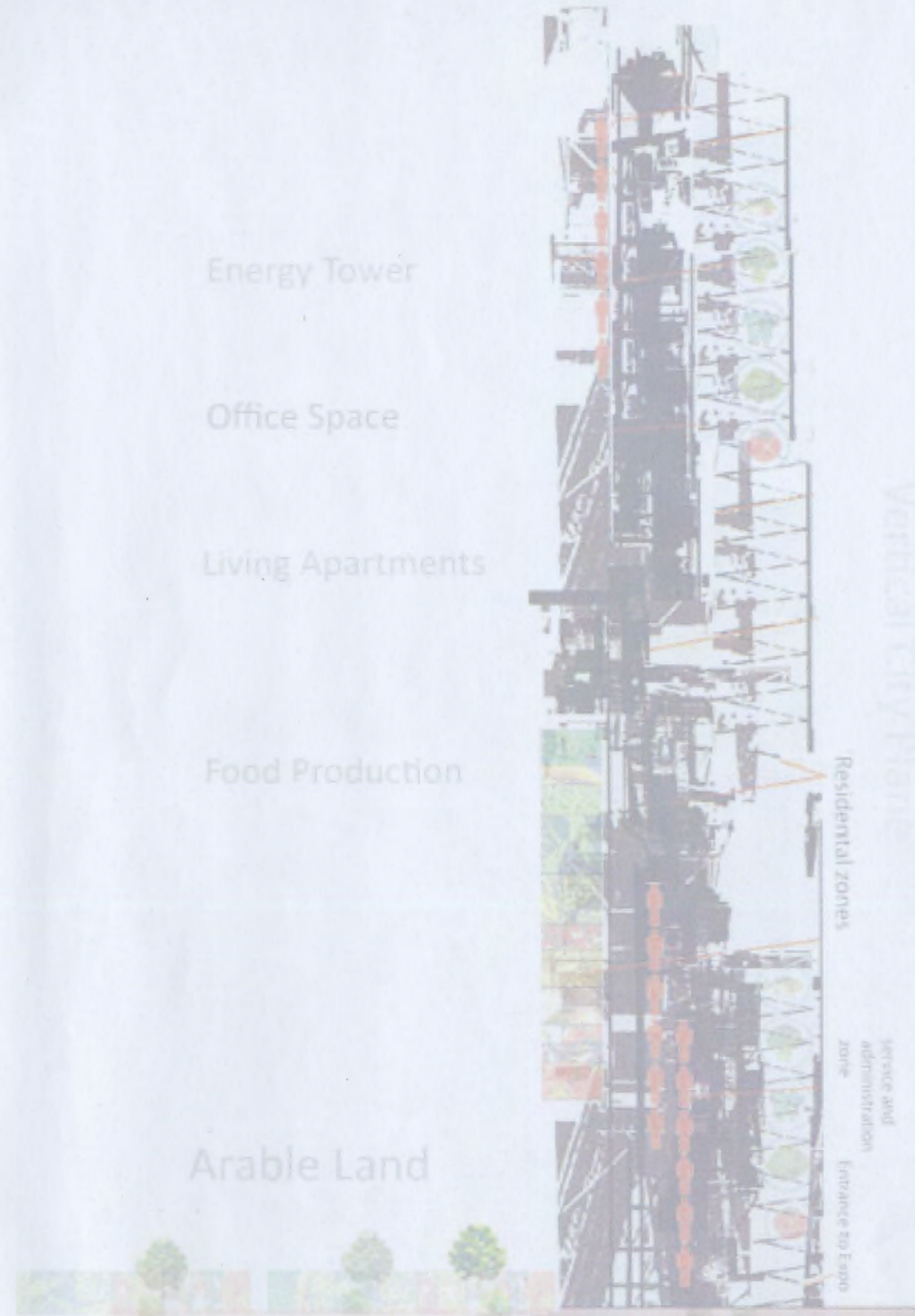
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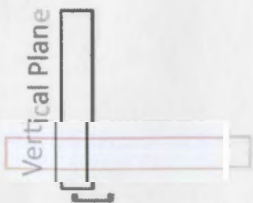
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# Section 1

*The current situation and a possible solution.*



# LIVING TOWER

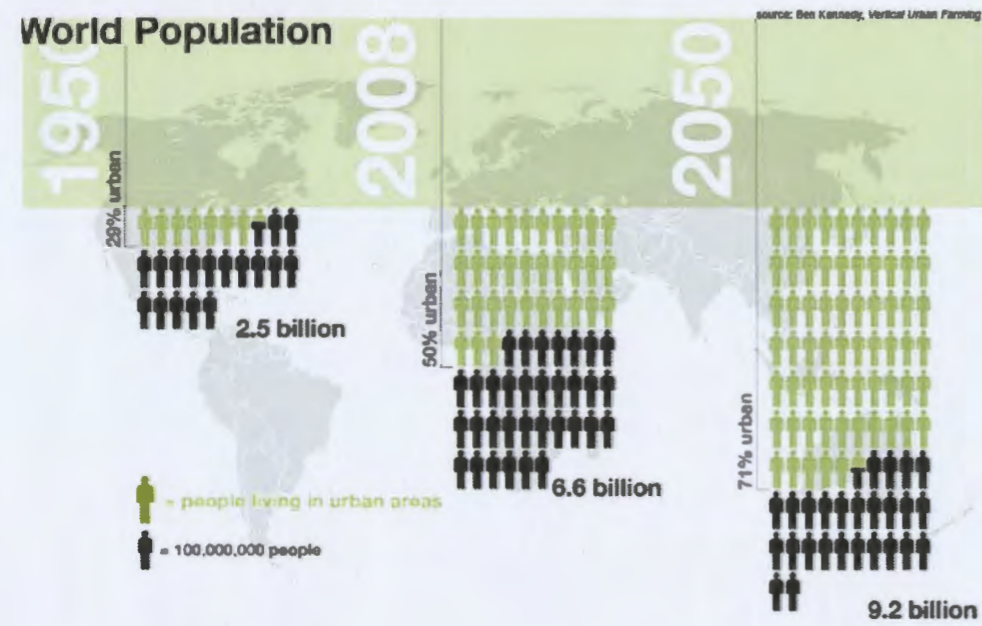


Fig. 1.1 Population prediction



Fig. 1.2 Weather related crop failures



Fig. 1.3 Sprawling over valuable arable land

## 1.1 The current situation

The severity of global issues we are facing today are rapidly increasing and are likely to have major environmental consequences. We already experience heavy pollution in our urban areas and significant climate changes every season. More than 80% of arable land worldwide is occupied; and 15% of this land has ended up as waste due to poor land-management. Rapid urban growth and the migration of people to urban areas have put the agricultural sector under severe pressure to supply food without harming the environment. This trend is expected to continue: the Vertical Farm Project (2009) estimates that by 2050 the earth will be populated by 9.2 billion people, and more than 71% of the earth will be urbanized (see Fig. 1.1).

The trend towards increasing arable land for crop production through deforestation is a growing phenomenon that has contributed to an unbalanced ecosystem. Irrigation causes serious water loss through evaporation, while almost none of the 70% of the world's potable water used by the agricultural sector is recycled; instead most of it vanishes into the air (The Vertical Farm Project 2009). Agricultural activities are by far the biggest contributor to pollution in terms of the fossil fuel used for shipping, transportation and ploughing (The Vertical Farm Project, 2009). Crop production has diminished over the years as weather-related crop failures increase with climate change (The Vertical Farm Project 2009) (see Fig. 1.2).

Due to population growth, urban sprawl has quickly spread across corridors and nodes of bio-diversity, and is either invading or threatening natural parks, reserves and valuable arable land (see Fig. 1.3). In her article 'Development land poser in Cape Town as city size expected to double by 2030', Anél Powell explains that the current extent of developed land in Cape Town will double in size by 2030 (Powell 2009, p. 3). She also claims that new development expansion of approximately two hectares per day is resulting in scarcity of suitable un-built land for future use. Cape Town has a wide network of protected bio-diversity bands or greenbelts, which maintain the balance of our ecological systems. However, these greenbelts are continually threatened by new uncontrolled and insensitive developments (see *Cape Times* article in Appendix A).

The minimum density level that is required to maintain sustainable growth is above 25 dwelling units per hectare (du/h). This optimises not only land use, but also social and transport facilities such as bus services etc (PSDF 2005, p. 22). Cape Town City currently averages 12 du/h while the density of its suburbs is almost half of this number. As a result, facilities and services have become uneconomical and many residents are out of reach of public transport. Considering that the basic needs of modern society includes sustainable agricultural production and healthy, dense housing; developments across the entire Cape Town Metropolitan area need to be controlled, contained, directed and phased to promote more sustainable and compact urban growth and more environment sensitive food production.

# LIVING TOWER



Fig. 1.4 The uniformity of suburban planning: Low rise, low density developments.

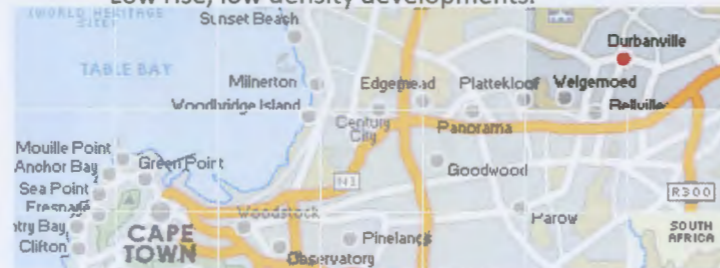


Fig. 1.5 Road map to Durbanville from Cape Town CBD.

## Higher Densities = Better Services

Gross development density of 50 people per hectare 12,5 du/ha	=	Large land take dispersed facilities No centre Bus may not be viable
Gross development density of 100 people per hectare 25 du/ha	=	Reduced land take Clear central facilities Bus should be viable
Gross development density of 150 people per hectare 37,5 du/ha	=	Everyone can walk Usage of local facilities increase Bus routes are more regular

Fig. 1.6 Supportive density table.

## 1.2 Contributors to the current situation

Many people cherish a dream of suburban living. Although mass migration to suburban areas has extremely negative environmental consequences and demands personal sacrifices such as increased travelling times, people relentlessly flock to the outskirts of the city to find freedom, space and privacy. According to *Radiant City* the average travelling time for a commuter from the suburbs to the CBD adds up to 91 days per year (Radiant City 2006) in an American context. Travelling to workplaces is not only about wasting time, but also about the amount of air pollution from automobiles due to the increasingly congested roads and distances between hubs. Air pollution has long been recognized as a constant threat to human health as well as to the Earth's ecosystems (Air Pollution, 2009).

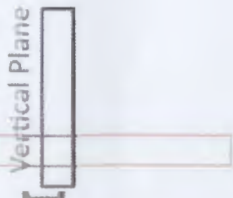
As the distance between the city and the sub-city increases, so the cost and effort required to install infrastructure and services also increase. The provision of access to distant and sprawling developments is highly uneconomical and environmentally unfriendly. Existing bio-diversity nodes and corridors are frequently disrespected. The planning layout for facilities in suburban areas differs from the traditional urban model, but still consists of all the same facilities: offices, living, shopping and civic buildings (schools, religious places, hospitals, etc.). Suburbs specialize in disaggregating the daily elements of life, forcing their inhabitants to drive to their destinations, usually with their own vehicle.

The suburban street is frequently a dead space, with no public interaction and no lively pedestrian atmosphere on the street (see Fig. 1.4). The backyard, which turns its back toward the 'public interface', is the preferred social space for gatherings and parties. Another problem that characterizes the suburb as an unfriendly environment is the lack of future planning for higher densities. This may be due to people's reluctance to accept this kind of development, or a consequence of current infrastructure that is neither sufficient nor equipped for high densities and tall buildings.

In order to create a high rise sustainable suburb, its boundaries have to be contained and its growth must be phased. A higher density build form is essential, and unless this strategy is vigorously promoted, we will experience continuous low-rise build developments that unceremoniously infringe on scarce and quality agricultural land. A typical example of this scenario is the suburb of Durbanville, located 40km north east of the Cape Town CBD. Durbanville is one of many suburbs on the urban edge where rapid sprawling is expanding aggressively over farm land. A map of the Cape Town Metropolitan area indicates other sites that are facing the same fate (see Fig. 1.7).

Durbanville originated during the 1800's as a quaint little farming village called 'Pampoenkraal' north of Bellville (*Durbanville history* n.d.). People started flocking to this village specifically for the lifestyle that it offered. Durbanville boasts with a low crime rate in South Africa, which promises safe and secure living conditions. It is a sought after lifestyle consisting of an open green plot, a spacious family size house and a main street with shops catering for basic needs. Property values have increased over 400% during the last decade and are still following an upward curve (*Durbanville history* n.d.).

'In order to create a high rise sustainable suburb, its boundaries have to be contained and its growth must be phased.'



# LIVING TOWER



The existing suburban model needs rethinking in terms of its ecological and infrastructural planning. Successful sustainable planning has the potential to develop self-sustaining environments that lead to self-sufficient lifestyles.

Figure 1.22 provides a graphical representation of how population densities can support infrastructure and services. Higher densities simply mean better services. Figure 1.6 indicates that at a low density of 50 people or 12.5 dwelling units (du) per hectare (ha) large amounts of land are uneconomically consumed and urban services such as public transportation hubs are not viable. As the population density increases more daily service and business centers can be reached by foot or bicycle and transportation stations become more viable. With 150 people or 37.5 du per ha, everyone can walk to work, school or to shopping centers and a greater degree of interaction between nearby facilities become viable. Durbanville's residential density equals 4-8 dwelling units per hectare, which equals 16-32 people per hectare. This low-rise, low-density development type has many consequences for the environment as mentioned above.

Fig. 1.7 Urban edge. Sites on the periphery intend to contain and redirect urban growth. Drawing by author.



*“Successful sustainable planning has the potential to develop self-sustaining environments that lead to self-sufficient lifestyles.”*

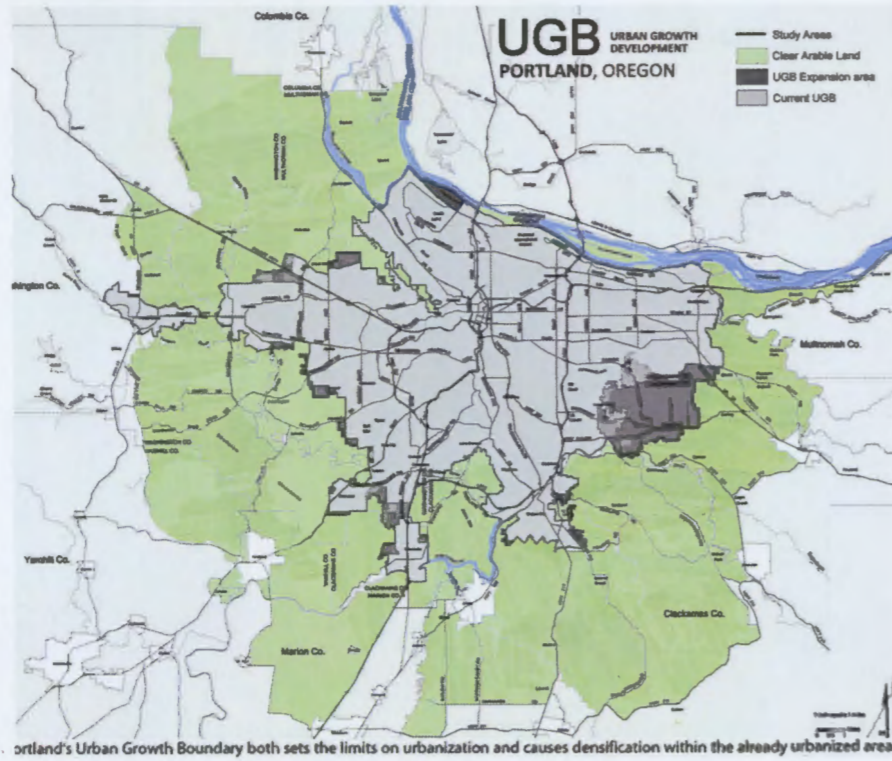


Fig. 1.8 Portland UGB. Drawing by author.



Fig. 1.9 Urban sprawl being rippled back towards the city. Drawing by author.

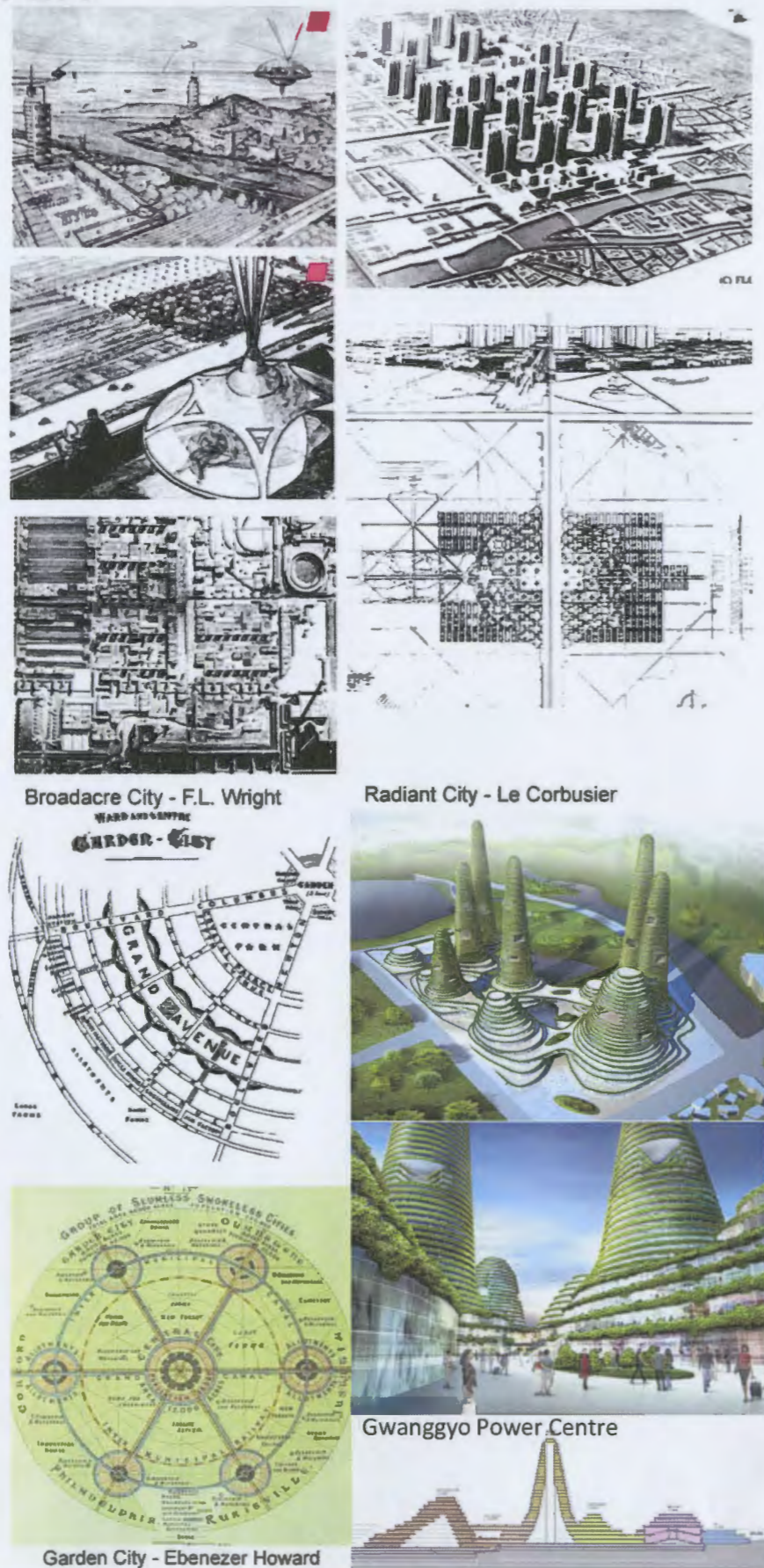
## 1.3 Alternative approaches to the situation

Radical interventions have to be introduced to contain, control, direct or phase growth in order to promote more sustainable, compact, neighboring urban development.

An *Urban Growth Boundary* (UGB) represents one method for protecting farms, forests and sensitive natural land from urban sprawl and for promoting the efficient use of land, public facilities and services inside the boundary. Urban Growth Boundaries correctly implemented, can promote urban and suburban revitalization. It can further encourage the development of more affordable housing, stimulate community development patterns that support more accessible public transport as well as enabling quick open-space retreats from urban centers (Boone et al. 2006, p. 172).

A good example of a UGB that has been successfully implemented is in Portland, Oregon, USA. Portland is a major metropolitan region with an Urban Growth Boundary (UGB) in place since 1970. The UGB proved to be a huge success as it now protects huge stretches of forest and farm land outside the edge of the UGB, and has also increased the number of houses planned inside the boundary from 129,000 to 300,000 (Boone et al. 2006, p. 176). The UGB was to a large extent responsible for revitalizing downtown Portland. Cape Town, Western Province boasts with less of a successful implementation of an UGB. Although an Urban Edge was determined for Cape Town in terms of the *Provincial Administration's Urban Policy of December 2005 (Provincial Urban Edge Guideline 2005)* the city has no distinct boundary line or boundary mechanism in place to control and contain urban sprawl. As a result, low rise developments have spread across farm lands and bio-diversity reserves with no protection barriers (Powell 2009, p. 3).

# LIVING TOWER



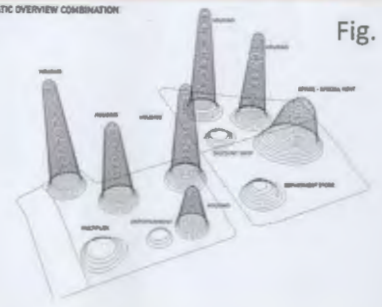
Broadacre City - F.L. Wright

Radiant City - Le Corbusier

Garden City - Ebenezer Howard

Gwanggyo Power Centre

Fig. 1.10 The different city design proposals that the author investigates



*"The Living City will integrate some of the characteristics and unique features of radical city design proposals"*

## Radical City Design Proposals

This study will investigate some city designs that played a prominent role during the time of their proposal as well as aspects that are still radical and innovative for today's standards. The author will propose an alternative city design approach that makes reference and draws from the following mentioned city designs:

Le Corbusier's *'Radiant City'* (1930-35) with its *vertical garden city* concept (Radiant City 2006), the *'Broadacre City'* by F.L. Wright labelled *'a landscape and not a city'* (Sdoutz 1999), the *'Garden City'* by Ebenezer Howard designed as *'the perfect blend of city and nature'* (Howard 1902) and most currently and influential to the concept of the proposal is the *'Gwanggyo Power Centre'*, a self-sufficient city designed by MVRDV (MVRDV 2008). The proposed concept is called the *'Living City'*.

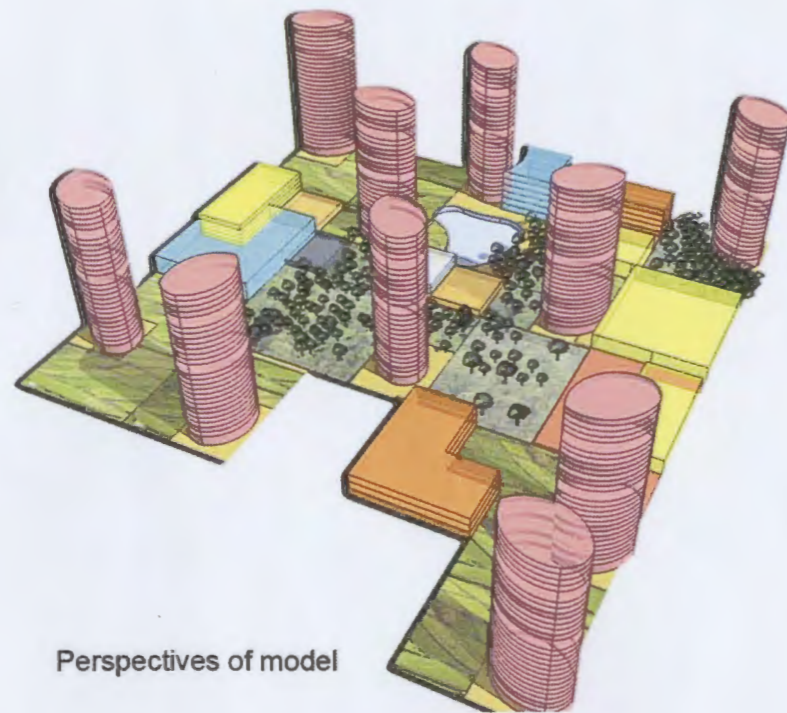
### 1.3.1 The Living City

The *Living City* (LC) model is a direct response to the trend of low density and low build form in suburban areas. It counters the current approach of major sprawling over bio-diversity nodes as well as valuable arable land. The LC is in itself an urban boundary line that contains sprawling in a sustainable way. This intervention reverses the ripple effect (of urban sprawling), which bounces off the barrier/boundary line to ripple back toward the city centre (see Fig. 1.9). Sprawling therefore returns where it came from and the consequence is a more intensified planning approach to stimulate dense population areas. The idea is to control sprawling to preserve the bio-diversity networks as well as to reserve and reclaim valuable agricultural land. A core component of the LC is the *Living Tower* which offers the production of food and living space for a thousand people in a self-sustaining tower discussed in the subsequent section.

The LC draws from Le Corbusier's *'Radiant City'* (1930-35) with its *vertical garden city* concept. The LC however offers a much more humane and interactive landscape and built environment (Radiant City 2006). Le Corbusier's intention was to dedicate the entire ground as a "gift" to the pedestrians. His buildings would be placed upon pilotis, five meters off the ground, so that more land could be given back to nature. The LC also intends to pedestrianise the entire model and provide more green nature through reclaimed land for parks, agriculture or recreation. Le Corbusier's notions originated from an authoritative approach where the man-made build tower/machine is separated from its landscape. Contrary to his, the LC promotes the belief that a cluster of different activities in a certain area nurtures valuable social interactions in a community.

Notes:  
The *Living City* is a term the author uses to describe his proposed sustainable city, which promotes healthier and higher living densities that includes mixed-use, multi-scale buildings to ensure social interaction. The *City* also focuses on reclaiming valuable arable land for agriculture, parks, reserves and recreational fields.

# LIVING TOWER



Perspectives of model

Fig. 1.11 Representation of the Living City on a 20ha site, including all required community facilities. Model by author.

Wright conceptualized his ideas during the 1924 industrial development at a time of major rural-to-urban migration, mass traffic congestion and an agriculture-to-industry change. We are facing a similar era where urbanization is not controlled and lack of urban space is becoming increasingly problematic. Wright's 'Broadacre City' (1923-65) plan was to achieve an Arcadian Lifestyle, where family values and spirituality were imperatives and where the environment became a landscape rather than a city. His goal was to decentralize the city into a sprawling *landscape* where every household owned an acre of cultivating land (Sdoutz 1999). The LC supports this model and is also concerned about the human lifestyles and values. The '*environment as a landscape rather than the city*' is a valid intervention but it depends on how the landscape is treated. The LC proposes a landscape where the scale of the build fabric varies to create a dynamic, diverse and intimate atmosphere (see Fig. 4.17). The treatment of the ground-plane becomes the most important generator of social activities. As in the *Broadacre City*, cultivating land that has been reclaimed will be widely integrated into the LC model. The LC differs from the *Broadacre City* in the higher residential densities and the more viable public transportation systems it would provide.

Ebenezer Howard spoke of his 'Garden City' design as 'the perfect blend of city and nature' (Howard 1902) (see Fig. 1.10). The Garden City, designed in 1902, was encircled with a greenbelt to control and direct the potential developments. The Garden City searched for a careful balance in the planning of the various facilities such as the industry sector, the agricultural sector and the residential sector. The Living City's aim is also to control and direct growth in a sustainable way with a greenbelt or an urban growth boundary line as well as to achieve the perfect balance between nature, city and user. The LC concept endeavours to maintain the important balance and connectedness between human, nature and city. It maintains that these relationships will determine the success of the city. The diversity in the building scale and type as well as the ground plane is fully pedestrian friendly, allows for an intimate and interactive usage of the spaces between the buildings. This attribute of the LC is a prominent component of MVRDV's design for the *Gwanggyo Power Centre* (GPC) in Seoul, Korea. The ground planes are continuously changing in an elegant way through different scales. '*On the lower floors the atriums are connected through a series of public spaces on various levels linking the towers and serving the outdoor facilities of the culture, retail and leisure program. The Power Centre creates a dense urban program with a green regard*' (MVRDV 2008) (see Fig. 1.10).

Daewoo Consortium and the local municipality awarded MVRDV's GPC first prize in 2008 and announced 2011 as the estimated completion date. MVRDV's idea of the Power Centre is to locate a mixture of facilities together such as public, retail, culture, housing, offices and leisure that generate life in new metropolitan nodes and encouraging further developments around them. These values are core principles in the future planning and growth of the LC. Interlinked facilities ensure social interaction from one facility to another (see Fig. 1.12). This is where Le Corbusier's Radiant City design failed. He separated the daily life elements causing deserted spaces during work hours and deserted offices spaces after work. The GPC plan consists of a series of overgrown hill-shaped buildings with great programmatic diversity. The site appears as an up-and-down vertical park with green rings shaping the outline of the buildings (see Fig. 1.10). The LC with its Living Towers as focal points promotes similar prospects to be in harmony with the surrounding nature.



# LIVING TOWER



Fig. 1.12 This illustration represents the type of environment that the Living City proposes, with open green spaces and diversity in the landscape treatment and the scale of the buildings. Sketch by author

These towers evolve from the ground upwards shaping green hills acting as green lungs to the community.

The LC has a social housing component that is partly subsidized by the upper income buyers. The idea of this component is to promote the accommodation of different classes in one building. This is done in a sensitive and caring way to provide equality in the community and to discriminate against no-one. Upper income buyers' prices are slightly higher in order to lower the price for the middle/lower income buyer. The aim of the towers is to integrate and accommodate all classes.

Public transportation facilities are located nearby with no tarmac streets interfering with the landscape and living conditions that are created within this city, while all facilities are within easy walking distance. Three levels of parking are provided in the basement of each tower and connected via an underground network. Cultivated land that has been reclaimed will be widely integrated into the model to provide the residents with ownership of the land.

The Living Tower (LT) is not only a core component of the LC, but it also forms the heart and soul of the LC. A significant feature of the LT is that it grows out of the landscape and becomes part of its surrounding nature. From the previous sections it is clear that a foundation has been prepared for the LT and this study will be dedicated towards the exploration of what the LT comprises of. It will also be concerned with the influence of the LT on its surroundings. The following sections will be dedicated to designing and discussing the LT.

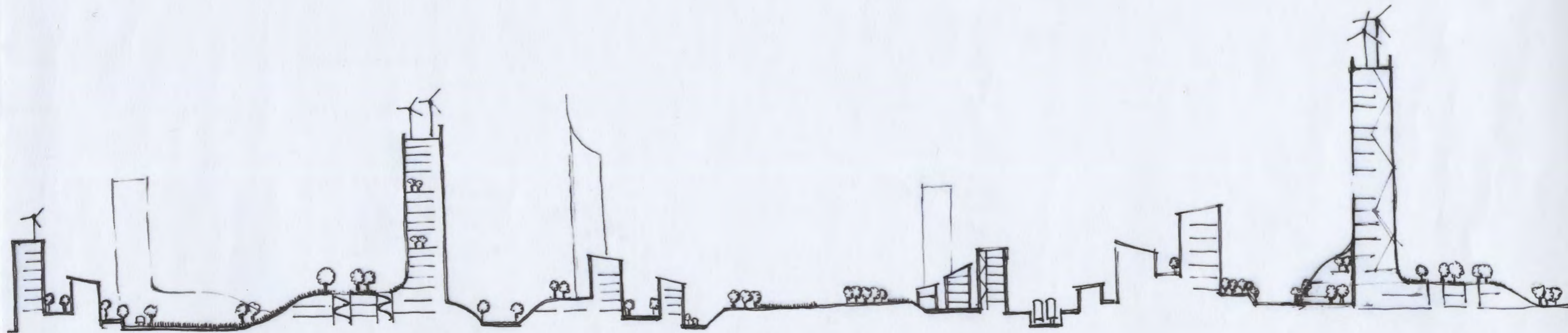
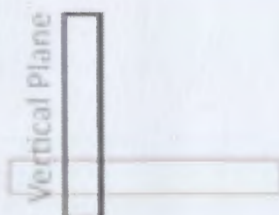


Fig. 1.13 Nature plays a major role in the design of the Living City. The key determinant is the relationship between the built environment and natural green spaces. Section planned by author.



*"The LC concept endeavours to maintain the important balance and connectedness between human, nature and city. It maintains that these relationships will determine the success of the city. The diversity in the building scale and type as well as the ground plane is fully pedestrian friendly, allows for an intimate and interactive usage of the spaces between the buildings."*

# LIVING TOWER

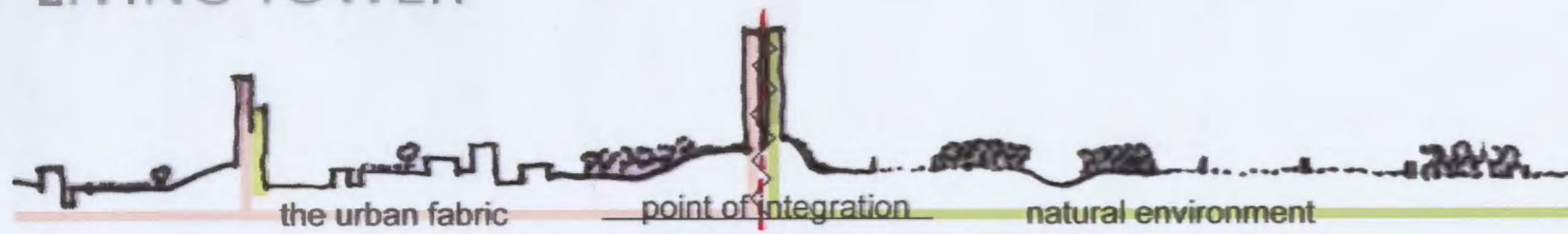


Fig. 1.14 The amalgamation of the urban fabric and the natural environment into one entity. These two aspects meet and interweave in the Living Tower.

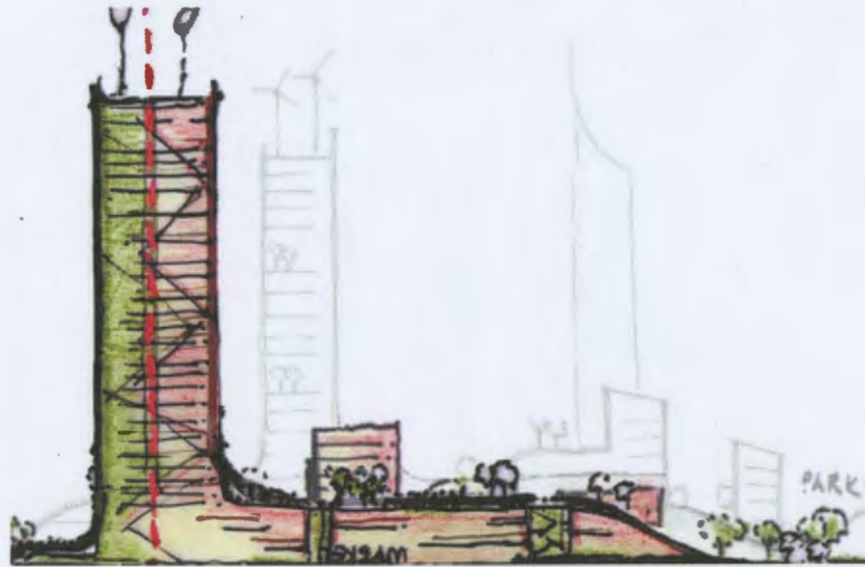


Fig. 1.15 A conceptual sketch of the Living Tower indicating the integration of the agriculture into a single tower. Sketch by author



Fig. 1.16 Tour Vivante by SOA Architects. A perspective and plan of the building showing the agriculture that spirals around the core

## 1.3.1.1 The Living Tower

The concept of the **Living Tower (LT)** can be defined as the unification of **Agricultural Production, Dwelling** and other activities in a singular vertical **Closed System**. The study will proceed by investigating the LT in general then continue to discuss the agricultural production, the dwelling, and the closed system respectively in more detail, focussing on how these components are integrated into a vertical tower.

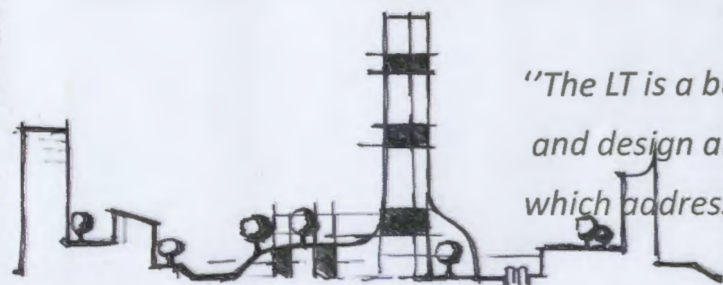
### The Living Tower

The LT is a building that demonstrates fascinating architectural skill and design and captivates the user and observer for its radical concept which addresses many issues and presents a dynamic, aesthetic appearance. The tower symbolizes revitalization through amalgamation of the agricultural land and the urban fabric; the living component and the agricultural component become one entity joined together to work towards a sustainable infrastructure and healthy, balanced living conditions.

Steve Featherstone, managing director of *Llewlyn Davies Yeang* wrote in the preface of the book *Ken Yeang: Eco Skyscrapers*, 'Justification for high-rise buildings lies in the recognition of its potential in delivering further sustainable planning and design solutions for the city' (Richards 2007, p. 7). High-rise buildings have become part of the urban planning scheme to accommodate the sudden urbanization in a healthy and sustainable way. Ken Yeang is a prolific Malaysian architect who specializes in making the skyscraper as ecological and human friendly as possible.

'Why should places of manufacture of consumption or food not find their place in the heart of city? And join by mixing housing; trade and production/ transformation that are so important for the city?' (SOA Architects 2006, p. 1)

SOA Architects posed this vital question and answered it by the design of the '*La Tour Vivante: an eco-tower*' building that combines the living and the production of food within one entity using various sustainable building techniques to minimize the ecological footprint left by traditional farming. They argued that this system will densify the city, yet the mixture of programs will make it possible to consider new practical and dynamic relations between agricultural production, housing, and trading as well as offering significant energy savings. The Parisian tower demonstrates that skyscrapers can be used for far more than just residential and business use while still retaining a design that is both provocative and aesthetically stimulating (see Fig. 1.16). The LT also specialize in more efficient farming with less environmental consequences and the higher density allows for more outdoor, social and open spaces at ground level. Other activities that feed off these components are the market/retail space, office spaces, restaurant, storage and parking. Parking is provided in the basement: in the form of 2/3 floors comprising 500/700 bays. A public transportation hub is important to the success of the LC and the LT. The Production Space (used for packaging, sorting and distributing) is a key element of the building and becomes a part of the self-sufficiency process.



*"The LT is a building that demonstrates fascinating architectural skill and design and captivates the user and observer for its radical concept which addresses many issues and presents a dynamic, aesthetic appearance."*

# LIVING TOWER



Fig. 1.17 An illustration of a vertical farm showing the different fruit and vegetables farmable in a high rise building.

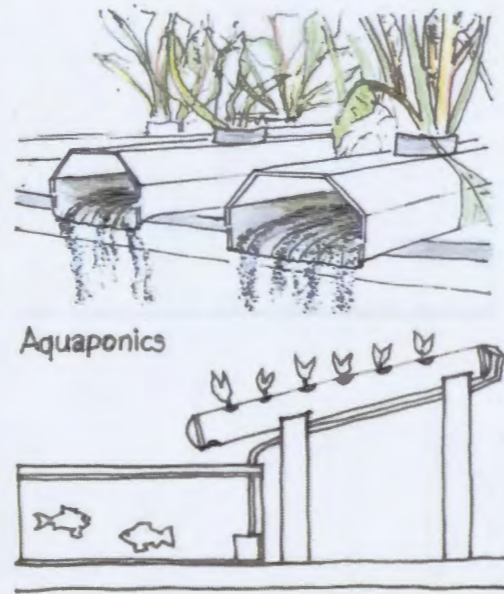


Fig. 1.18 Hydroponics and Aquaponics respectively, are popular methods of farming indoors without using soil, or using only water. Sketches by author.

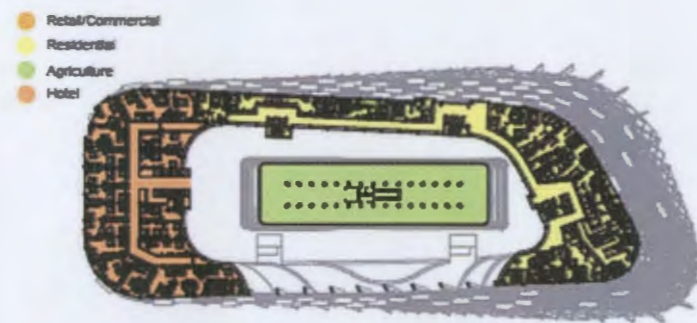


Fig. 1.19 A plan of Johnson's Aberrant Agriculture project showing the agricultural core and the distribution of the different crops on different floors.

The *living-vertical-farm* acts as an educational amenity for the community and it will be open for tours as well as for academic research. The aim is not to absorb the suburb with the new LT intervention; the idea rather acts as a model to gradually integrate the new way of planning, housing, farming and living with the rapid increase in population growth.

## The Living Tower as an Agricultural Production component:

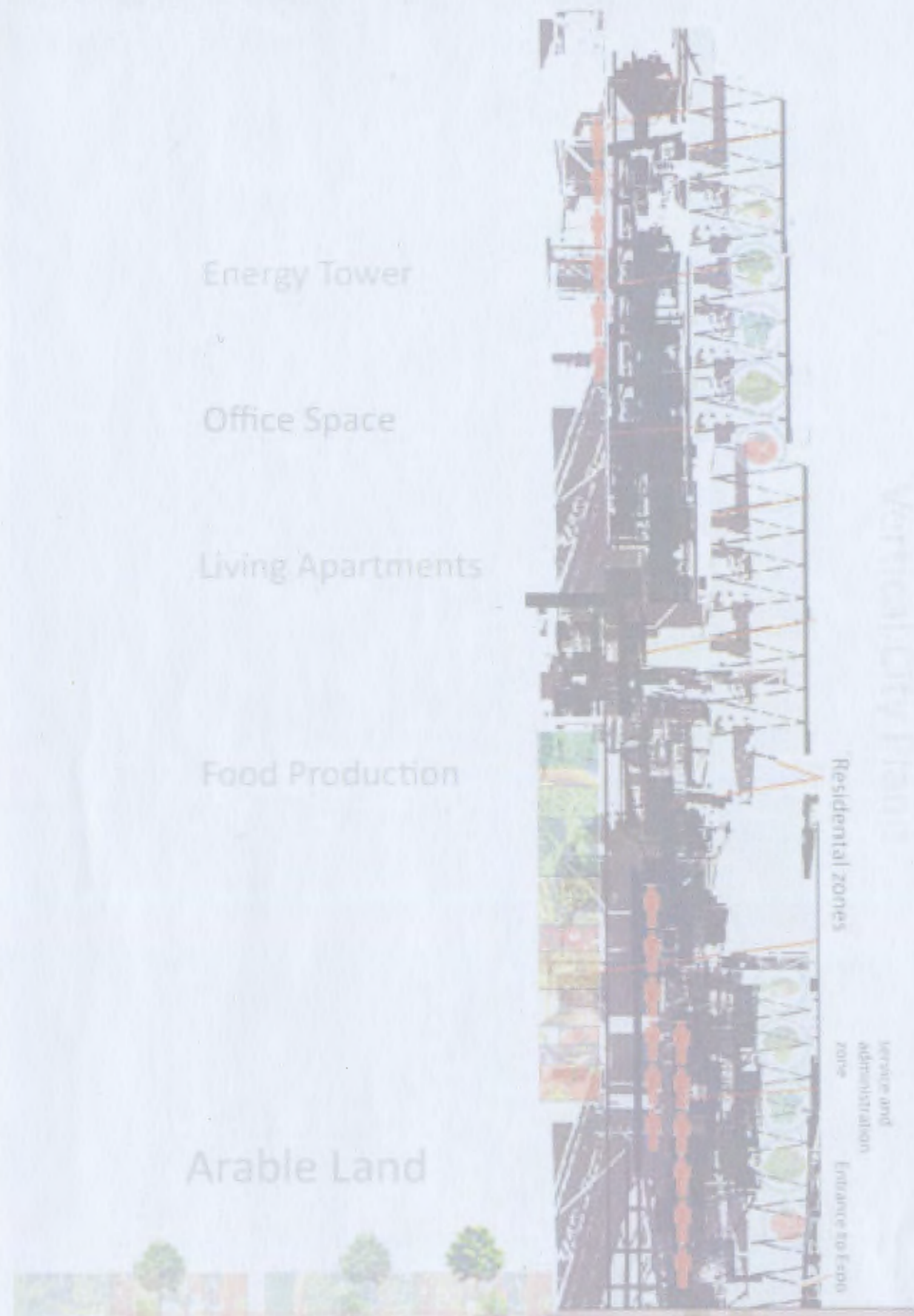
The Vertical Farming component (see Section 2) in the tower is one of the functions of the building that transforms the building into being self-sufficient. It operates within a continuous closed/cyclical system using surrounding resources to sustain life, hence The Living Tower.

Dickson Despommier a microbiologist, ecologist and professor of Public Health in Environmental Health Sciences at Columbia University, USA, developed the concept of vertical farming during 1999. Despommier further investigated the ideas and the conceptualization of vertical farming in buildings with his 'medical ecology' class in the last decade (The Vertical Farm Project 2009). A Vertical Farm is defined as an urban indoor high rise farm that produces food and water locally for the growing urban population in a sustainable way (The Vertical Farm Project 2009) (see Fig. 1.17).

Aquaponics combine fish farming (aquaculture) with Hydroponics (soilless plant culture). The natural, nutrient-rich water that is gained from fish farming is used as a very good and nutritious fertilizer for the growth of the plants. The plants consume the nutrients and purify the water that is again used in the fish tanks (Aquaponics Overview n.d) (see Fig. 1.18). The use of aquaponic methods as a crop growing medium is a fundamental component of the vertical farm. Its minimal space requirements permit massive densification of agricultural production to take place, as it enables the vertical stacking of produce (see Fig. 1.17). The benefits of farming indoors are abundant and increase multi-fold when farming occurs in a skyscraper:

- Year round crops in comparison with seasonal crops through the indoor controlled environment, especially with artificial lighting.
- Elimination of the environmental cost of transportation and shipping of produce from far away.
- No more weather related crop failures due to the enclosed environment.
- Diseases spread by livestock do not influence the crops as they do in traditional farming.
- In contrast to the 70% potable water loss through evaporation in farming, farming indoors condenses moisture in the air and recycles water with the *Living Machine* (discussed later).
- No more pollution of water sources by run-off.
- One indoor farming ha equals 10 to 15 outdoor farming ha (The Vertical Farm Project 2009).
- Plant and human waste are recycled and digested to produce electricity, water and food for plants, that continuously flows back into the system with the *Methane Digester* (discussed later).

# LIVING TOWER



The concept of sustainable farming within a confined building provides a radical alternative to conventional farming practices and planning methods, based on the combination of farming and living in the same skyscraper.

## What is sustainable farming?

Sustainable agriculture refers to the ability of a farm to produce food indefinitely, without causing severe or irreversible damage to an ecosystem. Farming that has positive environmental consequences should: recycle waste into electricity, food and water; produce food that needs not to be transported miles away; cultivate farms with intensive techniques that allow lands to be reforested; control water loss that happens through evaporation; limit weather-related crop failures; and produce food locally.

## The Living Tower as a Dwelling component:

The Living Tower's agricultural component acts as a green lung for the residents of the tower as well as for its surrounding environment. Nature is the combination of different systems working together to find an ecological balance. This translates into the basic fact that nature is the balanced existence of plants and living creatures together. They need one another to survive and thrive. Plants need the carbon dioxide that humans release and humans need the oxygen that plants release; it is a closed system in itself and will prosper when amalgamated in the same place. Therefore, the combination of the two represents the green lung that continuously breathes for the community.

Living in a skyscraper can be an overwhelming and daunting experience if the design conditions are not calculated ergonomically. A careful design can entail success for the entire community. In all his multi-storey buildings, Ken Yeang designed every floor through the eyes of its occupant (Richards 2007, p. 8). He attempted to achieve a 'ground floor experience', the feeling of freedom and openness on every level. The apartments in the LT incorporate this idea by all having access to a garden as well as a view on to the agricultural production, to generate a more grounded feeling on the higher floors.

The combination of the greenhouse with the living environment creates an interesting mixture which has many benefits. Section 2 of this study goes into detail regarding the integration of the elements that comprise the LT, and proposes ways to produce the most ideal, healthy, efficient and economical design solution (Section 4) for combining them.

*"This Vertical Farm will produce approximately 13,492kg of biological waste a week for a 1000 people and 13,492 kg of bio-waste will produce 1,123,931 kWh of electricity per year in a methane digester, well over half the vertical farm's electricity usage"*

# LIVING TOWER

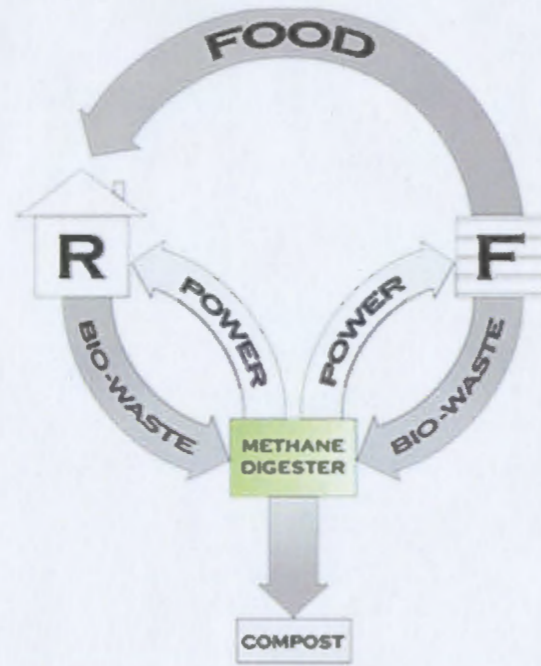


Fig. 1.20 A closed system between the Residential and the Farm

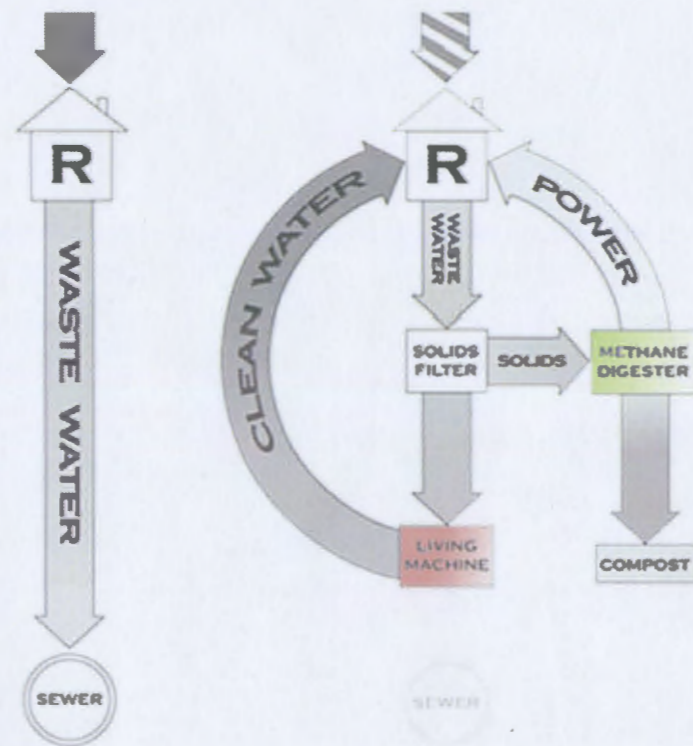


Fig. 1.21 The difference between a linear and closed loop

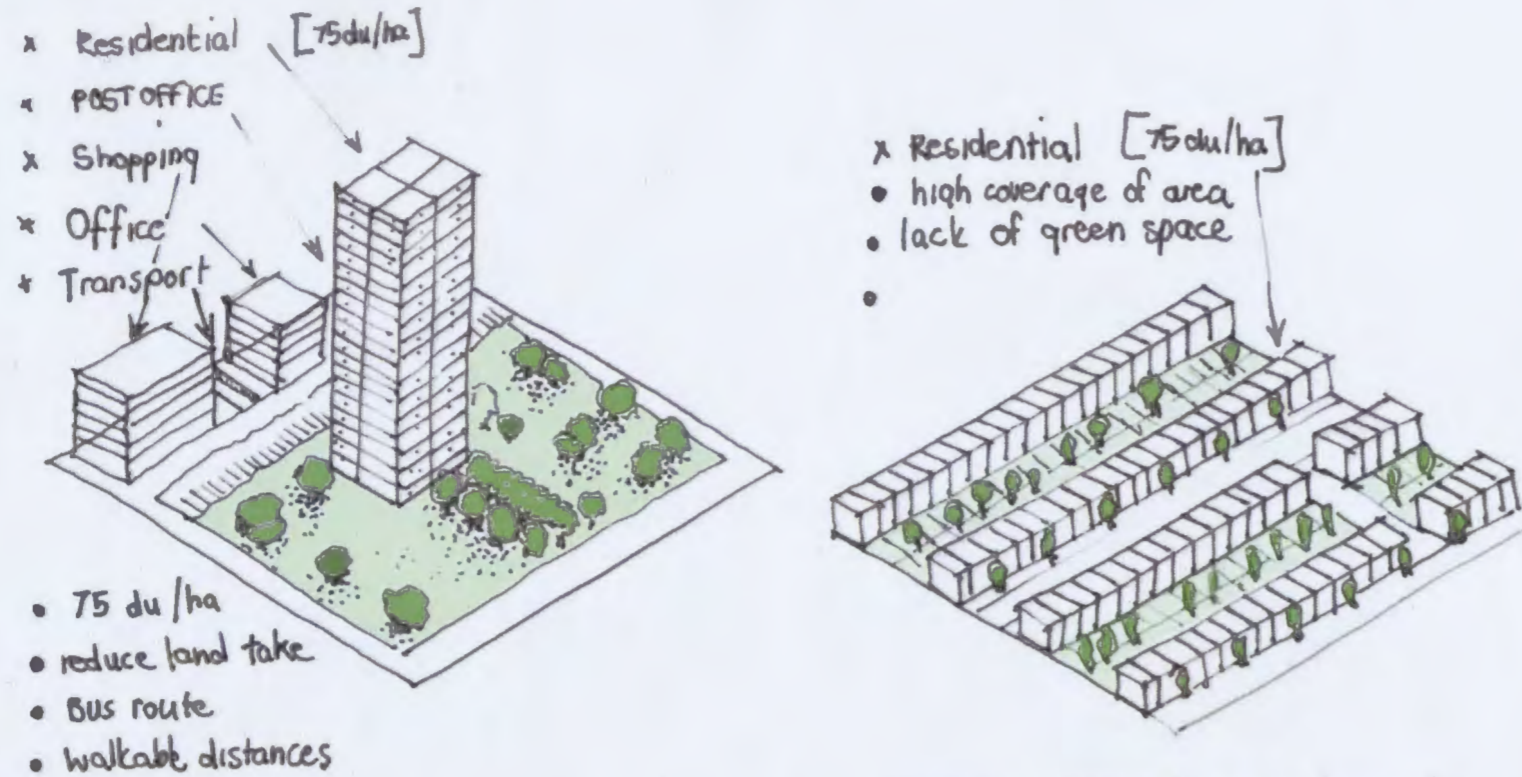
## The Living Tower as a Closed System component:

The LT works in a closed system that uses and re-uses the resources in its surrounding environment. Figure 1.20 shows the relationship between the methane digester, vertical farm (F) and residential buildings (R). As the farm produces food for the residential units, large amounts of bio-waste are collected from the farm's production and fed into the methane digester to produce electricity, powering the artificial lighting of the farm. Additionally the bio-wastes from the residents' consumption of the food are directed to the methane digester, producing power for their homes (Graff n.d, p. 6).

Figure 1.21 shows a comparison between the 'linear' water management of conventional buildings, and the cyclical system used in the LT. The nutrients within the wastewater are processed by the methane digester to produce both power and compost, while the Living Machine filters the water to be used for all non-potable uses, including irrigation for the hydroponic farm (Graff n.d, p. 6).

The brief understanding into the entity of a LT paints the picture of how the LC might appear and functions holistically. The following subsection will ascertain the possible solution of the LC as an alternative approach by using the Durbanville model in a comparative analysis. This exercise applies the same density tests and the same required facilities of a community for both models, which will explore the difference in densities and planning for a specific area.

# LIVING TOWER



SOURCE: ANDREW WRIGHT Associates

Fig. 1.22 Two models with the same density (75du/ha) but different in the 'land take', services, height, open spaces green spaces and other facilities on 1 hectare. The model on the left reclaim green land for recreation and other facilities whereas the other model is dedicated to residential for the lack of space for other facilities. Drawn by author.



Fig. 1.23 This site is in the northern part of Durbanville, Vierlanden. A 1ha area is highlighted to show the density of that 1ha. It is estimated that the area contain 8 dwelling units which equals 8du/ha.

## 1.4 Positive results of an alternative approach

What is the impact if the Living City replaces the low densities as well as reclaiming valuable arable land that has been lost due to explosive urban sprawling? The following density tests will determine the answer.

Task Force (1999) argues that the higher densities can simply mean better services (see Fig. 1.6). Figure 1.6 indicates that at a low density of 50 people or 12.5 dwelling units (du) per hectare (ha), large amounts of land are uneconomically consumed and other urban services such as public transportation hubs are not viable. As the density rate increases more daily activities can be reached by foot or bicycle and transportation stations become more viable. With 150 people or 37.5 du per ha, everyone can walk to work, school or shopping centre and a great deal of interaction between facilities nearby becomes visible.

Studies in South Africa and elsewhere have identified 100 people per ha (25du/ha) as the threshold where good supportive neighbourhood facilities, public transport services and walking become convenient. The average density is approximately 12du/ha including the City of Cape Town (PSDF 2005, p. 7:22).

An illustration between two different built typologies, Figure 1.22, indicates more vacant land around the higher residential building. The open land around the building can be integrated by other facilities that can generate social interaction.

### Durbanville: Currently

Population	:	50 000 people
Population Density	:	30pp/ha
Area	:	2 100 ha (21 km <sup>2</sup> )
Dwelling Units	:	12 500
Dwelling Units/ha	:	8 du/ha
		69.9% Separate stand Houses
		12.2% Town/Semi detach Houses
		9.8% Block of flats

### 1.4.1 Durbanville Density

**SITE:** The site chosen is a **20ha** site on the urban edge at Vierlanden, North Durbanville. All density tests apply to the same site  
 8 DU per hectare = 160 DU on 20ha  
 30 pp per ha = 600 people

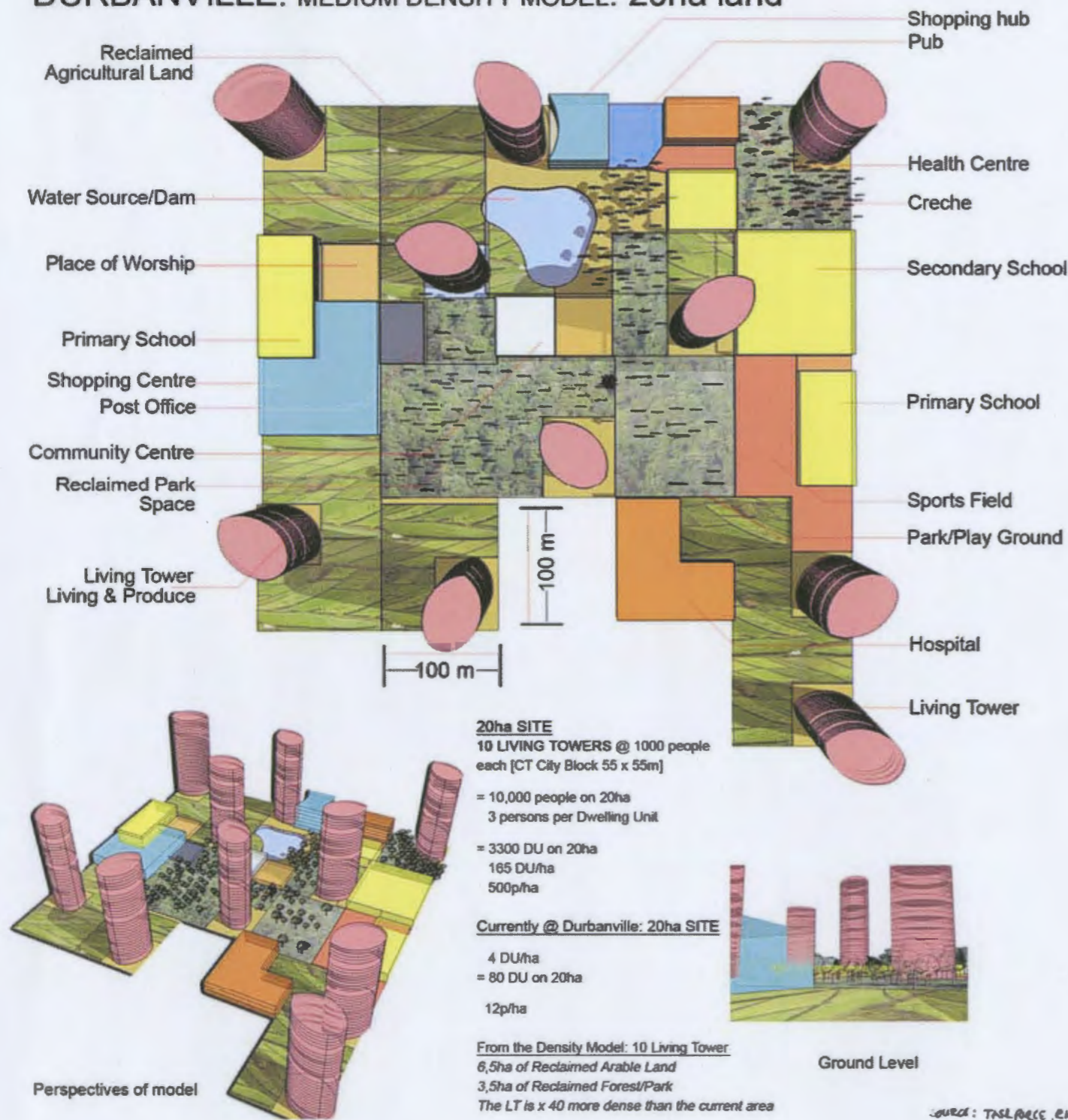
### Higher Densities = Better Services

Gross development density of 50 people per hectare 12.5 du/ha	=	Large land take dispersed facilities No centre Bus may not be viable
Gross development density of 100 people per hectare 25 du/ha	=	Reduced land take Clear central facilities Bus should be viable
Gross development density of 150 people per hectare 37.5 du/ha	=	Everyone can walk A range of local facilities increase Bus routes are more regular

*"Studies in South Africa and elsewhere have identified 100 people per ha (25du/ha) as the threshold where good supportive neighborhood facilities, public transport services and walking become convenient."*

# LIVING TOWER

## DURBANVILLE: MEDIUM DENSITY MODEL: 20ha land



### 1.4.2 Living City – Medium Density Model

Impose: **10 LIVING TOWERS** @ 1000 people each on the 20ha site [CT City Block 55 x 55m = 3000 m<sup>2</sup>]

10,000 people on 20ha  
 4 people per Dwelling Unit  
 = 2500 DU on 20ha  
 125 DU/ha  
 500pp/ha

Facilities required for 125 DU/ha: see *Appendix C* for table  
 (Source: Community Facilities Standard Woodstock)

### Results from the Living City Medium Density Model: 10 Living Towers

= **6,5ha** of Reclaimed Arable Land. This means land that was build on by low density developments. This land can now be pasture land, intensive agriculture or open sport fields  
 = **3,5ha** of Reclaimed Forest/Park. Land that is recovered and the area can be reforested, a recovery to the ecosystems.

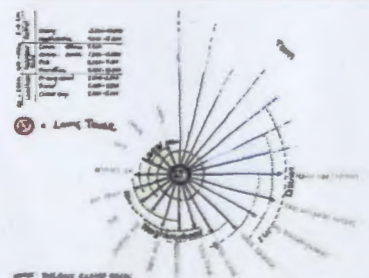
The LT is **17 times denser** than the current site in Durbanville

The LC will be able to accommodate the entire Durbanville population, **50 000** in:

Living Towers (LT) in 0.2 km <sup>2</sup>		
10,000 pp in	0.2 km <sup>2</sup> (20ha)	
<u>50 LT (50 x 1,000)</u>	<u>50,000 pp in</u>	<u>1 km<sup>2</sup> (100ha)</u>
Currently at Durbanville	50,000 pp in	23 km <sup>2</sup> (2300ha)

The LC can accommodate the entire Durbanville population with all the required facilities within 1 km<sup>2</sup>.

Fig. 1.24 Perspectives of the Medium Density Model including all the required facilities



*"The Living City can accommodate the entire Durbanville population with all the required facilities within 1 km<sup>2</sup>."*

# LIVING TOWER

## DURBANVILLE: HIGH DENSITY MODEL: 20ha land

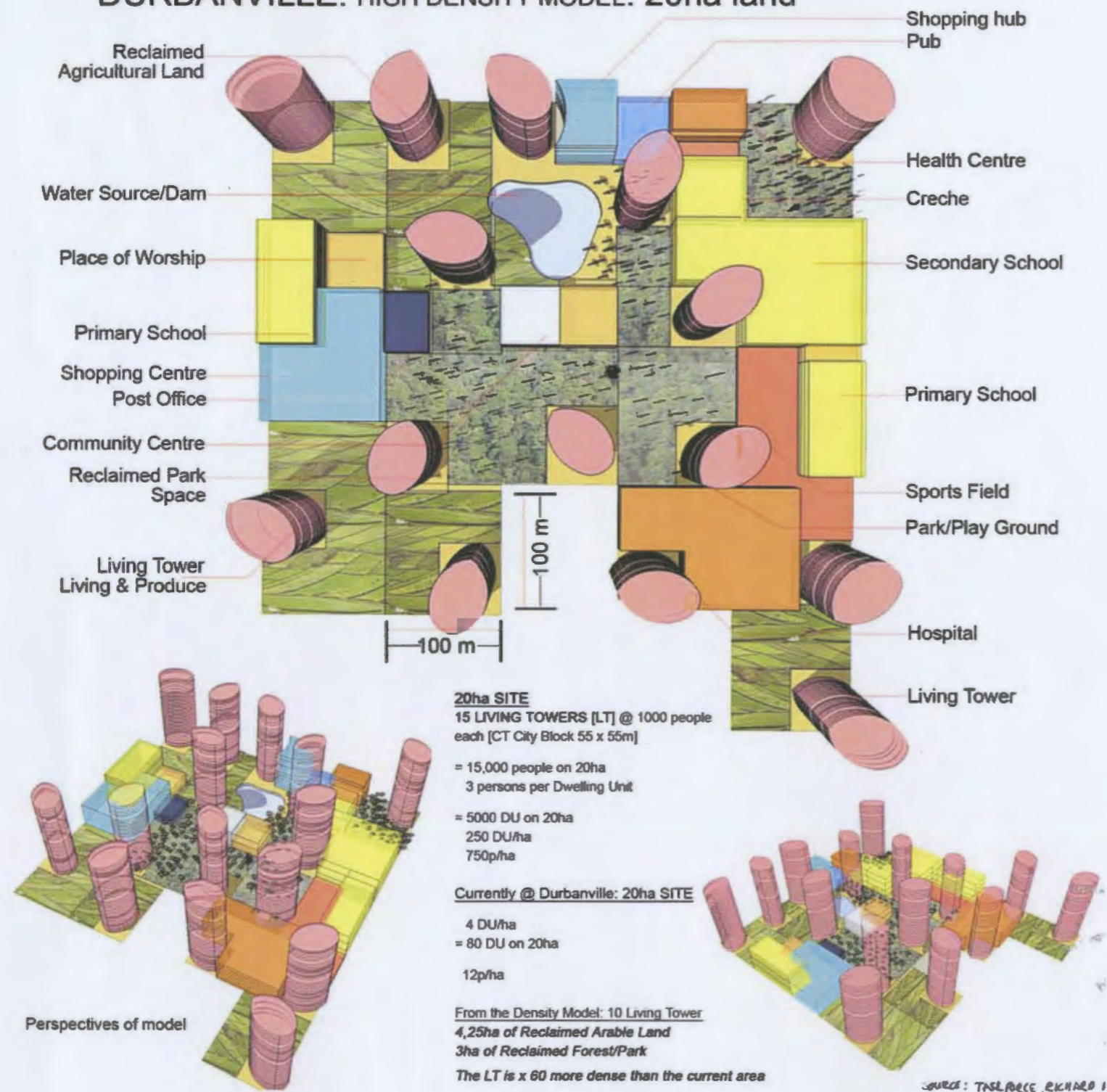


Fig. 1.25 Perspectives of the High Density Model including all the required facilities

### 1.4.3 Living City – High Density Model

Impose: **15 LIVING TOWERS** @ 1000 people each on the 20ha site [CT City Block 55 x 55m = 3000 m<sup>2</sup>]  
 15,000 people on 20ha  
 4 people per Dwelling Unit  
 = 3750 DU on 20ha  
 185 DU/ha  
 740pp/ha  
 Facilities required for 185 DU/ha: see *Appendix C* for table  
 (Source: Community Facilities Standard Woodstock)

### Results from the Living City High Density Model: 15 Living Towers

= 4.25ha of Reclaimed Arable Land. This means land that was built on by low density developments. This land can now be pasture land, intensive agriculture or open sport fields  
 = 3ha of Reclaimed Forest/Park. Land that is recovered and the area can be reforested, a recovery to the ecosystems.

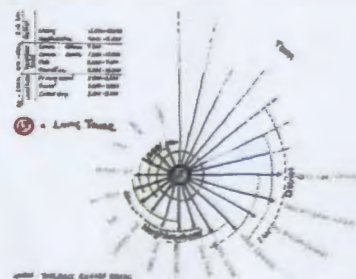
The LT is 25 times denser than the current site in Durbanville

The LC will be able to accommodate the entire Durbanville population, 50 000 in:

	15 Living Towers (LT) in 0.2 km <sup>2</sup>	15,000 pp in	0.2 km <sup>2</sup> (20ha)
	50 LT (50 x 1,000)	50,000 pp in	0.66 km <sup>2</sup> (66ha)
Currently at Durbanville		50,000 pp in	23 km <sup>2</sup> (2300ha)

The LC can accommodate the entire Durbanville population with all the required facilities within 0.66 km<sup>2</sup>.

The LC model represents a healthy, balanced, dense, environmental friendly and sustainable community that can expand till it reaches its growth boundary. The growth boundary is either a greenbelt or a bio-diversity corridor which will be continuously regulated to inform the direction and phasing of growth whether vertically or horizontally. The LC ideas provide a specific response to the current suburban model (subsection 1.2) in terms of planning and building for the future. The LC reinforces the combination of facilities, high densities, open land/park/reserves and a contained boundary that limits its development.



"The Living City can accommodate the entire Durbanville population with all the required facilities within 0.66 km<sup>2</sup>."

The result of reclaimed arable land, parks, and open space, as well as the establishment of dense living conditions within a defined space to encourage social interaction of people living in that space might provide new meaning to the concept of a living environment. By promoting much higher living densities as well as more ecologically friendly lifestyles, the LC model becomes a promising solution to develop a renewed balanced and self-sustaining suburban environment for the future.

### 1.5 The Living Tower as a proposed solution to the current situation

At present, suburban areas are predominantly characterised by low build-forms and low living-densities, which cause major issues for the environment and future growth in terms of travelling time, pollution and the need for distant infrastructural services. The existing suburban model needs rethinking especially in terms of ecological and infrastructural planning. The interventions proposed in this thesis respond to the issues mentioned above, and promote a sustainable and self-sufficient alternative to the current suburban model. The Living City's reclaimed land within a high population density model provides a balanced, healthy and interactive environment which should become the future suburban development strategy.

Drawing from previous city design proposals such as the Radiant City, the Broadacre City, the Garden City and the Gwanggyo Power Centre, the researcher found that the Gwanggyo Power Centre, which is the most recent proposal, has numerous similarities to the LC. The treatment of the landscape, the self sufficiency and the deep concern for the impact on the natural environment are parallel to the principles of the LC. The main component of the LC is the LT which offers the production of food and living for 1000 people in a self-sustaining tower.

Through this research and the accompanying density tests, the potential value of the LC model is demonstrated: to promote much higher living densities and to reclaim valuable arable land. The realization of the LC model offers self-sustainable lifestyles, where the production of food from the LT has no negative environmental consequences. The LT within the LC offers a radical alternative approach to current suburban planning strategies, based on the containment and direction of urban development in order to create an organic and sustainable future growth pattern. The key lies in establishing higher densities linked to better infrastructural services, and promoting bio-diversity networks such as parks, reserves, recreational/sport fields within the LC model.

The resulting impact will be seen in the extent of reclaimed arable land, parks, and open space; and the encouragement of social interaction among people accommodated in denser living conditions within a defined space. The adoption of the LC model will provide new meaning to the concept of a healthy living environment.

The following section will analyse the technical components of the LT that support the closed-system in more depth. The research will be focused on achieving the most effective integration of the various technological systems.

# Section 2

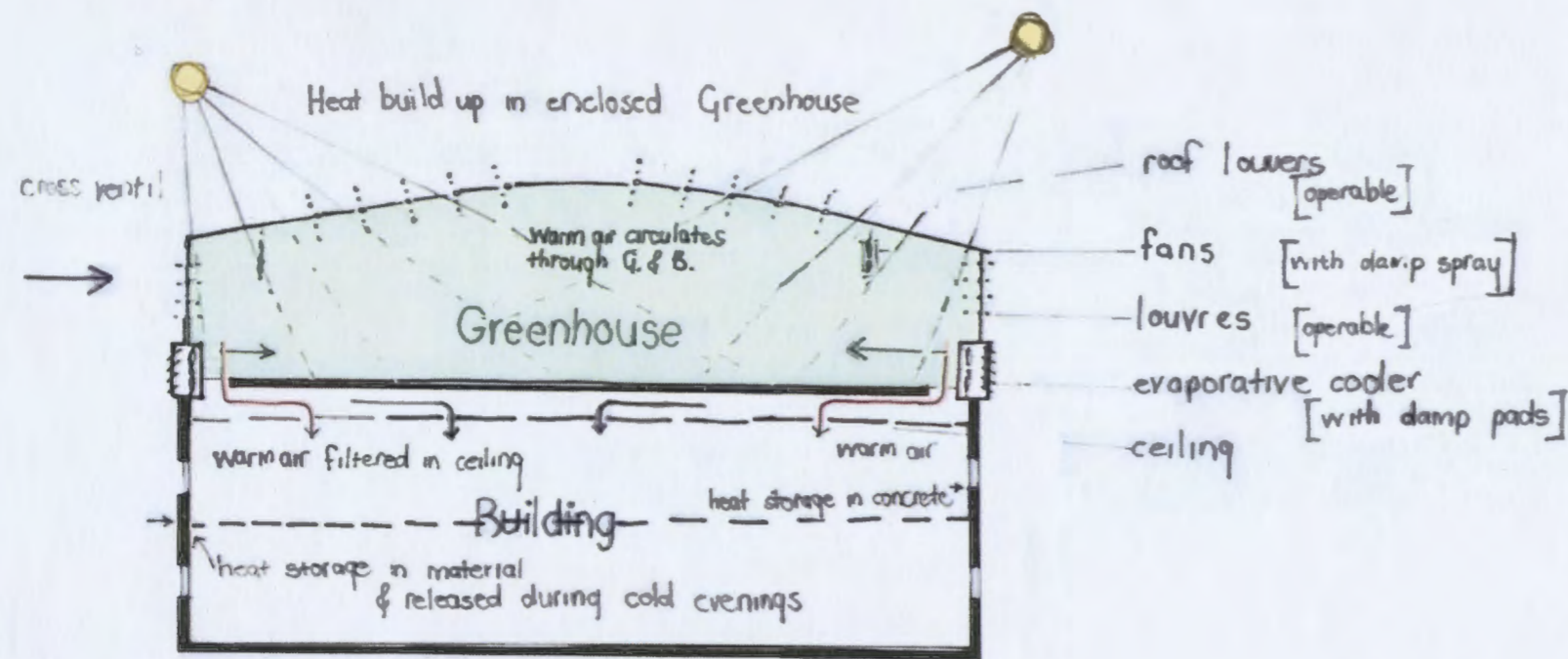
*The investigation of the solution; The Living Tower.*

The *Living Tower (LT)* is essentially a high-rise building (in a suburban context) that provides higher living-densities and produces food for its users through utilizing its surrounding resources to achieve a continuous cyclical system that sustains life in an ecologically friendly manner.

It is not possible to disassociate food and human beings, as human survival depends on food. In the past, the concept of integrating these two environments was either not pursued, or attempts to do so were generally unsuccessful. The integration of these two elements in a self-sustaining way which enhances living conditions and supports sustainable future growth constitutes an important aspect of the LT.

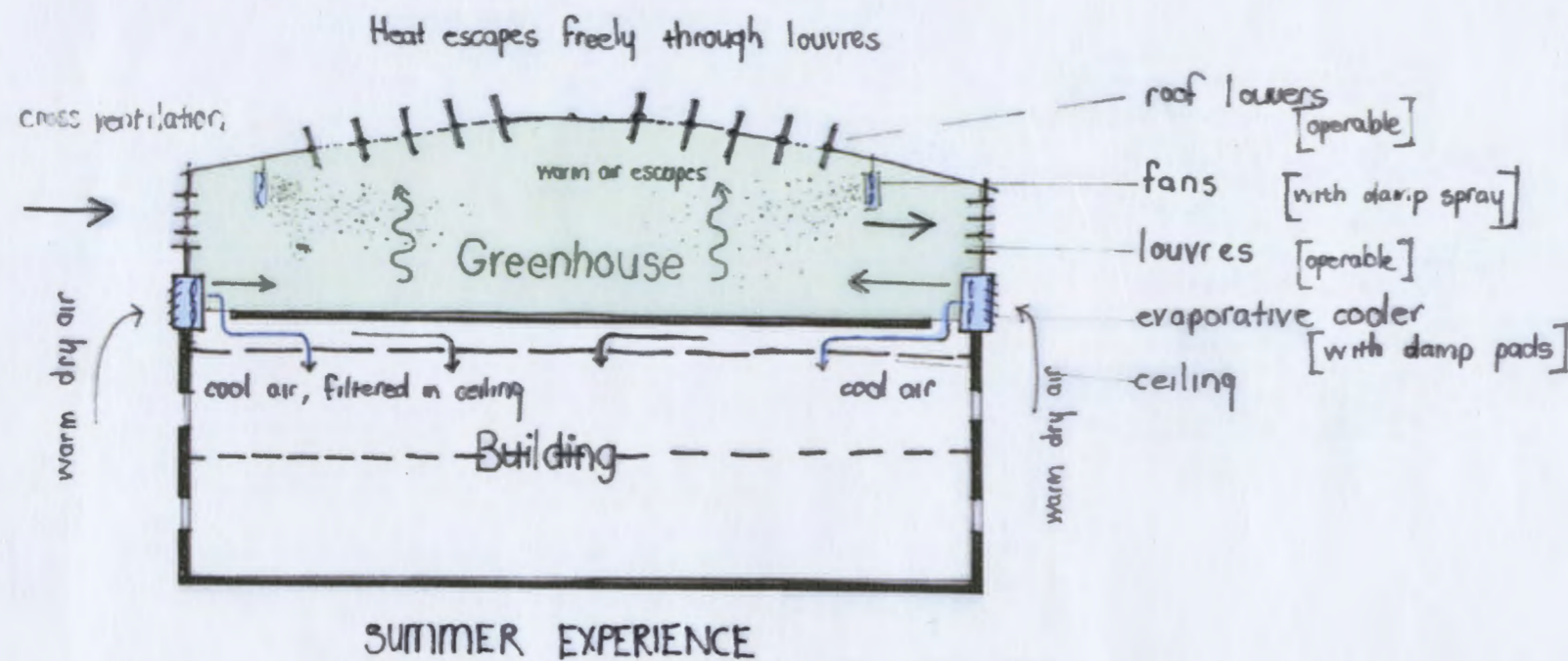


# LIVING TOWER

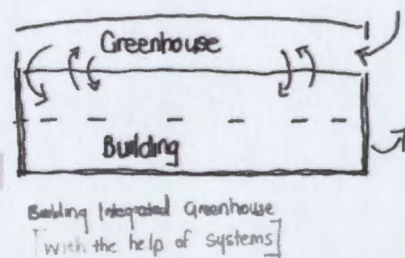


## WINTER EXPERIENCE

Fig. 2.1 Summer and Winter Experience with a mounted greenhouse. In summer heat escapes the greenhouse freely and in winter heat is stored within the greenhouse to heat up building. Sketches done by author.



## SUMMER EXPERIENCE



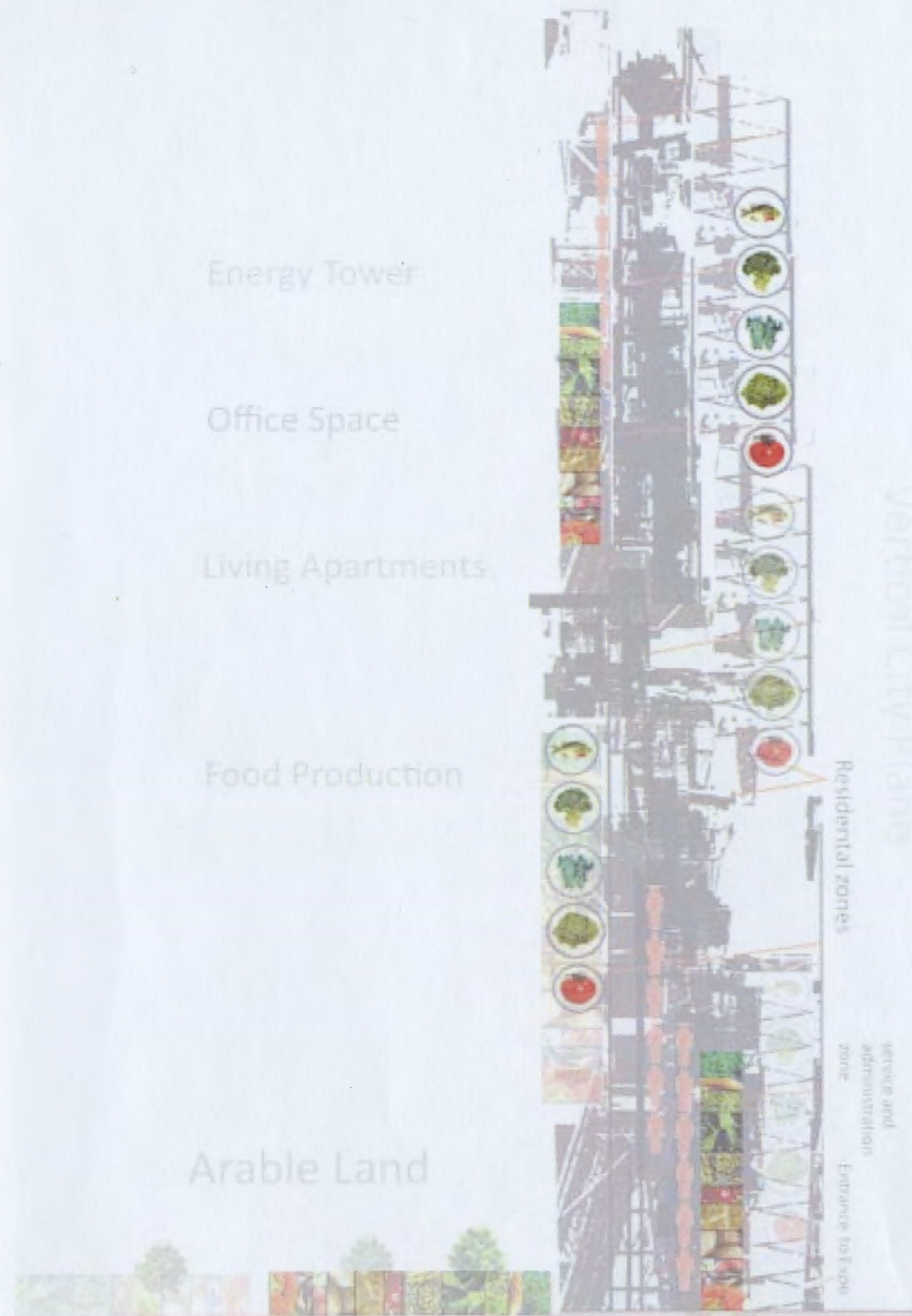
"By mounting an aquaponic greenhouse on the roof of a small building of the same floor plan area, considerable energy savings may be realized for the building".

The production of food indoors is not a new initiative; one early record of a recorded greenhouse dates back to thirteenth century Italy (*Greenhouse* 2009). One of the systems used to produce crops indoors is called aquaponics (the culture of producing crops with soilless ground). Aquaponics requires no soil, doubles the growth rate, enables year round production, quadruples the quantity of harvest, is organic as no pesticides are used, recycles water and thus reduces water consumption.

Theodore Caplow proved that when an aquaponic greenhouse is mounted on the roof of a small building of the same floor plan area, considerable energy savings may be realized for the building in a natural machine-free environment, particular in hot, dry climates, like Cape Town, where evaporative cooling is effective (Caplow 2005, p. 538). In summer the greenhouse shades the building from solar heat gain, while an evaporative cooling system in the greenhouse serves both structures (see Fig. 2.1). In winter solar heat gain in the greenhouse can be shared with the building, eliminating the need for additional heating (see Fig. 2.1). The aquaponic operation is independently viable for these integrating structures. Less than 9% of the cooling load is needed for the building with an evaporative cooling system which necessitates its inclusion in the design of a tower. The positive effect that these two components can have on the system when treated correctly, will significantly influence the design of the LT.

This section investigated the various elements that contribute toward the entity of the LT. The integration of agricultural greenhouses and living spaces forms the basis of the project and similar precedent studies will be interrogated to understand the essence of the integration. The study proceeds to test whether the integration of different systems can result in sustainability and to examine its potential influence on the environment in Section 3. The outcome will help to formulate some of the design principles and structural decisions that will give body to such a tower which will be showcased in Section 4.

# LIVING TOWER



## 2.1 Elements emerging from the Living Tower approach

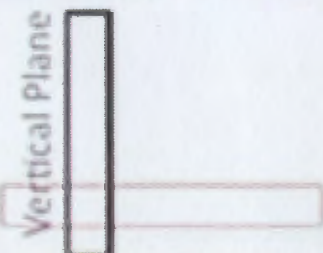
The localizing of the production of food, the filtration of water, generation of power, and the processing of waste establishes a cradle-to-cradle (or cyclical) flow of resources that will greatly enhance the ecological sustainability of urban living. If fewer food imports are required and less waste needs to be exported, it will significantly reduce the demand for service transportation. Taking a cue from ecosystem dynamics, the LT model was developed to mimic the natural process whereby the waste of one entity becomes the food of another, creating an efficient cyclical flow of resources.

The vertical farm is a fundamental element of the closed loop and contributes to a number of functional systems incorporated in the tower. It is thus essential to understand what components comprise a vertical farm, their workings and their functions. The equipment used for integrated greenhouses directly affects the human-occupied buildings that integrate vertical farming into their structure; this topic is addressed in more detail in the following subsection.

### 2.1.1 The Vertical Farm

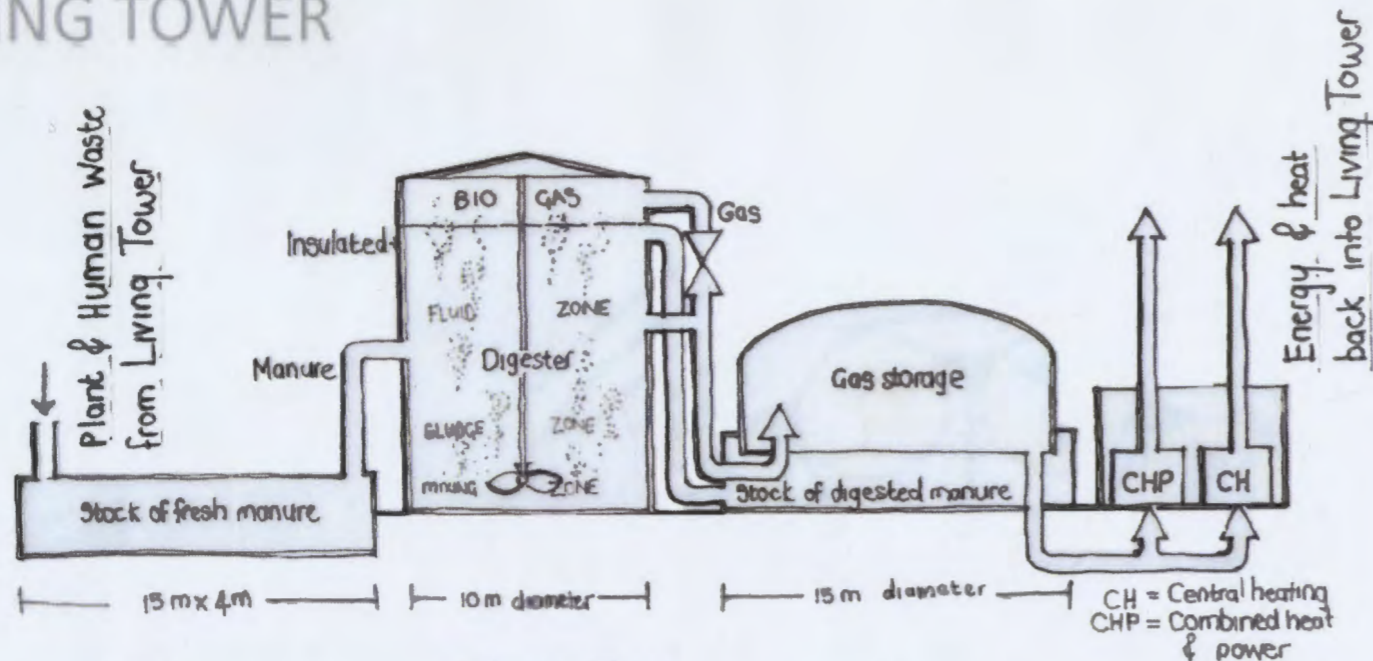
A vertical farm is an indoor 'high rise farm' that produces food locally for a growing population in a sustainable way. The vertical farm depends on effective solutions for integrating greenhouses to provide the most consistent climate control (Caplow 2005, p. 538). Since greenhouses require intense control of indoor environments, HVAC (Heating, Ventilation, and Air-Conditioning) are primary conditions that determine the effective use of buildings and the growth of crops. Systems that control temperature for optimum growth of crops and regulating temperatures for indoor working and living environments will be introduced in this section.

In order to develop an appreciation for the rest of the design of the LT, it is important to understand the systems that comprise a vertical farm (stacked greenhouses).



"A vertical farm is an indoor 'high rise farm' that produces food locally for a growing population in a sustainable way."

# LIVING TOWER



<u>1 Tank</u>	<u>2 Digester Tanks</u>			
$l \times b \times h [m^3]$	$2[\pi r^2 \times h] [m^3]$		$l \times b \times h [m^3]$	<u>Total</u>
$15 \times 4 \times 1.5$	$+ 2[3.14(5)^2 \times 4]$	$+$	$15 \times 4 \times 2.5$	$= 858 m^3$
$l \times b [m^2]$	$2[\pi r^2] [m^2]$		$l \times b [m^2]$	<u>Total</u>
$15 \times 4$	$+ 2[3.14(5)^2]$	$+$	$15 \times 4$	$= 198.5 m^2$

Fig. 2.2 Anaerobic Digester including the different processes the waste follows to become energy as well as the measurements of such a system within a building. Plant and human waste enters the system from the tower and energy and heat leaves the system to enter the tower again.

## 2.1.1.1 Anaerobic Digester (AD) (Methane Digester)

An AD supports a series of processes whereby organic waste is broken down: firstly, de-sludged; secondly, heated up and burned; and thirdly, digested and compressed in an oxygen free environment. These processes use extracted air from the waste material and methane-rich biogas is produced, thus facilitating renewable energy generation (see Fig. 2.2). Waste water from sewage systems can also be treated in the AD.

According to Despommier (*The Vertical Farm Project 2008*) a Vertical Farm that houses 1000 people will produce 13,492 kg of biological waste a week. In a methane digester, this quantity of bio-waste would produce 1,123,931 kWh of electricity per year, supplying well over half the vertical farm's electricity usage (see Appendix A). The use of anaerobic digestion technologies can help to reduce the emission of greenhouse gases in a number of key ways: by replacing fossil fuels, reducing vehicle movement (less food shipping), reducing methane emission from landfills, and displacing chemical fertilizers.

In Scott Johnson's thesis project 'Aberrant Agriculture', he proposed that a methane digester be installed in the basement to convert the sewage and plant waste into methane gas for energy and heating. The LT will utilize an AD to re-use these resources within the building. For instance, the plant and human wastes will be collected at the basement in a septic tank, and from there the processes of the AD will extract bio-gas and heat (see Fig. 2.2). The AD will also be located in the basement of the tower which will be well ventilated. The energy and heat gained will service the vertical farm as well as the occupants and through this process helps the resources to remain in a cyclical flow.

## 2.1.1.2 The Living Machine (LM) (Eco-Restorer)

The LM collects rainwater, irrigation water from the vertical farm, and waste water from the residential units. This waste water treatment system uses a series of micro-organisms, flora and aquatic life to treat the water.

The system works in three stages: In the first stage all the water is collected into a septic tank, in the second stage the water is pumped through a series of containers holding non-edible plants, and in the third stage the water is stored in an anaerobic reactor (see Fig. 2.3). The water that completes this closed cycle process is pristine. The LT will use the *Tidal Flow Wetland Living Machine*, which can produce 40,000 gallons of water per day for farming as well as for non-potable water uses of the residential units (*Living Machine 2008*). The waste water and the irrigation water gravitate towards a collector tank in the basement and from there the unclean water is pumped towards the roof (using wind turbines) for the processes of the LM to start.

The LM is located on the roof of the LT; it is approximately 3 m by 10 m in size, ensuring the flora receives adequate sunlight. By opening it for tours it can also act as an educational amenity for the community.

## Living Machine

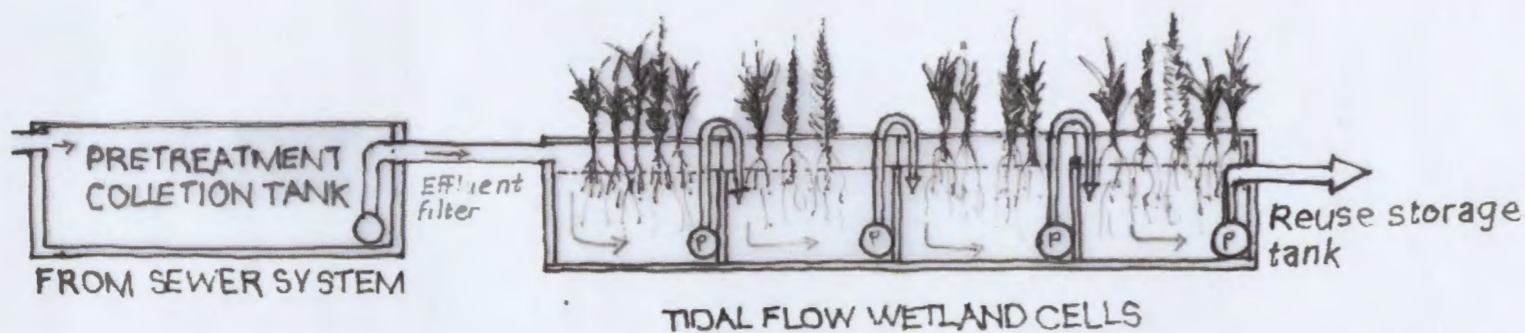


Fig. 2.3 The Living Machine or an Eco Restorer



An Anaerobic Digester calculator can be used to estimate the required space needed for the digestion of human and plant waste of 1000 people (see fig. 2.2).  
 = For 2 Tanks  
 = 200m<sup>2</sup> floor area  
 = diameter: 10m per digester  
 = height: taller than 10m for a digester

# LIVING TOWER

Name of crop	Hydroponic equivalent per acre	Agricultural average per acre
Oats	13,500 KG	8,100 KG
Soya beans	5,250 KG	2,100 KG
Potatoes	70 tons	36 tons
Beetroot	90,000 KG	45,000 KG
Cabbage	81,000 KG	58,000 KG
Peas	710,000 KG	112,000 KG
Tomatoes	810 tons	39 tons
Cauliflowers	135,000 KG	58,000 KG
Lettuce	94,500 KG	50,000 KG

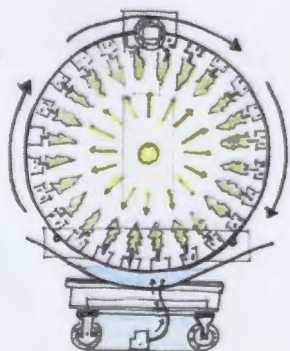
Fig. 2.4 The comparison between Hydroponics & Traditional farming

hydroponics: *hydro* (water) & *ponos* (labor), [growing plants in a soil-less medium with nutrients]



- consumes only 150 sq. ft. of floor space
- equates to 1,500 sq. ft. of farmland
- 6 stainless steel rotating cylinders, each 8' long
- rotation & gravity develop oils in plant for better taste & increase growth rate
- proximate intense light source within axis of cylinder to increase growth rate
- uses efficient compact fluorescent (114 kWh/day) or LED lighting systems (18.2 kWh/day)
- uses 99% less water than traditional farming

Fig. 2.6 Cylindrical hydroponic works on a carousel system that continuously rotates for the plants' roots to feed from the water and a light source in the centre for optimum growth



" The natural, nutrient-rich water that is gained by the fish farming is a nutritious fertilizer for the growth of the plants. "

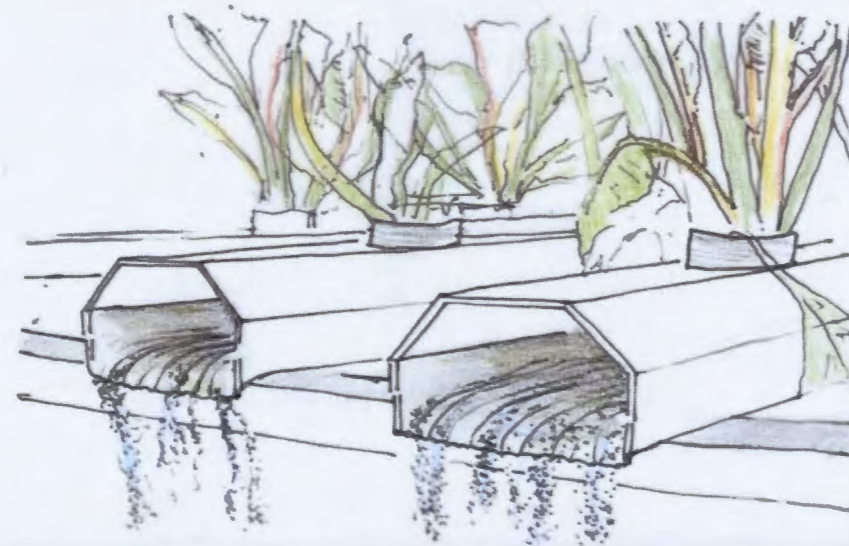


Fig. 2.5 Hydroponics: Plants grow in these PVC gully channels. The roots of the plants feed off the water irrigating down the gully. All sketches done by author.

## Aquaponics

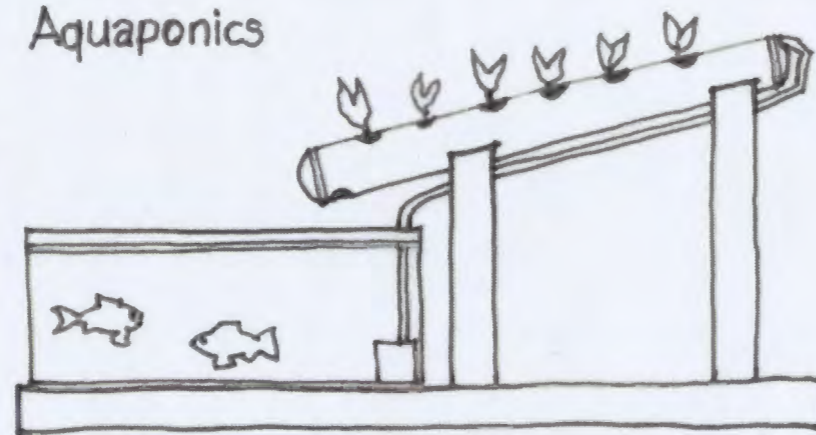


Fig. 2.7 Aquaponics: Water from a fish tank is pumped to the top of the PVC gully in order for plants to feed from the nutrient rich water as it drains back towards the fish tank .

### 2.1.1.3 Aquaponics

Aquaponics combine fish farming (aquaculture) with Hydroponics (soilless plant culture). The natural, nutrient-rich water that is produced by fish farming creates a nutritious fertilizer for plants. The plants consume the nutrients and simultaneously purify the water so that it can be used again for the fish tanks (see Fig. 2.7). The usage of aquaponics as the growing medium for crop production, is a fundamental component of the vertical farm. Its minimal space requirements permit the massive densification of agricultural production to take place, as it enables the vertical stacking of produce (Aquaponics Overview n.d).

The combination of hydroponics and aquaponics is much more efficient and productive than traditional farming (see Fig. 2.4). Aquaponics requires no soil, doubles the growth rate, enables year round production, quadruples the quantity of harvest, is organic as no pesticides are used, recycles water and thus reduces water consumption.

Aquaponics therefore fulfils a very important role by securing a farming process in the Living Tower that is intensive and efficient. The farming of fish and the production of plants feed off each other to lower costs and maintenance and improve the cyclical system within the tower. Used water from the aquaponics will gravitate towards the basement where the waste-water is collected. It will then be pumped to the roof with the help of the wind turbines, where it will be purified by the living machine and the entire process will be repeated (see Fig. 2.17). The irrigation system works with gravitational power which starts at the roof and irrigates all the aquaponics en route to the basement.

Hydroponics: Each plant in the vertical farm will be grown in a hydroponic unit that consist of a long gully channel similar to gutter rails irrigated by the nutrient solution flowing through the gully (see Fig. 2.5). Assuming that the floor area of the tower is 55m x 55m, then one floor will consist of 6-7 rows of growing gullies (see Fig. 2.10). Lettuce, herbs, and specialty greens (spinach, chives, basil, and watercress) have low to medium nutritional requirements and are well adapted to aquaponic systems. Plants yielding fruit (tomatoes, bell peppers, and cucumbers) have a higher nutritional demand and perform better in a heavily stocked, well established aquaponic system.

Aquaculture: Several warm-water and cold-water fish species are adapted to re-circulating aquaculture systems, including tilapia, trout, perch, Arctic char, and bass (Aquaponics Overview n.d). Tilapia is often the choice of fish for aquaponics as it is a warm-water species that grows well in a re-circulating tank culture. Tilapia is tolerant of fluctuating water conditions such as pH, temperature, oxygen, and dissolved solids.

Fish tanks vary in size, but a 9000 liter fish tank that measures 3,5m in diameter and 1,3m in height can contain 350 kg or approximately 1000 fish at a time. Each tank has a 100mm slope in order for the fish waste to drain to the lower end where it is circulated through the hydroponic system and back into the tank again (Aquaponics Overview n.d).

# LIVING TOWER

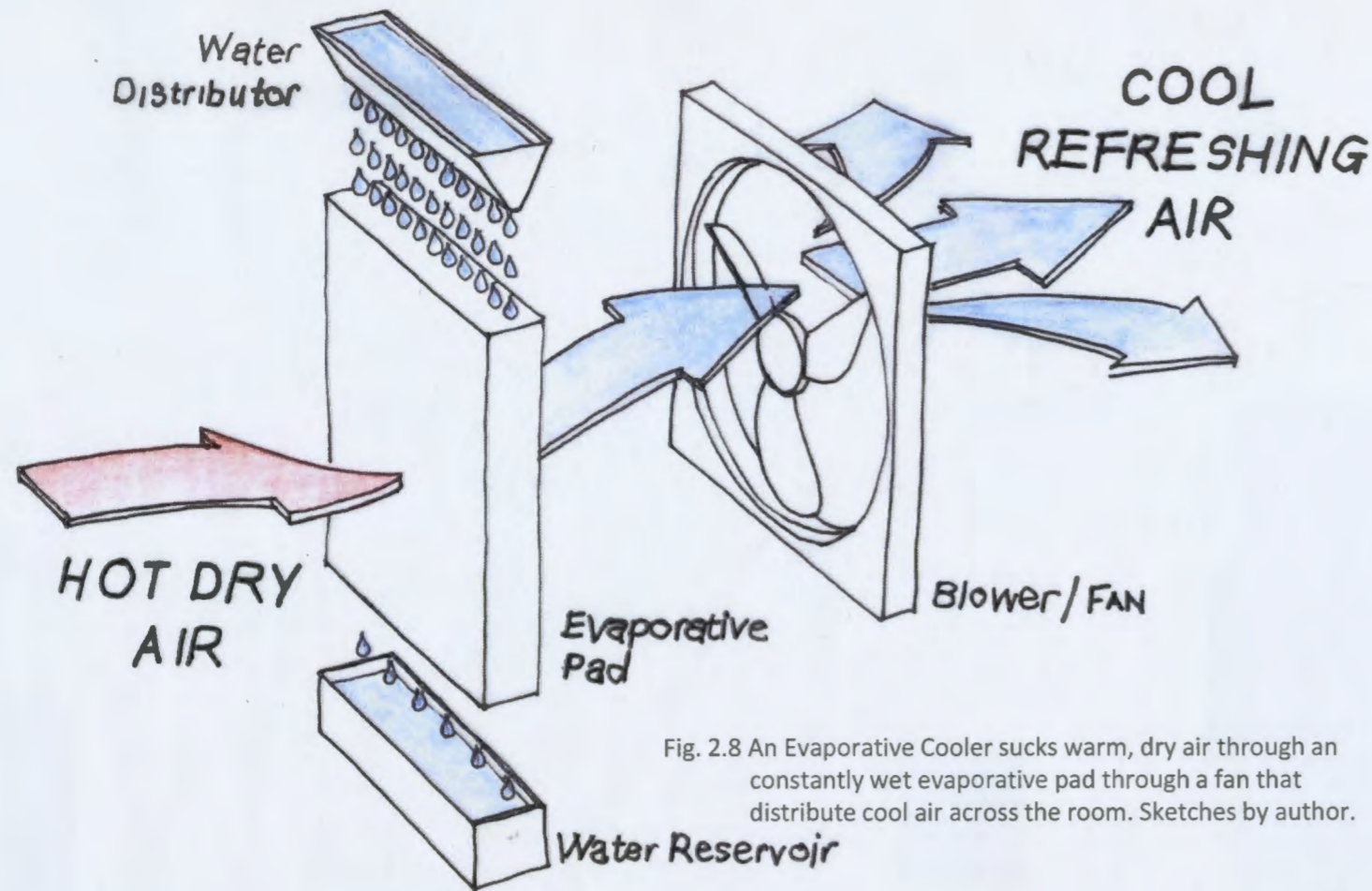


Fig. 2.8 An Evaporative Cooler sucks warm, dry air through an constantly wet evaporative pad through a fan that distribute cool air across the room. Sketches by author.

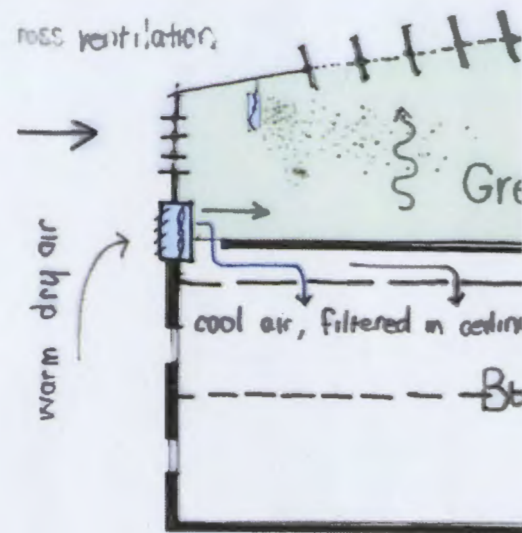


Fig. 2.9 The evaporative cooler in action

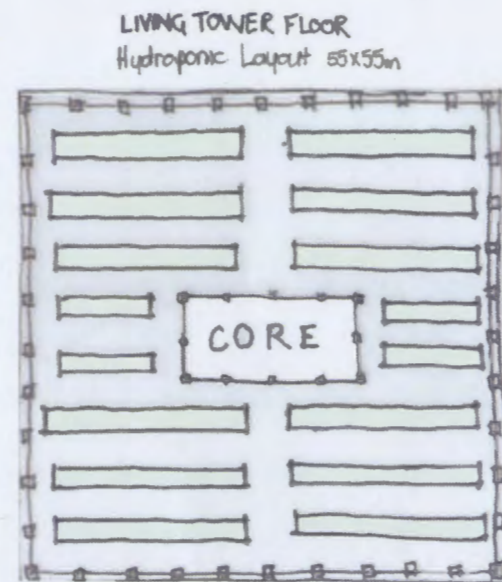


Fig. 2.10 Proposed greenhouse floor plan with rows of hydroponics

## 2.1.1.4 Evaporative Cooling

Intense temperature regulation is required in an effective greenhouse environment. To maintain an ideal temperature and relative humidity in the ranges 18-24°C and 30-70% respectively, evaporative cooling, bio-gas heating and natural draft ventilation are employed within the greenhouses of the vertical farm. Evaporative cooling is effective in places such as Cape Town which has a warm, dry Mediterranean climate with temperatures and humidity between 18-24°C and 30-70%.

Evaporative cooling is a natural occurrence in which an air-borne evaporated liquid comes into contact with an object or liquid which it then cools. The greater the temperature difference between the two, the greater the evaporative cooling effect. Evaporative coolers are devices that cool the air through evaporation of water. They are used to lower the temperature of air by using the latent heat of evaporation, changing water to vapor. Heat that is in the air is used to evaporate water and warm dry air is changed to cool moist air (see Fig. 2.8). An evaporative cooling system in the greenhouse is highly beneficial for the climate control of a building when a greenhouse is integrated into a building (see Fig. 2.9).

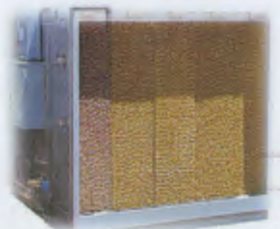
In the LT the evaporative cooler is a metal or plastic enclosed box with vents on the sides. Inside the cooler is a fan or 'blower', driven by an electric motor with pulleys and a water pump to wet the evaporative cooling pads on the sides. The coolers are located at the edges of the greenhouse floor or at the ceiling to release exhausted air outwards. The fan draws ambient air through the vents and the damp pad to generate cool air. The warm air evaporates water from the pads which are continuously re-damped to maintain the process. When this air is cooled, moist air is released via a vent into the building from the roof or the exterior wall (Evaporative Coolers 2009).

## 2.1.1.5 Lighting

Grow lights are lights that reproduce artificial natural sunlight. Different grow lights offer different colour temperatures and different plants need different amounts and colour temperature of light in order to grow properly. Vegetables prefer bright sunlight and therefore require a growth lamp such as the Metal Halide HID (High Intensity Discharge). The Metal Halide (MH) grow lights offer colour temperatures as high as 5500K and as low as 2700K; these provide optimum light conditions for plant growth and are also energy efficient with a long lifespan of up to 20 000 hours (Fitzpatrick et al. 2006, p. 27).

Proposed floor area of the Living Tower 55m x 55m with 7 rows of plants (hydroponics) per floor:  
 1 MD HID = 0.65m length  
 1 floor (Living Tower) = 55m x 55m  
 7 rows of plants/floor  
 1 bulb every 1m = 55 bulbs/fl.  
 7 x 55m = 385 bulb/fl.  
 (Bussa et al. 2007, p. 23)

The same calculations can be applied to the offices and other rooms that will use fluorescent lights. Fluorescent bulbs are 1.2 m in length, which means that each floor will require 27 bulbs per row x 7 rows per floor (see Fig. 2.10).



"Evaporative coolers are used to lower the temperature of air by using latent heat of evaporation, changing water to vapor."



Fig. 2.11 *Innovalight* plans to produce a liquid "silicon nano-material" using "quantum dots" which can be printed using the same roll-to-roll printing technology used for printing on paper. This means it will be able to put the ink on flexible surfaces like clothing and portable chargers (*The Green A-Team* 2008).

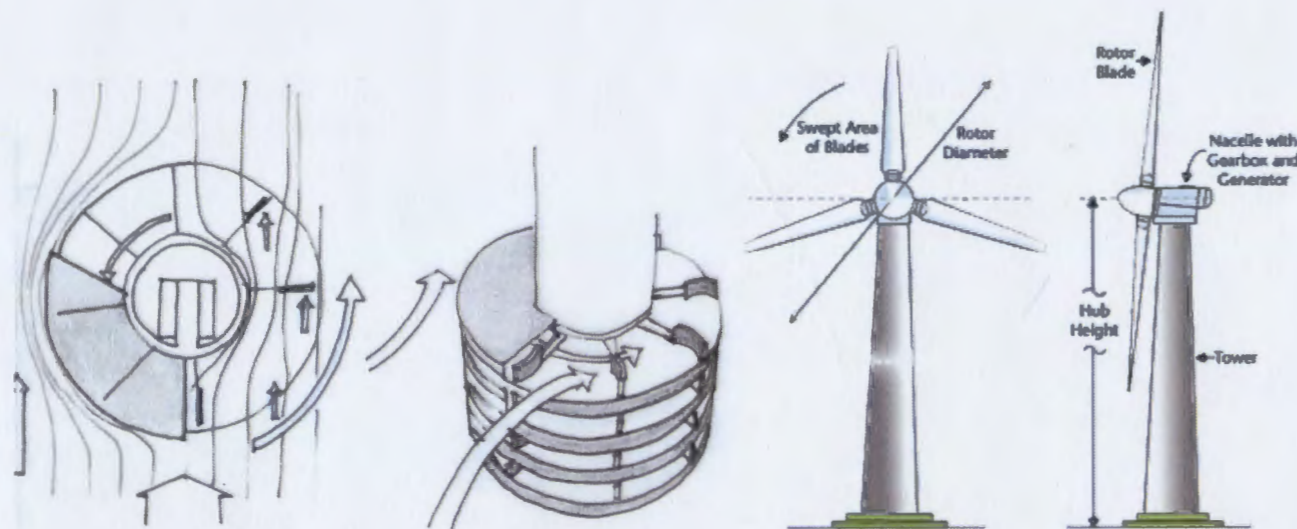


Fig. 2.12 The Dynamic Tower utilizes horizontal wind turbines between each floor, displayed in the left figure. The figure on the right illustrates a vertical wind turbine. The amount of energy generated depends on the wind speed and the length of the rotor.

## 2.1.1.6 Photovoltaic Cells

"Just the tiny fraction of the Sun's energy that hits the Earth (around a hundredth of a millionth of a percent) is enough to meet all our power needs many times over. In fact, every minute, enough energy arrives at the Earth to meet our demands for a whole year" (*Solar power - energy from the Sun* 2009). Photovoltaic panels (also known as solar panels) convert sunlight into electrical energy. An average solar panel converts 12% of the sunlight it receives into usable energy (Alam et al. 2005, p. 88).

Solar panel design has reached such an advanced stage that applying them on a facade will not detract from the appearance of a building or lose solar penetration. Solar panels will be a distinct part in the makeup of the LT. The northern facade, which has the most sun exposure, contains the greenhouses, which will mainly be covered by solar panels acting as the exterior layer of the building.

Photovoltaic panels: 2500 m<sup>2</sup> [applied at skin]  
 ['150 Watt' panel = 1 m<sup>2</sup>]  
 Cape Town\_'150W panel' W/ m<sup>2</sup>/day  
 = 6 kWh/ m<sup>2</sup>/day  
 = 2200 kWh/ m<sup>2</sup>/year  
 2500 m<sup>2</sup> x 2200 kWh/ m<sup>2</sup>/year  
 = 5 500 000 kWh/year  
 (SOA Architects 2006, p.5).

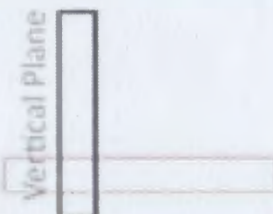
The Dynamic Tower by Fisher is an ultra modern building that uses the latest technological equipment to fulfil the desires of the design. The roof of each rotating floor has been sprayed with a photovoltaic ink that converts sun-energy into electrical energy (see Fig. 2.11). Photovoltaic ink can be coated on flexible sheets of plastic to fit the contours of any roof or other surface (*The Green A-Team* 2008).

## 2.1.1.7 Wind Turbines

The speed of the wind determines the efficiency of the wind turbine. Wind speeds of 12 miles per hour (m/h) produce 70% more energy than a site with 10m/h average wind speed (Fitzpatrick et al. 2006, p. 39). An increase in altitude also increases wind speed dramatically. Residential or farm size turbines have rotors as large as 15m in diameter; they are usually mounted 35m high (Fitzpatrick et al. 2006, p. 39).

Cape Town has an average ground wind speed of 12m/h. If the height of a tower is 100m then the wind speed increases to 14-16m/h (*windfinder* n.d.). A 1.5kW turbine (The GE Energy) has a rotor diameter of 70 m and at a wind speed of 16m/h can produce 4 kWh of energy (Fitzpatrick et al. 2006, p. 41). An equivalent wind turbine used on a 100m high tower in Cape Town could produce up to 1 400kWh of energy per year.

Wind turbines on the LT are directed towards the dominant winds of the region and produce electricity facilitated by the height of the tower. They produce electrical power of between 800 and 1500 kWh per annum. These wind machines are also used to pump the waste water from the tanks in the basement to the living machine on the roof where the water is purified (see Fig. 2.12, 2.17).



"Solar panel design is at such an advanced stage in the industry that to apply them on a facade will not detract from the appearance of a building or loose solar penetration."

# LIVING TOWER

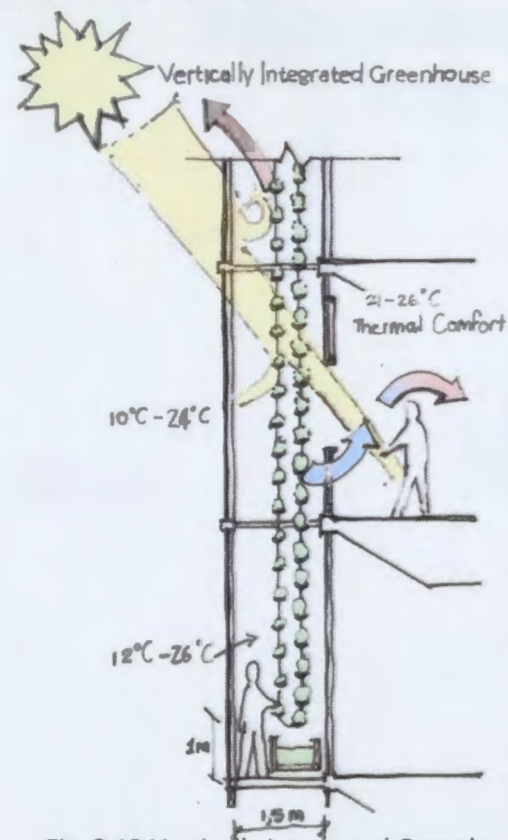


Fig. 2.13 Vertically Integrated Greenhouse.



Fig. 2.14 Double Skin Façade improves the temperature inside the building.

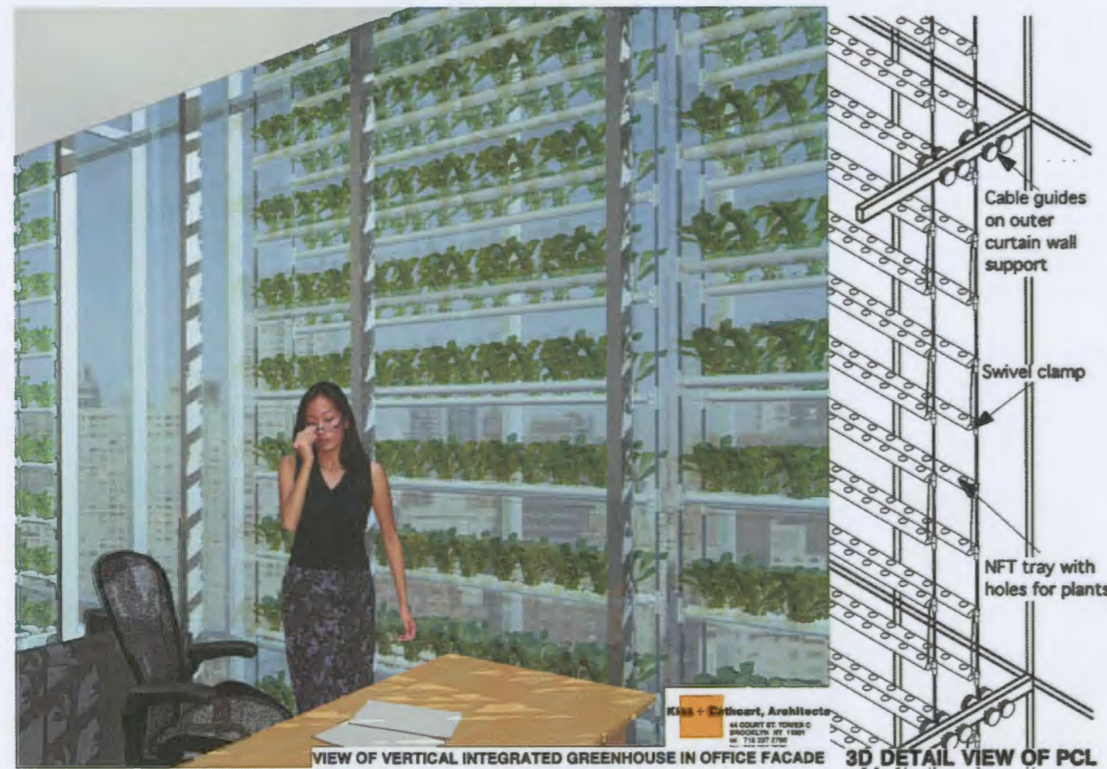


Fig. 2.15 Vertically Integrated Greenhouse. The Agriculture within the double glazing façade work with a pulley system to simplify the method of harvesting.

## 2.1.1.8 Glazing

In a double glazing facade, the outer layer will be a laminated structural glass that meets the strength and transparency requirements. The strength of these products comes from a layer of Poly-Vinyl-Butyral (PVB) that is injected between two outer layers of heat-strengthened laminated glass panes. The inner layer will have a low E coating to manipulate the incoming solar radiation.

The requirements for external structural glass are:

- 40 stories @ 4m/ story = 160m tall
- A LT block = about 55m x 55m
- 55m x 160 x 2.5sides = 22,000 m<sup>2</sup>

Sharp Electronics & Shimizu has developed a glass that combines LED's (Light Emitted Dioxides) and solar panel technology. This glass converts 7% of solar energy into electricity which can illuminate glass for 5 hours (Alam et al. 2005, p. 15).

## 2.1.1.9 Double Skin Façade

The Double Skin Façade (DSF) is a building facade that consists of two layers separated by a certain distance between them to accommodate various functions such as storing heat, generating the stack effect, running services, growing food, and the shading and cooling of the building. In the building sector, the DSF can reduce the energy used for heating and cooling of a high rise building by at least 30% (Caplow et al. 2008, p. 2).

A DSF is essentially a void space that is enclosed by a curtain wall. The void space captures solar heat during the winter, and buoyancy driven cooling flows in summer. Windows can also be opened in the summer time for a cross ventilation effect (Caplow et al. 2008, p. 2).

Ip Waimond applies the DSF on the entire southern facade of his *Vertical Farm* project (Ip n.d.). The DSF effectively removes unnecessary heat from the greenhouse by means of a stack effect, with a warm updraft that escapes through the roof and induces cooler air from the northern side across the grow area (see Fig. 2.14).

The DSF is an essential part of the vertical farm's climate control; without this system adequate temperature management would be impossible.

## 2.1.1.10 Vertically Integrated Greenhouse

The establishment of highly productive, environmentally sensitive, food production systems not just in our cities, but actually in buildings, offers a solution to one of the principal challenges that cities are facing. The Vertical Integrated Greenhouse (VIG) combines an energy efficient double skin facade with a hydroponic system for vegetable production. Crops are produced between the two skin layers on the northern side of the building (Caplow et al. 2008, p. 3). Apart from producing food, the VIG has the added benefit of reducing the building's maintenance cost by treating the air in a healthy way, as well as providing shade and evaporative cooling to the building's occupants.

During winter the VIGs capture solar heat to effectively warm and insulate the glazed façade of the building. On winter evenings the exhaust air from the building mass can be channeled through the DSF to maintain heat for plants. During summer days, the VIG acts as a shading device for the building's occupants and also produces constant fresh air when the operable windows of the DSF are opened. The VIG reduces solar heat gain by absorbing energy as latent heat, through transpiration. The VIG mitigates the heat island effect like a green roof.

" Establishing highly productive, environmentally sensitive, food production systems not only in our cities, but actually in buildings, offers a solution to the principle challenges cities are facing."

# LIVING TOWER

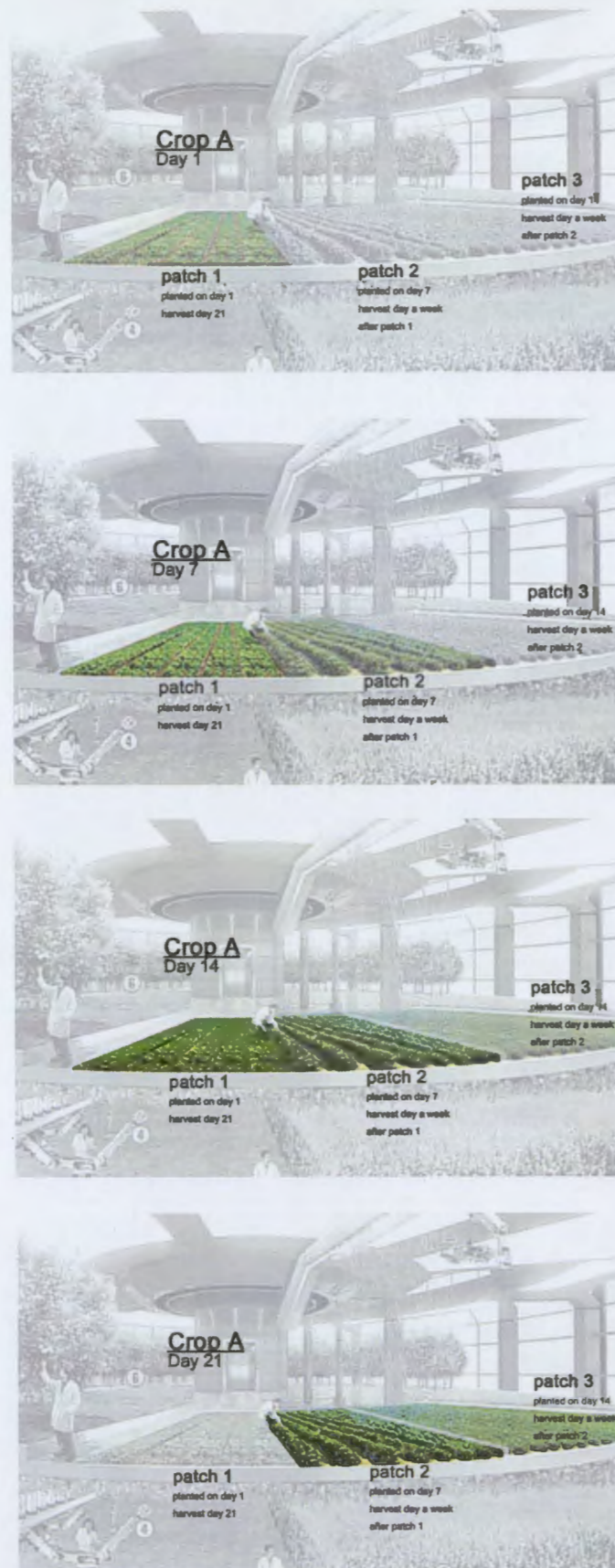


Fig. 2.16 Effective farming where crops are rotated to feed a 1000 people with fresh food weekly. Compiled by the author.

VIG is situated between the two layers of the DSF and measures 1.5 m wide. The void space contains stacked rows of hydroponic vegetable crops and can reach 40m high. Crops are cultivated in a system of trays, wires, and pulleys, referred to in the design as plant cable lifts (PCLs) (see Fig. 2.13, 2.15). A computer activated motor controls the positioning of the trays (Caplow et al. 2008, p. 4).

As a result; the negative environmental impact of growing produce, the distance that food travels before reaching urban consumers, and the environmental impact of buildings are all reduced significantly. The 2020 Tower designed by Kiss+Cathcart Architects fully employs VIG for the most effective production of crops. The entire south facade works with a PCL system within the DSF. Some of the benefits include: reduced pollution, decreased transportation cost, cooler building, water saving, land availability, and reduced impact on global warming (2020 Tower 2003).

## 2.1.11 Effective Harvesting

The LT would need to continuously produce fresh crops for its 1000 residents and guests. In order to produce fresh food on a weekly basis without overproduction, crops need to be planted in a so-called rolling schedule. Each patch provides the necessary number of crops required to sustain the weekly nutritional diet (see Fig. 2.16). For example, if crop A needs 21 days to reach maturity there should be 3 patches planted. Patch #1 would be planted on day 1, patch #2 planted on day 8 and patch #3 planted on day 15. As patch #1 becomes mature on day 21, patch #2 would require an additional week and patch #3 two more. As patch #1 is harvested a new patch should be planted in its place. As each patch progressively ripens, a new one is planted in its place. This ensures fresh crops each week, year round.

The number of crops required each year is divided by 52 weeks to determine how many crops are needed weekly. The number of plants needed per week is multiplied by the amount of space each plant occupies in order to determine how many square meters each patch should be. Then the total area of each patch is multiplied by the number of patches to determine how many square meters of growing area in total is required for one crop. This number is crucial as it dictates the total amount of energy needed per crop (Alam et al. 2005, p. 5).

For example the light needed for the growing of tomatoes to feed 1000 people per year: It is estimated that 49.7 tonnes (0.073Ha or 730m<sup>2</sup>) of tomatoes per year (Appendix A, Table 1) would be sufficient to feed the 1000 people in the LT. This is approximately 39 200 tomato plants per year, or 756 plants per week. Two patches of crops will be rotated to feed 1000 people; if a single plant needs 0.02m<sup>2</sup> to grow, then the area needed for tomato plants equals 14m<sup>2</sup> (Alam et al. 2005, p. 8).

The minimum light requirement for most plants is about 25 W/m<sup>2</sup>. For tomatoes, the required light energy is 90 W/m<sup>2</sup> as it is a fruit vegetable that requires more intensive light. Multiplying the light requirement by the crop area (2 patches of 14m<sup>2</sup> each) equals 2860 watts per second or joules per second.



“The Living Tower would need to continuously produce fresh crops for its 1000 residents and guests.”

# LIVING TOWER

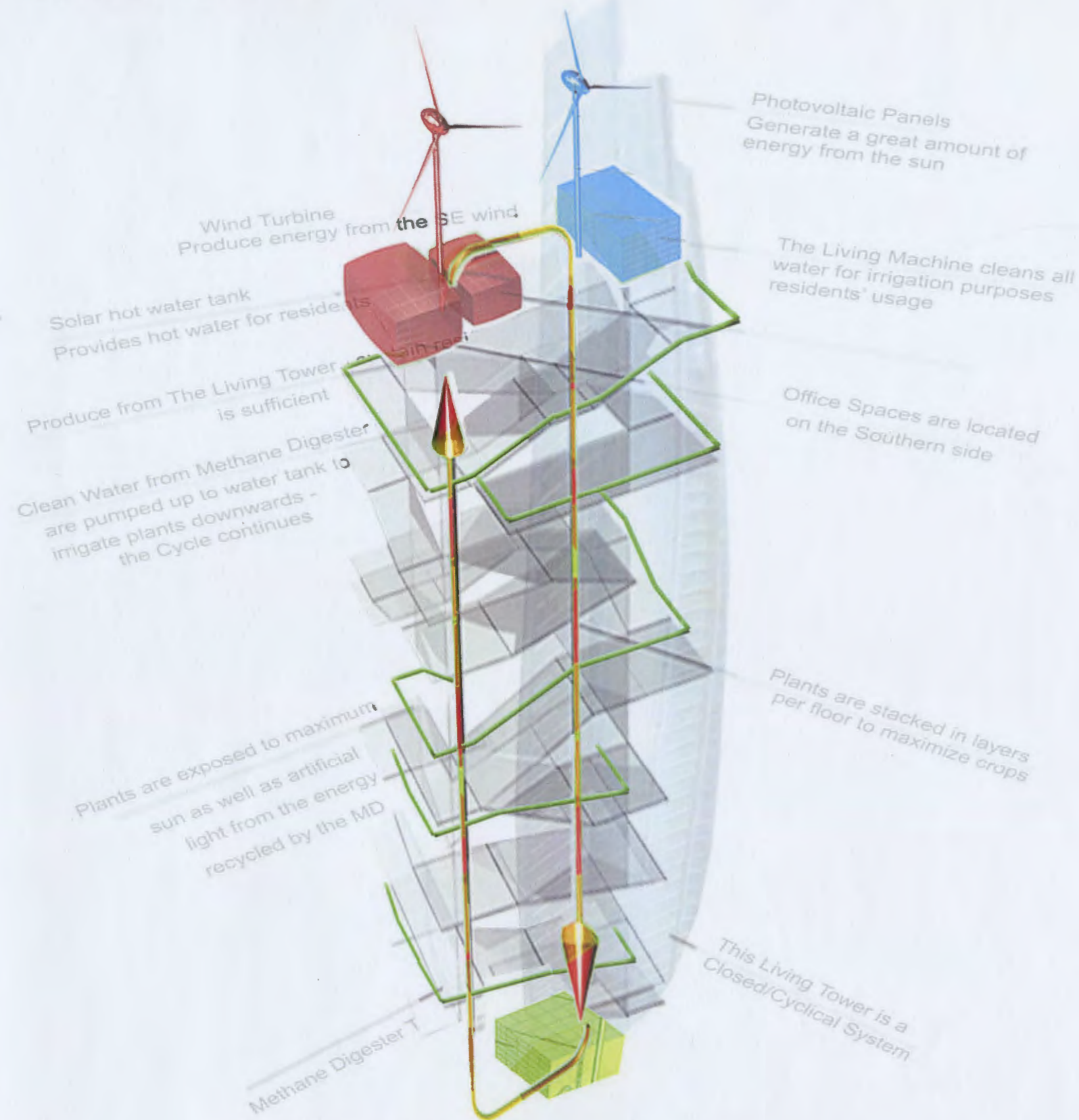


Fig. 2.17 The closed system, illustrating the continuous flow of resources that are renewed and used repeatedly.

To compare this value with the energy output from the methane digester, we need to convert 2860 Ws to kilowatts per hour, a measure of energy instead of power. To light this area we would need 2.86 kWh per day and for one week 20.01 kWh. If a tomato plant needs 15 hours of light to grow per day the required light energy will be 301 kWh per day and per week it will be 2107.10 kWh, or 110 000 kWh per year (Alam et al. 2005, p. 5)(See Appendix A, Table 2 for energy requirements of other crops).

If all the energy requirements of the crops produced in the vertical farm are added together, the total can be compared to the energy produced by the methane digester (Anaerobic Digester) to see how self-sustaining the LT is. Assuming that the AD generates energy from human and plant waste alone, then according to Despommier (*The Vertical Farm Project* 2008) a vertical farm that houses 1000 people will produce 13,492kg of biological waste a week. This quantity of bio-waste would produce 1 123 931 kWh of electricity per year using an AD. If the total energy required for the entire agricultural production in the LT is 2 054 300 kWh then the AD secures over half the vertical farm's electricity usage (see Appendix A).

Other sources of energy are the Photovoltaic Cells covering 2 200m<sup>2</sup> of the facade, which produce 5 500 000 kWh per year of solar energy; and Wind Turbines that generate 3 000 kWh (1500 kWh x 2) per year from wind speed. The combination of these energy sources provides the LT with a complete self-sustaining environment that reuses its resources continually.

## 2.1.2 Systems summary

From the analysis of the different systems referred to above, it becomes clear that renewable energy sources play a major role in securing a continuous closed system. The overall aim is that these sources should provide a self-sufficient lifestyle in one structure that has no negative impact on the environment. Summarizing the functions of the five major integrated systems (see Fig. 2.17, 2.33):

- The *Wind Turbines* (WT) produce energy from wind and continually circulate water by pumping it from the basement to the *Living Machine* located on the rooftop.
- The *Living Machine* (LM) collects the water (rainwater, waste-water and irrigated water) that the WT circulates upwards from a tank in the basement, in order to clean it for residential and irrigational use. Downward pipes from the LM gravitate water through the *Aquaponics* and the apartments.
- The *Aquaponic* (A) system starts by filling up the fish tanks first; from there, nutrient-rich water gravitates towards the gully channels in which the plants grow. When all the floors are irrigated, the water flows towards the *Anaerobic Digester* located in the basement.
- The *Anaerobic Digester* (AD) collects the 'used' water and waste (from humans and plants) which goes through a series of processes to produce bio-gas (an environmentally friendly energy form) from methane and heat, which is used to supply the apartments with electricity and warmth. This cyclical process continues in the building.
- The glazing incorporates *Photovoltaic Cells* which contain LED lights to illuminate the LT as well as contributing renewable energy from solar radiation to the resource flow of the building.

The study proceeds by finding examples to understand how these systems functions within a building!



"The Living Tower would need to continuously produce fresh crops for its 1000 residents and guests."

# LIVING TOWER

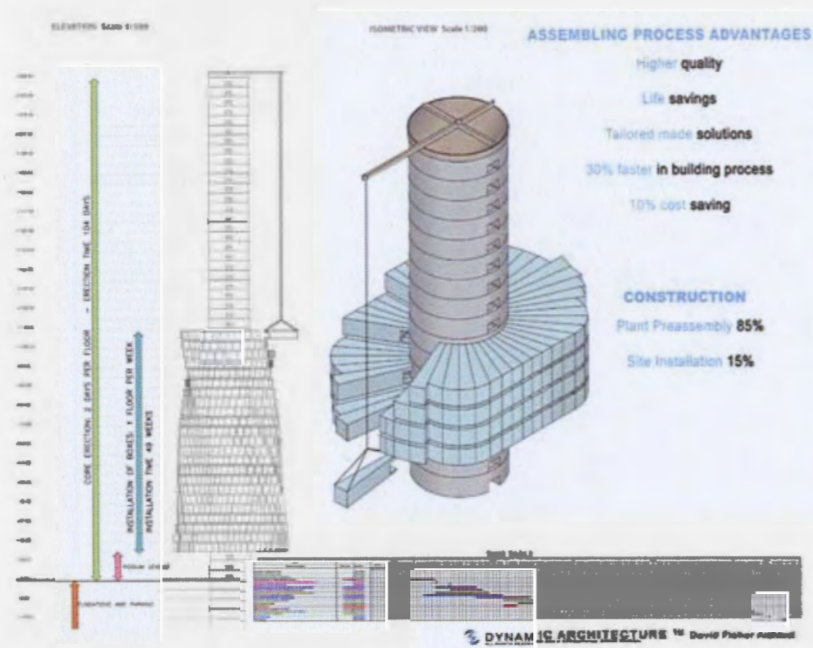


Fig. 2.18 Residential Units of the Dynamic Tower are hoisted up with a crane and slot in from top to bottom.



Fig. 2.19 The Dynamic Tower is a building that has the ability to rotate 360 degrees with individually controlled floors.

## 2.2 Examples of buildings that has integrated these major elements

This subsection will proceed by investigating projects that have attempted to integrating these systems, by describing the design solutions as well as their technological efficiency. The projects include: '2020 Tower' by Kiss + Cathcart Architects, 'Agro Housing' by Knafo Klimor Architects, 'Aberrant Agriculture' by Scott Johnson, 'Vertical Farm' by Waimond Ip, 'Dynamic Tower' by David Fisher and 'LA Vivante : eco tower' by SOA Architects.

### 2.2.1 The Dynamic Tower by David Fisher

The ruler of Dubai, Sheikh Mohammed Bin Rashid Al Maktoum, said '*Do not wait for the future to come to you...face it*' (Fisher, D n.d). This inspired David Fisher to design the first building in motion and the first 100% self-powered green building, providing energy for itself as well as the surrounding community through horizontal wind turbines between each floor together with solar panels. Each floor has the ability to rotate in its own direction resulting in an unique and ever-evolving shape (see Fig. 2.19).

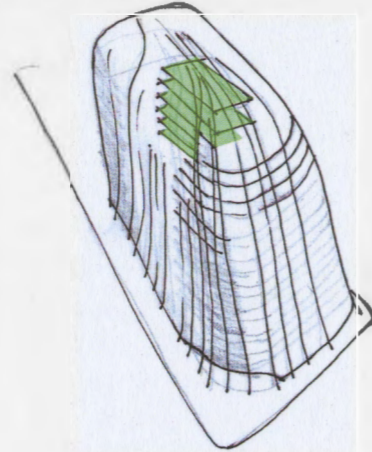
Photovoltaic ink is sprayed on the roof of each rotating unit and at any one time approximately 20% of each roof is exposed to the sun and to light. A building with 80 roofs thus equals the roofing space of 10 similar size buildings (Fisher n.d).

In response to Fisher's view that traditional vertical wind turbines have negative environmental and social effects, including the need for roads to be built and to maintain them, plus their noise and obstruction of views, he designed horizontally fitted wind turbines between each rotating floor (Fisher n.d)(see Fig. 2.12). The Dynamic Tower's horizontal wind turbines are practically invisible and extremely quiet due to their special shape and the carbon fiber material of which they are composed of. The 80-story building will have 79 wind turbine systems, making it a truly Green power plant. The tower will generate electricity for itself with a possible surplus for other nearby buildings, making it the first skyscraper designed to be entirely powered by wind and sun.

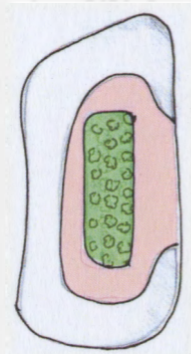
The tower is to be constructed in Dubai entirely of custom-made pre-fabricated materials (which is a study on its own). The assembly method to be used for parts of the Dynamic Tower will vastly reduce construction time (see Fig. 2.18). As a result it will offer substantial cost savings and provide an environmental friendly construction site with increased safety for workers on site. Each unit is pre-fabricated with all necessary equipment, from electric systems, floor to ceiling finishes, to bathroom-, kitchen- and living room furniture. The units are then fixed together to be lifted up the concrete core from top to bottom. Some of the residences have special elevators that will transport their cars to their respective floors to park directly at the entrance to their villas. All contact with the outside world will then be lost, reinforcing the negative social aspects of automobile use such as disaggregation of facilities and reduced social interaction.

# LIVING TOWER

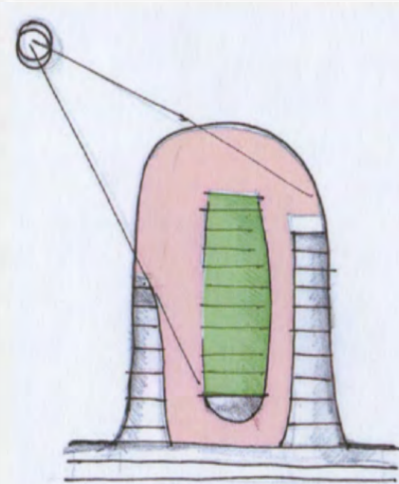
ABERRANT AGRICULTURE - SCOTT JOHNSON



PERSPECTIVE



PLAN



SECTION

Fig. 2.20 The Agricultural zone in the centre of the building

## 2.2.2 Aberrant Agriculture by Scott Johnson

Aberrant Agriculture is a thesis project on the shore of Lake Michigan in Chicago, proposed by Scott Johnson (Johnson n.d). His design concept incorporates two layers: an inner shell that comprises the agricultural core and an outer shell which includes the apartments, hotel and restaurant. The outer shell is sustained by the inner core shell. A thirteen story atrium around the core separates the two layers. The building can accommodate 1650 occupants. The ground floor space operates as a central market with retail space on the periphery of the plan, as well as distribution and storage space. The hotel caters for 750 guests and has 330 underground parking bays.

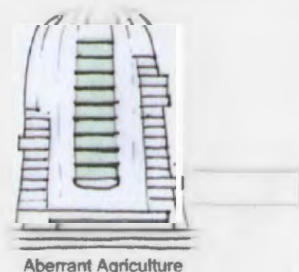
The agricultural core is the heart of the design, and its 28 000m<sup>2</sup> of cultivating space is intended to feed all the occupants of the building. One food type per floor has been accommodated by means of 12 stacked greenhouse floors.

The food types chosen for production in the core have been carefully selected based on their high concentration of essential nutrients, vitamins, minerals and protein, so as to provide a well-balanced diet. The crops (see Fig. 2.20) have been placed according to how much or how little natural and artificial light they will need during the growing process (Johnson, S n.d). This illustrates the importance of knowing the light requirements of each crop so that it can be optimally located within the Living Tower. Crops that bears fruit require the most light and should be placed on a higher floor than leaf vegetables that need lower levels of light.

The systems that are employed in this building have been selected to cut the cost of agricultural production and to reduce the amount of energy required for maintaining living standards. Systems that recycle water, plant waste, and passing wind work together to enable a living building, which in return feeds and supports its occupants (Johnson n.d). Water drawn from Lake Michigan is filtered and stored in underground collector tanks, for cooling, humidifying and irrigating the hydroponics used in the agricultural core. Water from the lake also supplies the grey-water systems in the apartments and hotel rooms.

The Aberrant Agriculture project uses cylindrical, rotating hydroponics machines that rotate plants every 45 minutes in order to prevent natural gravitropic settling (Johnson n.d) (see Fig. 2.6). Because the plants are in constant rotation, extra nutrients and vitamins are prevented from settling in their roots due to gravity, and as a result more nutritional plants are produced. Lighting tubes are positioned at the center of these hydroponic plant cylinders. These systems reduce the floor space needed for growing as virtual rows of plants are encapsulated within internally lit, rotating hydroponic cylinders which ensure a higher and healthier harvest.

A Methane Digester located in the basement of the design generates energy by burning plant and human waste, and extracts bio-gas that produces heat and energy for the building.



"The agricultural core is the heart of the design".

# LIVING TOWER

## 2.2.3 2020 Tower by Kiss + Cathcart Architects

The 2020 Tower is a visualization of what ecologically sustainable systems might look like in 2020. The National Museum commissioned Kiss + Cathcart Architects to design a building for the 2003 'BIG + GREEN' exhibition in Washington DC. In collaboration with ARUP Engineers, the design team's aim was not an utopian illustration of what might be expected in the year 2020, but a realistic new intervention demonstrating the quality of living that might be experienced in new urban environments shaped by eco-beneficial tall buildings (see Fig. 2.21).

Some of the systems are technologically advanced, but ARUP states that they are carefully engineered to be practical and economical by the year 2020 (*2020 Tower* 2003). Many of the technological systems used in the design have already been applied on a less-advanced scale in buildings around the world. Examples are the wind and solar power generators, on-site water treatment plants and vertically integrated agricultural spaces.

The proposed 2020 Tower site is unusually narrow, which made for extreme design challenges. The design of the two lengthy facades is crucial in terms of both aesthetics and functionality. *'The goal of a rigorous re-examination of all parts of the tall building -- program, structure, energy, water, HVAC, safety -- will add up to a building that is a healthier and safer place to be, more economical to operate, and a benefit to the surrounding environment'* (*2020 Tower* 2003, p. 1).

The main feature of the Tower is the sun-facing south facade. This facade responds to the challenge by integrating agriculture on the entire facade in a double glazing skin. The two skins are 1.5m apart, with the outer skin comprising laminated structural glass for safety and support. The Vertically Integrated Greenhouse (VIG) has numerous benefits for the building itself and for the environment. Throughout the year the VIG has climatic benefits: during summer the plants cool the building by acting as a shading mechanism, and cross ventilation through operable windows provides fresh air. This process ensures that the inside temperature is lower than the outside temperature. The void space in the double skin also promotes the stack effect and warm air escapes at the top. During winter the double glazing facade captures the warm air, which can enter the building by opening the windows. This ensures that the temperature inside is much greater than outside. The summer and winter conditions within the double facade are ideal for the growth of plants, which increases the quality and the number of harvests. This process also results in significant energy savings, as the use of mechanical air conditioning is cut down or even eliminated. The crops that are integrated into the building thus have a direct effect on the self sustaining living conditions. An innovative design solution has successfully amalgamated man and nature.

The 2020 Tower intend to accommodate 33 000 people of which 18% (4 600) is residents and 82% (28 400) working staff (*2020 Tower* 2003). The total area for the occupants of the buildings is 6.7 mil ft<sup>2</sup> and 35% of that is dedicated to the living and 65% towards the working environment (*2020 Tower* 2003). These figures of living and working are according to the current model of Manhattan in New York. The virtual site for the 2020 Tower is located in Manhattan.



Fig. 2.21 The 2020 Tower

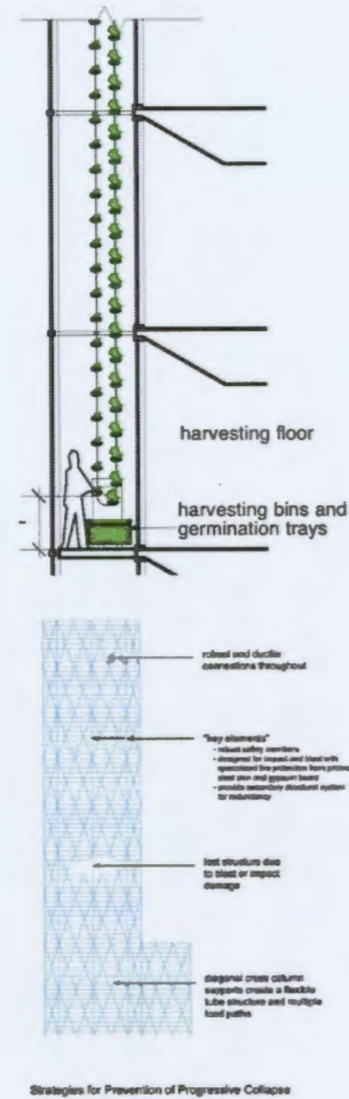


Fig. 2.22 The structural system of the 2020 Tower

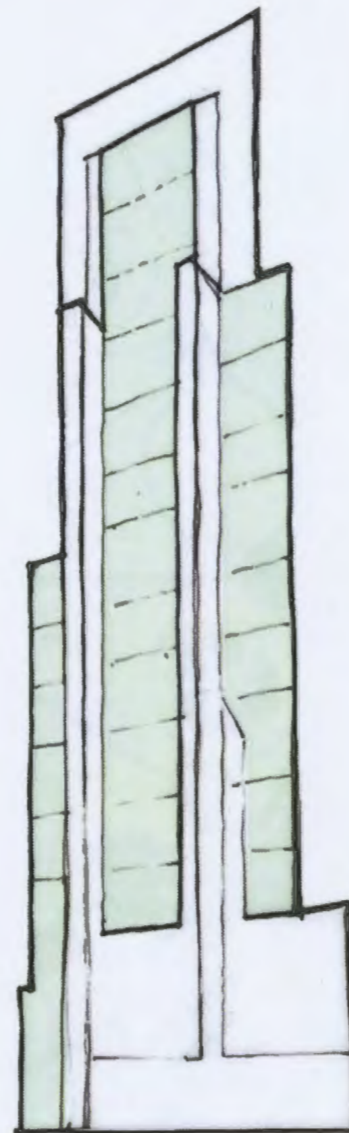


Fig. 2.23 Sketch by author, the applied agriculture on the facade



"The main feature of the 2020 Tower is the sun-facing south facade. This facade responds to the challenge by integrating agriculture on the entire facade in a double glazing skin."

# LIVING TOWER



Fig. 2.24 Tour Vivante, SOA Architects



Tour Vivante - Plan

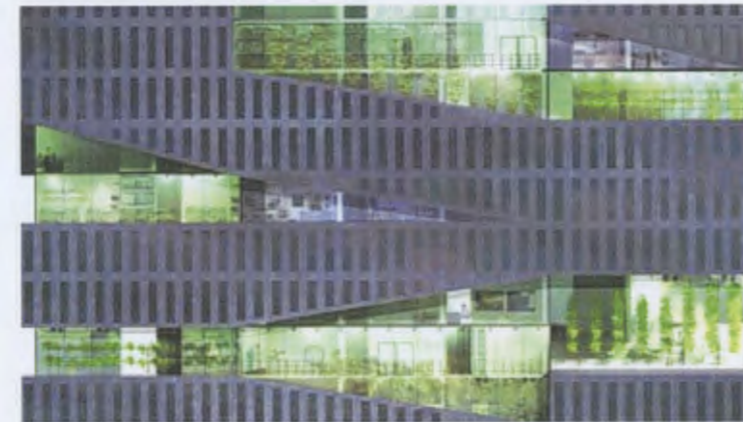


Fig. 2.25 The agriculture wraps around the core of the Tower

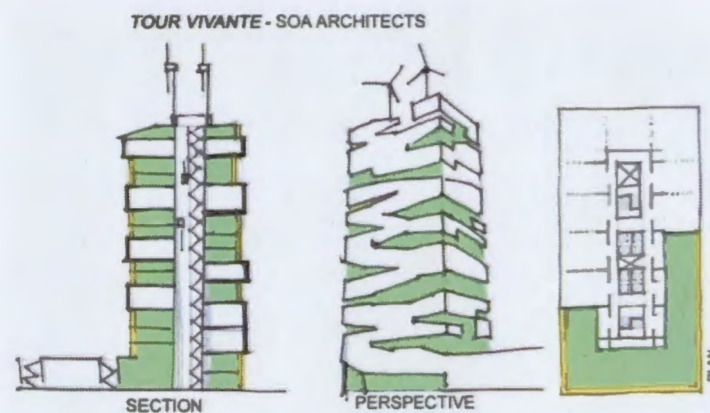


Fig. 2.26 Tour Vivante, section, elevation and plan, sketches by author

## 2.2.4 Tour Vivante by SOA Architects

The Tour Vivante is an ecological machine that merges production, consumption and life in a single vertical entity. The tower was designed in 2006 for a site in Paris.

The element that separates the production of food from the offices and apartments is a change in level that spirals around the core toward the roof. These two components (agricultural and living space) are intricately designed to achieve an effective, economical combination. The appearance from street level provides a visual distinction between the production of food and human occupation. This distinction is emphasized by the dedicated use of materials (see Fig. 2.24, 2.25).

Glass and concrete illustrate the different functions in a very distinct way: facilities such as apartments, offices, retailing, parking and restaurants are housed behind the window-punctured concrete façade; and behind the glass façade the production of food is visible from anywhere in the neighborhood. The concrete provides privacy, security and heat storage for inhabitants while the glazing provides optimum sunlight for the plants to ensure efficient growth.

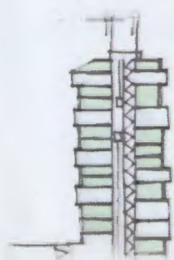
Apart from integrating agriculture (greenhouses) into the building, the 'La Tour Vivante: an eco-tower' also integrates other resources that support the ecological system of the tower.

**Windmills:** The two windmills are located on the roof facing the predominant winds. The electric power produced is about 200 to 600 kWh per annum. These wind machines are also used to pump recycled rainwater and grey water from the treatment solution in the basement for the irrigation of plants (SOA Architects 2006, p.5).

**Photovoltaic panels:** Photovoltaic panels measuring 4,500 m<sup>2</sup> have been included into the facades to generate electricity from solar energy. The windmills and the solar panels ensure that the TV is a self-sufficient building (SOA Architects 2006, p.5).

**Rainwater:** After the rainwater has been filtered, it is used for the facilities of offices and residences and for the watering of the hydroponics. Excess rainwater is collected, pumped by the wind machines, and then stored in tanks at the top of the tower (SOA Architects 2006, p.5).

**Black water:** The black water produced by the tower is recycled and purified in a treatment solution in order to feed and to fertilize the agricultural production of the greenhouses (SOA Architects 2006, p.5).



"The *Tour Vivante* is an ecological machine that merges production, consumption and life in a single vertical entity. The tower was designed in 2006 for a site in Paris".

# LIVING TOWER



Fig. 2.27 Agro Housing; perspective and section indicating the stacked greenhouses

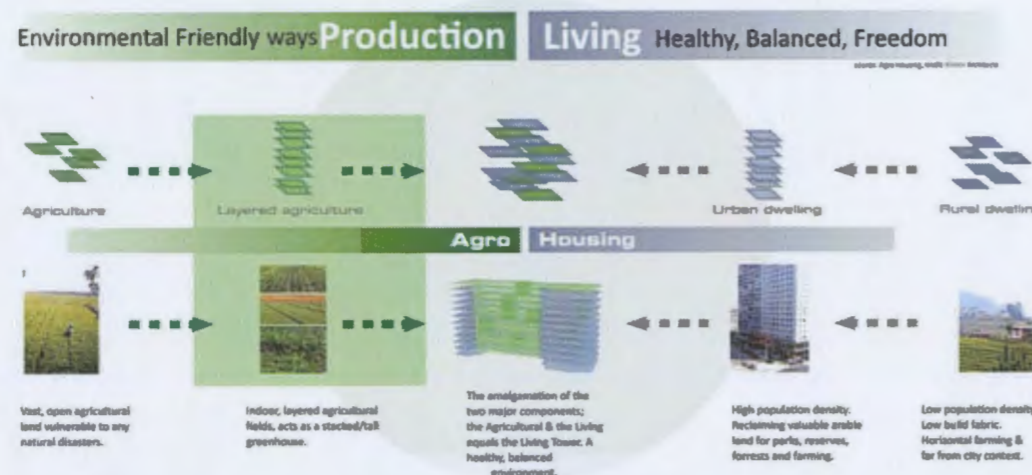


Fig. 2.28 The layering of greenhouses and dwelling units



Fig. 2.29 Each apartment in the Agro Housing has a green outdoor space

## 2.2.5 Agro Housing by Knafo Klimor Architects

The Agro Housing design won the 2nd International Architecture Competition for Sustainable Housing in China in 2008.

Knafo Klimor Architects argue that the current exponential growth in urbanization will lead to the random development of communities requiring expensive infrastructure and services, and exhausting natural energy whilst adding to air and water pollution. 'The concept of Agro housing is a presentation of a new urban and social vision that will address the problems of chaotic urbanization, by creating a new order in the city and more specifically in the housing environment (Knafo Klimo Architects n.d)'. The conceptual structure underlying Agro Housing is a combination of housing and stacked greenhouses, in which the residents have ownership over part of the greenhouse which they can cultivate for their own benefit or utilise as an additional income source.

Figure 2.28 explains the planned intervention which amalgamates farming and living in one building. Vast areas of open agricultural land are vulnerable to natural disasters, which increase in frequency as global warming continues. To rethink the traditional horizontal farming approach, the architects divided the fields and layered them vertically indoors, creating the effect of a stacked greenhouse. The housing aspect of the diagram in Figure 2.28 begins with an illustration of very low density population and low built fabric, far from the city, which is uneconomical in terms of providing infrastructure and services. To rethink this method, Knafo Klimor looked at a building that is more suited for higher population densities, which will reclaim the surrounding land and encourage open green spaces for recreation.

When these two aspects are mixed, you find a special relationship; a relationship which is healthy, balanced, environmentally friendly and has great energy saving benefits.

### 2.2.5.1 Components used in the greenhouse

The irrigation functions as a complete drip system, which has a controller to regulate the irrigation process. A water treatment solution is a vital component of the building as it recycles and purifies the water continuously to be re-used for irrigation.

The plants grow in a 'Growing gutter system' which uses soil-less material such as perlite, rock, wool, coco, peat, etc. A major component for a greenhouse is the heating/cooling control of the space to obtain the most desirable conditions for horticulture. Circulation fans and shading/thermal screens are applied for this (Knafo Klimo Architects n.d).

The roof is shaped inwardly to collect rainwater. Parts of the roof are also intensively planted with crops, but are also provided with protection against too much heat gain (see Fig. 2.27). Solar collectors are mounted on top of the roof.

In the centre of the building between the stacked greenhouses and the building is an atrium that is a void space from the ground floor right up to the roof level. This open space is very effective for climate control:



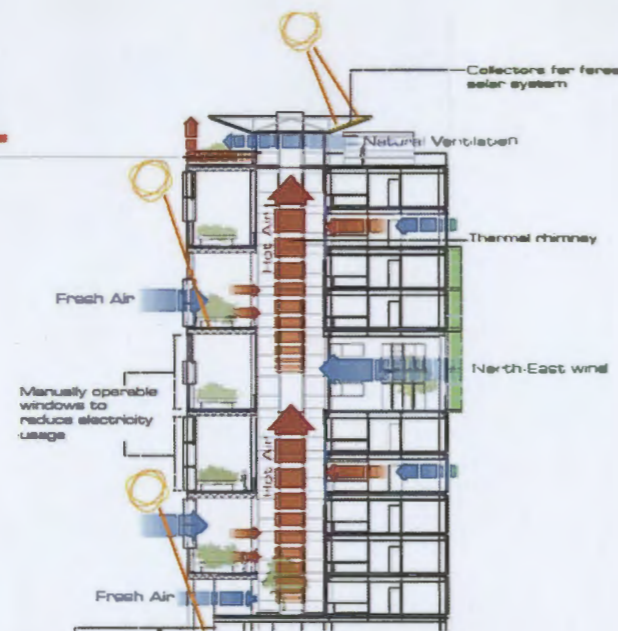
"When these two aspects are mixed, you find a special relationship; a relationship which is healthy, balanced, environmentally friendly and has great energy saving benefits."

# LIVING TOWER

## Summer

### Climate Control

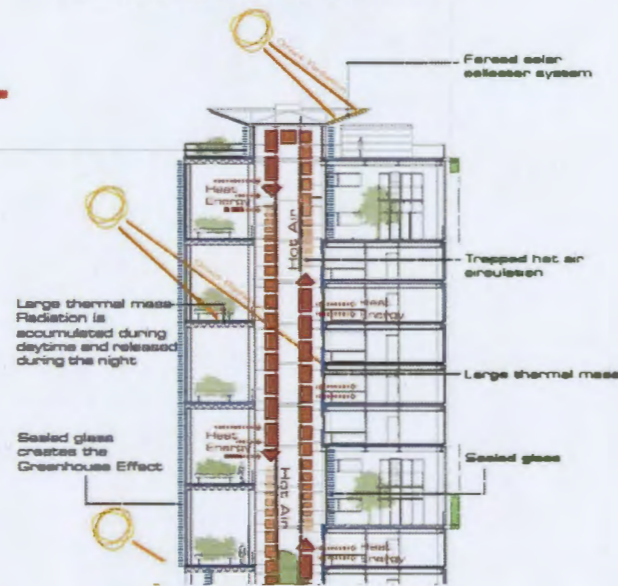
Manually operable windows create a 'thermal chimney.' This causes pressure differences and therefore enables air circulation in the apartments and public areas, sucking the hot air out of the building and allowing cooler fresh air inside.



## Winter

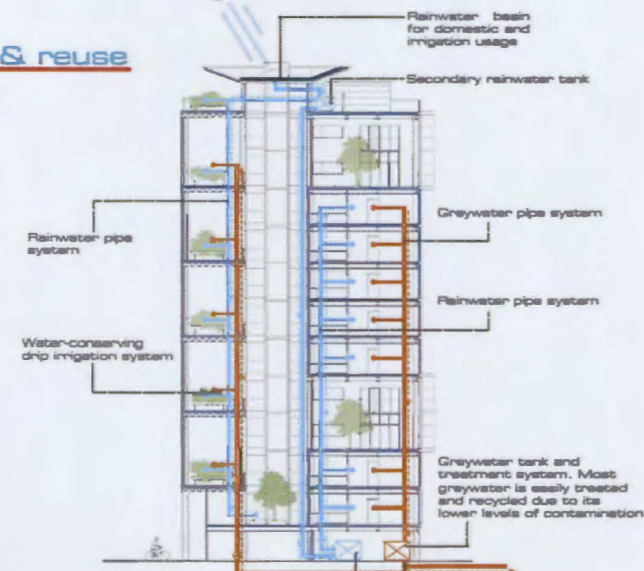
### Climate Control

Sealed glass keeps the hot air inside the building.



## Water conservation & reuse

### Climate Control



In summer: The manually operable windows create a 'thermal chimney effect'. This causes pressure differences which enable air circulation in the apartments and public areas, drawing hot air out of the building and allowing cooler fresh air inside (see Fig. 2.30).

In winter: The manually operable windows remain shut to prevent warm air from escaping (see Fig. 2.30). The solar collector system saves energy by managing the solar gain to be used effectively in the building. The hot air that is captured, circulates within the atrium space and heats the building. The large thermal mass (the material of the apartment building) accumulates heat during the day and releases it at night (Knafo Klimo Architects n.d).

Manually operable windows to the greenhouse reduce electricity usage while providing ventilation. The greenhouse also supports human interaction by serving as a venue for casual and professional meetings, while the roof garden offers an open air space for recreation, and the roof's Sky Club is designed to host social gatherings. The Agro Housing thus provides a diversity of spaces for the benefit of its occupants (Knafo Klimo Architects n.d).

The plan is designed to provide every apartment with a green space/garden. Apartments form a U-shape around the greenhouse as if identifying it as the heart of the project (see Fig. 2.29). The apartments are flexible in that all the partitions will be made of light plaster panels that can be moved and recycled easily.

Natural Resources: Each apartment is equipped with a hot water tank located at the floor's shared service area, which is fed by the hot water pipes from the solar collector. Each apartment is also equipped with a Ground Source Heat Pump (GSHP) which uses the natural heat storage capacity of the earth to provide heating and cooling (see Fig. 2.30 below).

Water conservation and re-use: The water that is collected on the roof is used to irrigate all the greenhouse levels. A grey-water tank and treatment system located on the ground floor economically treats and recycles all grey-water.

The Agro Housing has simplistically but effectively integrated agriculture, food production and living conditions into a single vertical system. The architects have taken full advantage of the climate control benefits obtained from the atrium between the stacked greenhouses and the apartment building. Systems such as the solar collector, the operable windows at roof level, Ground Source Heat Pumps and the water treatment solution, ensure a self sustainable building offering enhanced living conditions, which provides a revitalized alternative to community housing at the same time as it addresses current global issues.

Fig. 2.30 These diagrams illustrate how the different systems work together in different times of the year as well as the conservation of water in the building.

# LIVING TOWER

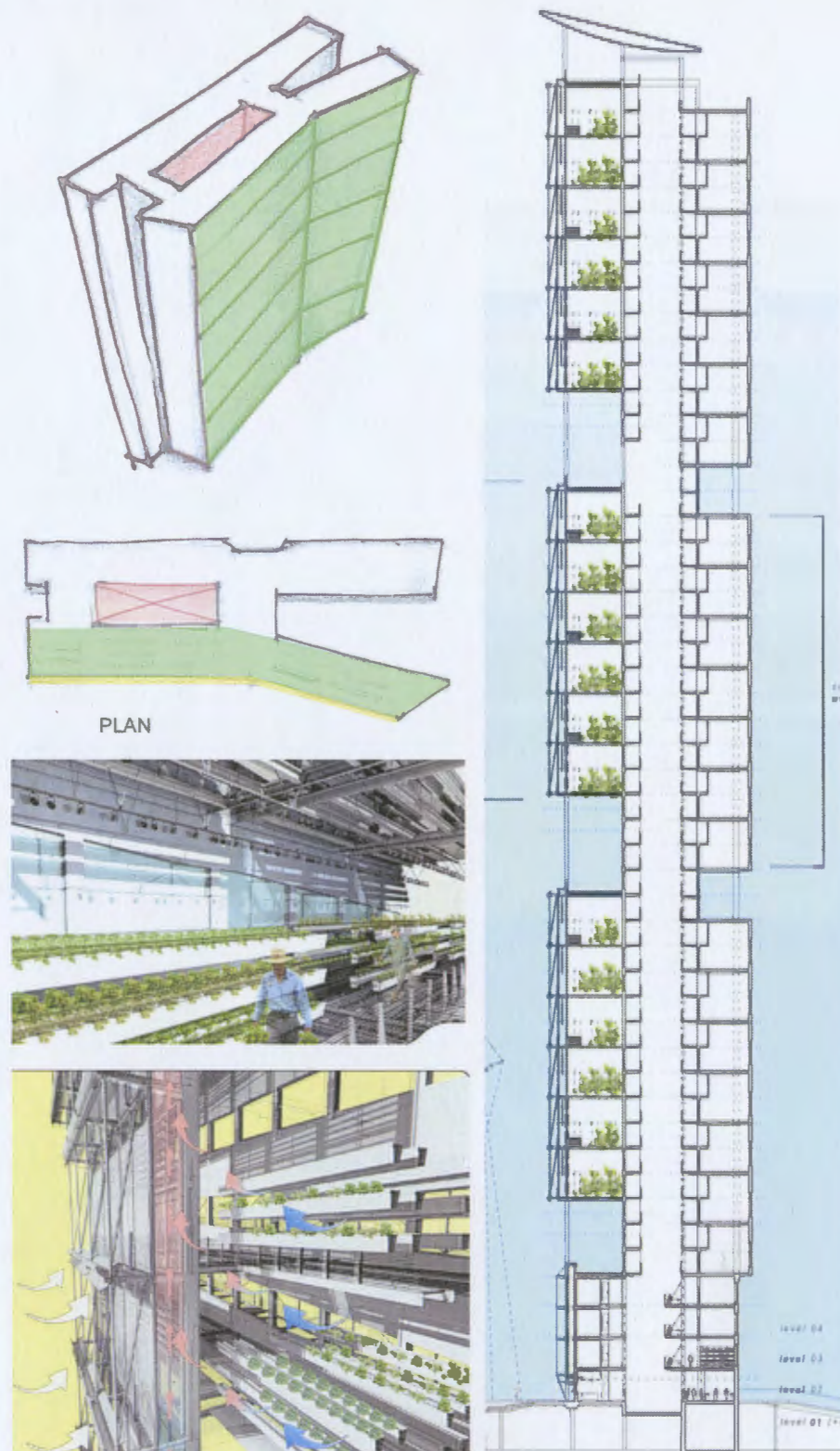


Fig. 2.31 These sketches and perspectives of the 'Vertical Farm' show the orientation of the agricultural component in the building also the atrium that improves the comfort in terms of controlling the temperature.

## 2.2.6 Vertical Farm by Waimond IP

Waimond Ip's *Vertical Farm Project* involves the collaboration of a vertical farm and living units. The *Vertical Farm* is a combination of elements seen in the *Dynamic Tower* as well as in the *Agro Housing*.

Most of the building is made off-site from pre-fabricated material. On-site, these materials are hoisted on to the primary structure using a crane, in a method similar to that of the *Dynamic Tower*. The agricultural section of the building receives optimum sunlight by facing south (in the northern hemisphere), while spaces for living and other activities face north. Ip's design incorporates an atrium that is mainly used for climate control within the stacked greenhouses on the south side of the atrium. Cool air enters the building from the ground and cross ventilation is induced as the updraft moves upward to less dense air and escapes at the roof (see Fig. 2.32); this is similar to the process applied in *Agro Housing* by Knafo Klimor Architects. The atrium effectively supports ventilation, heating, cooling and climate control.

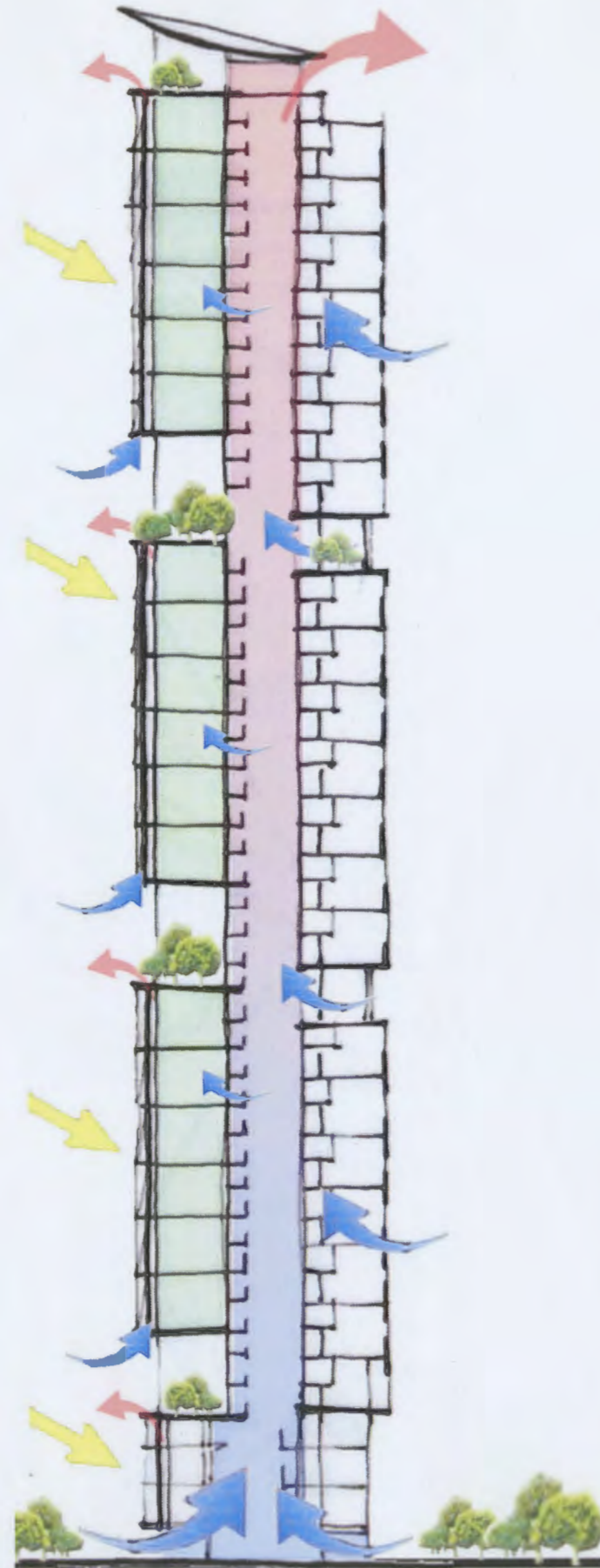
The application of a double skin facade on the south side of the building also plays a major role in controlling the temperature of the greenhouses (see Fig. 2.31). Maintaining the air conditioning of a greenhouse at a consistent temperature is more demanding in terms of its energy requirements than the heating of residential accommodation. Therefore, numerous building techniques are used to ensure that the air conditioning in the greenhouse is energy sufficient. The double skin facade captures heat in winter and acts as a shading device in summer; manually operable windows provide continuous cross ventilation in summer and keep heat inside in winter; and fans are installed to support an evaporative cooling process during hot dry weather.

Another important design consideration which Ip incorporated into his project, was the scale between a single greenhouse and a single apartment unit per floor. The greenhouse requires a minimal height of 6m for effective evaporation and air treatment, as well as making the stacking of crops easier and healthier. Air flow needs to cross the greenhouse comfortably to maintain a temperature that produces effective plant growth. The greenhouses were therefore designed to be 6m in height, and the apartments are all double-storey with the same height. Despite the narrowness of each prefabricated unit, the double storey can accommodate 2 to 3 bedrooms. The greenhouse and the apartment both have their entrance at the same level, making the vertical movement twice as quick and cost efficient. The *Agro Housing* project used the same method when integrating the vertical farm into the apartment building.



"a double skin facade on the south side of the building also plays a major role in controlling the temperature of the greenhouses."

# LIVING TOWER



## 2.3 Research findings from these examples

All of the projects discussed in the previous section, integrate some sort of multi-functional system into their design to make it functional, viable and aesthetically pleasing. Apart from the Dynamic Tower, which makes use of modular construction, all the designs effectively integrate a vertically stacked greenhouse into the building (see Fig. 2.33). Through careful examination and analysis of these designs, their common aspects and principles have been identified. These findings will directly influence the design of the proposed LT and the integration of its systems to ensure that they work harmoniously together.

**The Atrium:** Firstly, an atrium is often used as a comfort controller that adjusts temperatures by controlling the airflow within the building (see Fig. 2.33). Warm air rises, which causes a rising updraft toward the roof, and in turn induces cool air from outside to cross-ventilate the building into the atrium. There is a unique combination between the atrium space (pink) and the agricultural space (green) (see Fig. 2.33). The *Vertical Farm* and *Agro Housing* projects illustrate the use of atrium space as a distinctive divider between the agricultural and the living components. In these cases the atrium supplies services to the greenhouse as well as controlling the temperature according to the seasons.

The atrium provides a certain spatial quality that makes one experience the building in a different and impressive way. The atrium gives scale to a building from the internal views, it creates a distinction between the functions, it is used to run services that feed into the agricultural section and it becomes an interactive social space.

**Sky-courts:** Secondly, sky-courts demonstrate the effective use of social green space in a skyscraper, as they increase cross ventilation across the building which cools down the temperature in the building. The sky-court is a very green terrace or court that provides a quick escape from the built environment to refresh the mind and soul. Sky-courts also break the uniformity that the built environment generally portrays, by interrupting the rhythm of manmade structures with random green spaces in the sky that are visible from the street. Ken Yeang is a firm believer in introducing sky-courts into his eco skyscrapers. The '*Business Advancement Technology Centre*' (BATC) in Germany is one of many examples of the important role that sky-courts play in his buildings. Yeang says that apart from the climate control advantages and visual and ecological connectivity between floors, sky-courts create a humane habitable green environment (Richards 2007, p. 66, 67).

**Double Skin Façade:** Thirdly, the Double Skin Façade (DSF) also plays a major role in the designs of the projects. The DSF's function is similar to the atrium in terms of the stack effect that it induces. The *2020 Tower* goes a step further to introduce Vertical Integrated Agriculture (VIG) within the double façade (see Fig. 2.21-23). This intervention utilizes the space between the two skins very effectively and offers an ecological and economical benefit to the building (see section 3.1.10 *Vertically Integrated Greenhouse*).

DSF is a necessity for the greenhouses to be able to control the temperature for the most efficient growth of crops. Areas on the facade that face the sun and do not accommodate greenhouses, will surely also integrate the VIG system for its numerous advantages.

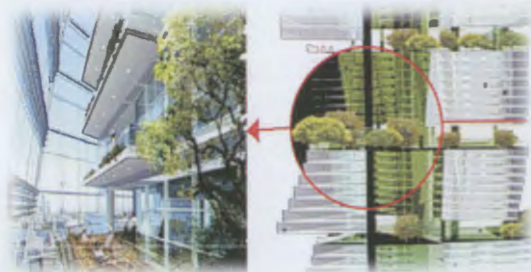


Fig. 2.32 This sketch by the author illustrates the collaboration of the atrium, the sky-courts, the double skin facades, the building integrated greenhouses (stacked) and the dwelling units in one closed entity.

# LIVING TOWER

Greenhouse versus Apartment: Fourthly, the floor to ceiling height of the greenhouses needs to be double the height of an apartment. In the *Vertical Farm* and *Agro Housing* projects, two apartment floors are equivalent to the height of one greenhouse (see Fig. 2.32). The potential design problem is solved by making the apartments double storey dwelling units, which means that the elevators only need to stop at every second floor. This reduces operational costs significantly, as elevator costs are determined by the number of stops in a building, which is a significant factor in a skyscraper.

The design of the LT incorporates key characteristics from the designs of these precedence studies. The challenge remains that the overall design has to carefully integrate the different systems so that they work harmoniously and successfully together in a single vertical system.

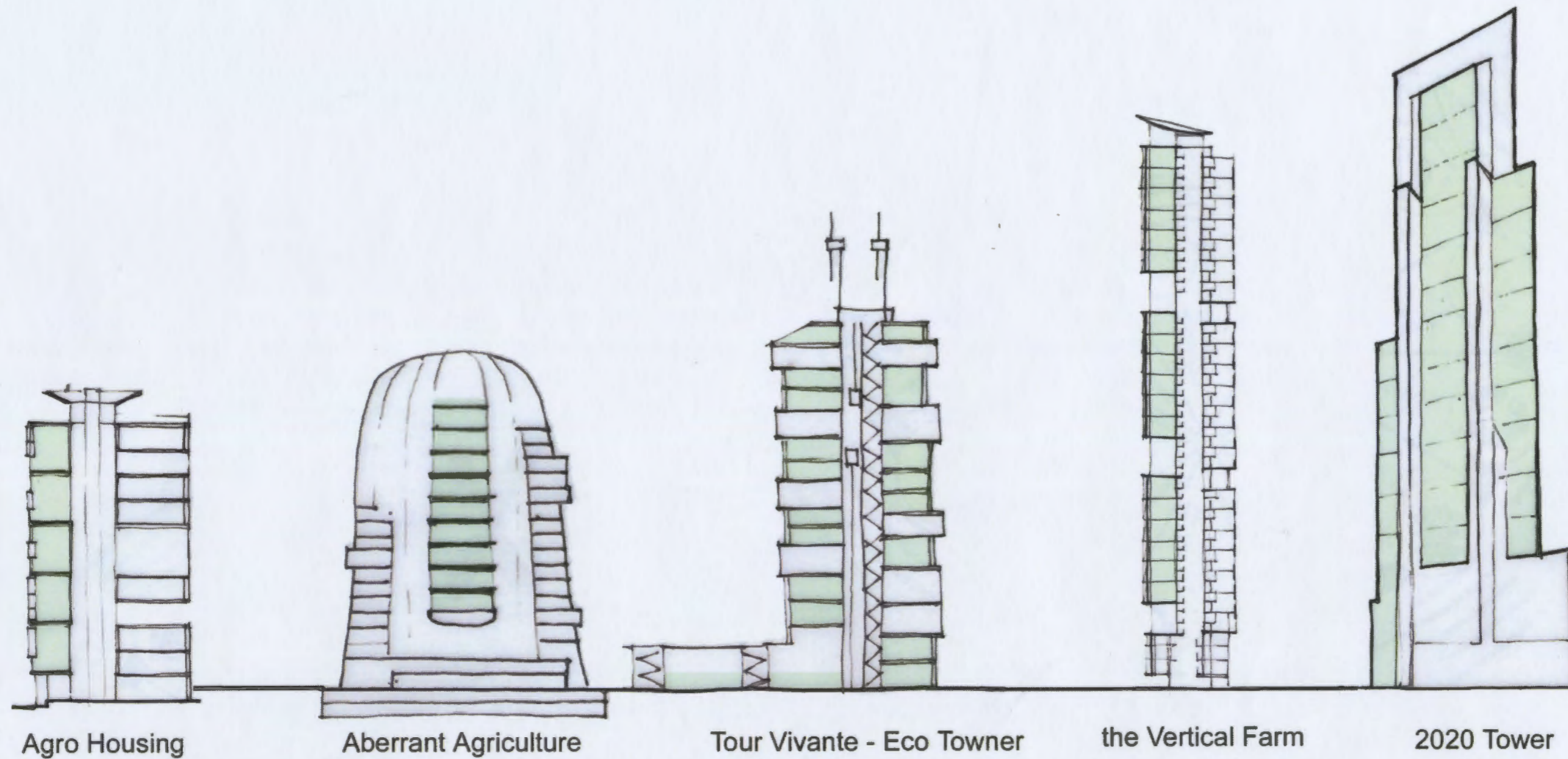
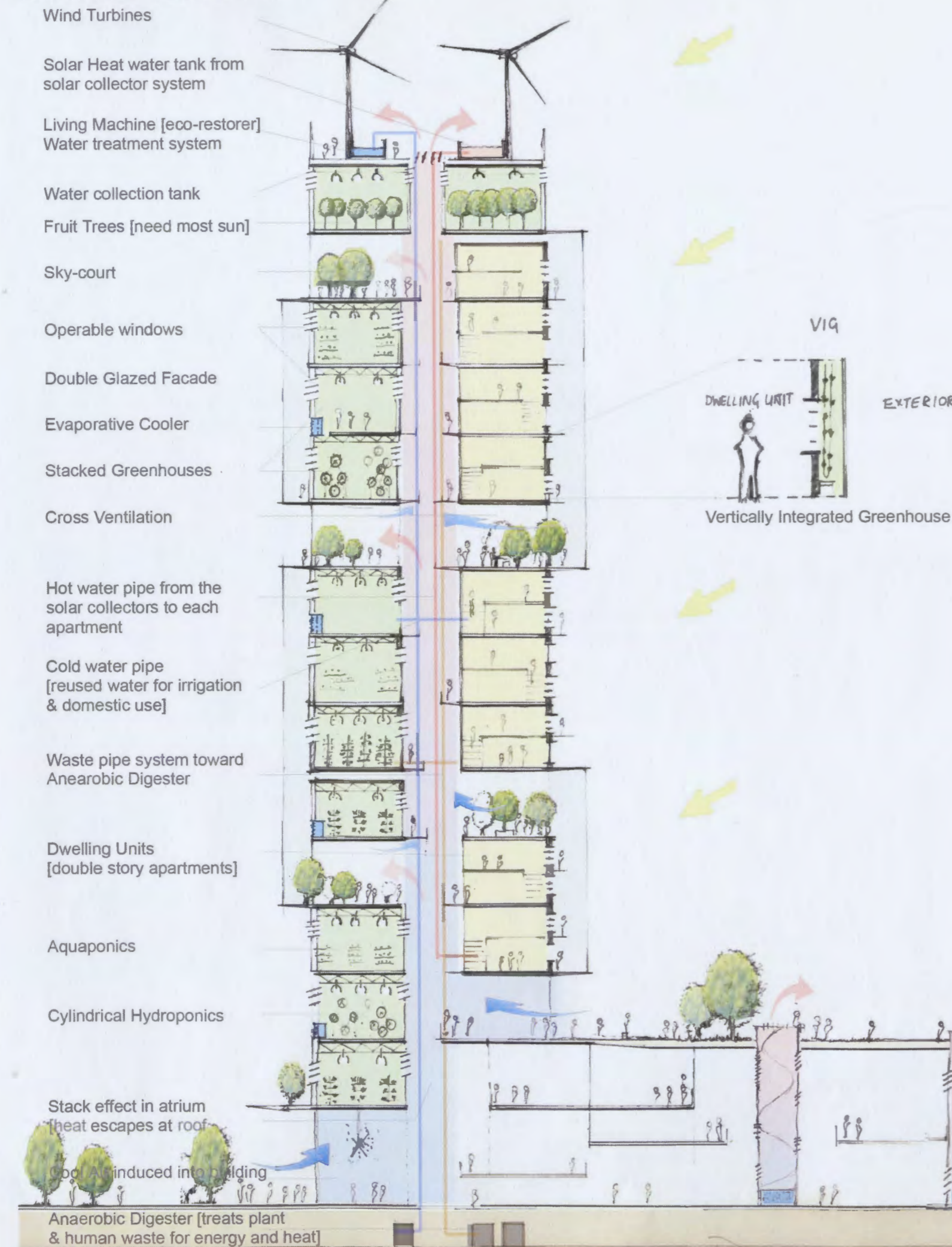


Fig. 2.33 This figure illustrates the integration of agriculture (greenhouses) into the design of the projects in this study. The typology of arranging greenhouses in different patterns and locations provides room for creativity with the Integration of agriculture. Key determinants for the location of the greenhouses include; sunlight, circulation around the greenhouses, easy access to the greenhouses, continuous new air flow, and good natural ventilation.



# LIVING TOWER



## 2.4 The amalgamation of selected integrated systems in the Living Tower

To conclude this section, the author will look at some of the implications derived from this study that will guide the design (see Section 4) of the LT. Some of the elements are fundamental to making a tower function as a closed system where the flow of energy resources is renewed or closed. These elements act as layers that comprise the body of the tower.

- The first and the core layer of the body of the tower is the atrium. This is located centrally and is void to support airflow and temperature control during winter and summer times. The atrium is also a spatial configuration to divide spaces.
- The second layer that shapes the body of the tower is the sky-courts. The sky-courts connect with the atrium to force warm, exhausted air outwards and to cross-ventilate cool air from one side of the tower to the other. These courts function as green oases in the sky that generate social interaction and provide a natural environment for occupants.
- The third layer is the stacked greenhouses that are separated from the stacked dwelling units by the atrium. The greenhouses are stacked to ensure the largest crop production possible, and to simplify the irrigation that gravitates down through the greenhouses. The evaporative cooling system used in the stacked greenhouses helps to control the temperature of the dwelling units and the greenhouses during summer and winter without the need for mechanical air conditioning.
- The fourth layer that is a requirement for the greenhouses and the atrium is operable windows. This layer also ensures that no mechanical air conditioning is needed. By closing the operable windows at the top of the atrium heat is captured within the atrium; when they are opened, the warm air escapes at the top and creates cross-ventilation by inducing the flow of cool air from open windows below.
- The fifth layer that forms the body of the tower is the height of a greenhouse unit against the height of a dwelling unit. A greenhouse (6m) is approximately twice the height of a single dwelling unit. The design solution that shapes the tower is the doubling of each dwelling unit in order to provide access at the same level for each greenhouse and dwelling unit.

Fig. 2.34 This figure illustrates the integration of the different layers that are mentioned in the conclusion. The building is a completion of the different elements studied in this thesis. Sketch by author.

# LIVING TOWER

- The sixth layer is the double skin façade, which has a similar function to the atrium in terms of the stack effect. The double skin façade stores heat in winter and releases warm air from the top in summer. The skin adds to the control of comfort temperature in different seasons without mechanical ventilation.
- The seventh layer is an improvement on the functions of the double skin façade. Agriculture is applied within the double skin to provide food, comfort and energy saving for the tower. The vertically integrated greenhouse system is applied within the glazed facade facing the sun. In addition, the system can rotate for easy harvesting throughout the year and to ensure that crops grow under ideal conditions within the façade.

A number of other elements that improve the continuous and harmonious flow of systems within the body of the tower, while at the same time generating energy, are the following:

- The Wind Turbine pumps the waste-water from the collector and septic tank in the basement while generating energy from the wind load.
- This waste-water is filtered and purified in the Living Machine.
- The clean water then gravitates towards the ground while irrigating the aquaponics and serving the apartments.
- After this process the water and waste go through the Anaerobic Digester to produce bio-gas and heat from the waste for the building.
- The collected water in the basement is then pumped back to the roof by the Wind Turbine to continue the process.

The LT, with the vertical farm component, promotes the concept of urban sustainability. The many systems that it integrates such as the aquaponics, the evaporative cooling system, the atrium, the living machine, the methane digester, the vertically integrated agriculture, the double skin façade and the dwellings set in a vertical tower, result in significant benefits for its human occupants, the surrounding environment and the future city that constantly faces the problem of over-population.

In line with the purpose of this thesis which integrates multiple systems to support aquaponics) and high density living in a single vertical system and the aquaponic system (production of food), could not only provide sustainability but could also exerts a positive influence on both nature and society.

In order to establish a deeper validity to the situation of this thesis, Section 3 will measure the sustainability and viability of such a building in its current context whereby the energy generated will be weighed against the energy consumed as well as determining the amount of reclaimed land the LT gains.



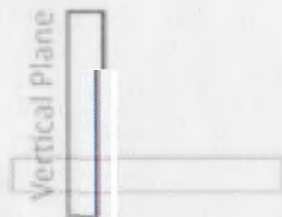
# Section 3

*The sustainability and the viability of the Living Tower.*

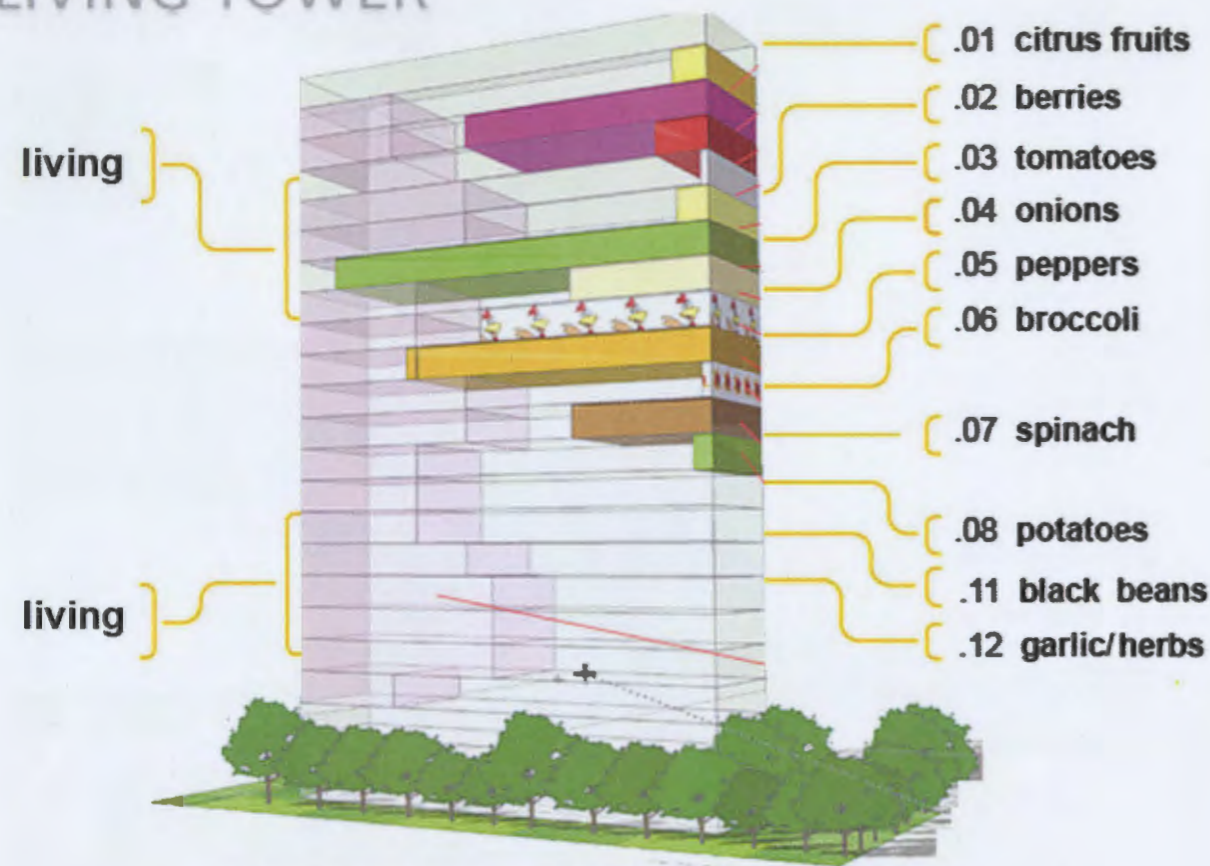
The Chairman of the *Council on Tall Buildings and Urban Habitat* David Scott argues in the book *Eco Skyscrapers* that "Energy conservation is being tackled on many fronts, particularly in the design of tall buildings where the potential to save energy is so great" (Richards 2007, p. 8).

Despite all the criticism that tall buildings are of un-ecological building type, involve labour intensive construction and have huge cost implications, they also have the potential of contributing towards a sustainable future. If the design focuses from the outset, on utilising the local climatic conditions such as renewable resources to support different functions in the building innovatively, it will further contribute towards an ecological build environment that has a positive effect on our eco system.

A high-rise building is essentially a significantly intensive concentration upon a very small footprint. The benefit of many floors being stacked on one another means less energy usage per capita because of the sharing of different facilities and recourses. In a high density living building less building material would be used to low density development which require the repetition of similar construction components.



# LIVING TOWER



**.01 Citrus fruit** – high in vitamin C and lots of essential nutrients, good sugar, fiber, potassium, and calcium while containing no fat, sodium or cholesterol

**.02 Berries** – extremely high in anti-oxidants, vitamin C and potassium, said to help short-term memory

**.03 Tomatoes** – packed with vitamin C & A, high in potassium, iron and anti-oxidants

**.04 Onions** – have antifungal and antibacterial properties, high in anti-oxidants, lowers cholesterol and blood pressure

**.05 Peppers** – rich in vitamin A, C and K, help promote proper blood clotting, strengthens bones and protects cells from oxidative damage

**.06 Broccoli** – high in fiber, vitamin A (mostly beta-carotene), vitamin C, calcium, fiber and folic acid

**.07 Spinach** – high in phytonutrients and anti-oxidants, fiber, vitamin C, folic acid (decreases heart disease), calcium, iron, potassium and the list goes on

**.08 Sweet potatoes** – loaded with carotenoids, vitamin C, potassium, and fiber

**.09/.10 Eggs (chickens)** – great source of high-quality protein and amino-acids while low in calories, one of the only foods with naturally occurring vitamin D, promote healthy hair and nails

**.11 Black Beans** – small in size, high in fiber & iron, darker beans have higher concentrations of the good stuff

**.12 Garlic** – loaded with phytochemicals to fight cancer, inflammation and infection, lowers cholesterol and blood pressure

## 3.1 The limitations and parameters of the Living Tower

“So what are the limitations of the project, what are the parameters of the design, or is it endless?” The key aspects driving the conceptualization of the LT are: sustainability, efficiency, renewing natural resources and the reclaiming of valuable arable land. These factors will shape the project and needs to be carefully addressed and interrogated in depth in search of the perfect balance our eco-systems require. Other factors such as the cost and the height of the buildings also have a direct impact on the sustainability of the project.

Three models comprising towers of 15, 30 and 45 storeys respectively will be compared to find the most effective and efficient height for the different factors mentioned above. Four conditions play a major role in establishing the most optimal height for a tower and are discussed below:

### 3.1.1 Land used for traditional Agricultural Production versus Land used within the LT to produce the same amount of crops (Fig. 3.2-3.4).

To work out the total of land required for the production of all the crops the area required per crop to feed a single person is multiplied by the amount of residents within the tower. It is important to note that within the LT, the crops are stacked in three layers per floor. Indoor farming has the advantage of controlling the temperature to produce crops seasonally, whereas outdoor crops can only be produced once a year. Outdoor crops are also vulnerable to the unpredictable and constant climate changes. If these aspects are taken into consideration, it amounts to the outdoor area taking up nine times more space than the LT.

Calculations on the right of the diagrams (see Fig. 3.2-4) indicate the area required per crop in the LT versus the conventional farming. It is clear from the diagrams (see Fig. 3.2-4) the amount of area that the LT can ‘reclaim’ within a 2000m<sup>2</sup> building footprint, assuming all the crops are produced.

From these diagram (see Fig. 3.2-4) it is clear that the difference between the three models is obvious and therefore can confidently support the 30 storey LT being the most effective and efficient in terms of reclaiming land.

Fig. 3.1 The food types chosen for production in the core have been carefully selected based on their high concentration of essential nutrients, vitamins, minerals and protein, so as to provide a well-balanced diet. The crops have been positioned according to how much or how little natural and artificial light they will need during the growing process (Johnson, S n.d).

# LIVING TOWER



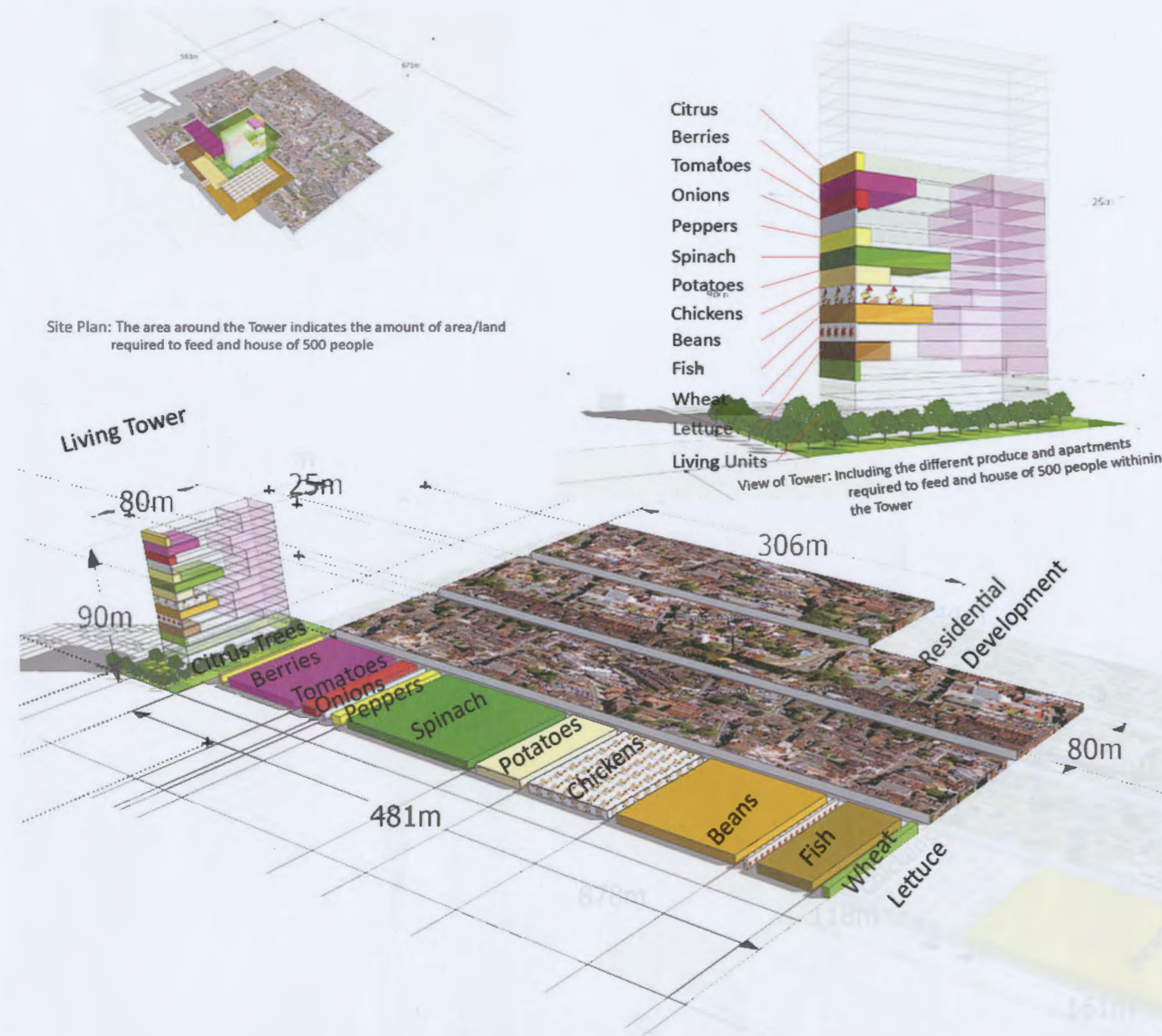
**The Living Tower - 200 people, 5-10 Floors, footprint 2000 m<sup>2</sup>, 5 000 m<sup>2</sup> Living Area (30%)**

Produce (in order of most sunlight required)	Area required for 200 people	Area in building (3 layers per floor)	Area on land (3x less crops a year)
Citrus Trees	37.5	37.5	112.5
Berries	840.0	280.0	2,520.0
Tomatoes	187.5	62.5	562.5
Onions	25.0	8.3	75.0
Peppers	104.0	34.7	312.0
Spinach	1,350.0	450.0	4,050.0
Potatoes	464.5	154.8	1,393.5
Chickens	787.0	262.3	2,361.0
Beans	1,075.0	358.3	3,225.0
Fish	56.5	18.8	169.5
Wheat	232.0	77.3	696.0
Lettuce	60.5	20.2	181.5
<b>Sub-total</b>	<b>5,219.5</b>	<b>1,764.8</b>	<b>15,658.5</b>
	footprint	2,000.0	15,658.5
Residential		20,000.0	200,000.0
<b>Total</b>		<b>21,764.8</b>	<b>215,658.5</b>
	footprint	2,000.0	<b>215,658.5</b>
Cattle	200,000(20 ha)		200,000(20 ha)

Table : This Table illustrates the difference between Area Required, the Area in the Tower required & The Area on open land required for the consumption and housing of 200 people. All areas in sq. m

Fig. 3.2 Layout: The Living Tower versus the total area on land that can be produced and housed within one Tower with a footprint of 2000 sq. m . This is the required area to feed and house 200 people.

# LIVING TOWER



The Living Tower - 500 people, 15-20 Floors, footprint 2000 m<sup>2</sup>, 10 000 m<sup>2</sup> Living Area (30%)

Produce (in order of most sunlight required)	Area required for 500 people	Area in building (3 layers per floor)	Area on land (3x less crops a year)
Citrus Trees	75.0	75.0	225.0
Berries	1,680.0	560.0	5,040.0
Tomatoes	375.0	125.0	1,125.0
Onions	50.0	16.7	150.0
Peppers	208.0	69.3	624.0
Spinach	2,700.0	900.0	8,100.0
Potatoes	929.0	309.7	2,787.0
Chickens	1,574.5	524.8	4,723.5
Beans	2,150.0	716.7	6,450.0
Fish	56.5	18.8	169.5
Wheat	929.0	309.7	2,787.0
Lettuce	121.0	40.3	363.0
<b>Sub-total</b>	<b>10,848.0</b>	<b>3,666.0</b>	<b>32,544.0</b>
	footprint	2,000.0	32,544.0
Residential		20,000.0	200,000.0
<b>Total</b>		<b>23,666.0</b>	<b>232,544.0</b>
	footprint	2,000.0	232,544.0
Cattle	400,000(40 ha)		400,000(40 ha)

Table : This Table illustrates the difference between Area Required, the Area in the Tower required & The Area on open land required for the consumption and housing of 500 people. All areas in sq. m

Fig. 3.3 Layout: The Living Tower versus the total area on land that can be produced and housed within one Tower with a footprint of 2000 sq. m. This is the required area to feed and house 500 people.

# LIVING TOWER



Fig. 3.4 Layout: The Living Tower versus the total area on land that can be produced and housed within one Tower with a footprint of 2000 sq. m . This is the required area to feed and house 1000 people.

# LIVING TOWER

## Living Tower Energy Consumption vs. Energy Produced (kWh)

Source: World Resource Institute

	15 storeys [500 residents]	30 storeys [1000 residents]	45 storeys [1500 residents]	
<b>Energy Consumption</b>	<b>Residential</b> <small>South African energy consumption per capita</small>	1 880 000 <small>322 kgoe = 3760 kWh/year per capita</small>	3 758 000 <small>322 kgoe = 3760 kWh/year per capita</small>	5 640 000 <small>322 kgoe = 3760 kWh/year per capita</small>
	<b>Commercial &amp; Office</b>	1 260 000 <small>180 kWh/m<sup>2</sup> @ [7000m<sup>2</sup> Office &amp; Commercial space]</small>	2 160 000 <small>180 kWh/m<sup>2</sup> @ [12000m<sup>2</sup> Office &amp; Commercial space]</small>	3 060 000 <small>180 kWh/m<sup>2</sup> @ [17000m<sup>2</sup> Office &amp; Commercial space]</small>
	<b>Vertical Farm</b> <small>grow lights, water, filters, pumps, cooling</small>	1 027 150	2 054 300	3 100 000
	<b>Sub-Total</b>	<b>4 167 150</b>	<b>7 972 300</b>	<b>11 800 000</b>
<b>Energy Production</b>	<b>Wind Power</b>	700 <small>2 turbines = 600 kWh/yr</small>	1 000 <small>3 turbines = 1000 kWh/yr</small>	1 200 <small>4 turbines = 1200 kWh/yr</small>
	<b>Solar Power</b> <small>150W panels = 1m<sup>2</sup> = 6 kWh/day=2200 kWh/yr</small>	3 300 000 <small>2200 kWh/yr * 1500m<sup>2</sup> [area applied to façade]</small>	9 900 000 <small>2200 kWh/yr * 4000m<sup>2</sup> [area applied to façade]</small>	13 200 000 <small>2200 kWh/yr * 6000m<sup>2</sup> [area applied to façade]</small>
	<b>Anaerobic Digester</b> <small>Digest plant &amp; human waste -produce bio-gas &amp; heat</small>	561 966 <small>digest 6,000 kg of plant waste</small>	1 123 932 <small>digest 13,942 kg of plant waste</small>	1 685 898 <small>digest 20,000 kg of plant waste</small>
	<b>Sub-Total</b>	<b>3 862 666</b>	<b>11 024 932</b>	<b>14 887 098</b>
<b>Total</b>	<b>-304 484</b>	<b>3 052 632</b>	<b>3 087 098</b>	

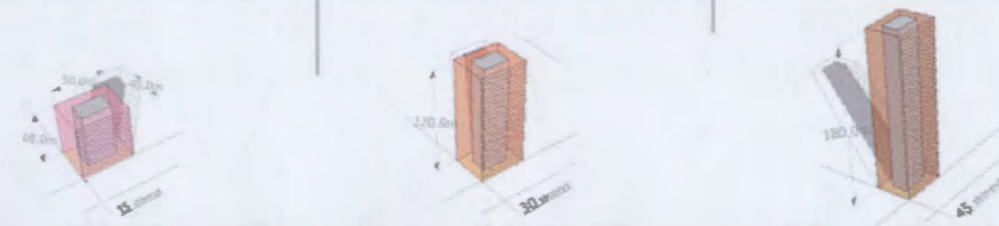


Fig. 3.5 The calculations in figure 3.5 indicate that the thirty storey LT would be the most sustainable in terms of the energy it gains, making it an energy efficient and positive entity in this context.

### 3.1.2 The Energy Consumed versus the Energy Generated within the LT.

The main energy consumers within the LT are the stacked greenhouses (vertical farm), the residents and the office users. Each of these are carefully calculated to find the total amount of energy consumed in the LT (see Fig. 3.5 for calculations). The source of these calculations was retrieved from the 'World Recourse Institute' website.

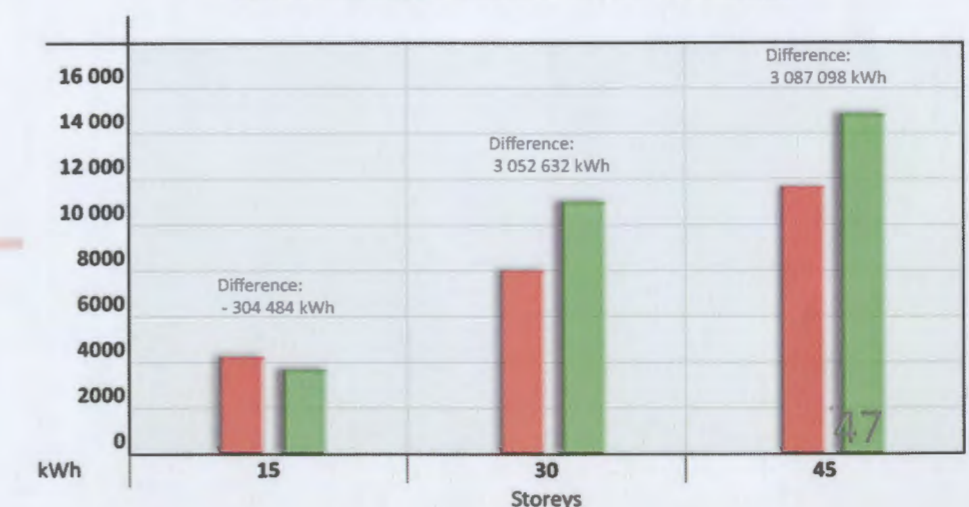
All the energy required for the vertical farm (plant growth, the aquaponics, pumping, filtrating as well as the whole production process of the crops) are added (Graff *n.d.*, p12, 13). The energy needed for the offices are determined by a square meter-age of office space and the same process for the apartments (WRI 2007).

The main energy generators are the wind turbines, the solar panels and the Anaerobic Digester (AD). As the tower height decreases, the façade area also decreases and less solar panels needs to be added and less wind turbines are used. The AD needs a certain amount of plant and human waste to work efficiently and be cost effective. According to the Vertical Farm Project website, the organic waste of 1000 people and more is effective for the AD (The Vertical Farm Project 2009).

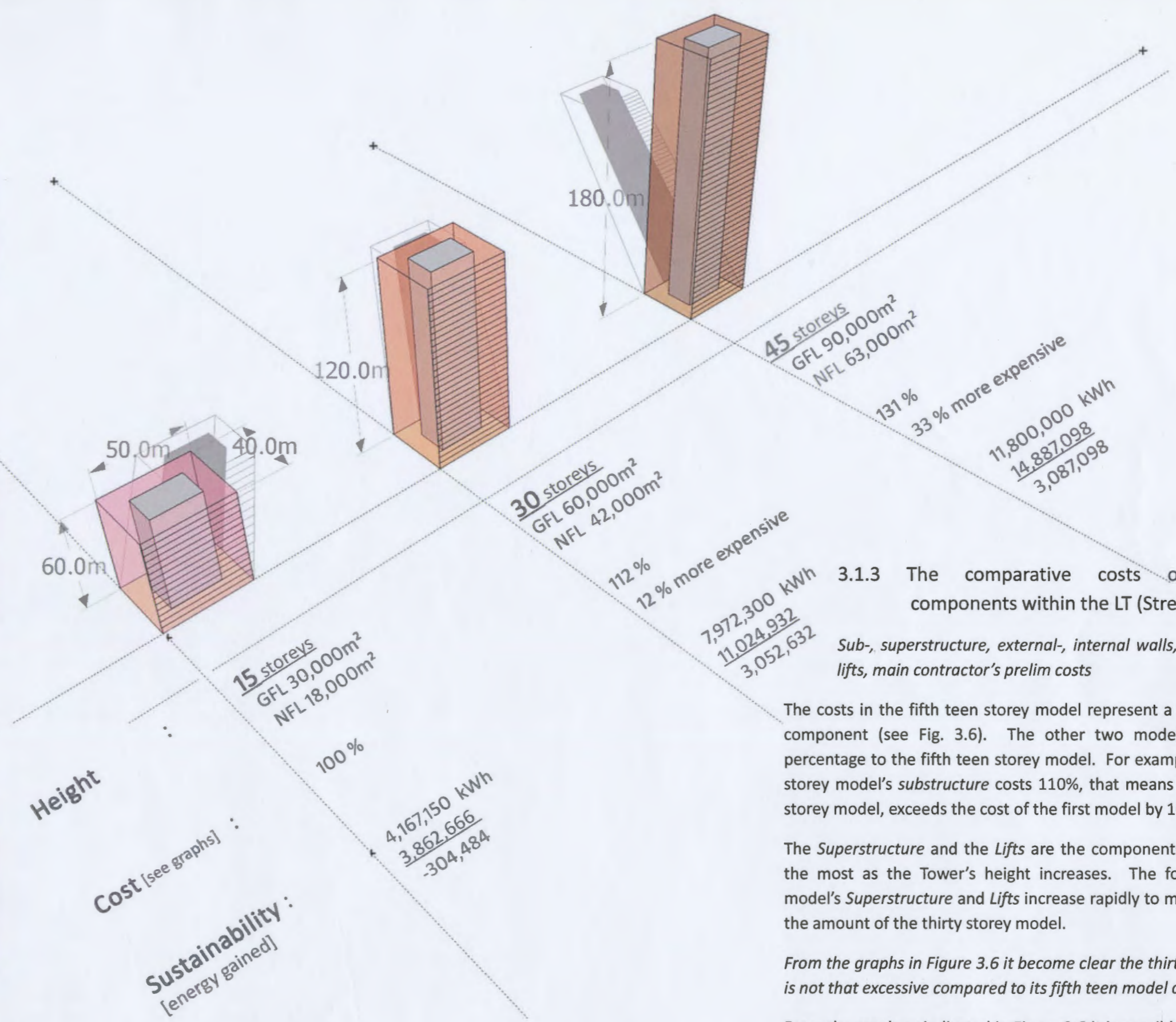
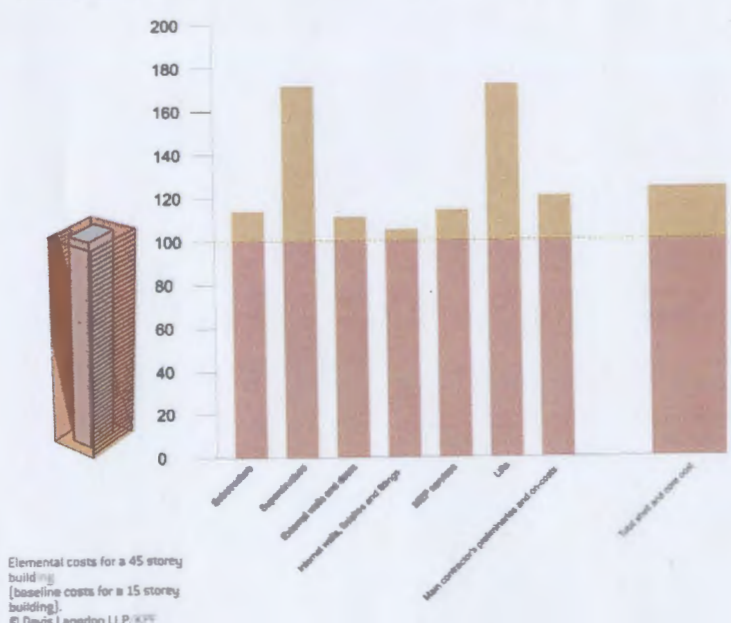
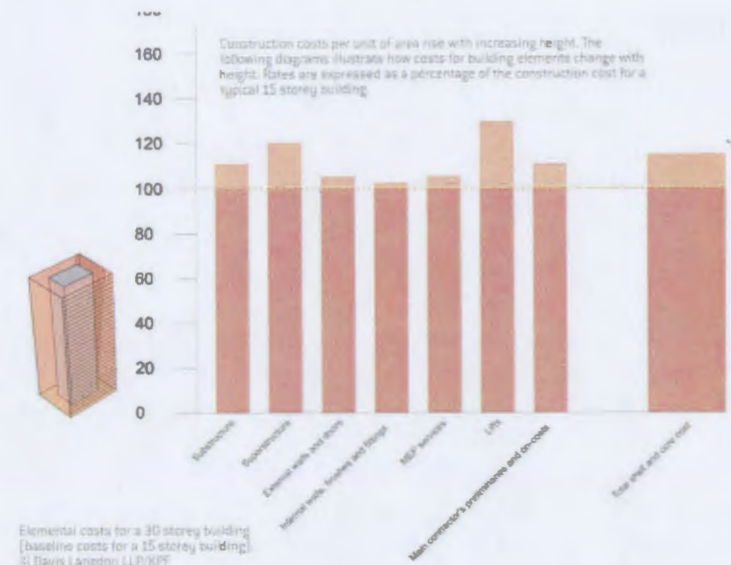
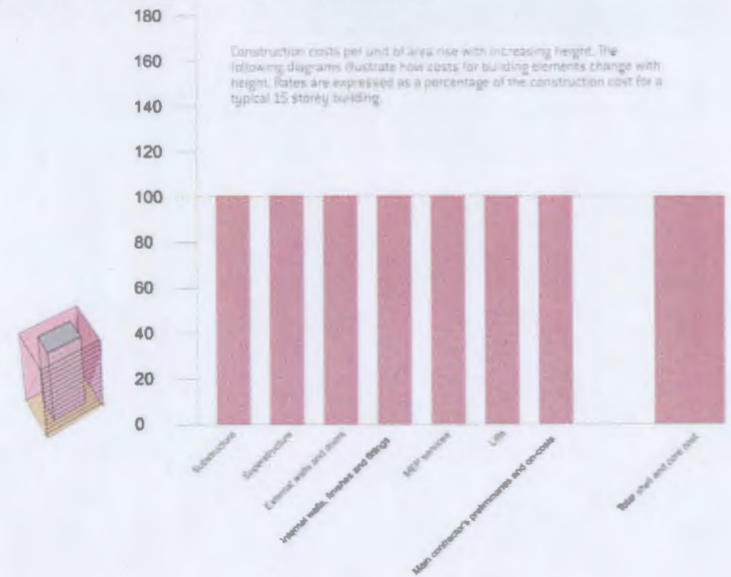
The calculations in figure 3.5 indicate that the thirty storey LT would be the most sustainable in terms of the energy it gains, making it an energy efficient and positive entity in this context.

The outcomes of these calculations suggest that it is imperative that a design focuses on the use of natural resources. Natural resources encourages a positive contribution to the environment and when they from an integral part of the design of a tower; it becomes possible for such a tower to be a complete self sustaining entity that will be an asset to its surrounding in terms of: energy and food production; reclaiming land for reforestation, repairing eco-systems and reserving parks and green spaces.

Energy Consumed versus Energy Produced



# LIVING TOWER



### 3.1.3 The comparative costs of different components within the LT (Strelitz 2005).

Sub-, superstructure, external-, internal walls, MEC services, lifts, main contractor's prelim costs

The costs in the fifth teen storey model represent a 100% for each component (see Fig. 3.6). The other two models compare in percentage to the fifth teen storey model. For example if the thirty storey model's *substructure* costs 110%, that means that the thirty storey model, exceeds the cost of the first model by 10%.

The *Superstructure* and the *Lifts* are the components that increase the most as the Tower's height increases. The forty-five storey model's *Superstructure* and *Lifts* increase rapidly to more than twice the amount of the thirty storey model.

From the graphs in Figure 3.6 it become clear the thirty storey model is not that excessive compared to its fifth teen model counterpart.

From the result as indicated in Figure 3.6 it is possible to argue with confidence that the thirty storey model is effective, sustainable, reclaim ample land and use optimal renewable resources. With the parameters in place, the design process will continue in the following section.

Fig. 3.6 From the graphs in figure 3.6 it become clear the thirty storey model is not that excessive compared to its fifth teen model counterpart.

# Section 4

*Spatial and graphical design explorations of the Living Tower.*

The design section is a graphical and spatial elaboration of the research findings in the previous sections. It uses conceptual models and sketches with supporting tables and diagrams to represent and demonstrate the innovative design idea more concisely.

The design of the LT calls for innovative, unprecedented design solutions to address the issue of higher living densities and ecologically friendly lifestyles, and to reduce the growing imbalances in our ecological system.

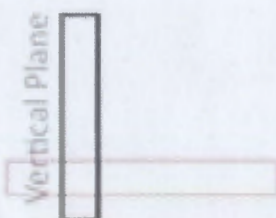
Many of the initial design considerations are derived from the calculations and research done to justify and validate the sustainability of the LT. Key site determinants such as valuable agricultural soils, ground water resources, ecological resources (bio-diversity corridors), protected natural areas (sensitive land) and scenic routes helped to narrow down the sites. These site determinants indicated that the urban edge of Durbanville was the most viable area for such a site. By further mapping bio diversity corridors, potential agricultural land, sensitive land, reserves and parks with GIS technology the ideal ecological friendly area for a LT was located just off the M58, Adderley Road at Vierlanden, Durbanville.

Other design considerations from the research findings are the responds to the local climatic conditions and how that would shape the tower. For instance, the sun-, wind-, and slope directions shape the facades and building direction for optimum sunlight gain and aerodynamic qualities against prevailing winds.

The design section illustrates the collaboration and the amalgamation of elements like the atrium, greenhouses, sky-courts and other renewable energy sources to secure a fully and well integrated self-sustaining entity referred to in this study as the LT.

The key goal of the LT is to respond to the environmental issues mentioned, through repairing our damaged eco-system by creating an integrated lifestyle. It is a lifestyle where different functions collaborate within a specific area and where mixed-used and social activities thrive. It also brings the natural-, human- and build environments together in activities such as farming, high density living, office spaces, education places, markets, retail and other social environments.

The holistic planning approach of the LT, values the principles that are set out, therefore careful design strategies are followed and many options are explored to successfully achieve a well balance system.



# LIVING TOWER

## Urban Edge Boundary - Determined by:

- valuable soils - for agriculture & mining
- ground water resources
- ecological resources - biodiversity corridors
- protected natural areas - sensitive land
- high potential agricultural resources & activities areas
- cultural & heritage resource area
- scenic routes - tourism significance
- visual sensitivity - skyline, ridgeline, hilltops

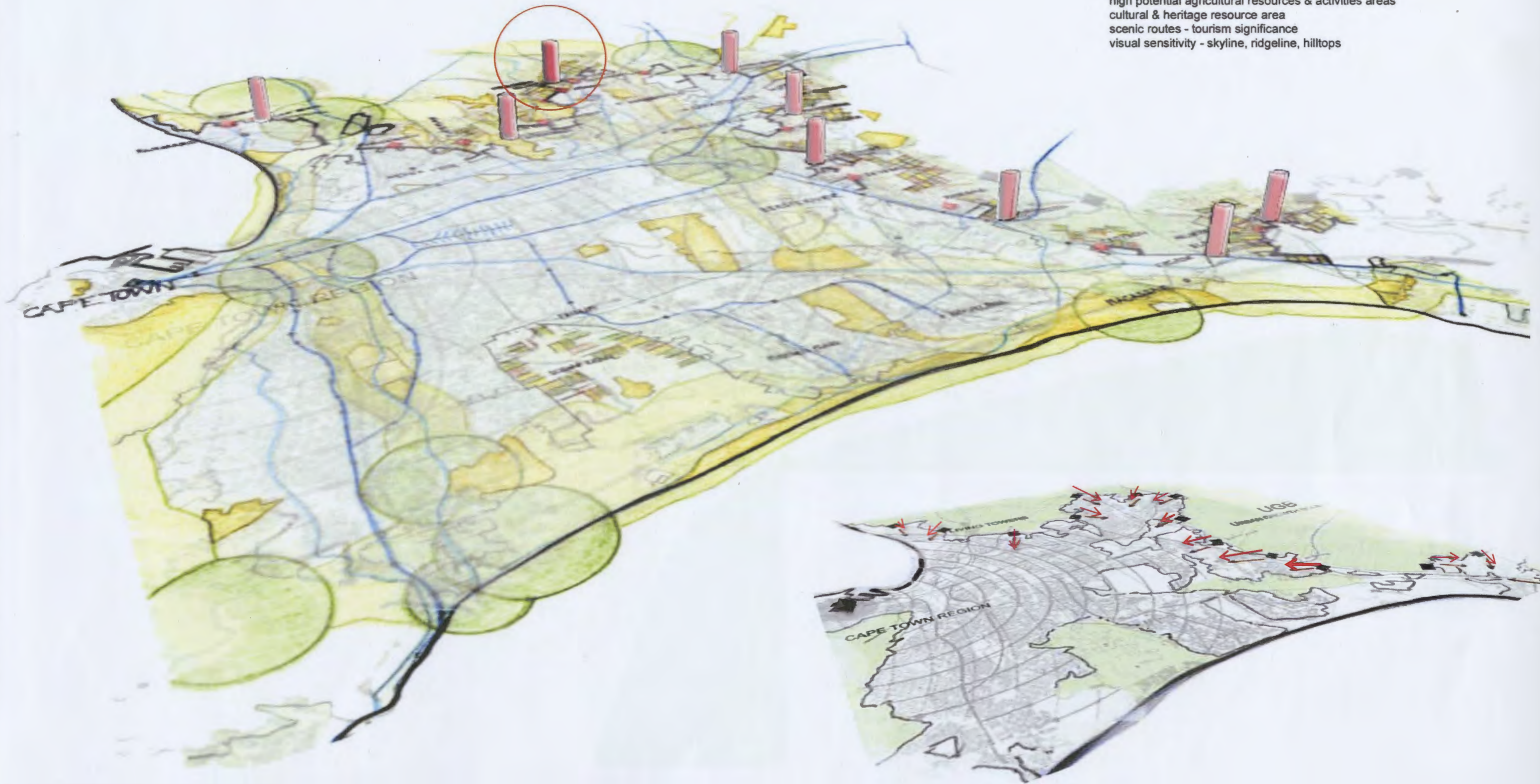
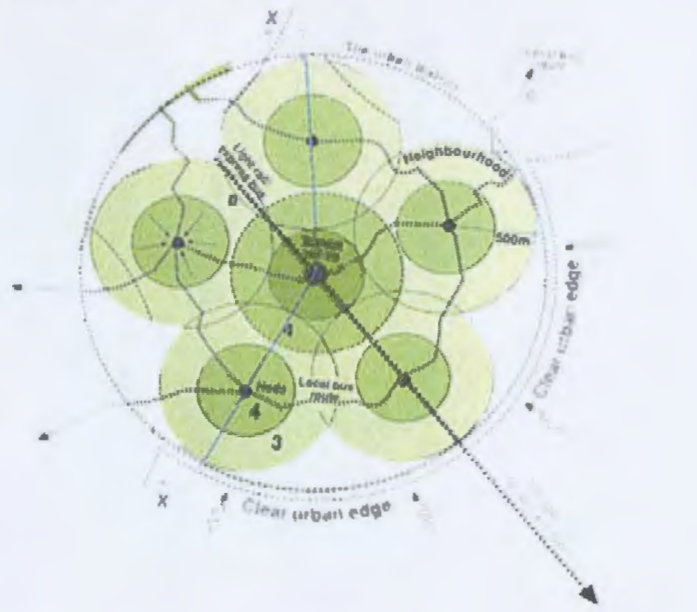


Fig. 4.1 The current Urban Edge Boundary Line, indicating the sprawling across sensitive and valuable arable land without noticing, suggested by Living Towers as a concrete line to which sprawling bounce off and return to the City centre. Key determinants for the site choices were; the periphery of urban sprawl, the border of biodiversity networks, the border of the dense low-rise build-fabric, transportation hubs and where valuable arable land has been lost due to sprawling. Drawing by author.

# LIVING TOWER



**A clear movement hierarchy from city centre to the home**



a 'Living City' proposal.  
The boundaries and growth developer are clearly determined by the ecological resources in and around the area. This type of suburb is centred around a distinct boundary, ecological or man-made. These images represent the type of growth development that can be expected for the future. The result is a compact, self-sustain friendly living environment.



## GIS Mapping:

The mapping of all the ecological resources, the protected and sensitive land became an integral part in setting out boundaries for designated development areas. The Durbanville street grid has developed over reserves, bio diversity corridors and highly potential agricultural land.

The GIS (Geographic Information System) mapping indicates that most of the developed land of Durbanville are potential arable land therefore the idea of compacting the suburb into high living density towers makes all the more sense which then provides the opportunity for vast deforestation, agricultural production, reserves, parks and repairing the damaged eco system.

“Particularly in site planning, we must first understand the properties of the locality’s ecosystem before imposing any intended human activity upon it”(Richard 2007, p.24).

Fig. 4.2 Durbanville and Bellville region mapped. On the left is a representation of the Living City on the periphery of Durbanville. The model is based on the work of the Urban Task Force in the UK with the help of Richard Rogers. Mapping by author. (Task Force 1999, *Towards an Urban Renaissance*, Crown Copyright, London)

“The ecological resource were mapped and defined pockets to where the ideal site for developments would be without harming the sensitive, protected land”

# LIVING TOWER



## The Site:

The 10 ha Site is located on the periphery of Durbanville just outside Vierlanden, called Phisantekraal. The M58, Adderley Road pass nearby the steep north facing site viewing over the marvellous Hottentotts Holland Mountain range as well as the rolling Durbanville Hills.



Fig. 4.3 The location of the site is near the urban edge boundary line on the North Western part of Durbanville.

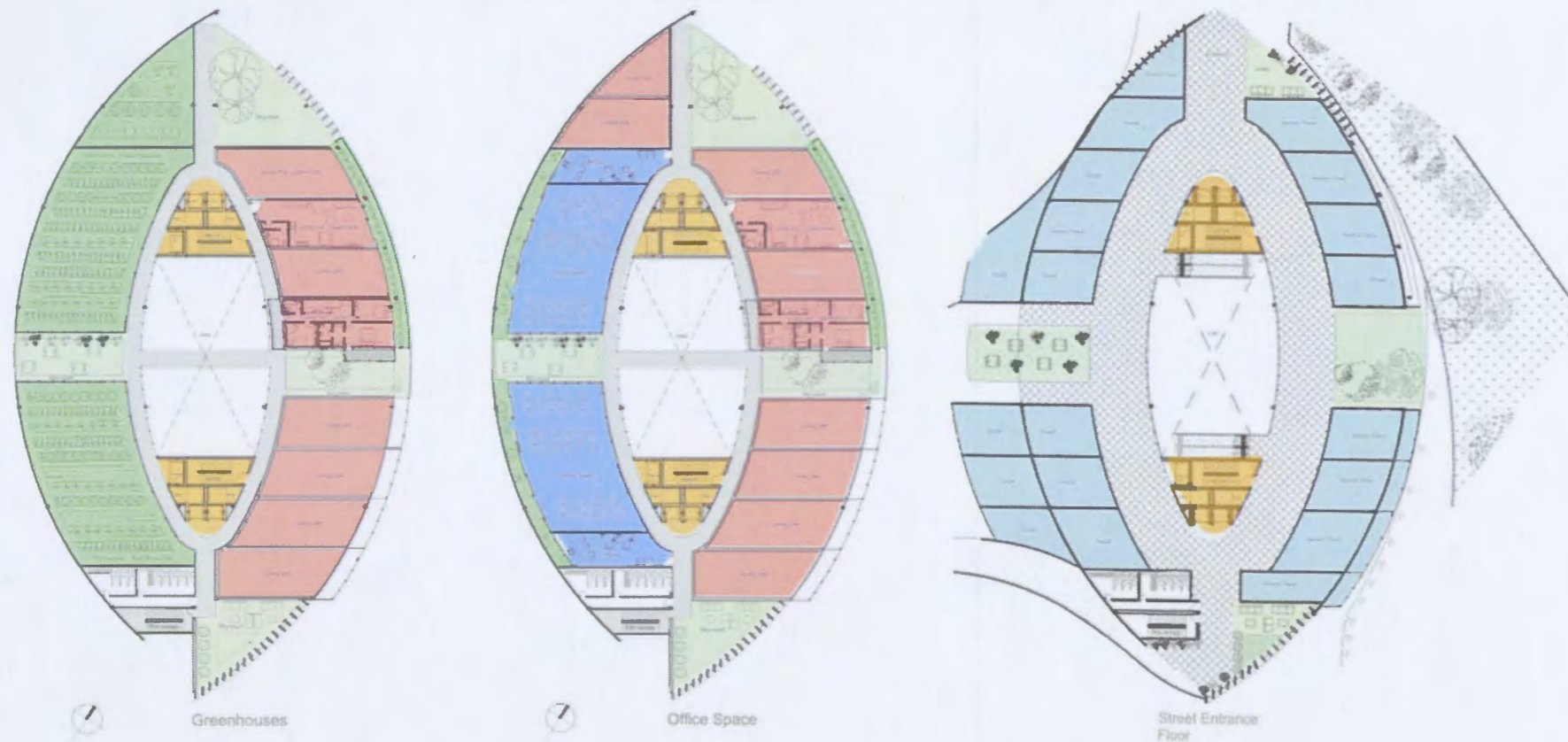
# LIVING TOWER



Fig. 4.4 A Panoramic view across the site (bottom left) showcases the pristine beauty of the landscape and to the far right the low density sprawling are visible. The site is located on the Urban Edge Boundary line to become a prominent suggestion of the edge and to contain, control and re-direct development towards the City centre. The site slope down towards the Phisante Kraal dam. This is the lowest area amongst the rolling Durbanville hills. The Hottentots Holland mountain range in the back drop complete the picture perfect location.



# LIVING TOWER



## The Living Tower - 1000 residents

### Overall Spatial Requirements

Type	number of floors	area per floor m <sup>2</sup>	total area m <sup>2</sup>	perc. of building %	total units	net floor area m <sup>2</sup>	gross floor area m <sup>2</sup>	percentage of gross floor area %	percentage of net floor area %
Living Space (apartments)	30	500	30000	43%	250	1300	1900	26%	38%
Agricultural Space	20	700	14000	20%				37%	54%
Office Space	8	700	11200	16%				37%	54%
Supermarket/Retail	2	1050	1550	2%				55%	81%
Production Space	2	1000	1000	1%				53%	77%
Equipment Library	1	500	500	1%		800	3000	26%	38%
Restaurant/Education Point	1	800	800	1%				42%	62%
Storage	3	250	750	1%				13%	19%
Service Core	35	180	6300	9%				9%	14%
Parking Space (basement)	3	5000	18000	26%		5000	6000	83%	
Service Floors	3	1300	3900	6%		1300	1900	68%	
<b>Total</b>	<b>35</b>		<b>70000</b>						

### Initial Design Principles:

- Balance between City, Nature & Humans.
- Higher and healthier density living - a mixed used and multi-scaled planning.
- Reclaimed land, parks, arable land and reserves
- Human and interactive landscape
- Cluster of activities in a area nurtures social interaction
- Treatment of ground plane
- Grows out of landscape and becomes part of surrounding nature.

The design of the tower focuses on restoring the balance between nature and human as well as repairing the damaged eco system in the long term. Bringing daily functions of life together: work with play with food.

### The Living Tower:

- Localizing the production of food,
- The generation of energy,
- The processing of food

### Programme Schedule:

The activities include living-, office-, retail-, lobby-, production spaces as well as agricultural production (greenhouses). The location of these activities are mainly influenced by the outside climatic conditions.

Durbanville has a Mediterranean climate, which include hot and dry summers and cold to mild rainy winters. The Living spaces are located towards North for most sunlight (see fig. 4.6) whereas the greenhouses predominantly face West/South because the greenhouses can build heat up quickly with the glazed facades as well as working with artificial 'grow' lights.

Fig. 4.5 Accommodation schedule indicating the Gross Floor Area and Net Floor Areas of the different programs.

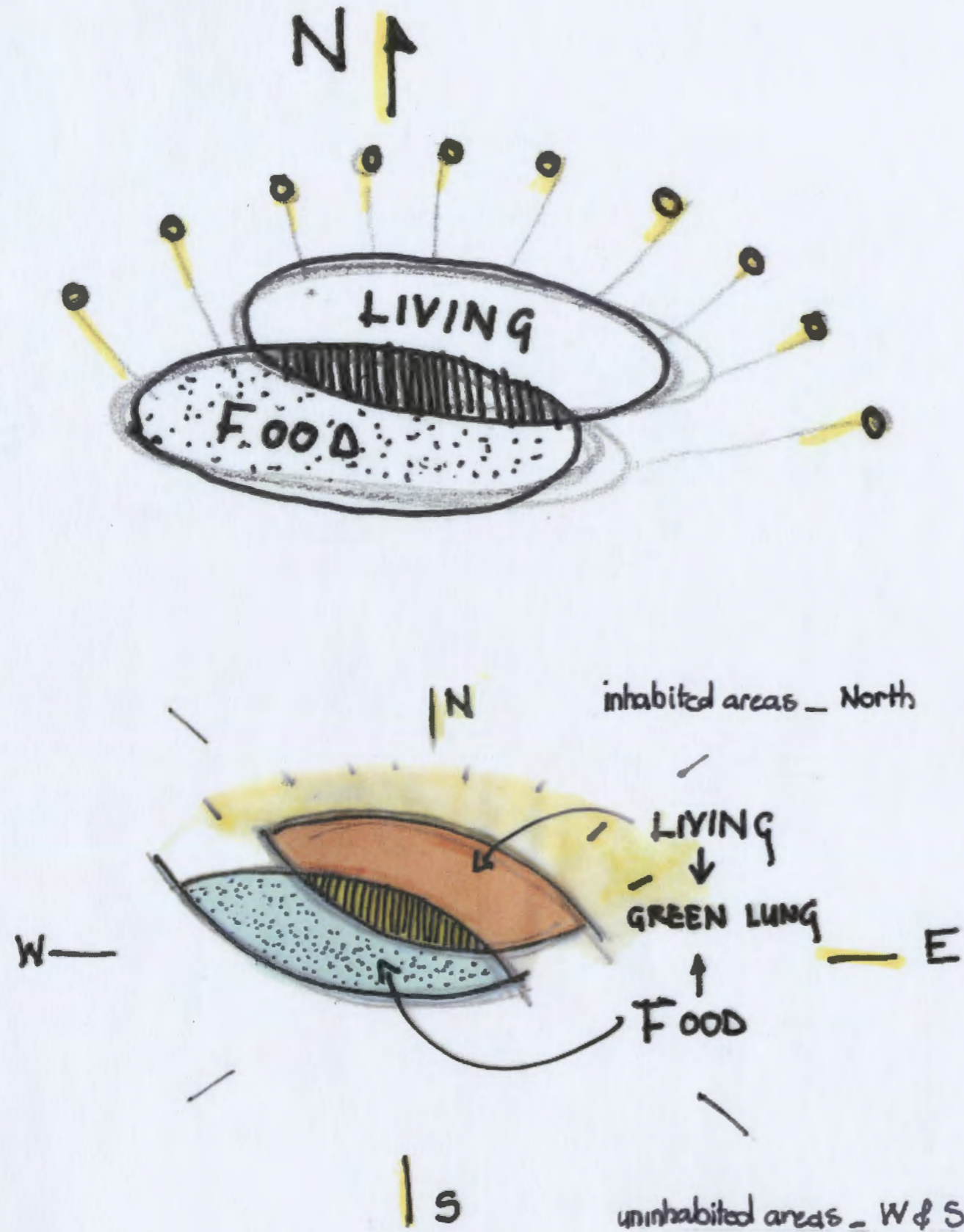


Fig. 4.6 Conceptual explorations of the local climatic conditions.  
Drawings by author.

## 4.1 Important design considerations

### 4.1.1 The Core Design

The core design is a significant part of the planning scheme especially in a high-rise building as loads and vertical circulation increases considerably as the height of the building increases. The elongated oval shaped plan requires a central core that includes other structural components closer to the periphery of the plan.

The idea of splitting the core into two is derived from various programmes within the building serving different functions as well as helping to achieve better structural performance throughout the whole building (see Fig. 4.11). "Dividing elevators into groups to serve different zones makes a positive contribution" (Strelitz 2005, p.34). Shear walls on either end of the building support the core structural component from lateral and seismic forces (see Fig. 4.12).

The KONE Elevator program calculates the amount of elevators required for the number of users, the building height, the floor size, the floor height and its frequency of occupancy. For a 1000 residents, a 120m tall structure and a 7000 square meter office space the number of lifts average 10. The two lift-banks created, serve the offices and the residents with the agricultural production (greenhouses) respectively:

Two 1500kg good lifts in each bank open toward the greenhouses, including the podium production plan where all the produce are sorted, packaged, stored and distributed to the fresh-market, restaurant or exported outside.

Two fireman's lifts and staircases are separated in the plan, according to official average human reaching distance in case of a fire event.

### 4.1.2 The Shape

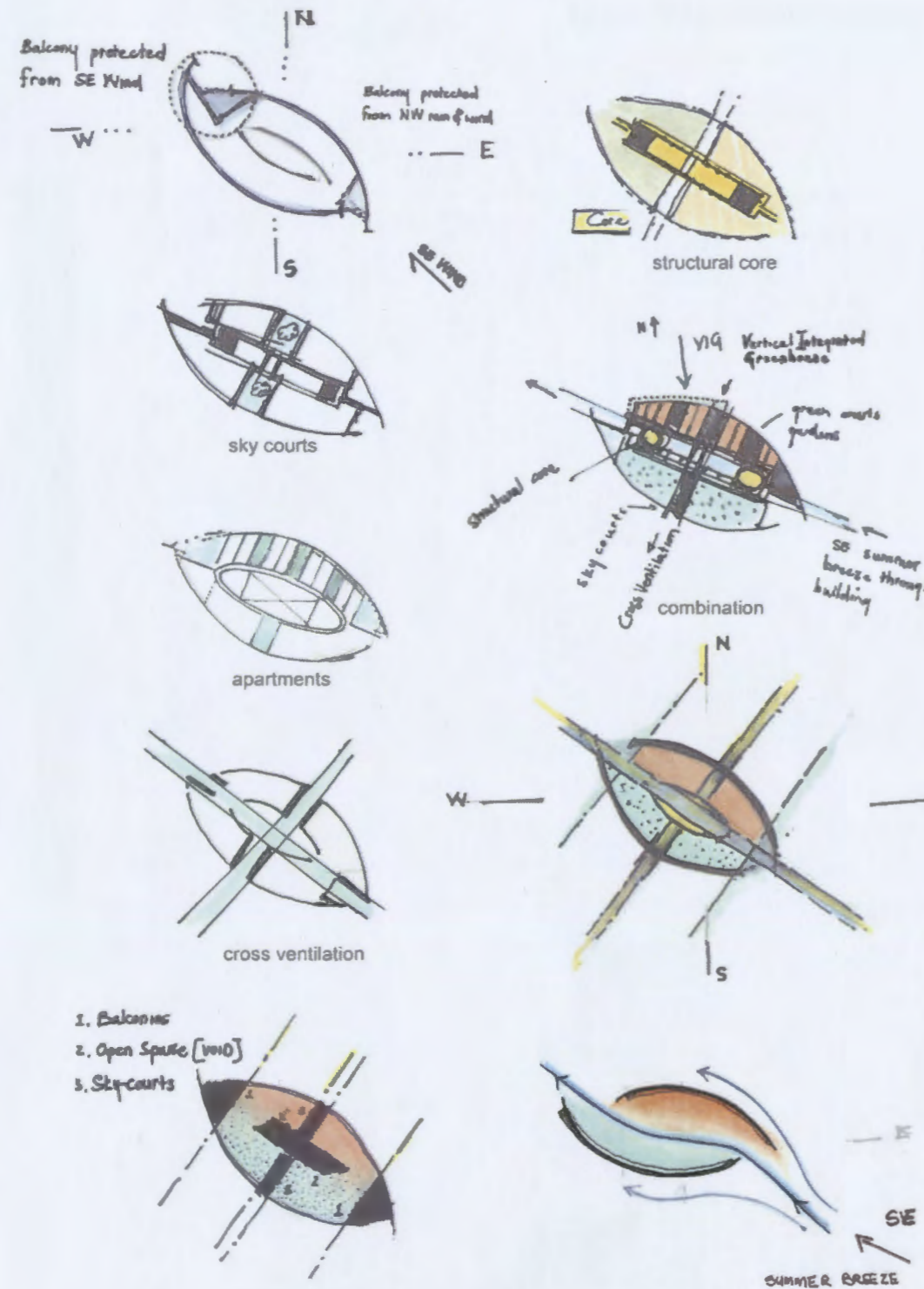
The design specializes in making a tall building as ecological and human friendly as possible; a lifestyle that is re-integrated with nature, where natural resources thrive and where the build environment respond to the user in spatial and functional terms.

Climatic conditions at the site as well as the research findings from the previous sections, are the two major elements that influenced and directly shaped the formal qualities and the positioning of programme in the LT. The building responds to the sun- (see Fig. 4.7), wind- (see Fig. 4.7) and slope direction of the site.

Comfort- and ergonomic design, shape the lifestyle that the LT offers and the design and location of the living units therefore receive first priority in planning. The majority of the North side are exposed to sun and light and will be controlled through elements such as solar panels, sunscreens, overhangs and vertically integrated greenhouses incorporated in the façade design, to achieve the most satisfied comfort all year round.

# LIVING TOWER

## Conceptual:



The stacked greenhouses are all located on the South and West façade. The plants that bear fruit require the most direct sunlight (for instance citrus trees and berry plants) and will face North, North-West and West and will be located on the higher levels in the Tower. The leaf plants require no direct sunlight and grow well under artificial 'grow' lights.

The shape was also determined by important functions such as the central atrium space surrounded by the greenhouses and the apartments. The facades are shaped to achieve optimum exposure to sunlight as well as an aero dynamic quality that channels strong South-Easter and North-Wester winds, hence the two elongated oval shaped facades that meet at the ends (see Fig. 4.7).

### 4.1.3 The Atrium

The incorporation of the Atrium located at the heart of the plan has the same function as a breathing lung in a body. The oxygen that the stacked greenhouses produce (through the plants) and the carbon dioxide produced by the humans from the living units ventilate toward the central void where the air meet and exchange in order to provide the users with ample oxygen.

The Atrium is also used to control the internal temperature that will naturally ensure that the necessary comfort levels are maintained. Greenhouses and build massing store heat and during winter season operable louvers at the top of the atrium are closed to accumulate hot air for circulation through the building (see Fig. 4.13). The opposite effect is achieved during summer when louvers are kept open for hot air to escape at the top of the atrium through a 'thermal chimney effect' when hot air rises and induce cool air through cross ventilation (see Fig. 4.14).

### 4.1.4 Greenhouses

The Greenhouse design focuses on adaptability and flexibility in order to change produce- or programme type if required. This focus is achieved through various different volumes of greenhouses, where the plants will be supported by a scaffolding type structure that allows free ventilation, movement and flexibility.

Air flow and temperature control in a greenhouse are the most important aspects for successful crop production and well ventilated buildings. Careful design considerations were applied in terms of continuous natural ventilation through extensive operable louver design, evaporative coolers and through passive system modes such as the stack affect (see Fig. 4.14).

Fig. 4.7 Conceptual diagrams: exploring climatic design issues, to enable the best performance for the climatic conditions of Durbanville. Spatial and formal considerations are also explored. These diagrams investigate the perfect positions and angles for the most economic and sustainable energy use. It focuses on using maximum natural energy in order to sustain the building.

# LIVING TOWER

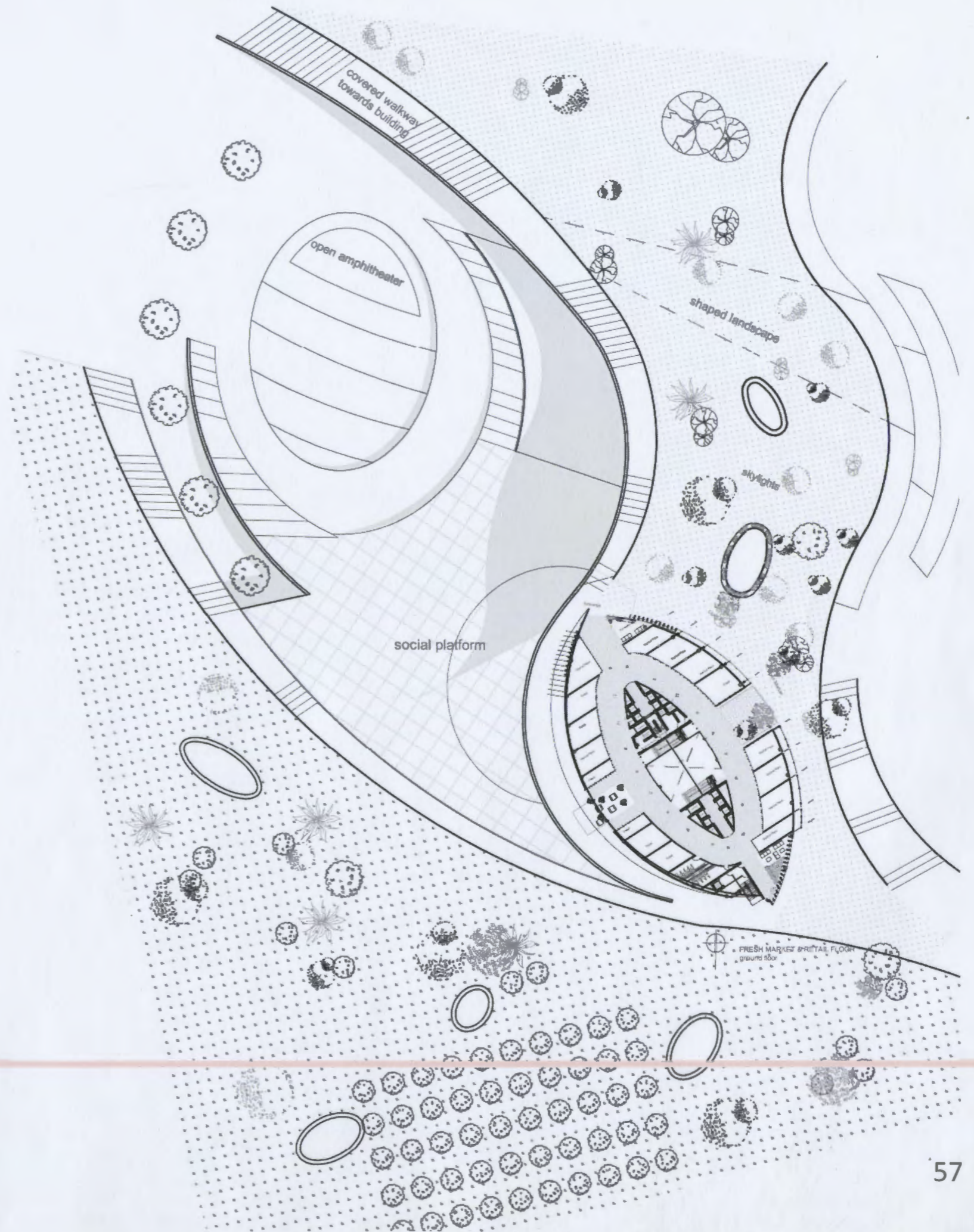
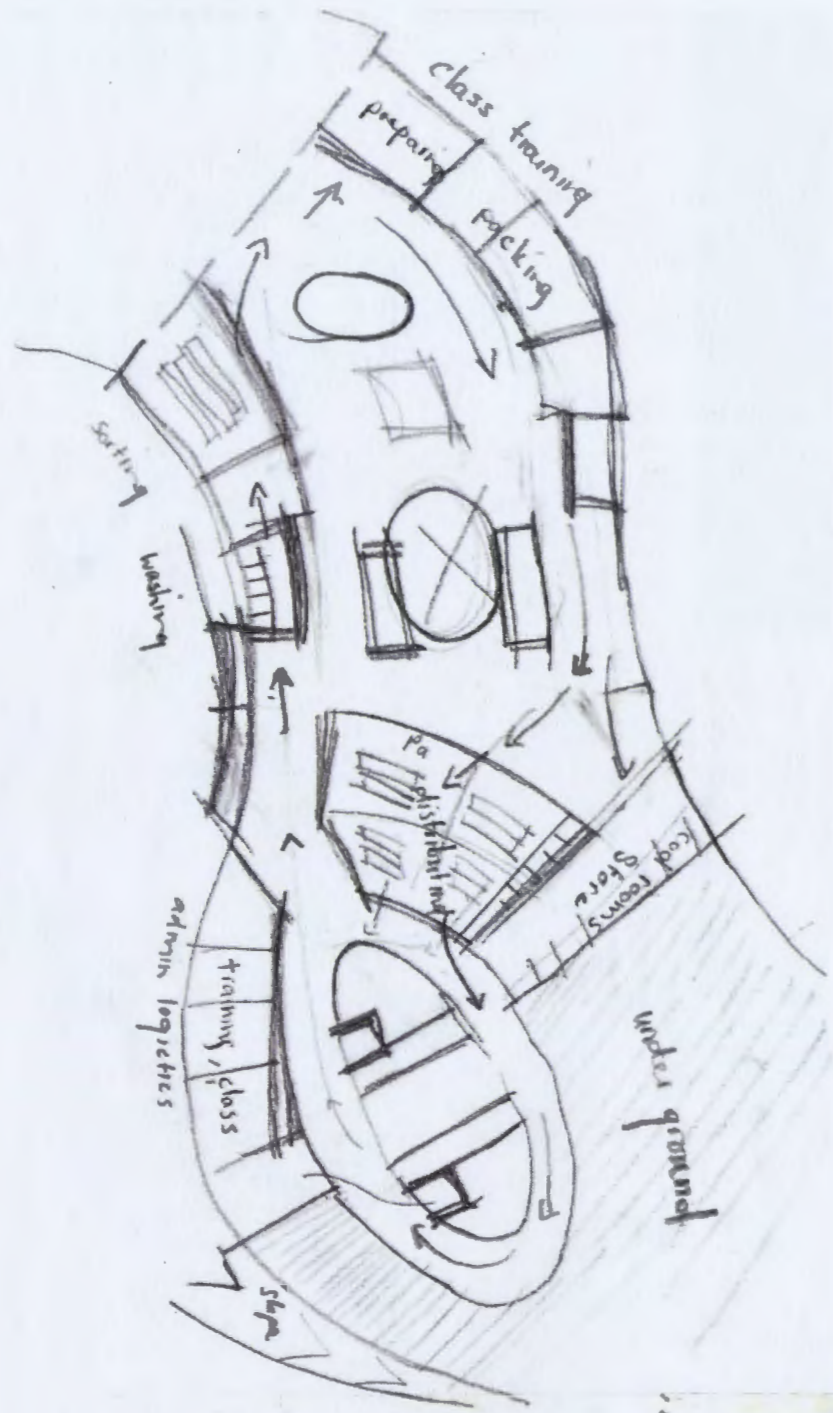


Fig. 4.8 Plans of the Living Tower. Production plan and ground plan. Drawing by author.

# LIVING TOWER

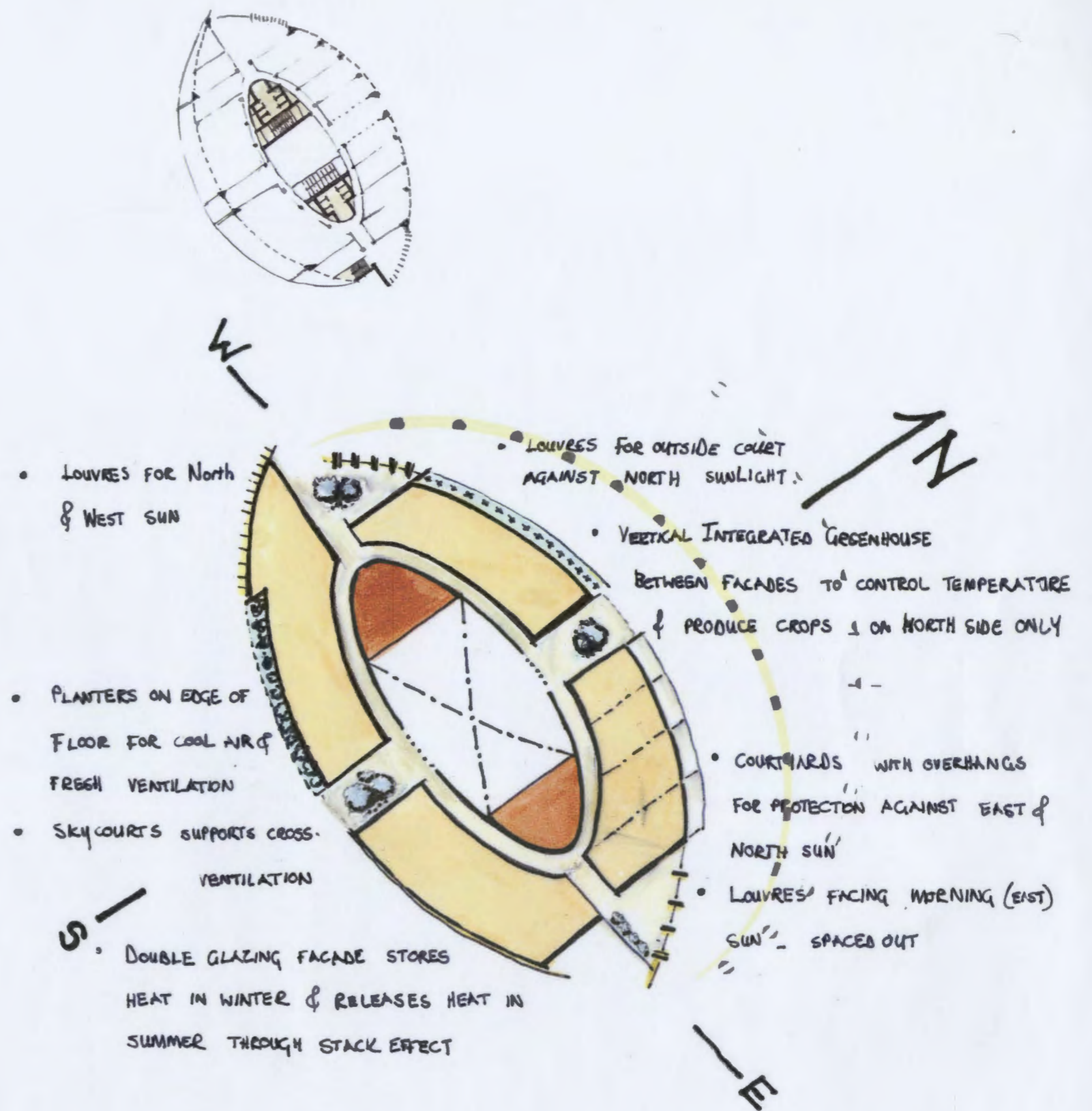
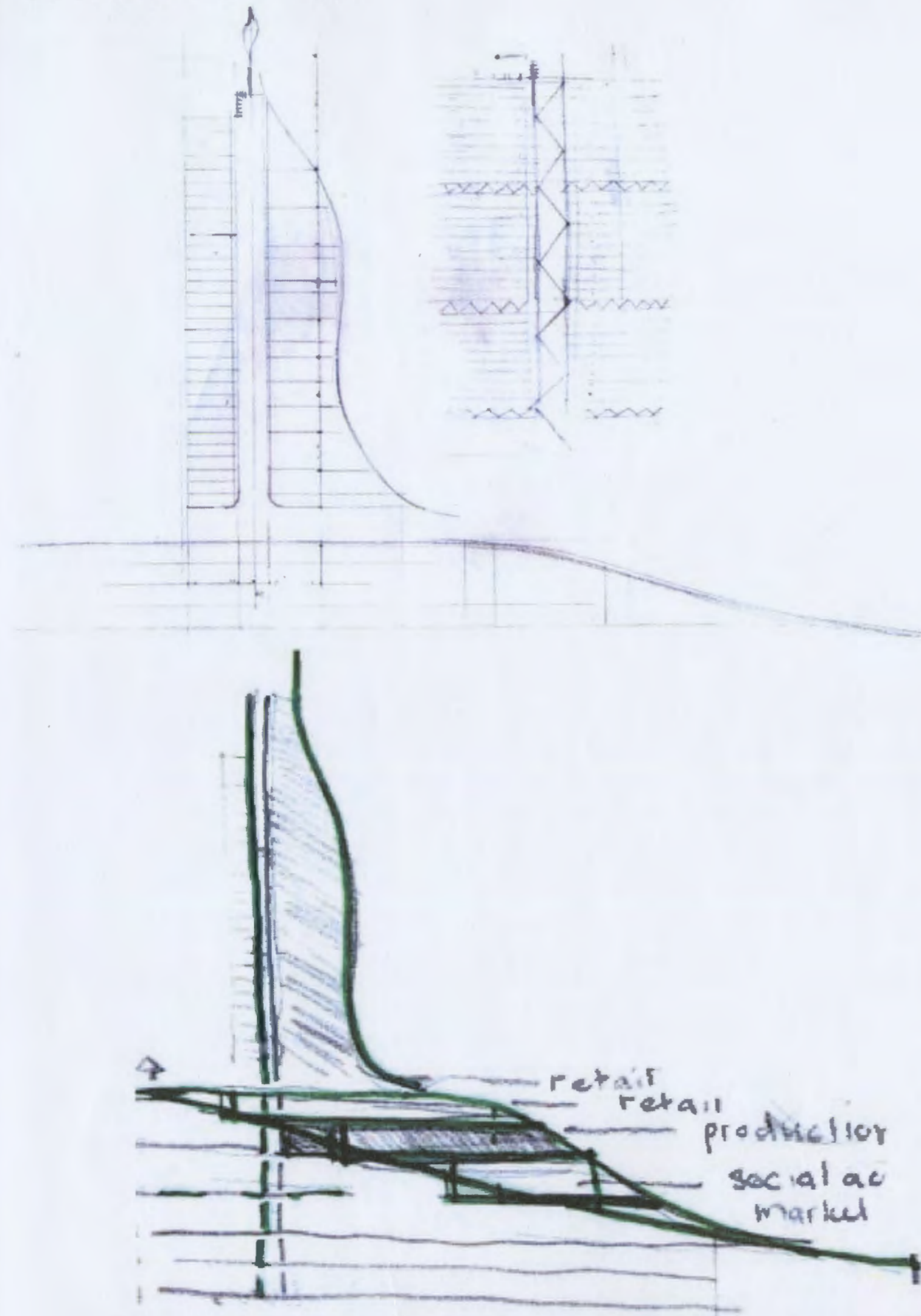
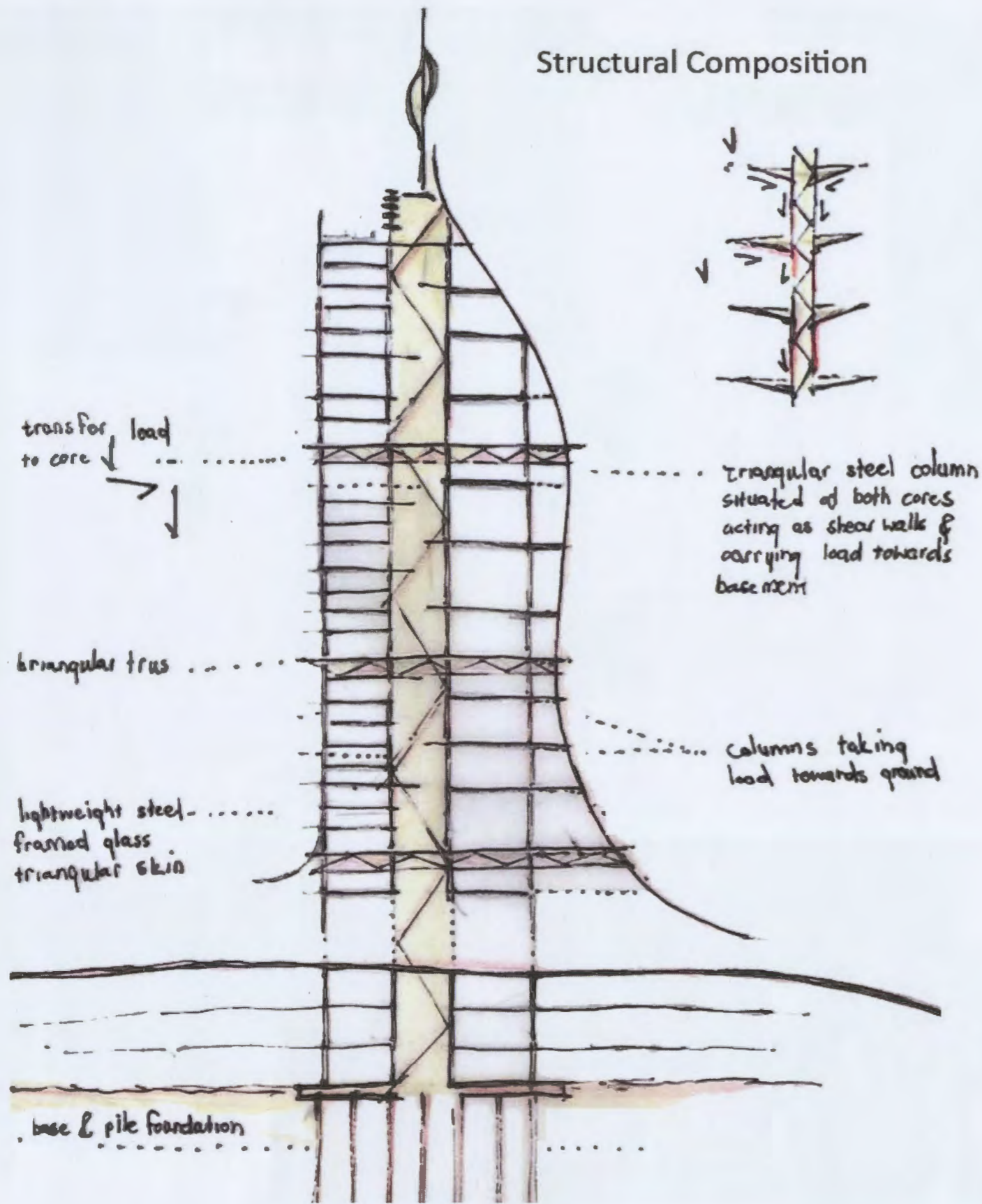


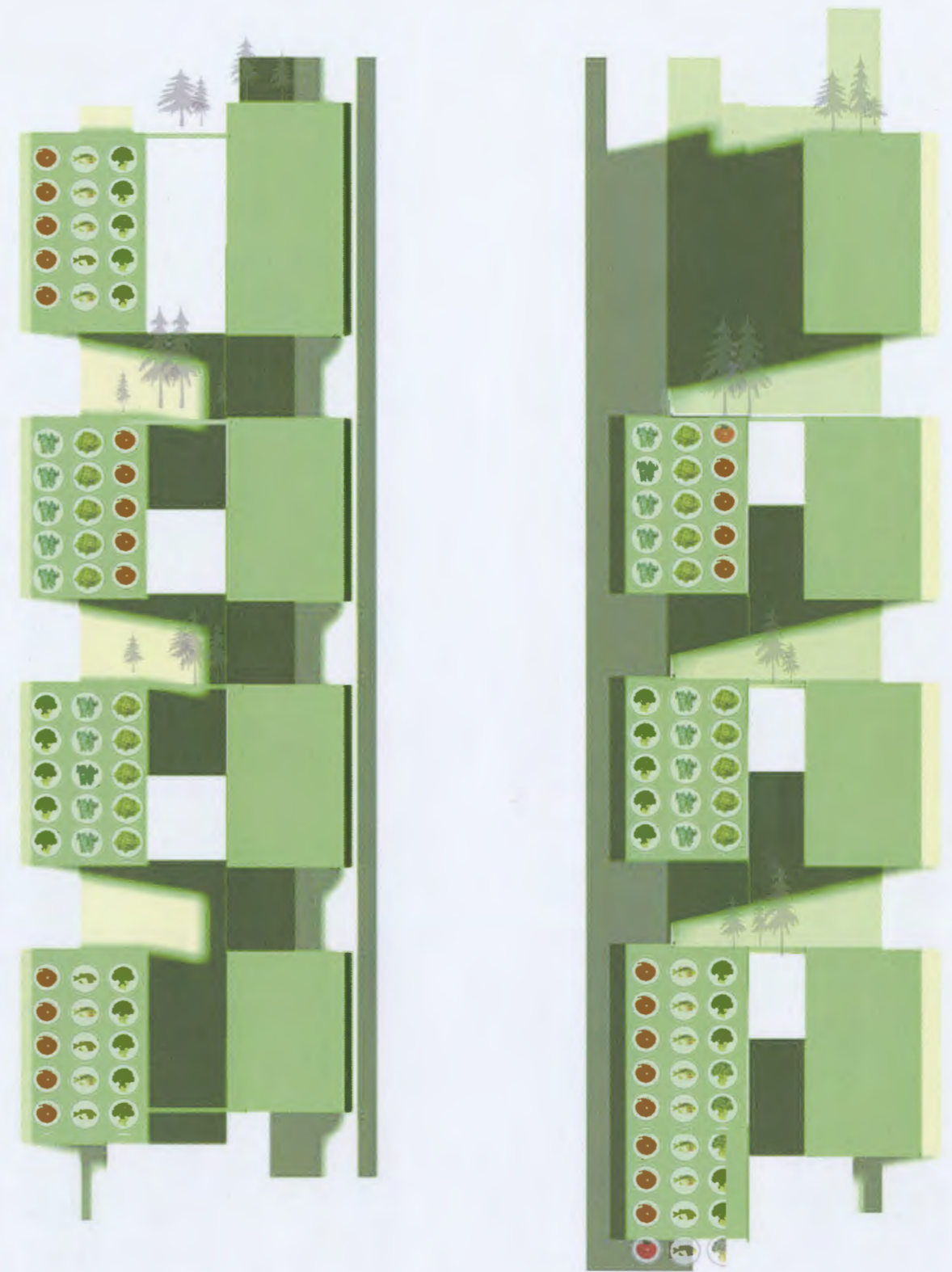
Fig. 4.9 These sectional sketches indicate the elegant growth of the shape out of the local landscape. The curve ends at the top of the tower at the wind turbines which use the drift to generate more energy. The figure to the right illustrate the different systems employed against the climatic impact on the building. Drawing by author.

# LIVING TOWER

## Structural Composition



## Sunlight entering the centre of the building



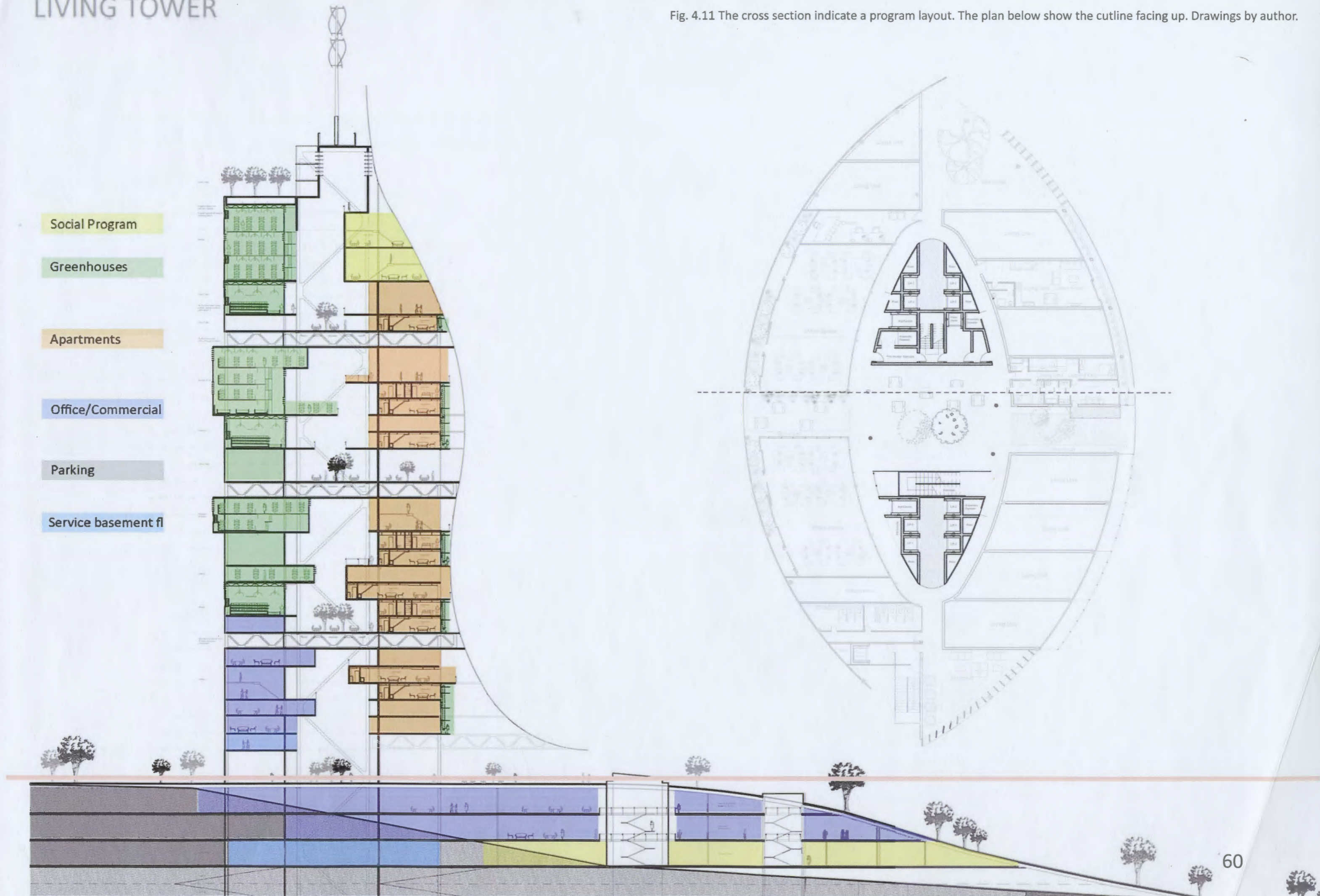
Summer sun into atrium facing west

Winter sun into atrium facing north

Fig. 4.10 A composition of the structural assembly carrying loads towards the foundation. On the Right, a sun-diagram in different seasons display the entree of sunlight into the building. Drawing by author.

# LIVING TOWER

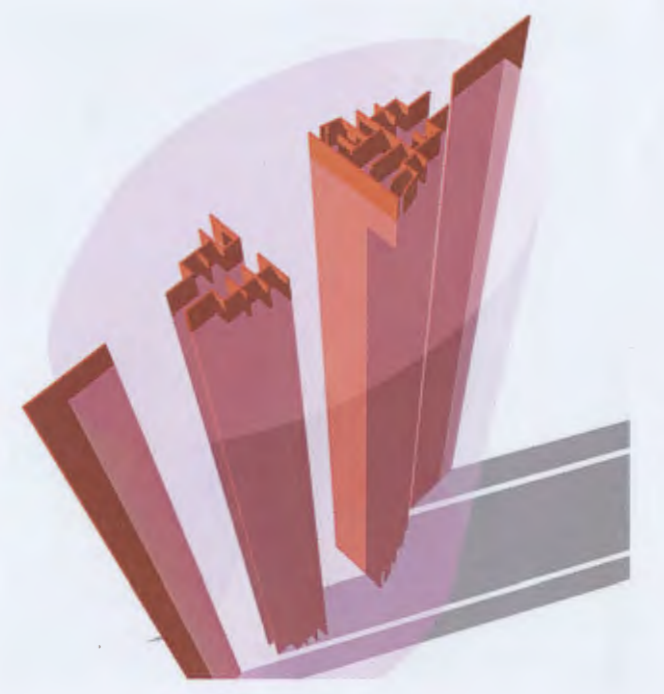
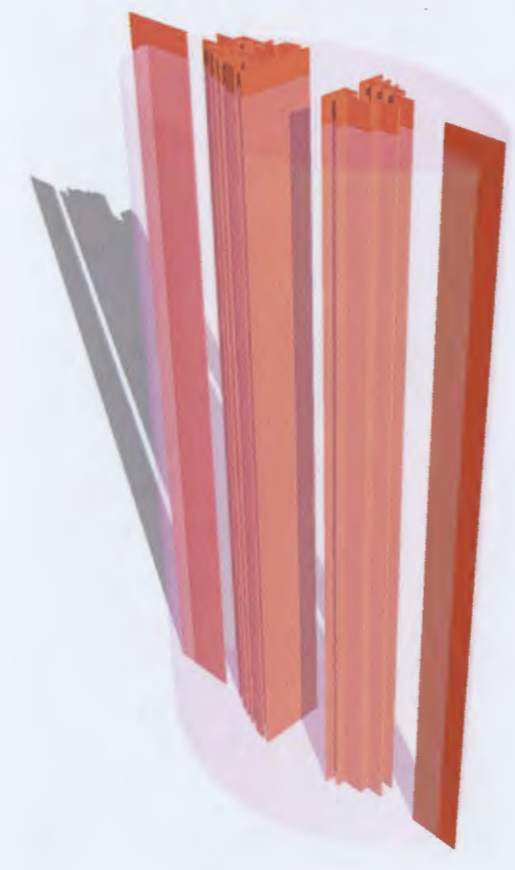
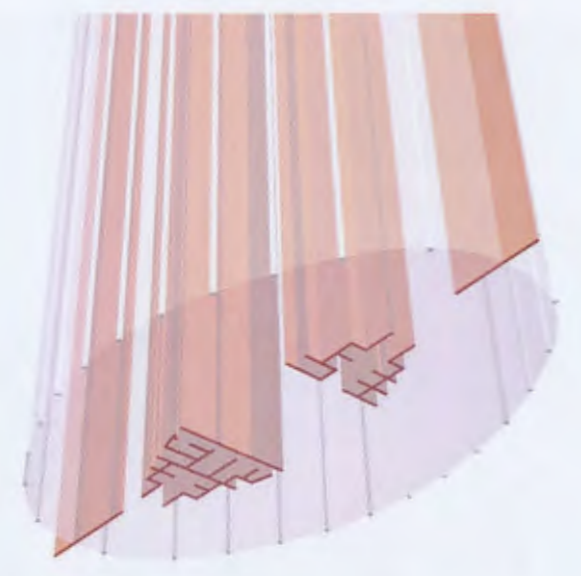
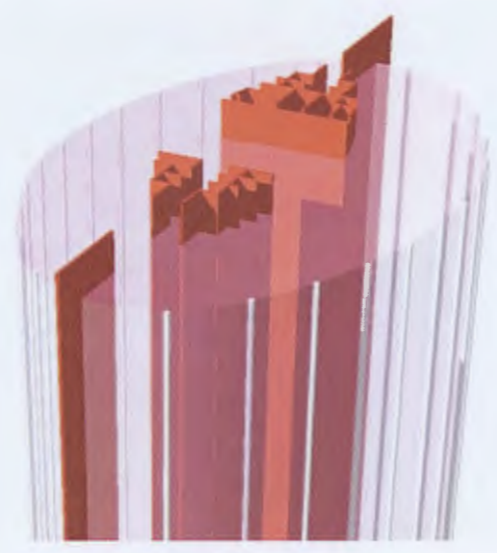
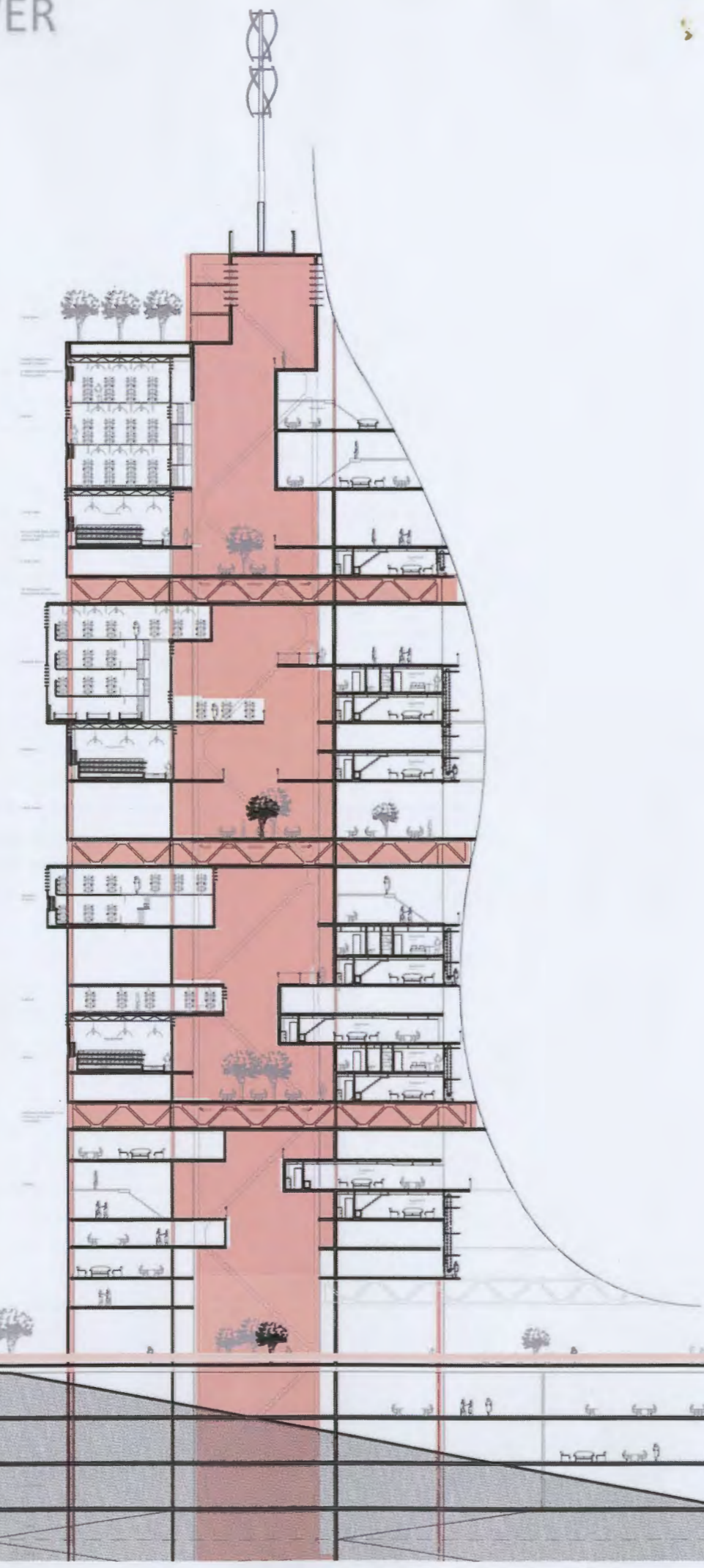
Fig. 4.11 The cross section indicate a program layout. The plan below show the cutline facing up. Drawings by author.



# LIVING TOWER

Fig. 4.12 The structural composition: composed of the central core, the shear walls and the columns on the periphery of the plan. The sketches below explore this compositions from all angles. Drawings by author.

Structure



# LIVING TOWER

## WINTER

Warm air rises, which causes a rising updraft toward the roof, and in turn induces cool air from outside to cross-ventilate the building into the atrium. The hot air that is captured circulates within the atrium space and heats the building. The large thermal mass (the material of the apartment building) accumulates heat during the day and releases it at night. The manually operable windows at the ceiling remain shut to prevent warm air from escaping.

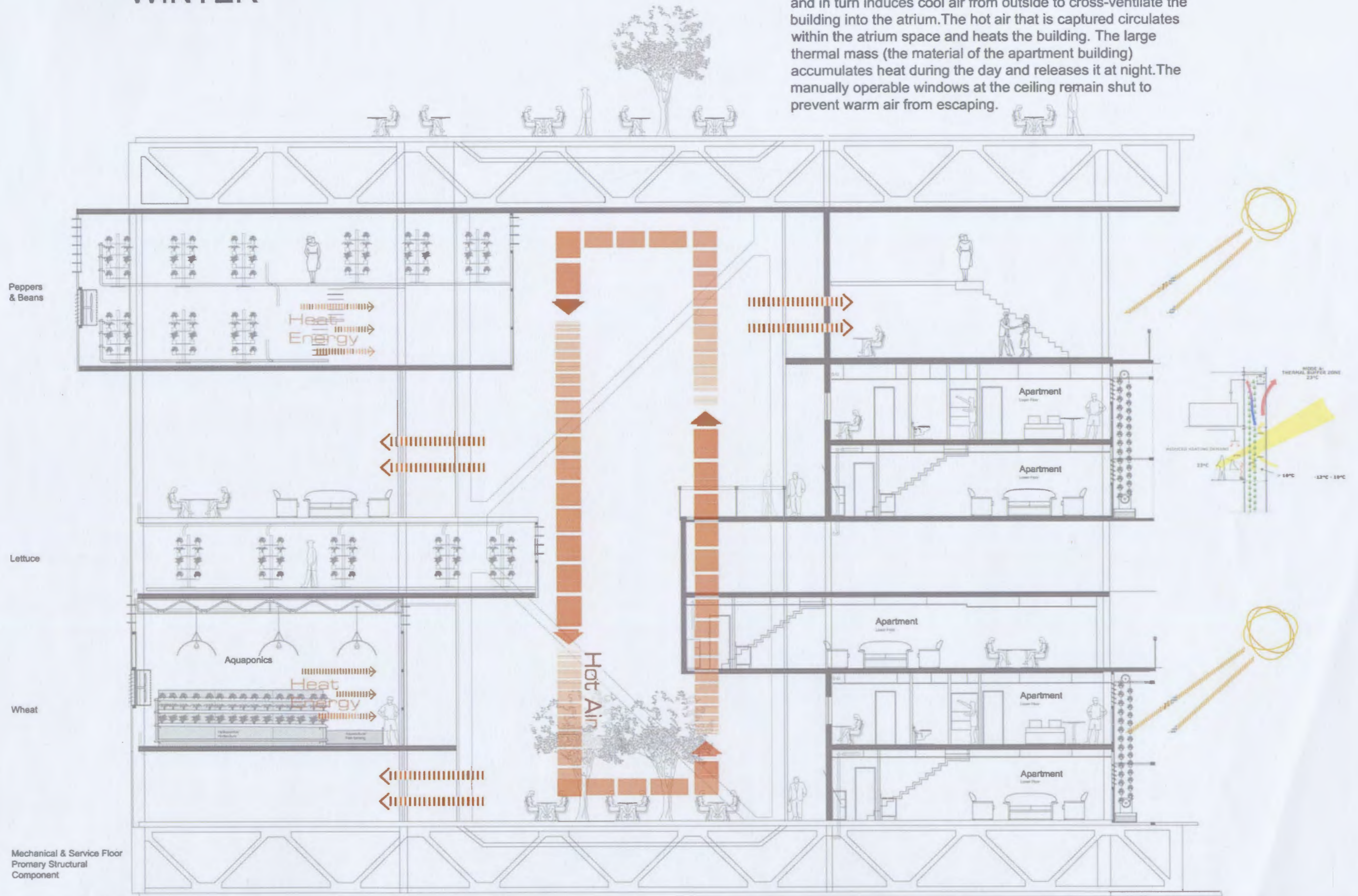


Fig. 4.13 A central section of the cross section illustrating the internal air conditions during winter time.

# LIVING TOWER

## SUMMER

The manually operable windows at the ceiling or roof creates a 'thermal chimney' effect. This causes pressure differences which enable air circulation in the apartments and public areas, drawing hot air out of the building and allowing cooler fresh air inside.

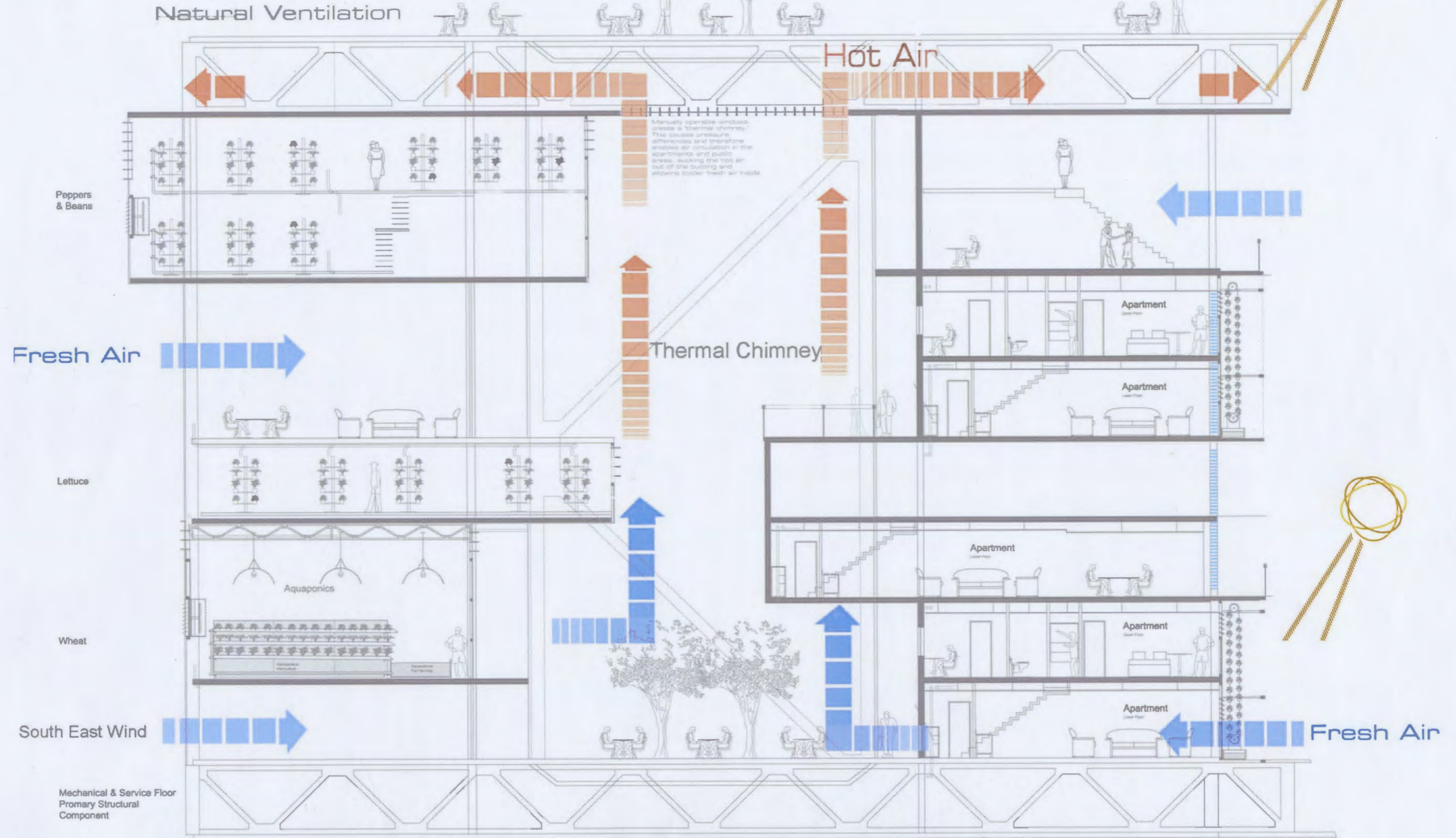


Fig. 4.14 A central section of the cross section illustrating the internal air conditions during summer time.

# LIVING TOWER

## ANAEROBIC DIGESTER

Water conservation and reuse

Potable water gravitate from the Anaerobic Digester Tank in the Core towards a Apartment/Greenhouse. Used household or irrigation water gravitate to the AD Tank below the floor. This process is repeated through all the floors.

AD Tank kept at 37 degree Celsius by a pipe running through all the tanks

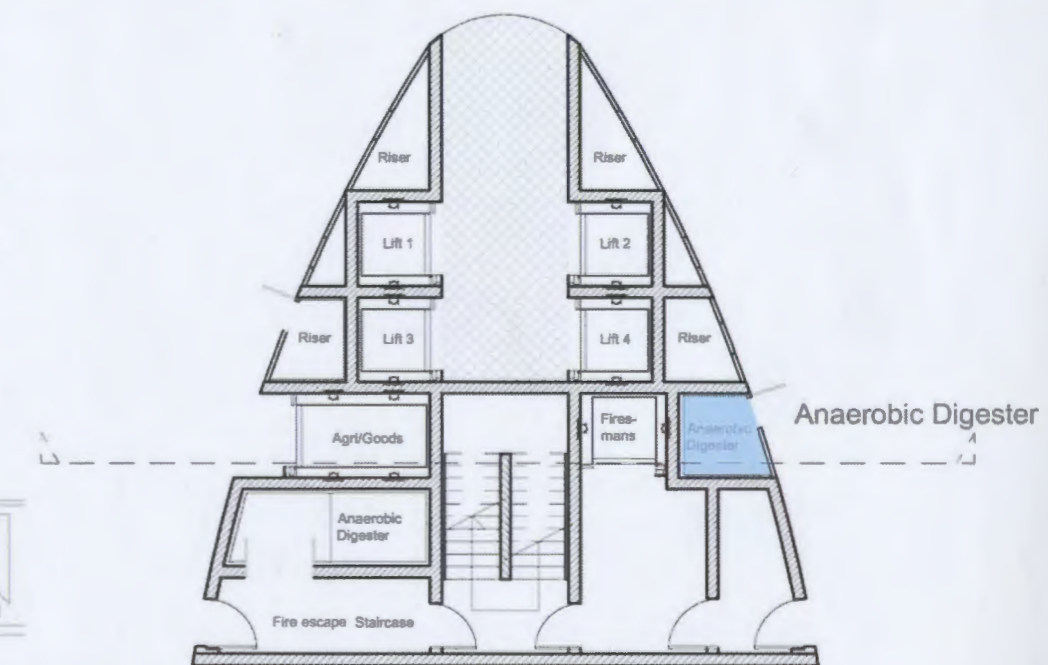
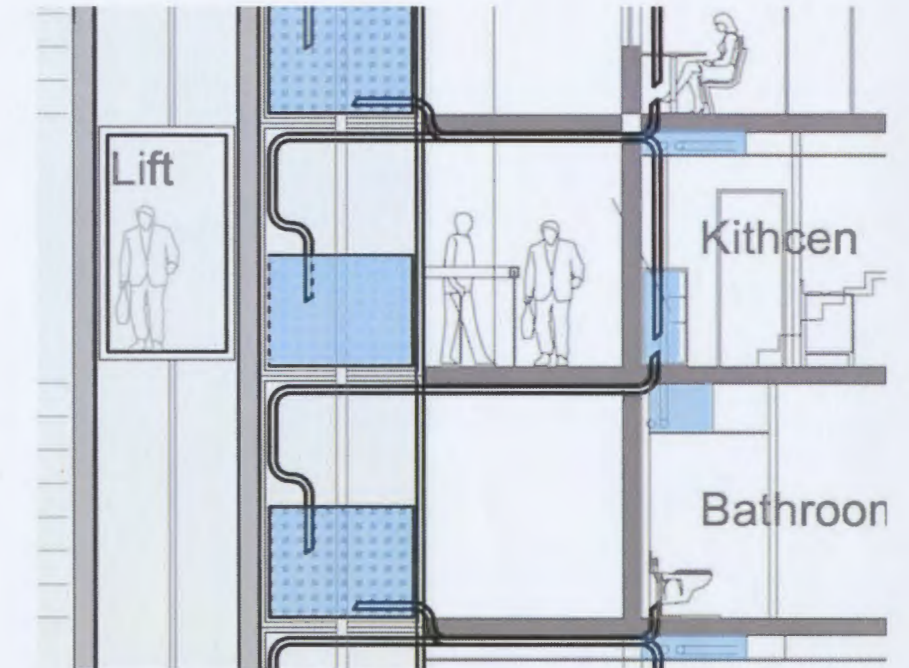
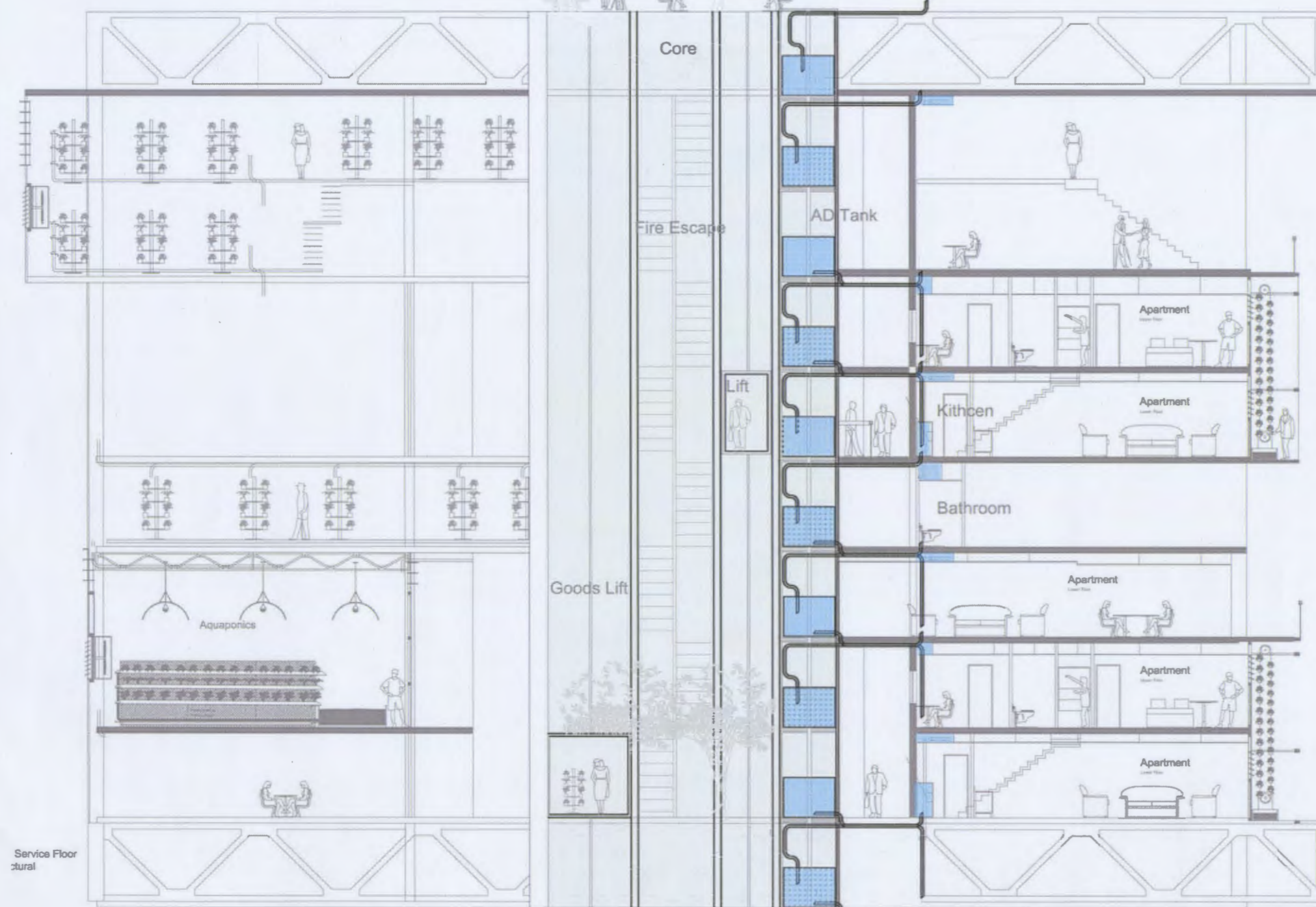
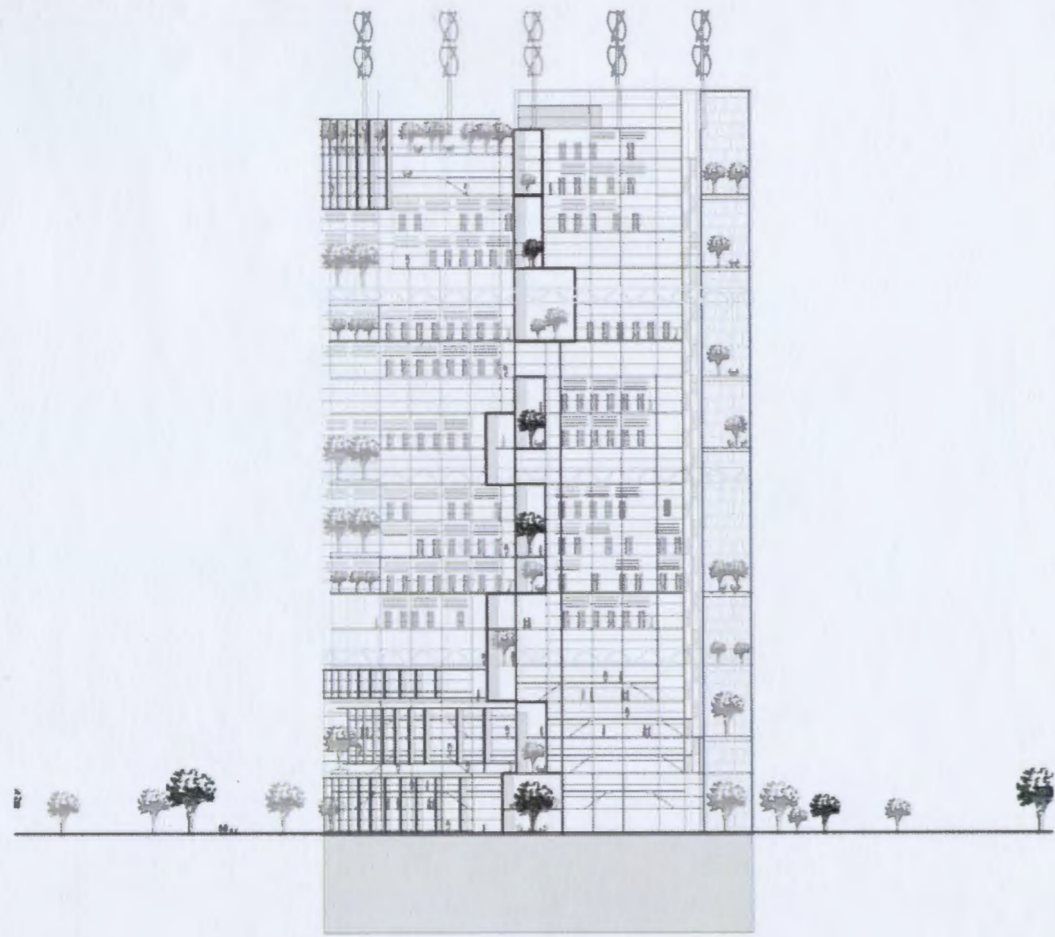
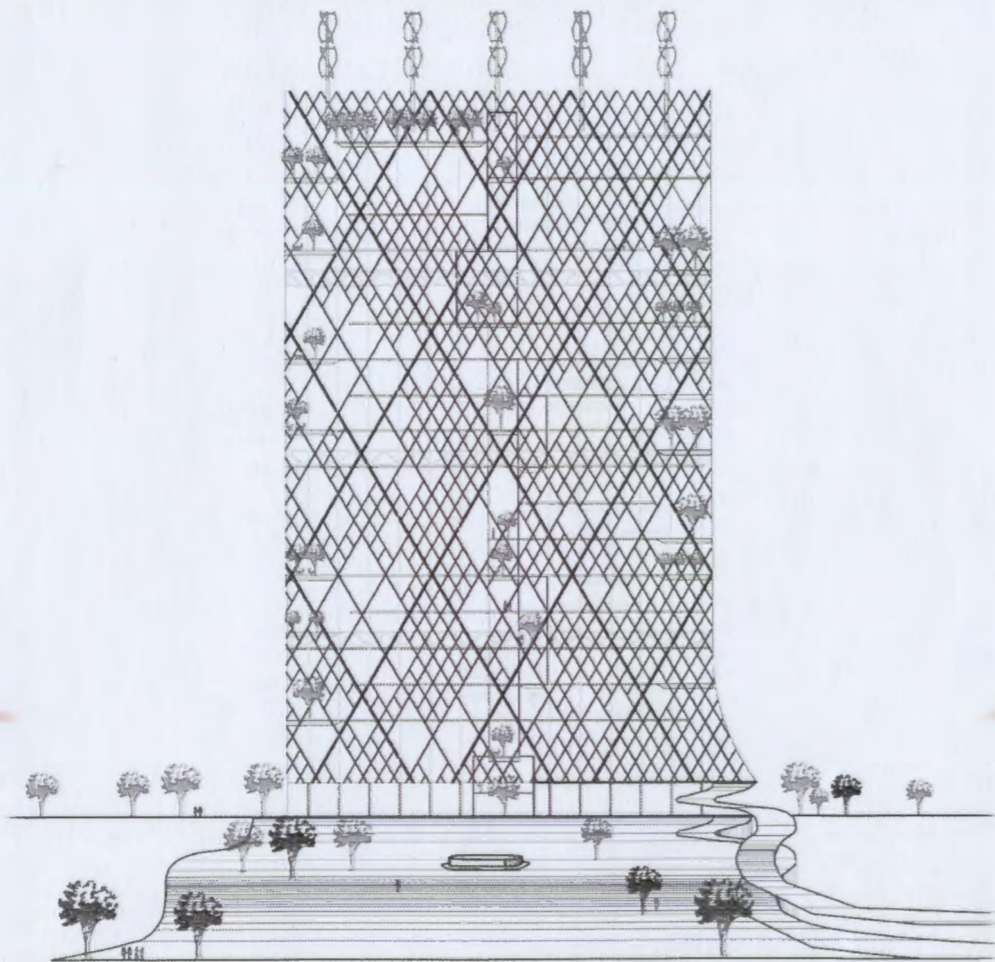


Fig. 4.15 A central section of the cross section illustrating the water conservation in a closed entity of the LT. The recycled water irrigate the greenhouses as well as grey water for each apartment gravitating towards the basement.

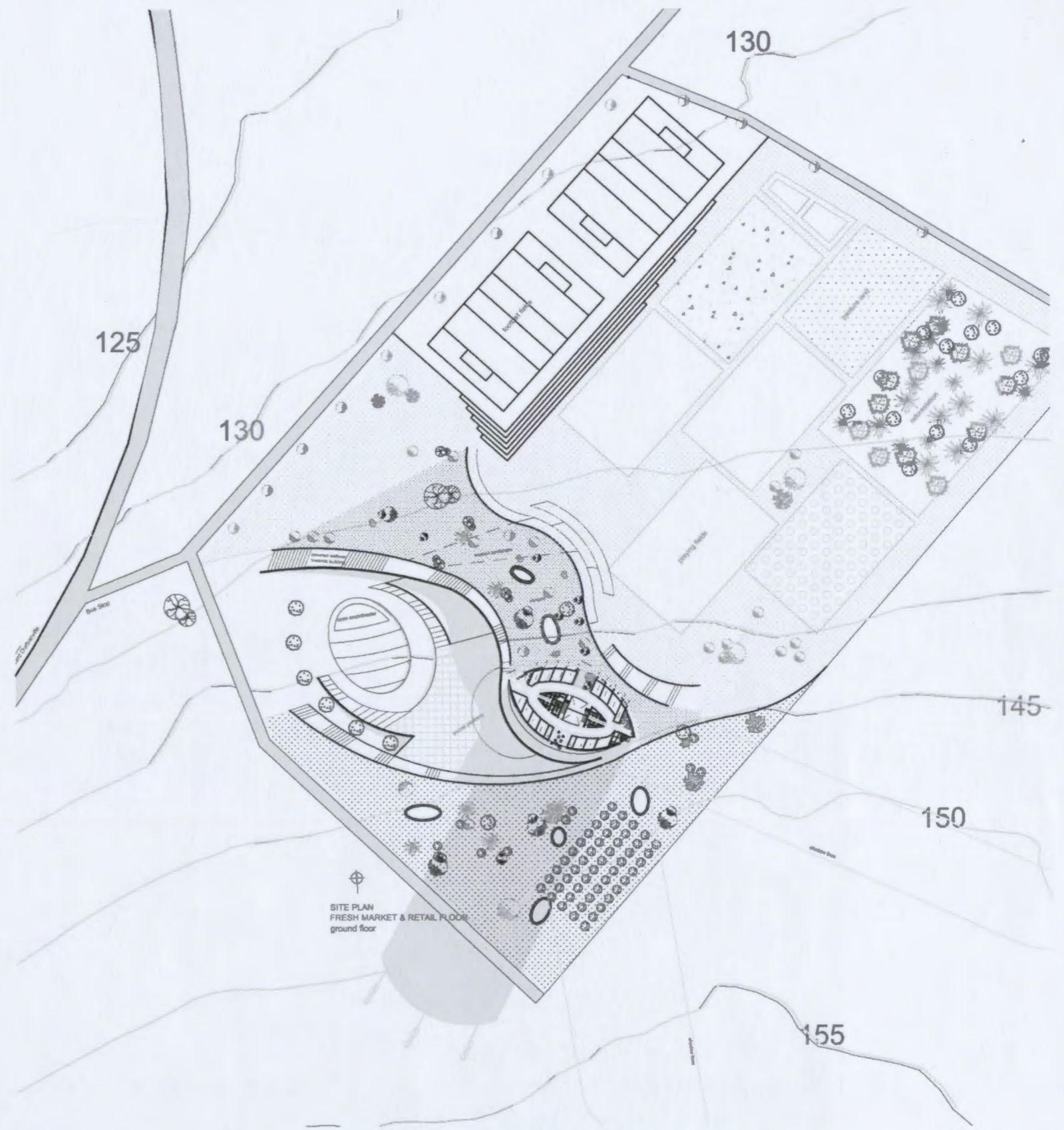
# LIVING TOWER



South West Facade



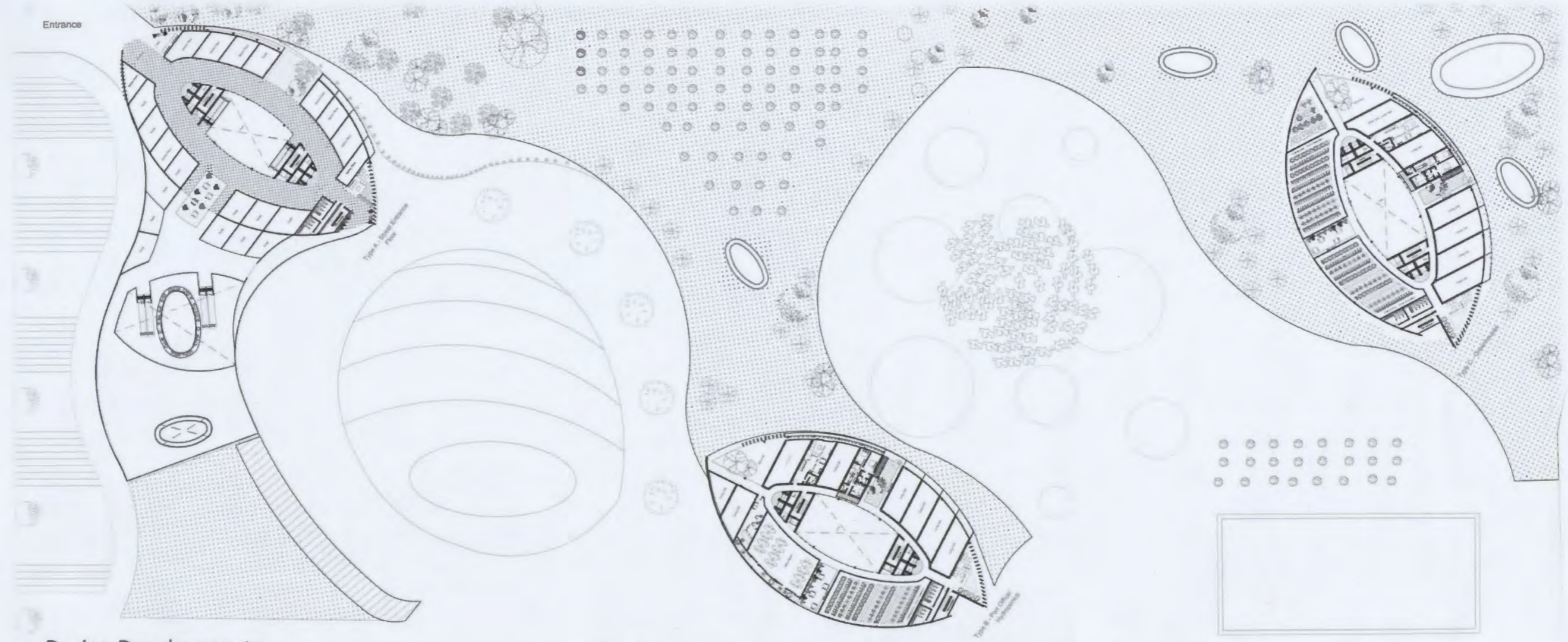
North East Facade



SITE PLAN  
FRESH MARKET & RETAIL FLOOR  
ground floor

Fig. 4.16 Drawings of Elevations and the site plan .

# LIVING TOWER



## Design Development:

### Site Development:

This is a plan of the site containing three LIVING TOWERS interweaved in an interactive landscape (see visuals below). The proposed plan caters for many activities and functions and accommodates 3 x 1000 people in these towers. The plan form part of the Living City design, which is a new way of suburban planning (see Theory Document). The groundplane is a landscape that imitate the rolling hills of its context by bending and shaping the plane to wrap around

## Visuals:

Visual Development:  
These visuals illustrate a Living Tower development that forms part of the Living City proposal. How nature and the build form intermingle to enhance social interaction is an important aspect of the design.

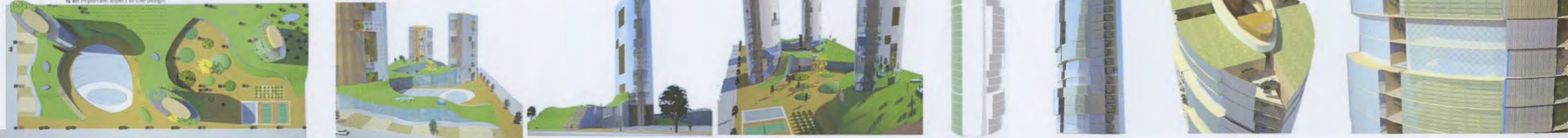


Fig. 4.17 These drawings explore what a Living City could be like. With the ground plane taking on the shape of the Durbanville hills. Drawings by author

LIVING TOWER

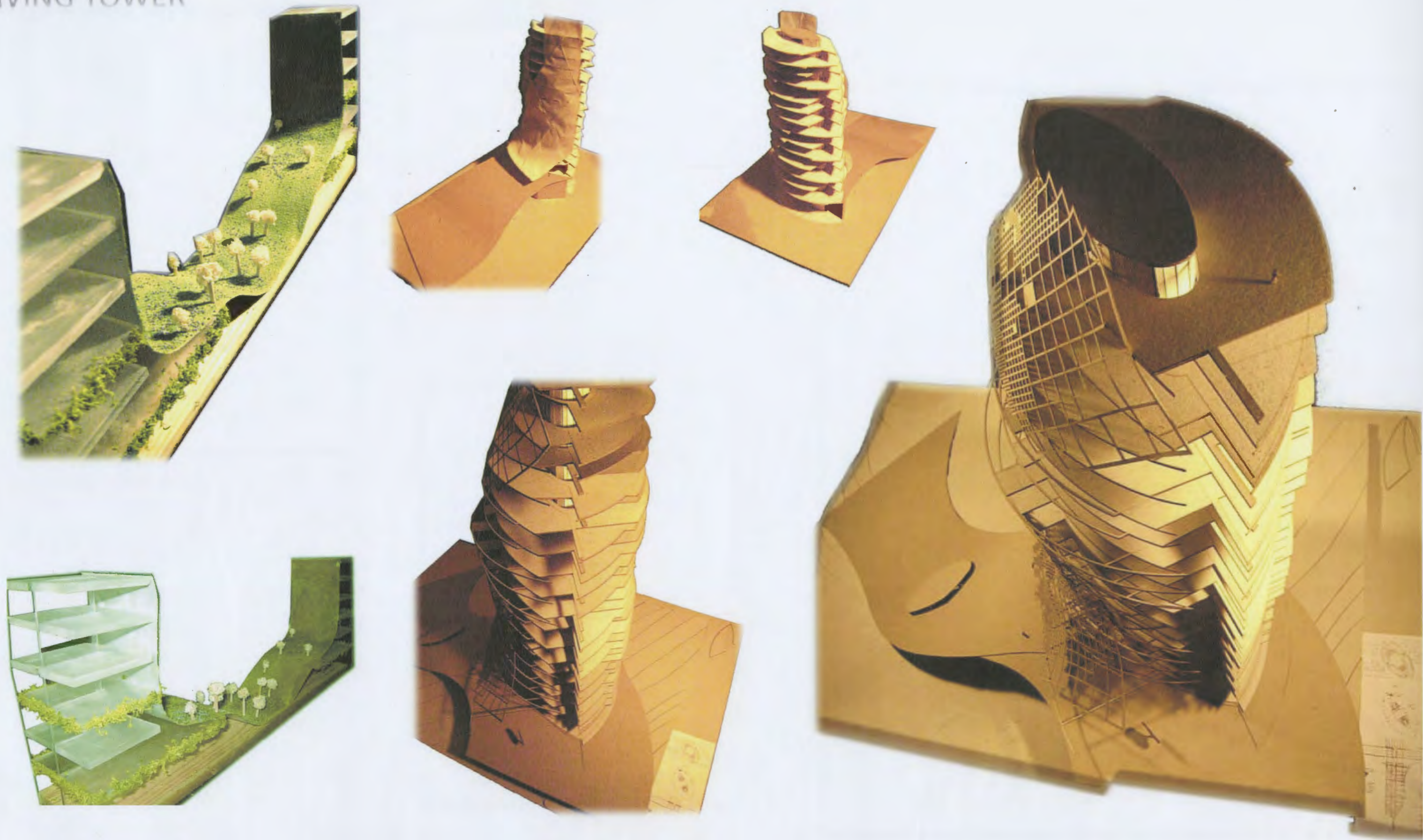


Fig. 4.18 Conceptual and Working models. A Spatial exploration. Models by author

# LIVING TOWER

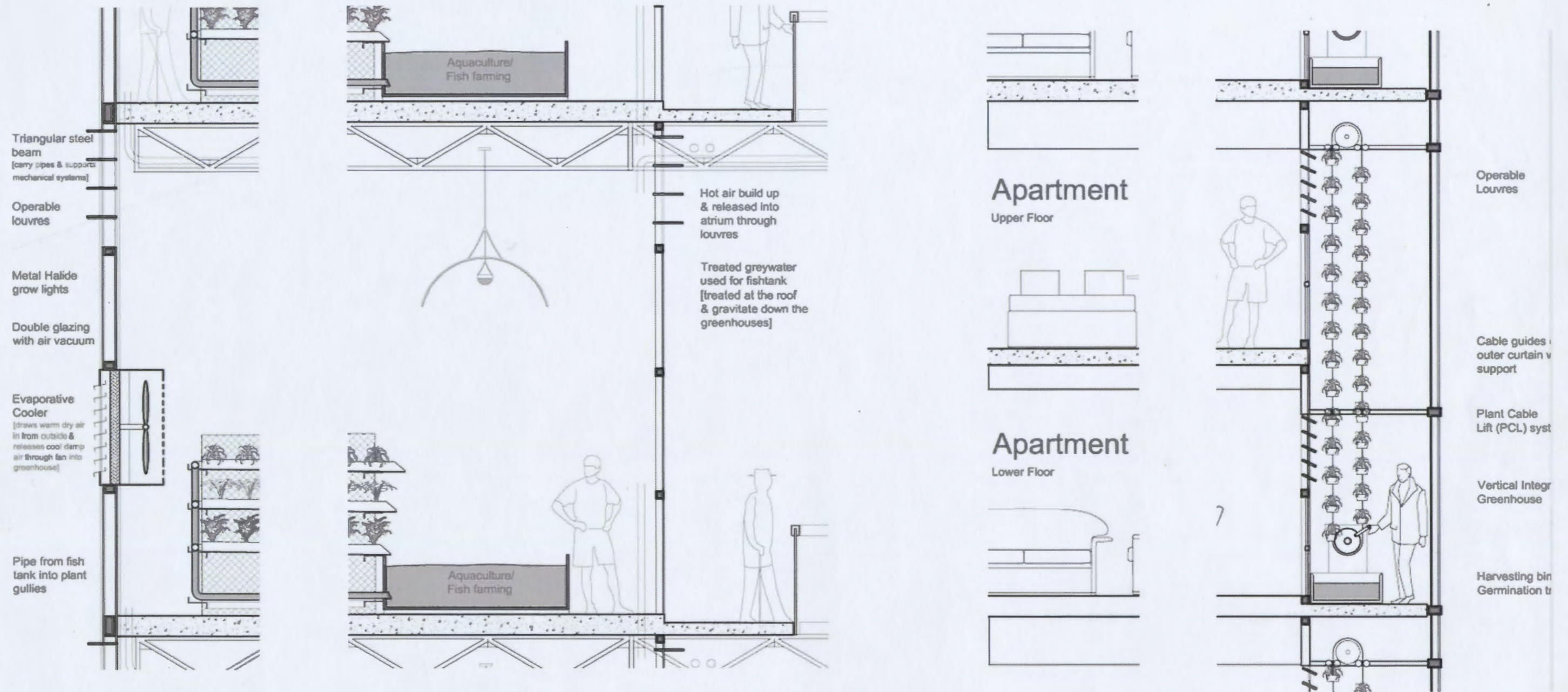


Fig. 4.19 Details. Some of the integrated systems are seen in these details such as the evaporative cooler, the aquaponics and the vertical integrated greenhouse.

## 5. Conclusion

This thesis document evolved through different sections culminating in a fourth and last design section. This design section graphically represents the amalgamation of all the issues, the research, the calculations and the design considerations explored within the context of the Living Tower.

In the first section the Living City is proposed as a possible solution to the current dilemmas, of low-rise sprawling with infrastructural and environmental consequences, by promoting much higher living densities as well as more ecologically friendly lifestyles. The proposal of the Living City includes the Living Tower as a central component. In this study the Living Tower model is further explored, tested and developed to be key in developing new balanced and self-sustaining suburban environments for a sustainable future.

The integration of the natural and human environment in a tall building, through various systems, calls for innovative, unprecedented design initiatives such as; the *vertical integrated greenhouses*, the *stacked greenhouses* as temperature control mechanisms for the building, the *atrium* as ventilator and the *anaerobic digester* as energy and heat generator from plant and human waste. These systems are amongst those that have more than two functions and form the core integrated systems in the design development. Solar, wind and other renewable energy resources are included in the design to secure a sustainable ecology for its inhabitants. Sky-courts, the living machine, operable louvers, double skin facades all work effectively and efficiently together with the other incorporated systems.

The Living Tower merges functions and activities such as farming, dense living, parks, office spaces, education places, markets, retail and other social initiatives. This integration of high density living and farming activities contribute towards repairing our damaged eco system by protecting sensitive land and by enhancing social interaction. The holistic approach of the Living Tower thus achieves a successful and well balance system that exerts a positive influence on both, nature and society.

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- Figure 1.13: Living City, Section Plan: Drawn by author
- Figure 1.14: Living Tower: Integration of Urban and Natural: Drawn by author
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- Figure 1.16: Tour Vivante Tower: <http://www.verticalfarm.com/designs.html>
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- Figure 1.22: Dynamic Tower: <http://www.verticalfarm.com/designs.html>
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- Figure 1.24: Medium Density Model: by author of this thesis
- Figure 1.25: High Density Model: by author of this thesis
- Figure 1.26: Appendix A: Cape Times Article by Anel Powell, Cape Times 4<sup>th</sup> March 2009, p. 3
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- Figure 2.25: Agriculture spiral around the core: <http://www.verticalfarm.com/designs.html>
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## 7. Picture References: Section 3

Figure 3.1: Produce stacked in buildings according to sunlight and water required. Drawings by author

Figure 3.2: Five to Ten storey tower. Drawings by author

Figure 3.3: Fifth-teen to Twenty storey tower. Drawings by author

Figure 3.4: Thirty to Forty storey tower. Drawings by author

Figure 3.5: Energy calculations for models. Drawings by author

Figure 3.6: Cost graphs of each tower. Drawings by author

## : Section 4

Figure 4.1: Urban Edge Boundary: sketch by author

Figure 4.2: GIS Mapping: sketch by author

Figure 4.3: Site, Ortho photo map: sketch by author

Figure 4.4: Panoramic picture of site: sketch by author

Figure 4.5: Accommodation schedule: sketch by author

Figure 4.6: Conceptual sketches, climatic condition: sketch by author

Figure 4.7: Conceptual sketches, climatic condition: sketch by author

Figure 4.8: Sketch plans: sketch by author

Figure 4.9: Sketch section: sketch by author

Figure 4.10: Structural composition: sketch by author

Figure 4.11: Programmed section: drawing by author

Figure 4.12: Structural section: drawing by author

Figure 4.13: Winter experience: drawing by author

Figure 4.14: Summer experience: drawing by author

Figure 4.15: Water conservation: drawing by author

Figure 4.16: Elevations and site plan: drawing by author

Figure 4.17: Site Development plan and 3-D models: drawings by author

Figure 4.18: Models by author

Figure 4.19: Details of systems: by author

Figure 4.20 Cape Times Article

Figure 4.21 Table 1, Table 2, Table 3.

Figure 4.22 Community facilities required for the different models

## 8. Appendix

### Appendix A

# Development land poser in Cape Town as city size expected to double by 2030

**ANÉL POWELL**  
Metro Writer

THE City of Cape Town, estimated to be almost 35 000 hectares in size in 2007, will double by 2030.

This means it is expanding by 650ha annually, increasing by what is the equivalent of two rugby fields in size every day.

Kevin Sinclair-Smith, of the city's strategy and planning department, said yesterday that there was not much land left in the metropole for development.

According to a report submitted to the city's planning and environment committee, the areas left for development included valuable agricultural areas, biodiversity areas, environmentally sensitive areas and areas with natural features that needed to be protected from urban development.

The city's "dramatic" urban expansion since 1977 means there is limited suitable land left for future growth.

Using the latest available aerial photography, taken in 2007, the city's urban growth monitoring project has analysed the city's urban development since 1945.

Urban growth has been great-

est in the northern areas of the metropole, including Blouberg.

Mitchells Plain and Khayelitsha have grown by 897ha between 1998 and 2007.

Sinclair-Smith noted in the report that, while Cape Town was growing faster than ever before in number of hectares a year, the percentage growth rate had slowed.

The city is seven times larger than it was in 1945.

Since 1977, the city has been growing at a fairly constant 2 percent, with the rate declining to 1.5 percent. City and population growth were similar until 1988, when the population growth outstripped the city's growth.

Sinclair-Smith said formal market housing trends led to more smaller residential units and higher density accommodation such as townhouses.

Many of the city's poorer residents live in high-density settlements, including backyard dwellings and informal settlements, meaning population growth will have relatively little impact on the physical growth of the city.

The report will form the basis of the city's urban planning pol-

icy and spatial development framework. As the demand for land increases, the city has been advised to opt for densification rather than spatial growth.

Sinclair-Smith said possible expansion options included the Fisantekraal corridor near Durbanville.

It was reported at a workshop hosted by the provincial government that cultural landscape, such as Durbanville Hills, was under "heavy pressure" for development.

Areas that were deemed provincial cultural landscapes should be put forward for world heritage status to get protection at local government level.

"The protection of large areas of privately-owned land is often contested and complicated, especially when it is undeveloped and where there could be expectations for development," said Clive James, of the city's environmental resource management department, in a report to the planning committee.

He said the city had to declare cultural landscapes as conservation areas so their boundaries could be protected when developments were being considered.

News Paper Article: Powell, A 2009, Development Land poser in Cape Town as City size expected to double by 2030, Cape Times, 4 March, p.3



Fig. 4.20 Cape Times Article

## Appendix B

Veg/Fruit	Tonnes/Yr	HA/Yr	m <sup>2</sup> /Yr	Floors (1.4K m <sup>2</sup> )	Floors (3 layers/fl)	Value (+) \$ per lbs	Gross Income
Lettuce	18.2	0.0242	242	0.17	0.06	\$1.49	\$59,822
Cucumber	16.5	0.02	200	0.14	0.05	\$1.58	\$57,575
Eggplant	27.1	0.11	1,100	0.79	0.26	\$1.49	\$89,102
Strawberries	27.5	0.336	3,360	2.40	0.80	\$2.99	\$181,074
Peppers	24.8	0.0416	416	0.30	0.10	\$3.95	\$216,144
Carrots	42.4	0.0344	344	0.25	0.08	\$0.50	\$46,720
Spinach	59.6	0.54	5,400	3.86	1.29	\$2.49	\$327,186
Soybean	59.6	0.43	4,300	3.07	1.02	\$0.26*	\$34,164
Green peas	48.0	0.099	990	0.71	0.24	\$0.25*	\$26,460
Tomatoes	49.7	0.073	730	0.52	0.17	\$0.99	\$108,385
			17,082	12.20	4.07		\$1,146,633
Chicken broilers	5126	0.43	3,149	2.25	0.75	\$11.67	\$10,746
Chicken layers	472	20,800 dzn	102	0.07	0.02	\$2.25/dz	\$46,800
Wheat	108	0.073	1,858	1.33	0.44	\$0.14*	\$33,334
Potatoes	108	1.7082	1,858	1.33	0.44	\$0.99	\$235,718
Tilapia			113	0.08	0.03	\$8.99	\$24,610
			7,080	5.06	1.69		\$351,208
<b>TOTAL</b>					<b>5.75</b>		<b>\$1,497,841</b>

(+) Prices taken from downtown Toronto Lablavs - March 7, 2008

\* Prices taken from Canadian Ministry of Agriculture website; actual saleable value much higher

Fig. 4.21 Table 1, Table 2, Table 3.

These tables indicate the quantitative data analysis for the 1000-person Living Tower.

- Table 1 calculates the amount of vegetables and fish needed to feed 1000 people as well as the cost implications.
- Table 2 specifies the energy required for the growth of each crop as well as for the entire building.
- Table 3 lays out the amount of waste that the crops and fish produce in a year. This data will be used to work out how much energy the tower can gain by using a Methane Digester.

This Vertical Farm will produce 13,492kg of biological waste a week. 13,492 kg of bio-waste would produce 1,123,931 kWh of electricity per year in a methane digester, well over half the vertical farm's electricity usage.

PLANTS	# of plants per year	# of plants per week	area req. per patch (m <sup>2</sup> )	req. energy Watts/m <sup>2</sup>	req. energy Watts / Week	req. energy Watts / Year	required kWh per year
Tomato	39,288	756	14	90	2,107,050	109,566,597	110,000
Eggplant	1,320	25	5	25	133,532	6,943,652	7,000
Peppers	7,385	142	13	25	230,640	11,993,290	12,000
Soybeans	431	8	6	25	151,408	7,873,230	7,900
Green Peas	448	9	6	25	219,045	11,390,345	12,400
Spinach	42,048	809	218	25	22,823,799	1,186,837,533	1,187,000
Carrots	194,667	3,744	22	25	607,922	31,611,925	31,700
Cucumbers	405	8	3	170	625,911	32,547,383	32,600
Wheat	406,015	7,808	60	25	1,521,619	79,124,195	79,200
Lettuce	121,576	2,338	61	27	832,154	43,272,029	43,300
Strawber.	23,292	448	42	76	9,562,841	497,267,740	497,300
Chicken Br.	5,650	109	11	13	278,208	14,466,815	14,500
Chicken Lay.	520	n/a	179	13	371,717	19,329,274	19,400
<b>Total</b>							<b>2,054,300 kWh</b>

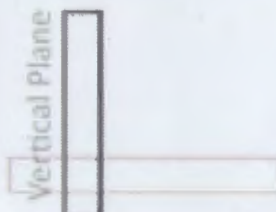
SOURCE	Yearly Waste (lbs)	Weekly Waste (lb)	Weekly Waste (g)	Weekly Waste (kg)
Tomato	109,480	2,105	955,002	955
Eggplant	119,600	2,300	1,043,280	1,043
Peppers	164,160	3,157	1,431,980	1,432
Soybeans	262,800	5,054	2,292,425	2,292
Green Peas	317,520	6,106	2,769,751	2,770
Spinach	87,600	1,685	764,142	764
Carrots	23,360	449	203,771	204
Cucumbers	72,880	1,402	635,738	636
Wheat	268,896	5,171	2,345,600	2,346
Lettuce	13,373	257	116,656	117
Strawberries	5,123	99	44,691	45
Chicken Layer Guano	-	-	-	192
Broiler Guano	-	-	-	124
Broiler Mortality+	-	-	-	99
Broiler Carcass ++	-	-	-	90
Tilapia Mortality +++	-	-	-	44
Tilapia Leftover ++++	-	-	-	105
Tilapia Excrement	-	-	-	176
<b>TOTAL WASTE</b>				<b>13,432</b>

(+) These are assuming a high end rate of 18% mortality and chickens weighing 5 lbs.

(++) This is the weight of each carcass after being stripped of meat and bones.

(+++ This assumes that 20% die before reaching maturity with a weight of 250 kgs

(++++ This is byproducts of gutting (60% of total weight of a 450 kg fish)



## Appendix C

### Medium Density Model

#### COMMUNITY FACILITIES STANDARDS:

	No. Facilities Reqd.	Total Area/Fac (Ha)
<b>EDUCATIONAL FACILITIES</b>		
Creche'	3.14	0.23
Primary School	6.29	4.00
Senior Secondary School	2.36	1.56
<b>AMENITIES</b>		
Playgrounds	7.86	2.66
Sportsfields	2.36	
Neighbourhood Park		
<b>HEALTH FACILITIES</b>		
Clinic	1.57	0.12
Day Hospital	1.65	
Community Hospital	1.57	2.29
<b>SOCIAL FACILITIES</b>		
Old Age Home		
Community Centre	1.57	0.41
Place of Worship	8.25	0.87
Libraries		
<b>PUBLIC SERVICE FACILITIES</b>		
Police Station	0.79	0.16
Post Office	0.00	0.00
Fire Station	0.30	
Administration		
Corner Shops	28.21	0.28
<b>OTHER FACILITIES</b>		
Service Station	3.14	
Shopping Centre		

### High Density Model

#### COMMUNITY FACILITIES STANDARDS:

	No. Facilities Reqd.	Total Area/Fac (Ha)
<b>EDUCATIONAL FACILITIES</b>		
Creche'	4.29	0.31
Primary School	8.57	5.45
Senior Secondary School	3.21	2.13
<b>AMENITIES</b>		
Playgrounds	10.71	3.62
Sportsfields	3.21	
Neighbourhood Park		
<b>HEALTH FACILITIES</b>		
Clinic	2.14	0.16
Day Hospital	2.25	
Community Hospital	2.14	3.12
<b>SOCIAL FACILITIES</b>		
Old Age Home		
Community Centre	2.14	0.56
Place of Worship	11.25	1.19
Libraries		
<b>PUBLIC SERVICE FACILITIES</b>		
Police Station	1.07	0.22
Post Office	0.00	0.00
Fire Station	0.41	
Administration		
Corner Shops	38.46	0.38
<b>OTHER FACILITIES</b>		
Service Station	4.29	
Shopping Centre		

Fig. 4.22 Community facilities required for the different models

