THE DESIGN OF AN AQUACULTURE PLANT FOR THE LOWER SWARTKOPS VALLEY, EASTERN CAPE

Philip Skein 210015128
Student : Philip Skein

Student number : 210015128

Institution : School of Architecture
Nelson Mandela Metropolitan University

Lecturers : Andrew Palframan
Boban Varghese

Promoter : Gavin Maclachlan

Proposal : The design of a Aquaculture-plant for
the Lower Swartkops Valley, Eastern Cape

Date : 20 October 2015
 DECLARATION BY CANDIDATE

Name : Philip Skein

Student number : 210015128

Qualification : Masters of Architecture (Professional)

Title of project : The design of a Aquaculture plant for the Lower Swartkops Valley, Eastern Cape

In accordance with rule G4.6.3 I hereby declare that title above-mentioned treatise is my own work and that it has not previously been submitted for assessment to another university or for another qualification.

Signature :

Date : 20 October 2015
ACKNOWLEDGEMENTS

This treatise is dedicated to my parents for their undying moral and financial support through-out the course. Also towards God, for giving me the strength to carry through in dire times. I’d also like to extend my sincere thanks towards the following people.

Treatise promotor: Gavin Maclachlan

5th year studio masters:
Andrew Palframan
Boban Varghese
Towards a greener future..
This treatise originated as a response to the current environmental issue that is currently threatening the existence of biodiversities within the Swartkops Estuarine region. The increasing amount of illegal and negligent human-related activities within the Estuary has seen an rise in degradation and destruction of our natural ecosystems with the issue of water pollution recently acquiring crisis stage. Being brought up in Uitenhage, the close proximity of the Swartkops River naturally served as an endless resource of outdoor activities over the years. Witnessing the current degraded state of my beloved river served as motivation for this treatise which is an attempt to address and reconcile our relationship with the natural environment.

The issues facing the natural environment of Swartkops will be looked at in depth and sets of integrated interventions will be proposed in order to minimise further anthropocentric effects on nature. The project will attempt to develop a restorative design framework that will achieve ecological-, economical-, and social sustainability whilst voicing conservation awareness through the promotion of sustainable industry in the region. The project will address issues of natural degradation on various scales in order to develop an holistic approach that will restore and sustain the local- and national value of the Swartkops Estuary. The series of interventions will eventually lead to the design of a building located in Swartkops Village.

Figure A: Artist’s depiction of the effects of industrialism upon Mother Earth
# CONTENTS

## CHAPTER 1 - Introduction
- Background: 2
- Problem statement: 7
- Proposal: 9
- Methodology: 10
- Theoretical approach: 11
- Aims and objectives: 15

## CHAPTER 2 - Understanding context
### PART 1
- Contextual analysis and urban framework development: 16
  - Structuring elements at metro scale: 18
  - Structuring elements at sub-metro scale: 21
  - Structuring elements at precinct scale: 23
  - Precedents: 27
  - Urban intervention at sub-metro scale: 33
  - Urban intervention at precinct scale: 37
### PART 2
- Site selection and analysis: 41
  - Site selection: 42
  - Nature of site: 43
  - Composite informants and constraints: 51

## CHAPTER 3 - Exploring programme
### PART 1
- Defining programme: 54
  - Algae production: 56
  - Fish farm: 58
  - Scientific research: 60
  - Overview: 61
### PART 2
- Nature of activities: 62
  - Scientific research: 63
  - Algae production: 65
  - Fish farm: 72
  - Summary: 85
### PART 3
- Architectural investigation: 86
  - Defining algae architecture: 87
  - Laboratory typology: 91
  - Programmatic issues: 106
  - Precedents: 107

## CHAPTER 4 - Design development
- Stakeholders: 118
- Accommodation schedule: 119
- Design development: 121

## CHAPTER 5 - Final design
Figure B: The Swartkops River (Photo: Prof Nadine Strydom)
Chapter 1: INTRODUCTION

Background
Problem statement
Proposal
Methodology
Theoretical approach

Figure 1.1: View from the Swartkops River
BACKGROUND

The Swartkops Estuary is one of the last living urban estuaries in the world and currently ranked 11th on the importance scale out of 300 estuaries in South Africa. It’s rich biodiversity and unique natural structure provides a safe and resourceful habitat for various fish- and bird species alike. Along with this high ecological value, it holds high value to humans both within and without the estuary. It acts as a source of food and jobs to many residents of poorer settlements located along the riverbanks who utilise the river on a daily basis to serve their living and cultural needs. The Swartkops Estuary along with the adjacent Aloe Nature Reserve, also provides for a large range of recreational activities for occupants and tourists of the major city of Port Elizabeth such as fishing, boating, bird-watching and canoeing.

The threatening issue of environmental pollution and destruction of natural biodiversities in the Swartkops Estuary has recently reached a crisis level. The growing problem of natural degradation that began with the phenomenas known as industrialisation and urban sprawl are now not only threatening the integrity and health of eco-systems within the river but also the livelihoods without. Located approximately 15km outside the CBD of Port Elizabeth, the estuary forms part of the city’s industrial artery stretching to Uitenhage. This region has seen a rapid development in industrial practices involved in extractive and manufacturing processes which has had an increasingly detrimental effect on the environment. The increase of informal settlements along the banks of the river has led to the rise in urban storm- and waste water pollution in the river along with illegal practices such as poaching and overfishing stressing natural populations of fauna and flora species alike. (http://www.heraldlive.co.za/save-swartkops-river/)
BACKGROUND - Water pollution

Figure 1.4: Panoramic view of sewerage input at Motherwell canal

Figure 1.5: Motherwell canal major source of pollution

Figure 1.6: Stormwater flowing in a channel which was eroded through infill material in the wetland

Figure 1.7: Illegal dumping of litter on the northern bank of the Motherwell Canal

Figure 1.8: Polluted wetland

Figure 1.9: Concrete lined stormwater channel discharging stormwater into the wetland

Figure 1.10: Rubble and litter at one of the stormwater outlet headwalls

Figure 1.11: Polluted wetland

Figure 1.12: Sewerage pump station with clear evidence of blockages and overflows
BACKGROUND - Natural biodiversity

Figure 1.13: Aerial view of Swartkops River mouth

Figure 1.14: Phragmites australis at Redhouse

Figure 1.15: Invasive aquatic plants, water fern (Azolla filiculoides) and water hyacinth (Eichhornia crassipes), at Perseverance

Figure 1.16: Sarcocornia perennis

Figure 1.17: Chenolea diffusa

Figure 1.18: Rhus longispina

Figure 1.19: Spartina Maritima

Figure 1.12: Aerial view of Swartkops River mouth
Angling activity in the Swartkops River is exceptionally high. As a result of its close proximity to a major city (Port Elizabeth) and the large number of urban formal- and informal settlements, the river has seen a dramatic increase in angling related activity both legal and illegal. A large amount of shore- and boat based fishing has been observed showing a direct indication of the existing population pressures. The rise in the demand for bait has seen to an increased amount of number illegal and environmentally detrimental activities with governmenting parties exhibiting poor control over bait-collecting limits and methods of extraction. Recent environmental studies has indicated high levels of trace metal in the tissue of many fish species presenting major human health risks such as leukemia. (http://www.zwartkopsconservancy.org/new-study-of-fish-in-swartkops-river-not-safe-to-eat/)
Bird watching forms part of one of the many recreational activities that the Swartkops Estuary provides for. Although these activities may not seem to impact bird populations directly, some of them are causing reason for concern. These birds descend upon exposed mudflats at low-tide where they forage on invertebrate species such as Mudprawn. An increase in bait-collecting activity along with power boating restricts these foraging patterns immensely. Urban development along the river affects the ecology of these natural systems and will result in altered or lost habitats. (Swartkops Integrated Environmental Management Plan: Draft Situation Assessment, 2009)
PROBLEM STATEMENT

The impact of climate change and loss of biodiversity is an ever impending global threat with water pollution being an increasing danger to fresh- and salt-water estuarine-biodiversities across the South Africa.

The Swartkops Estuary forms part of thirty nine estuaries that were given a high priority status for rehabilitation with environmental management plans continuously being set out to address the various issues regarding conservation of these areas. Despite this, the rising amount of naturally degrading human activity along the river has reached a new low with the river on the verge of attaining ecological disaster zone status. (http://www.heraldlive.co.za/save-swartkops-river/)

The Swartkops Estuary is an essential aquatic ecosystem attracting high density development as a result of the large variety of ecosystem goods and services it provides. Some of these include the natural purification of pollutants, aesthetics that attract tourism, recreation such as swimming and boating, a source of food and bait for fishing, high levels of biodiversity. Sites such as Perseverance are used for cultural Xhosa rituals but poor water quality has affected many of their traditions.

It is essential that the ecosystem health is improved so that the entire system can continue to provide ecological- and human services. The need for awareness of the importance conservation of our natural bio-diversities as well as the need to develop sustainable industry in the region has been identified.
Figure 1.42: Diagram of issue
This project will be an attempt to reconcile and restore the natural environment within realistic boundaries and provide a sustainable framework for the future industry and conservation to occur. The project will serve as a catalyst for future sustainable industrial methods to be developed in order to restore the nature balance of the eco-systems within the Swartkops Estuary. Through including existing industries, the project will create a platform to encourage future sustainable development in the region.

The project seeks to address social, economical and ecological issues of the region in order to develop a sustainable conservative approach. These restorative initiatives will be applied on various scales through-out the project to eventually lead to the design of a building.

The building itself will serve as a research platform for the effective study and monitoring of eco-systems within the estuary. The building will also serve as the hub for the integrated research and production of integrated aquaculture. These programmes will operate in a socially, economical and ecological sustainable way to ultimately restore the value of the Swartkops Estuary as a natural national asset and local living resource.

Figure 1.43: Hollistic sustainability diagram
The research process will be conducted in order to gather a deeper understanding of the various issues at hand and to develop an well-informed approach for the design of an Aquaculture plant in the Swartkops Village. The project began with an observation of the current degraded state of the Swartkops River which led to more in-depth research on the subject matter. A pure research approach has been applied throughout the project to address the very real environmental issues that threatens bio-diversities in the region. Research of a qualitative nature will be gathered from various sources to be analysed and summarised. Given the particular nature of the project an aspect of quantitative research will also be conducted to address the tangible and scientific nature of the issue in order to conduct fully informed decisions. This will be done through the collection of relevant numerical and factual data from environmental reports in order for critical, informed engagement with the issue. ie water conditions (salinity; nutrient content; temperatures). Various literature studies will be conducted in the form of documents, books, research- and treatise papers as well as articles and publications on the internet in order to gather a theoretical understanding on the subject matter. Primary research such as analysing site, conducting interviews, photographic survey and observation will be conducted as well as secondary research such as reviewing of existing written information, drawings and audio visual material relating to the topic. Sets of conclusion on the research conducted will be formed to inform a design approach. Precedent studies on similar projects will be conducted in order to gain an understanding of the typological composition of the building which informed and guided design decisions. Consultation with design lecturers and various professionals has guided the process and the final outcome of the design. The research and conclusions will be presented in the form of a physical model, presentation boards containing the design process and final drawings, and a written document.
THEORETICAL APPROACH

“Rather than working with nature, we’ve been setting ourselves and our environment apart; we’ve been blind to the devastating impact our choices have had on the natural environment. As a result the global environment has become so degraded that, given current trends there is some question as to whether it can continue to support human life over a long term.” (Bob Berkebile, 1996)(http://www.context.org/iclib/ic35/berkebil/)

In this interview Bob Berkebile states that humans should go beyond the point of minimising the environmental affects associated with design decisions and instead develop ways in which we can begin to restore our relationship with the natural environment. The theory behind such an approach is known as **restorative environmental design**. This project will utilise this theory and its components as theoretical lenses to inform an holistic design approach through-out various scales.

**Restorative Environmental Design:**

Restorative environmental design (R.E.D.) acknowledges William McDonough’s theory of ecological health who argues that sustainability cannot be achieved through low environmental impact design alone and we should create buildings that produce more energy than it consumed during its lifetime and construction period in order to achieve complete sustainability. a Building that becomes the net-exporter of energy. R.E.D design takes this theory a step further.

Restorative environmental design approaches does not only minimise the detrimental effect of building but also seeks to restore the environment and promotes a harmonious relationship between man and nature. (Kellert, 2004:3)

The two key principles that guide restorative environmental design include:

- **Biophillic design for the occupants**
- **Ecological footprint**
1. Biophillic design for the occupants

This theory is based on the notion that man has a natural affinity for nature and seeks to foster beneficial relationships with the natural world in order to achieve mental wellbeing. It has been implemented in various mundane work settings to improve productivity and mental- as well as physical health.

Three kinds of experiences of nature represent the basic categories of a biophilic design framework.

1. **Direct experience of nature**:
   Actual contact with environmental features in the built environment.
   eg. Light; Air; Water; Plants; Animals; Weather; Natural landscapes and ecosystems.

2. **Indirect experience of nature**:
   Contact with the representation or image of nature, the transformation of nature from its original condition, or exposure to particular patterns and processes characteristic of the natural world.
   eg. Images of nature; Natural materials; Natural colors; Simulating natural light and air; Naturalistic shapes and forms; Evoking nature; Information richness; Age, change, and the patina of time; Natural geometries; Biomimicry

3. **The experience of sense of place**:
   Spatial features characteristic of the natural environment that have advanced human health and wellbeing.
   eg. Prospect and refuge; Organised complexity; Integration of parts to wholes; Transitional spaces; Mobility and wayfinding; Cultural and ecological attachment to place.

(http://www.biophilic-design.com/)

“Nature is a part of our humanity, and without some awareness and experience of that divine mystery man ceases to be man.”  
- Henry Beston, writer
Figure 1.44: Linear production and consumption process

Figure 1.45: Industrial air pollution
2. Cradle-to-cradle design

Traditional, conventional industrial processes occur in a linear production line with an open end. In this process natural resources are extracted and utilised for the manufacturing of a product that ends up at the consumer. A small amount of these products are recycled or re-used while the bulk of the waste are disposed without sufficient treatment into our natural environments. Unlike the linear production process of most man-made industries, natural ecosystems are resilient and completely self-sustaining cyclical processes which leaves zero waste in the environment. The diagram below illustrates the concept of the closed-loop ecological system seen in nature.

Cradle to cradle design attempts to conceptualizes industrial activity as a man-made ecosystem that operates in a similar way to natural ecosystems, where the waste or by product of one process is used as an input into another process. It is thus a biomimetic approach to design. One that interacts with natural ecosystems and attempts to move from a linear to cyclical or closed loop system that is essentially waste free. Like natural ecosystems, cradle to cradle design is in a continual state of flux which models industrial systems on the processes seen in natural ecosystems with the aim to contribute to a more sustainable future. (https://en.wikipedia.org/wiki/Cradle-to-cradle_design)

**Figure 1.46: The natural food web**

- **Producers (plants)**
- **Consumers** (Herbivours/Carnivours)
- **Decomposers** (Bacteria/fungi)
- **Abiotic chemicals** (CO2, O2, Minerals)

**Figure 1.47: Cradle to cradle design**
AIMS AND OBJECTIVES

A Series of objectives has been set out as milestones to achieve the overall aims of this treatise.

AIM
To design an sustainable water research facility and integrated aqua- and algae culture plant within the sensitive natural context of the Swartkops Estuary that will promote environmental conservation and development of sustainable industry whilst restoring value to the area.

OBJECTIVES
- Development of a holistic urban design framework that will address ecological, social and economical issues within the Swartkops Estuary in order to provide a platform for the design of a building.

- Compose an integrated programme that will effectively address the various issues at hand as well as catalyze the development of future sustainable industry in the region.

- Investigate the nature of activities and relationships between different processes (farming of fish and algae) and research.

- Investigate relevant architectural typologies in order to understand the principles behind their spatial and physical composition.

- Investigate the various processes involved in the industry of algae farming and re-circulating aquaculture in order to create an environmentally sustainable closed loop system to be integrated within the facility.
Chapter 2 : UNDERSTANDING CONTEXT

This section will be dedicated to investigating the problem of environmental degregation through-out scales to gather an understanding of the origins- and nature of the problem. Sets of conclusions will be drawn from analyses that inform an integrated urban design approach that promotes restorative sustainability in the region.

PART 1 - CONTEXTUAL ANALYSIS AND URBAN FRAMEWORK DEVELOPMENT

- Swartkops river at metro scale
- Swartkops Estuary issues at sub-metro scale
- Swartkops Village issues at site scale
- Precedents
- Urban intervention at sub-metro scale
- Urban intervention at site scale

PART 2 - SITE ANALYSIS

- Site selection
- Nature vs man-made
- Composite informants and constraints
### Part 1: CONTEXTUAL ANALYSIS AND URBAN FRAMEWORK DEVELOPMENT

<table>
<thead>
<tr>
<th>Area</th>
<th>Structuring Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Swartkops River</td>
<td>Structuring elements at metro scale</td>
</tr>
<tr>
<td>The Swartkops Estuary</td>
<td>Structuring elements at sub-metro scale</td>
</tr>
<tr>
<td>Swartkops Village</td>
<td>Structuring elements at precinct scale</td>
</tr>
</tbody>
</table>

### Summary of Analysis

- **Precedent investigation**
  - Ecological restoration
  - Socio-Economic restoration

### Urban Strategies and Interventions

- Urban strategy at sub-metro scale
- Urban intervention at sub-metro scale
- Urban strategy at precinct scale
- Urban intervention at precinct scale

*Figure 2: Aerial view of Swartkops River mouth*
The Swartkops River meanders through a highly urbanised and industrialised region of the Eastern Cape making its way through industrial and residential nodes along the industrial artery between Uitenhage and the harbour of Port Elizabeth. In the districts of Uitenhage and Despatch there are considerable residential and industrial development, mainly associated with the wool and motor industries, and industries involved with extractive processes. Major contributors to the deterioration and destruction of natural habitat can be directly and indirectly linked to industrial and residential activities adjacent to the river. As a result of the rapid expansion urban areas, the river is subject to the effects and influences of these developments (Binning and Baird, 2001, pg 461). Increased industrial activity and high density low-cost housing development has seen an rise in stormwater pollution in the river and has affected the health of fish and invertebrate species as well as the health of the people that consume them on a daily basis.

THE SWARTKOPS RIVER - Diagram of problem at metro scale

Catchment
Reach
Estuary
Area of most industrial pollution
Area of high degree urban stormwater run-off pollution (to be investigated)
Tidal Head
THE SWARTKOPS RIVER - Natural structure

Catchment

Figure 2.6: Groendal dam
Figure 2.7: Catchment topography
Figure 2.8: Catchment vegetation

Reach

Figure 2.9: Swartkops river near Uitenhage
Figure 2.10: Invasive Water Hyacinth
Figure 2.11: Natural vegetation

Estuary

Figure 2.12: Landscape at Perseverance
Figure 2.13: Natural structure at estuarine-head
Figure 2.14: Marshlands at Swartkops Village
The Swartkops Estuary is physically demarcated in the region between Perseverance and the WWTW (wastewater treatment works) and are subject to degradation from human activity within and without this region. Poor water quality as a result of urban stormwater run-off and regular sewage overflows in the Motherwell and Chatty river regions has been identified as the primary sources of water pollution in this region. The degradation of natural wetland systems has been observed as a result of man-made infrastructure and littering taking place around informal settlements. Sewage spills occasionally occur at the WWTW and are then discharged into the river resulting increased nutrient- and bacterial content within the river. (Assessment of the health of the Swartkops Estuary, 2014, pg 3)

**PROBLEM STATEMENT AT SUB-METRO SCALE**

- Freeway and railroads acts as barriers
- Degradation of natural purifying systems such as wetlands.
- Bridges restricting natural flow tendencies of river
- Insufficient flow rates at tidal head
- Man-made infrastructure degrading natural habitat
- Severe discharges of urban stormwater and sewage effluent directly and indirectly into Swartkops and Chatty rivers
- Railstations degraded and under-utilised
- Unmonitored industrial polluted waters entering estuary from upper reaches.
- Excessive bait collecting and over-fishing resulting in habitat and species loss.
- Growth of invasive plant species at tidal head due to high nutrient content of water.

The following key areas of management has been identified by Environmental reports and needs addressing:

- Water quantity and quality
- Conservation
- Exploitation of living resources
- Land-use and infrastructure
- Institutional and management structures
- Sustainable livelihoods
- Tourism and recreational use and
- Education and awareness (Assessment of the health of the Swartkops Estuary, 2014, pg 6)
THE SWARTKOPS ESTUARY - Diagram of problem at sub-metro

Perseverance A.
Brickfields B.
Marine Salt Industries C.
Swartkops Power Station D.
Railway Marshalling Yard E.
Fishwater Flats Waterworks F.
Carbon Black Factory G.

Estuary head
Train Station
Urban run-off pollution
Urban Settlement
Industrial zone
Point pollution
Waste site
Factory
SWARTKOPS VILLAGE - Nature of problem at precinct scale

The recreational and economical value of the town and its natural context has been greatly affected by human activities such as industry and informal settlement and resulting water pollution. The closing down of the Swartkops Powerplant led the town into economic decline which resulted in the degredation of buildings and infrastructure. The town is boxed-in through a series of man-made barriers such as the railroad and R75 with natural restrictions such as critically endangered land and the Swartkops river restricting further urban expansion. The man-made barriers disconnects the town from informal settlements such as Zwide and Kwadesi restricting access for the lowest common denominator. Service roads leading to the Power Plant and rail-side warehouses has affected the natural structure of environment and has resulted in damming of water and habitat loss. The poor maintendance of roads within the town and lack of an efficient stormwater drainage system has contributed to the further pollution of the river. Economic decline has resulted in a series of degraded and under-utilised buildings and disconnected neglected green spaces no longer serving any function within the town. Further issues of pollution through littering has affected the purifying integrity and recreational appeal of natural wetland systems.
SWARTKOPS VILLAGE - Structuring elements at precinct scale

Built fabric
Access
Use Zone

- Primary roads
- Secondary roads
- Railroad
- Degraded land
- Under-utilised green space
- Degraded wetlands
- Flooded Salt pans
SWARTKOPS VILLAGE - Diagram of problem at precinct scale

Figure 2.16: Degraded jetties along water front
Figure 2.17: Railroad station fenced from street activity and lacks public hierarchy.
Figure 2.18: Under-utilised green spaces
Figure 2.19: Under-celebrated viewing corridors leading from main commercial road
Figure 2.20: Cooling channel acting as man-made barrier
Figure 2.21: Unmonitored sewage flow at Zwide
Figure 2.22: Stormwater ponding
Figure 2.23: Lack of thresholds promoting street
The need exists to develop an appropriate urban intervention that will address social, economical and ecological issues within the Swartkops Estuary in an environmentally sustainable manner to restore value to the area and Swartkops Village. An holistic approach should be used to achieve a restorative solution that will be sustainable for the future. Ways in which value can be restored on economical, social and ecological levels will now be investigated to develop an appropriate site specific intervention.

**SUMMARY OF CONTEXTUAL ANALYSIS**

TO BE INVESTIGATED:

1. Rehabilitate degraded natural areas (ecological)
2. Incorporate nearby communities (social)
3. Catalyst for sustainable industry (economic)

**Precedents done on:**

A) Ecological restoration  
B) Socio-economic restoration
A) ECOLOGICAL RESTORATION

This section explores methods to improve the ecological health of the Swartkops river through addressing issues of Urban Stormwater Run-off management and natural habitat restoration. A series of man-made interventions will be investigated to be applied in the project throughout scales to restore the purification integrity of natural and man-made systems.

ISSUES: Polluted Urban stormwater run-off
Conservation Awareness
Habitat degradation

1. STORMWATER MANAGEMENT

Urban stormwater runoff is a major source of water pollution in Swartkops Village. Water contaminated with waste and sediment enters the estuary directly as it runs over impervious road surfaces during extended periods of high rainfall. The use of roadside water channels equipped with detention basins and local vegetation will allow for the improved management and purification of stormwater before it is released back into the river. The use of indigenous trees and plants will not only provide a habitat for bird species but also connect green pockets of space in a visually pleasing way that will enhance natural characteristics of place within the town.

- Removal of contaminants through infiltration.
- Reduced pollution through sedimentation
- Protects bio-retention areas from unwanted sub-surface water.
- Use of native vegetation and trees enhances sense of place through site specific intervention.

Use of streetside channels

Figure 2.24: Street-side stormwater channel, 21st Street, Paso de Robles

Figure 2.25: 21st street, Paso de Robles

Figure 2.26: Spokane stormwater project

Figure 2.27: Use of stone and mortar in street side stormwater channels.
The use of water channels for stormwater management is effective in areas of formal urban settlements where existing infrastructure and municipal service exist. Informal settlements is however a different challenge due to the unstructured expansive nature of informal settlement and lack of infrastructure. Areas like Motherwell and Zwide are examples of this condition and has been identified as areas of most severe urban stormwater run-off water pollution into the river.

The restoration and introduction of natural and artificial wetlands will restore the purification integrity of vegetation around these areas before they enter the river. This is also a way to restore the habitat of many bird and invertebrate species.
Ecological infrastructure

Through the application cut and fill landscaping and the planting of indigenous vegetation and trees, urban wetlands present the opportunity to become public places of interaction whilst restoring habitat of various species. These wetlands are not only public spaces of interaction but provide a ecological service in the purification and management of urban stormwater run-offs without the extensive costs of drainage infrastructure. They therefore fulfill in the requirements of providing a solution that is ecologically, socially and economically sustainable.

BENEFITS
- Management of stormwater to prevent flooding
- Purification of stormwater to prevent river pollution
- Re-establishment of natural habitat of bird, fish and invertebrate species.
- Use of native vegetation and trees enhances sense of place through site specific intervention.
B) SOCIO-ECONOMIC RESTORATION

This section will look at relevant ways in which jobs can be created and provide alternatives for surrounding industry in the region to operate in a more environmentally friendly manner. These jobs will be for the inhabitants of Swartkops Village and nearby communities of Motherwell and Zwide. These initiatives must not only supply work for the unemployed, but become a way in which nearby industries can operate in an economically and environmentally restorative way. The treatise will act as a pilot project to catalyze these initiatives on an urban scale.

ISSUES: Industrial related activity pollution - Waste water treatment plant a source of water pollution.

- Urban stormwater pollution - High nutrient content of water leading in algae growth
- Unemployment of informal settlement residents - Resulting in illegal practises such as excessive bait collecting, overfishing and poaching

INVESTIGATE: - Sustainable wastewater treatment initiatives to be incorporated with existing wastewater treatment works.

- Sustainable and relevant job creation opportunities within the Estuary.
1. ALGAE WASTE WATER TREATMENT

Spills of sewerage wastewater at the WWTW (Waste Water Treatment Works) are a regular occurrence which effects the water quality and nutrient content in the riverine reaches of the estuary. This is mainly due to poor management and over loading. The need exist for a more economically and environmentally effective management plan.

Serious interests in natural methods for wastewater treatment have reemerged. The using of aquaculture systems as engineered systems in wastewater (domestic and industrial) treatment and recycling has increased enormously over the past few years, they are designed to achieve specific wastewater treatment and can simultaneously solve the environmental and sanitary problems and may also be economically efficient (http://www.ncbi.nlm.nih.gov/pmc/articles/PMC4052567/).

The application of algae cultivation, to capture and re-use nutrients found in wastewater, can be applied to the treatment of municipal wastewater, dairy effluent, aquaculture, dairy manufacturing waste and other similar high-nutrient waste streams. An Algae Wastewater Treatment Plant uses sunlight and local algae species to remove nutrients and other contaminants from wastewater while presenting the opportunity to generate large quantities of electricity to power the entire system whilst still having excess electricity left to re-distribute. (http://www.algaeenterprises.com/wastewater-treatment) This process presents the opportunity to purify wastewater whilst producing biomass for bio-fuel production and electricity generation. It is thus an environmental restorative approach as it produces more energy than it consumes in the long run.

**Figure 2.35 : Algae based wastewater treatment**

**Figure 2.36 : Treatment Plant Algae Wheel (Indiana Dunes)**

**Figure 2.37 : Southeast wastewater treatment plant in San Francisco**

**BENEFITS**

- Minimal input energy for cultivation
- Absorbs CO2 from polluted air
- Utilizes natural sunlight
- Nutrients fed through wastewater

Algal-based biorefinery could potentially integrate several different conversion technologies to produce biofuels.
2. SEAWEED FARMING

Seaweed farming is a process that has been adopted and implemented in various countries as a job creation alternative for many low income communities. The simplicity and cost effectiveness of this process together with the international export demand of seaweed for the production of agar and carrageenan products makes this enterprise a promising direction for the improvement of economic conditions within a low income context. (Wikipedia) Seaweed is also a renewable food source that can be grown all year round in almost any conditions regardless of climate and depth. Its natural ability to provide a habitat and thus increase numbers of herbivorous fish and shellfish species makes this process not only economically but ecologically sustainable. This method of ocean-based agriculture is thus a relevant approach to create jobs and restore the habitat of overfished fish species in the Swartkops Estuary.

BENEFITS
- Minimal input energy for cultivation.
- Low security risk
- Creates habitat for various fish species
- Community job creation possibilities
- Re-establishment and maintenance of existing degraded natural and artificial wetland systems as a continuous green buffer to naturally purify urban stormwater run-off.
- Revitalisation of railway stations to re-establish recreational and economical value of towns along the estuary through connection.
- Incorporation of algae in Fish Water Flats Waste Water Treatment Works to produce bio-oils for the development of biofuel products. Facility to receive biofuel refinery for commercial application.
- Establishment of algae farm at Marina Salt pans for commercial use to serve as third and final phase of introducing algae industry achieving high profit region.
- Establishment of Seaweed farming on floodbanks initiative to serve as secondary natural purifier of polluted waters coming from upper reaches whilst creating natural habitat for stressed aquatic species, and providing jobs for nearby communities. (Seaweed to be re-used in building)
- Harvesting of invasive plant species to create jobs and restore natural equilibrium.
- Re-use of flooded salt pans as algae farm to purify polluted Chatty river inlet and create jobs for communities.
- Installation of low flow weir with fishway at tidal head for effective water quality monitoring and control over flooding and flow rates.
URBAN INTERVENTIONS AT SUB-METRO SCALE

1. Installation of flow weir
2. Natural and artificial wetland re-establishment
3. Seaweed farm initiative
4. Railstation revitalisation
5. Wetland re-establishment and maintenance

Figure 2.42: Diagram of sub-metro intervention
Macro-algae(seaweed) farming initiative

Certain areas in the tidal zone of the Swartkops River has been identified as viable locations for the cultivation of Gracilaria(Seaweed). Members of the communities of Motherwell, Zwide and Swartkops Village will be given employment opportunity for the cultivation and harvesting of the seaweed at regular intervals. Methods of cultivation are described in more detail in the production process section of the document.
Micro-Algae farming initiative

Phase 1: Catalyst to sustainable industry; Medium scale cultivation; Bio-fuel research technologies; Medium-scale export
Phase 2: Full-scale refinery; Incorporated into waste water treatment process; Commercial viability
Phase 3: Full-scale cultivation through application of existing salt pans; Commercial viability
STRATEGIES AT PRECINCT SCALE

Figure 2.45: Urban strategies at precinct scale
STRATEGIES AT PRECINCT SCALE

1. GATEWAYS
   - Defining Gateways

2. VIEWING CORRIDORS
   - Enhancing viewing corridors through the framing of views via trees or built up edges.

3. GREEN INTEGRATION
   - Integration of green systems to connect isolated and unutilized green pockets to create green public nodes and enhance sense of place.

4. SPATIAL HIERARCHY
   - Enhancement of civic nodes in order to establish public spatial hierarchy.

Removal of environmentally degrading infrastructure and re-use of degraded structures.

Improving accessibility through establishment of integrated public transport node and improved pedestrian movement routes.

Regulation of water for restorative uses and enhancement of place.
INTERVENTION AT PRECINCT SCALE

The intervention involves the design of a public transport node to improve connection to the town via rail and bus travel thus catering for the lowest common denominator as well as tourists. The rail station creates a civic public space attempting to re-establish spatial hierarchy within the town fabric. The proposal also involves the management of urban storm water to activate green pockets and enhance characters of place. Streets are created along public nodes to establish a connection between the recreational harbor(site) and the rail station.

Figure 2.46: Intervention at precinct scale
The design of the public transport node includes a bus depot along the main industrial artery (R75) in an attempt to improve the connection between surrounding settlements and Swartkops Village and to activate back of building railway space. Water is used as a spatial structuring element according to its function in the public realm i.e. Formally structured in civic space; Informally structured in natural public parks. Green zones are utilised to serve the primary school as sports fields or as public wetland-parks in the town.

Figure 2.47: Railstation design
Part 2: SITE SELECTION AND ANALYSIS

The site analysis will be conducted using the recreational harbor of Swartkops Village as premise. The harbor has become physically disconnected from the fabric of the town due to the establishment of the old Swartkops Power plant back in the mid 20th-century. The factory required water for the cooling of machinery which led to the construction of the massive concrete cooling channel which can still be seen as a remnant of the industrial activity of the mid 20th century. Today, the cooling channel no longer serves any purpose other than disconnecting the harbor from the town, forming a barrier and safety hazard for pedestrian activity. Despite this the harbor is still a major recreational node in the area receiving plenty of visitors over weekends and public holidays. It is consistently used for fishing purposes by recreational- and subsistence anglers alike.

- SITE SELECTION
- SITE ANALYSIS
- COMPOSITE INFORMANTS AND CONSTRAINTS (SITE ISSUES)

Figure 3.1: Harbour entrance (Photo: Author)
SITE SELECTION

Criteria for site selection include the following:

**Access to water**
- Field research done via boats
- Water for production processes
- On-site water research

**Service accessibility**
- Maintenance
- Export

**SITE 1:**
The site is connected to water on 3 edges each consisting of a different ‘type’ of water. The western edge of the site faces the existing man-made cooling channel indicating a strong sense of linearity. The northern edge faces the estuary forming with a retaining wall forming the boundary between land and tidal saltwater. The eastern edge faces the sheltered water of the harbor used primarily for boat launching and fishing. The site is well connected to main transport routes and lies within close proximity of the bus depot and train station for access and export purposes.

**SITE 2:**
The site is located on a linear north-eastern strip of land adjacent to the mouth of the harbor. The site has glorious views towards the Swartkops River mouth as well as up the estuary. This site is virtually surrounded by nature with endangered salt marshes to the east restricting any further urban development. Physical and legal restrictions of the site might prove to be problematic for the type of building.

*Figure 3.2: View from N/E corner of harbor
Figure 3.3: Possible sites*
SITE ANALYSIS - Nature of site

Site 1 has been chosen as it seems to be more suitable for the functional requirements of the selected building activities showing a higher degree of connectivity through access routes. The service nature of the cooling channel provides a unique opportunity for re-use within the programme. The site will now be analysed in terms of its natural and man-made structuring elements.

<table>
<thead>
<tr>
<th>Natural structuring elements:</th>
<th>Man-made structuring elements:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Water quality</td>
<td>- Powerplant cooling channel</td>
</tr>
<tr>
<td>- Tidal influence</td>
<td>- Existing roads and pathway(access, noise)</td>
</tr>
<tr>
<td>- Climatic conditions(wind, sun, rain)</td>
<td>- Existing buildings</td>
</tr>
<tr>
<td>- Natural views</td>
<td>- Harbour walls</td>
</tr>
<tr>
<td>- Significant trees and vegetation</td>
<td>- Industrial vernacular</td>
</tr>
<tr>
<td>- Topography</td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.4: Western view towards site
SITE ANALYSIS - Natural informants

Topography

Tidal influence

Figure 3.5: Natural view points
Figure 3.6: Existing vegetation
Figure 3.7: Underutilised waterfront

Figure 3.8: Harbour water levels
Figure 3.9: Boating channel water levels
Views

Figure 3.10 : View towards harbour

Figure 3.11 : View towards Estuary

Figure 3.12 : View along walkway

Trees and vegetation

Figure 3.13 : Sacocornia perennis

Figure 3.14 : Spartina Maritima(Cordgrass)

Figure 3.15 : Aloe perfoliata

Figure 3.16 : Milkwood

Figure 3.17 : Flooded marshlands

The site exhibits a strong visual and physical connection towards nature despite the strong presence of industry in- and around the harbour premises. Under-utilised natural viewpoints and degraded infrastructure along the river waterfront presents the opportunity to revitalise the area for improved pedestrian and fishing use. Existing vegetation on site such as Aloe and Milkwood should be retained and protected.
The site is fairly exposed to the elements. Low storey buildings (1-2 storeys) to the west offers minimal protection with the eastern edges being completely vulnerable to coastal winds. Being within close proximity to the Swartkops River Mouth means high levels of salt in the air which will affect the material choice of the building.
Water body study

Water is observed as a major structuring element on the site. 3 different conditions is observed each one consisting of each own characteristics and dynamics. These include: Harbor water, river water and channel water.

**Water temperature:** 18.4°C - 20.9°C  
**Salinity:** 30 ppt  
**pH content:** 7.1 - 9.1
Man-made informants

Circulation

Use zoning

1. Cooling channel
2. Fishing spots
3. Environmental Control Office
4. Angling club
5. Yacht club
6. Residential houses
7. Bus depot

Vehicular :  
Pedestrian :  
Industrial :  
Residential :  
Recreational :  
Municipal :  
Infrastructure or lack thereof

![Image](image1.png)  : Stormwater collection
![Image](image2.png)  : Harbour retaining wall
![Image](image3.png)  : Degraded dirt pedestrian walkways
![Image](image4.png)  : River retaining wall

Buildings within harbour premises

![Image](image5.png)  : Yacht club
![Image](image6.png)  : Angling club
![Image](image7.png)  : Environmental River Control Office

Nature - privatised, active  Nature - privatised, active  Nature - privatised, inactive
Man-made informants

Edge conditions

Man-made barriers

Industrial vernacular

Figure 3.29: Cooling channel

Figure 3.30: Swartkops Powerplant, industrial vernacular

Figure 3.31: Noisy R102
COMPOSITE INFORMANTS AND CONSTRAINTS

Problems:
1. The old power plant cooling channel as a barrier physically disconnecting the harbour from the rest of the town.
2. Lack of infrastructure such as efficient stormwater systems as well as pedestrian walkways are observed.
3. Existing recreational buildings acting as enclaves and lacking public integration.
4. Degraded natural habitat due to excessive human and vehicle activity.
5. Close proximity of residential buildings towards the site will have to be dealt with in a sensitive manner.
6. Underutilised natural view points.
7. Water in and around the site is polluted presenting major health risks to recreational users.

Opportunities:
1. The inactive cooling channel presents the opportunity of utilising water from the river.
2. Natural view points presents the opportunity to create viewing nodes as a destination to terminate waterfront movement.
3. Natural landscape and orientation of site allows for glorious views over the estuary.
4. The presence of recreational buildings in the premise presents the opportunity for a mixed-use water front condition to be developed.

Figure 3.32: Composite informants and constraints
SITE ISSUES

Responding to different waters edge conditions
Responding to existing residential and recreational buildings and activities on site.
Responding to existing landscape and vegetation
Responding to estuarine climatic conditions
Responding to industrial vernacular
This section will be dedicated to investigating the various components that make up the programme of the proposed building. Sets of activities will be investigated and analysed in order to gather an understanding of the nature of these activities and their physical and spatial requirements as well as their relationship with one another. Ways in which these activities can be integrated with one another in the most efficient and sustainable way will be looked at. Architectural investigations into the typologies of the activities will be carried out in order to gather an understanding behind the relevant governing design principles of the building types. Sets of conclusions in the form of programmatic issues will be drawn. Precedent studies will be integrated from relevant projects of the past to assist in the development of an appropriate design response.

**PART 1 - Defining the programme**

1) Algae production
2) Fish farming
3) Research
4) Overview of activities

**PART 2 - Exploring the nature of activities**

1) Research
2) Algae production
3) Fish farm
4) Summary of activities

**PART 3 - Architectural investigation**

1) Algae architecture
2) Laboratory typology
3) Precedent studies
Part 1 : DEFINING THE PROGRAMME

Algae production
Fish farming
Scientific Research
Overview of activities
The programme is composed according to the key issues that has been established through the contextual investigation. These include the following:

- The **NEED** for monitoring, rehabilitation and testing of water and ecology within the estuary.
- The **NEED** for ecological responsible industry to be developed.
- The **NEED** for public awareness concerning bio-diversity conservation within the Swartkops Estuary.

The following activity types has been identified to work together in an integrated way to form a single building programme:

- Scientific research
- Fish farm and Algae production (Aquaculture)
- Public education and awareness

![Diagram showing Aquaculture plant and related activities](image.png)
1.1 ALGAE PRODUCTION

Why algae?

With the current rate of depletion of fossil fuel resources and the impending threat of environmental pollution and climate change, the NEED for the development of alternative sustainable biofuel resources has arisen. Algae production shows massive potential in this field having the ability to yield up to 300 times more oil per acre than conventional crops (rapeseed, palms, soybeans, jatropha) and a harvesting cycle of 1-10 days compared to other yearly crops. (http://www.oilseedcrops.org/algae/) The concept of algae production has been proven to be significantly more sustainable than conventional methods. Characteristics include high biomass productivity; an almost 100% fertilizers use efficiency, the possibility of utilising marginal, infertile land, salt water, waste streams as nutrient supply and combustion gas as CO2 source to generate a wide range of fuel and non-fuel products. (http://www.fao.org/docrep/012/i1704e/i1704e.pdf)

Local context

South Africa is a carbon dioxide- (CO2-) intense economy, with more than 75% of the country’s primary energy requirement sourced from fossil fuels. The urgent need exists to reduce fossil fuel dependence, reduce carbon footprint and diversify energy mix and supply with research currently taking place primarily at universities, as well as at scientific and industrial organisations to better understand and develop biotechnologies for commercial application. Nelson Mandela Metropolitan University InnovaCon Centre in Port Elizabeth is currently leading development into this relatively untapped field of renewable energy production in South Africa and has been developing pioneering technology over the last three years with the aim of reaching commercial scale. (http://www.engineeringnews.co.za/article/algal-biofuels-seen-has-having-potential-but-much-research-still-needed-2010-04-23)

Algae based products:

- Biodiesel
- Hydrocarbons
- Ethanol
- Biogas
- Thermochemical treatment
- Hydrogen
- Bioelectricity
- Staple food
- Health foods and pharmaceuticals
- Ingredients for processed foods
- Livestock consumption
- Fish consumption
- Cosmetics
- Chemical industry
- Fertilizer
- Fibres for paper

Figure 4.1: Estimated gallons of oil yielded annually per acre of biofuel crop (Source: International Energy Agency; Department of Energy; UOP LLC)
The **NEED** thus exist to promote further dedication into the development of algae-based biotechnologies for commercialisation and sustainable renewable energy production as an alternative.

**PROPOSAL**

A component of the proposed facility will be used for the sustainable cultivation and refinery of algae into biomass, bio-oils and bio-fuel for export and research purposes. Operations will be conducted on a pilot scale to bridge the gap between lab research and commercialisation. The project will voice awareness of sustainable renewable energy and could work in collaboration with surrounding industry eventually becoming a profitable and alternative sustainable energy resource for the future.

**Aims of Algae plant**:

- Optimisation of methods and development of bio-technologies for the production of algae-based biofuels
- Minimising detrimental human impacts on the environment (water pollution, CO2 emissions)
- Restoration of our natural water resources.
- Creating a platform for industry and research to work coherently towards commercialisation of algae as renewable energy source in the region.
Why fish farm?

South Africa’s aquaculture industry, though still in its infancy, has been identified by government as a key priority sector because of rising demands for seafood and potential to supplement over-stressed wild-caught fish stocks with farmed fish products. ([http://www.medioclub-southafrica.com/tech/4038-the-growth-of-fish-farming-in-south-africa](http://www.medioclub-southafrica.com/tech/4038-the-growth-of-fish-farming-in-south-africa))

Fish Farming involves the controlled cultivation of fish species in growing systems for the purpose of selling for profit, research, re-stocking or providing food security in local communities. This activity has been established and developed as a response to urbanisation, high unemployment, rising transport costs, a deteriorating marine environment, and global warming. ([http://www.thefishfarm.net/](http://www.thefishfarm.net/)) As stated earlier, local fish populations within the Swartkops River are facing enormous threats due to over-fishing and water pollution. Fish caught by subsistence fishermen present major health risks to all who consumes them, especially to the many poorer residents of informal settlements who are restricted i.t.o. access to health care. The NEED thus exists to provide an alternative local safe food source that will ease the strain on local dwindling fish populations.

Existing aquaculture ventures in Eastern-Cape over the past 4 years:

- A prawn-farming venture in the Coega IDZ
- A kob hatchery in the East London IDZ
- The expansion of a successful abalone farm on the Eastern Cape east coast
- A marine caged fin-fish project in the Nelson Mandela Bay
- An in-land kob farming operation 30km outside East London

([http://www.ecdc.co.za/ecdc/fisheries](http://www.ecdc.co.za/ecdc/fisheries))
Reasons for fish farm:
- Food security provision for low income areas
- Relieved stress on fish populations
- Improved economical fish-market of Swartkops Village
- Safe food source

PROPOSAL
The project will cultivate selected species on a small-intensive scale in order to continuously provide a food source for the poorer surrounding communities of Motherwell and Zwide whilst relieving pressure on fish- and prawn populations that have become stressed due to overfishing in the Estuary. Fish that will be farmed within the facility will also be sold within Swartkops Village at local fish markets to boost the economy of the town and provide a safe food source for local inhabitants. Locating the farm within the building will also allow for the effective study between inter-related study fields such as water, algae and biology.

Aims of fish farm:
- To intensively produce fish as food source for local communities in a environmentally sustainable manner.

- Creating a dedicated fish-farming research and development programme to establish production technology for high priority species that can reduce the challenges to farming these species and optimise efficiency.

- Making relevant information developing a fish-farm available to the public through a tourist interface to reduce the research and pilot cost burden.

- Reducing the strain on local fish populations due to excessive and illegal relating practices.
1.3 SCIENTIFIC RESEARCH

Research facilities are buildings where scientists study a particular scientific field for the purpose of increased knowledge on a certain subject or the development of particular technologies in a specified field.

The facility will allow for productive collaboration between ecological- and renewable energy research fields and will cater for scientists and PhD students from Nelson Mandela Metropolitan University.

The **NEED** of environmental conservation has been identified as one of the key issues that needs addressing within the estuary. The provision of a research building in the Swartkops Estuary will facilitate the regular effective monitoring, testing and studying of water conditions and biodiversities. The research section of the building will be made up of components that also cater for the study of algae (biofuels) and fish which will be cultivated on site. The research facility will allow for improved exposure and access to the relevant issues threatening biodiversities within the estuary and will operate within the guidelines established in up-to-date Environmental Management Reports.
1.4 OVERVIEW OF ACTIVITY TYPES

1. PRODUCTION OF MICRO-ALGAE:
Micro-algae to be cultivated on site for the purpose of development of research in the field of bio-technology as well as production of renewable energy. A variety of indoor and outdoor methods and techniques will be used to achieve optimal production for viable commercial application.

2. FISH FARM PRODUCTION:
Selected fish species (Spotted grunter, Dusky kob) to be intensively cultivated on a local scale to provide food security for local communities and be sold within the town to boost local economy as well as development of knowledge for fish farming of species currently in research stage. Seaweed species ‘gracilaria’ to be cultivated in and around site to provide jobs for local communities.

3. SCIENTIFIC RESEARCH:
Field and lab research to be conducted in the fields of renewable energy, biotechnology, water quality and ecology.

4. PUBLIC AWARENESS:
The facility will consist of a public component that will allow for education in the various study fields to achieve increased awareness of conservation and current and future sustainable programmes.
Part 2 : EXPLORING THE NATURE OF ACTIVITIES

<table>
<thead>
<tr>
<th>Section</th>
<th>Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1 Scientific research</td>
<td>- Field research</td>
</tr>
<tr>
<td></td>
<td>- Laboratory research</td>
</tr>
<tr>
<td>2.2 Algae production</td>
<td>- Cultivation</td>
</tr>
<tr>
<td></td>
<td>- Harvest and extraction</td>
</tr>
<tr>
<td></td>
<td>- Refining</td>
</tr>
<tr>
<td>2.3 Fish farming</td>
<td>-</td>
</tr>
</tbody>
</table>
2.1 SCIENTIFIC RESEARCH FACILITIES - Field research

Field research involves the on-site monitoring, measuring and sample collecting of specimens and samples. Field researchers will retrieve information from the estuary to be brought back for in-depth analysis within controlled laboratories after being decontaminated in wash-up zones. The scope of field research activities will include:

- Monitoring and surveillance of natural ecosystems.
- The regular collection of samples within the river and at critical pollution points.
- Surveillance of particular fish and bird species within the estuary. (tagging)
- Monitoring of progress and effects of proposed seaweed farming initiative

Facilities field researchers will require:
- Boat store and launch pads
- Equipment store
- Wash-up areas
- Equipment and boat repair workshops

Figure 4.8 : Tagging
Figure 4.9 : Water sample collecting
Figure 4.10 : Diving expeditions
2.1 SCIENTIFIC RESEARCH FACILITIES - Lab research

**WET LABS:**
Wet laboratories are laboratories where chemicals, drugs, or other material or biological matter are handled in liquid solutions or volatile phases, requiring direct ventilation, and specialised piped utilities(wiki-pedia, https://en.wikipedia.org/wiki/Wet_laboratory). These areas are going to be dedicated for the cleansing and decontamination of samples collected from the estuary and from the algae- and fish production sections within the building.

**DRY LABS:**
Dry labs are controlled environments where indepth research and study is conducted on the dried and processed samples collected from wet labs. These areas are usually highly efficient and flexible with adequate service distribution systems for the control of research conditions such as room temperature, water supply, gas supply etc. These facilities will be used for theoretical development and the analysis of collected samples from the estuary and/or production facilities.
2.2 ALGAE PRODUCTION

The process of algae production is a predominantly privatised activity that is made up out of primarily 3 stages i.e. cultivation; harvest and extraction and product refining. These activities take place between indoor- and outdoor spaces and operate in coherence with research facilities. These interrelated activities and their production methods will now be investigated in order to gather an understanding of the requirements for the design of a functional Pilot plant facility. The building will facilitate the comparision between different cultivation methods, algae-strains and conditions in order to develop research in the field for commercial application and will operate coherently with laboratories.

The following factors should be investigated before designing an algae production and research facility:

1. What specific strain of algae will be cultivated for which purpose and at what scale?
2. How will algae be produced at optimal growth?
3. Is there a public component?

Figure 4.13 : Diagram of production process
2.2 ALGAE PRODUCTION - Strain selection

Choosing a specific strain is important to determine the type of growth system best suited for optimal production. The facility will utilise a variety of strains in order to develop several existing and new bio-technologies in the production of biofuel. Primary growing systems cultivating micro-algae will also continuously produce bio-oils for export purposes whilst secondary systems will cater for testing of testing strains in the field of biofuel. Certain strains (Spirulina) will be cultivated to produce feed for the fish farming section. Algae cultivation will also play an essential role in the purification and treatment of water within- and without the facility that will be re-used within wet-, ablution- and fish farming facilities. As stated earlier, production will be based on a pilot scale which lies in-between research- and commercial scale applications. The following species has been selected for cultivation based on local viability:
2.2 ALGAE PRODUCTION - *Micro-algae production overview*

Stages of production

**Figure 4.21: Production components**

**Figure 4.22: Production process spatial layout**

**Figure 4.23: Micro Algae Production stages**
2.2 ALGAE PRODUCTION - Macro-algae(seaweed) production overview

**Cultivation**

Seaweed is cultivated manually using a combination of raft- and monoline methods within the tidal reaches of the river. (see contextual section)

**Harvesting**

Grown seaweed is harvested through rafts or boats and brought back to the facility for processing.

**Washing**

Seaweed is unloaded into washing bays to remove any accumulated debris and organisms.

**Drying**

After the seaweed has been washed it is moved to racks to be dried by the wind and the sun.

**Packaging**

Dried seaweed is monitored for quality and packaged for exporting or storage.

**Export**

Packaged seaweed is transported to the harbour of Port Elizabeth through either boat or train from where the product is then transported to global and local agar production facilities.
2.2 ALGAE PRODUCTION

**Cultivation (indoor/outdoor):**
Micro-Algae can be grown using a combination of bio-reactors and open pond systems using resources from the local environment. The physical growth requirements of algae include water, CO2, light(natural/artificial) and sufficient nutrients. Regular monitoring of these systems are conducted during the growth period through the use of control rooms that can be computer operated. Physical observation and testing also occurs during this period and samples are collected and taken to labs for further testing. This activity can occur in outdoor or indoor growing facilities with the potential of being made accessible to the public for the benefit of education and awareness of the sustainable industry. Primary and secondary cultivation methods will be used throughout the building to fulfill the aim of maximized production and technological development in the field. Growth requirements will be obtained using the polluted resources in the area such as river- and waste water containing high nutrient contents as well as CO2 from the surrounding polluted air. The cultivation method will utilise both natural- and artificial light to establish and maintain a continuous and adaptable production process.

**LIGHTING METHODS**
Direct or indirect light is need for the cultivation process of photosynthesis. Sunlight or artificial LED lightsources can be used for algae growth.

**GROWING METHODS**
1. BIO REACTORS (indoor/outdoor)
2. OPEN PONDS (outdoor)

Figure 4.30 : LED Lighting used in indoor growing facilities
Figure 4.31 : Sunlight used in outdoor open pond growing systems

Figure 4.32 : Algae raceway ponds
Figure 4.33 : Outdoor ponds
Figure 4.34 : Flat plate photo-bioreactors
Figure 4.35 : Vertical Tubular photo-bioreactors
Figure 4.36 : Plastic bags
Figure 4.37 : Flat panel
Figure 4.38 : Horizontal Tubular photo-bioreactors
Figure 4.39 : Re-circulating water systems
2.2 ALGAE PRODUCTION

**Harvest and extracting (indoor):**
The harvesting process involves removal of purified water from algae mass through the use of separators. This system can be computerised but still requires monitoring and continuous adjustments during the process. After harvesting the algae paste is moved on to the extracting stage where mechanical and chemical methods of extraction are utilised to remove algae oil from the paste substance. This type of activity is more privatised in nature and requires continuous monitoring and adjustment throughout the process.

**HARVESTING METHODS**

- Mechanical harvesting
- Chemical Methods
- Centrifugation
- Flotation
- Cross-flow electro-filtration
- Ozoflotation
- Electrochemical harvesting

**DRYING METHODS**

- Drum drying
- Spray drying
- Incinerators
- Toroidal Dryer
- Sun drying

![Figure 4.40: Centrifuge](image)

![Figure 4.41: Algae slurry in centrifuge](image)

![Figure 4.42: Algae biomass](image)

![Figure 4.43: Dried algae chunk](image)

![Figure 4.44: Algae rotary drum dryer](image)

![Figure 4.45: Spray dryer](image)
2.2 ALGAE PRODUCTION

EXTRACTION METHODS

This stage involves the extraction of algae oil from biomass to be further processed into bio products. These methods are broadly classified into two groups and can work in conjunction with one another.

1. Mechanical extraction: - Expression/Expeller press
   - Ultrasonic-assisted extraction

2. Chemical extraction: - Hexane solvent method
   - Soxhlet extraction
   - Supercritical fluid extraction

Expeller pressing will be utilised for the extraction of 75% of the oils from algae. This is a single step process and involves mechanical pressing at high pressures. ([http://making-biodiesel-books.com/about-algae/algae-oil-extraction/](http://making-biodiesel-books.com/about-algae/algae-oil-extraction/))

Refinery (indoor):

Involves the process of developing algae oils to create bioproducts. The oil extracted can be converted to biodiesel via transesterification reaction. The residues from oil extraction are excellent feedstock for making other fuels and products via different processes.
2.3 FISH FARMING

The following factors should be considered in order to design an efficient and sustainable fish farming facility.

- Deciding on a species for farming
- Deciding on an appropriate cultivation system
- Investigating water treatment and control
- Public integration and awareness

![Image: Stages of fish farming](image)

Figure 4.48: Stages of fish farming

![Diagram: Relationship of production process with research facility](image)
1. SPECIE SELECTION

Choosing the right species for a fish-farming project is essential to the success of the fish-farm and the impact the farm will have. The choice of culture species is closely linked with the objectives of the development and the context in which the species will be farmed. (http://www.fao.org/docrep/t8598e/t8598e05.htm) As stated earlier in the document, over-fishing and pollution has stressed the population and health of various fish species within the Swartkops Estuary presenting health and food security risks towards the poorer black communities in the area. The following species has been identified as the predominant overfished species and will be cultivated, distributed and studied within and without the facility.

**Spotted grunter (Pomadasys commersonii):**
This fish specie is currently classified under research scale cultivation. (DAFF annual report, 2011, pg 2) This specie is currently classified under research scale cultivation in South Africa. (DAFF annual report, 2011, pg 2) This specie will be cultivated with the aim of developing research to optimize growing conditions for pilot plant scale production within the facility.

Diet: Mudprawn, Worms, shrimp, crab, molluscs, mussels
Water Temp: 16-30 C
Type of cultivation: Intensive

**Dusky kob (Argyrosomus japonicas):**
This fish specie is currently classified under pilot scale cultivation. (DAFF annual report, 2011, pg 2) This specie is currently the countries largest export. Cultivation methods are well established which will allow for the efficient and profitable production of this specie whilst the cultivation of other species are investigated and tested to achieve optimal production.

Diet: Carnivorous
Water Temp: 22 C
Type of cultivation: Intensive
2.3 FISH FARMING

2. TYPE OF SYSTEM

When designing a fish farm one should first consider the function and to what end the fish will be produced i.e. commercial scale - high export profits; rural aquaculture - food security. This will determine the intensity and scale at which fish will be produced as well the selection of a particular cultivation system. There are generally 2 scales at which fish can be produced:

A. Extensive farming
Extensive fish farming utilises natural photosynthetic production of food (algae, plankton, mollusks, crustaceans) to feed the fish. This type of farming isn’t the most productive, but it requires little labor, low overhead, and very little input from the farmer. Extensive farming is the most sustainable and does the least environmental damage, but it isn’t always economically viable and it doesn’t work for every species. (http://www.marksdailyapple.com/introduction-fish-farming-aquaculture/)

**Advantages:**
- Minimal labour
- Low overhead cost
- Can be applied to existing infrastructure (farm dams)

**Disadvantages:**
- High security risk (Birds; Robbers)
- Low production rates
- Limited specie viability

B. Intensive farming
This type of fish production involves the cultivation of fish in close controlled environments at high production rates. A high degree of knowledge of the particular specie is required for growing conditions to be optimised for consistent high yields throughout the year. This type of system is viable for the production of dusky kob, but not for Spotted Grunter as lack of knowledge of the specie still restricts commercial application. (DAFF annual report, 2011, pg 2)

**Advantages:**
- High consistent production yields
  - High degree of control
  - Minimal space requirement

**Disadvantages:**
- High running costs (feed, electricity, equipment)
  - Increased risk of disease (high stocking densities)
  - Requires high degree of knowledge and monitoring
  - High degree of labour

---

Figure 4.52: Extensive pond system

Figure 4.53: Intensive tank culture
2.3 FISH FARMING

Farming method selection

**Raceways (semi closed)**

This method works by diverted water from natural sources such as streams to cultivate fish. This is considered a minimal risk method assuming sufficient waste treatment system and fish escape prevention. This system is considered mostly in the cultivation of rainbow trout. (seachoice.org)

**Ponds or tanks (semi-closed/ closed)**

This system can be either semi-or fully closed systems and require an effective waste treatment method to be considered a low risk method. Recirculating aquaculture system (RAS) technologies can be included to optimize sustainability. (seachoice.org)

**Recirculating systems (closed)**

These systems are characterized by the recirculation of treated fish waste water. Through avoiding contact with natural water sources they minimize the risk of pollution, parasite transfer and fish escapes. This type of system allows for the cultivation of almost any type of fish. (seachoice.org)
2.3 FISH FARMING

Type of enclosure
When deciding on a type of cultivating vessel the following should be considered in order to be economically viable:

- The ease of which a enclosure can be cleaned
- Capability to effectively manage fish within the vessel

A rounded tank type enclosure has been chosen for the cultivation of fish. Tanks should be effectively designed to allow for easy drainage of wastes. Water moving in a circular flow will carry the solids to the central drain, from where they can be piped towards mechanical filtration. This type of enclosure seems like the best option as it reduces labor cost as well as stress on the fish. Prefabricated glass coated steel tank kits will be used as they provide the most economical option. (http://www.aquacare.com/products/fish-farming-tanks/)

Advantages over ponds and raceway systems:
- Reduced stress on fish
- Reduced labour cost
- Cost of construction
- High growth-to-feed ratio
- Ease of water handling

Disadvantages over ponds and raceway systems:
- Harvesting difficulties
2.3 FISH FARMING

Number and size of tanks

The production of food fish in large circular tanks has produced large cost savings in comparison to raising the same quantity of fish in more but smaller tanks although using a single tank for the entire growth period of a fish is not economically productive.

The two main factors to consider is:

- Tank rearing capacity
- Fish mortality and loss of growth

The number of tanks should be limited to 3 types for the different stages of growth in order to achieve a balance between utilising the rearing capacity of each tank and minimising stress (mortality) of fish through minimal transportation between vessels. Tank depth should be designed with regard to access for monitoring and harvesting.

Figure 4.62: Fish hatchery tanks

Figure 4.63: Large tank opposed to smaller tanks with same number of fish

Figure 4.64: 3 tanks for different stages of growth opposed to single tank for entire growth period

Figure 4.65: Permanence vs flexibility
2.3 FISH FARMING

Aeration
Oxygen management involves the process of adding oxygen to water which influences growth rates, feed conversion rates, and overall fish production. Atmospheric oxygen can be supplied to the tanks through surface agitation with aerators or through blowers. Surface aerators may not be cost effective or efficient in evenly distributing oxygen throughout large commercial-scale systems. (http://www.aces.edu/dept/fisheries/aquaculture/documents/recirculatingVT.pdf)

Blowers will be used to evenly distribute oxygen to all the culture tanks as it is the most effective for the type of cultivation intended.

Heating
Water temperature strongly influences feeding and growth rates of cultured fish. The species selected for cultivation fall under cool water species (18-26 C). These temperatures should be maintained throughout the growing periods for optimal growth and can be achieved by well insulated building design. Methods to achieve optimal growing temperatures include: Solar heating, Heat exchangers, Direct water heating. Room temperatures should be kept at 2-4 degrees above water temperature to limit the effects of condensation. High summer temperatures should be controlled by an efficient ventilation system design. (http://web1.cnre.vt.edu/extension/fiw/fisheries/fishfarming/RecirculateAquaSys.html)

Temperatures will be retained through good thermal architectural design combined with an heat exchange system. This approach proves to be the most economic as it utilises natural conditions and low maintenance equipment.
2.3 FISH FARMING

Feeding

A complete feed, containing all the essential minerals and vitamins for healthy fish growth, and composed specifically for the fish species being reared, is necessary for fish production in the selected system. It is recommended that feeding a commercial feed of dry, floating pellets so that the feeding activity and health of the fish can be easily observed at the water surface. Fish feed should be stored in cool, dry areas and can be either hand-fed or distributed to culture tanks through automatic feeding systems. (http://www.aces.edu/dept/fisheries/aquaculture/documents/recirculatingVT.pdf)

An automatic feeding system will be utilised as it will prove to be the most economical for the type of cultivation system (semi-intensive). This method ensures consistency and reduced labor costs. Fish feed will be produced on site by utilising other culture systems of feed production such as algae farming. Sufficient cold store facilities should be provided within the facility for the storage of feed as well as easily accessible service and maintenance circulation.

Figure 4.70: Automatic feeder system
Figure 4.71: Hand fed method
Figure 4.72: Spirulina algae fish feed
Figure 4.73: Chlorella algae fish feed
2.3 FISH FARMING

3. Water circulation and purification

POSSIBLE WATER CIRCULATION SYSTEMS

The following site specific systems has been identified for consideration.

This approach consists of a land-based re-circulating system. Waste water within culture tanks consisting of solid and dissolved wastes is extracted and re-circulated and purified through a series of mechanical and biofilters to be re-used for cultivating fish.

![Figure 4.74: Closed land based system](image)

This is a partial re-circulating system which directly extracts polluted water out of the existing cooling channel on site and distributes it through a series of mechanical and biofilters in order to achieve acceptable water quality levels for fish cultivation. Waste is then extracted from culture tanks, purified and distributed back into the channel.

![Figure 4.75: Semi-closed land based system](image)

This approach extracts water from the estuary directly into cultivation mediums. Waste water is then released directly into the estuary. This approach is not sufficient as it doesn’t fulfill water quality- and environmental requirements for fish farming.

![Figure 4.76: Open land based system](image)

WATER EXTRACTION

The close proximity of an old cooling channel presents the opportunity for water extraction from the Estuary. The current water conditions are however unsuitable for healthy fish farming and will require a series of purification systems before it can be used. Water should be pumped during high tide to minimize mixing of sediments, pollutants and debris.

![Figure 4.77: Diagram of water extraction](image)

![Figure 4.78: Existing cooling channel](image)

WATER STORAGE

-Extracted purified water will be distributed to storage reservoirs from where water content and quality can be carefully controlled and adjusted before further distribution to culture tanks. These tanks will continuously be filled with purified water from the river.

-Rainwater collection should utilized for re-use within the building to improve sustainability. These storage tanks can be used for cleaning, ablution, and wet lab functions within the facility.
2.3 FISH FARMING

Water filtration

Water filtration systems are important when trying to minimise environmental impacts and recirculating waste water from cultivation tanks for reuse purposes. Filtration involves the removal of waste and toxins from the water and can be divided into two distinct types: - Mechanical filtration (removal of wastes)
- Biofilter (converts toxic nitrogenous wastes to less toxic nitrate)

It is important to combine both filtration methods at appropriate stages to ensure optimal purification in order for water to be re-used within the facility.

A. MECHANICAL FILTER

As stated earlier mechanical filtration involves the removal of suspended- and settled solid wastes within an fish culture tank.

These solids can be removed through the following systems:
- Filter cloth
- Drum filter
- Bag filter

Drum filter

This high tech method of mechanical filtration is considered the best method and is used in various systems across the world. (fishhelpline.co.uk)

The main advantages of this system over other mechanisms include:
- Filters down to 20 microns with ease which allows for the effective filtration of free swimming parasites and all waste particles.
- This type of system is self cleaning which allows for enormous savings on time and labor.
- High level of compaction. Can vary from large to small.
- Due to the quick removal of waste the nitrate levels remain lower with less water adaptions needed.

The main disadvantage of this system is initial cost, although its efficiency and lack of maintenance makes up for this disadvantage.

Sludge concentration

Resulting sludge production from mechanical filtration presents a storage and economic problem in many fish farms. Sludge treatment and disposal options available include: transfer to domestic wastewater treatment facilities, landfill dumping, infiltration through soil filters and use as a crop fertilise. The close proximity of the Wastewater Treatment Works allows for the possibility of linking sludge tanks to the main sewage line to be distributed for treatment. Another possibility is to re-use the sludge as a fertilizing product for local agriculture in the region. (http://www.researchgate.net/publication/238392707_A_system_for_the_treatment_of_sludge_from_land-based_fish-farms)
2.3 FISH FARMING

B. Trickling biofilter
A trickling filter is a fixed-bed, biological reactor that operates under aerobic conditions. Pre-settled wastewater is continuously ‘trickled’ or sprayed over the filter. As the water migrates through the pores of the filter, organics are aerobically degraded by the biofilm covering the filter material. Water can then be processed for secondary sedimentation through an under-drain system. Resultant biomass can then be harvested for processing. (http://www.sswm.info/content/trickling-filter)

Advantages of such a system:
- Compaction (easily applicable in densely populated urban settings)
- Effective reduction of organic matter

Disadvantages of such a system:
- High tech construction
- Requires skilled staff for operation

Design factors to consider:
- Type of filter media to be used
- Spraying system
- Configuration of the under-drain system
C. HYDROPONIC BIOFILTER

Hydroponics is an effective way to purify water in intensive fish farming systems. Plant roots and rhizo bacteria remove nutrients from the nutrient-rich effluent water. The nutrients generated from fish manure are utilised as liquid fertilizer to hydroponically grow plants. The hydroponic beds functions as a biofilter leaving purified water to be recirculated back into the fish tanks. ([http://www.backyardaquaponics.com/Travis/aquaponic.pdf](http://www.backyardaquaponics.com/Travis/aquaponic.pdf))

Advantages of such a system:
- The waste products of one biological system serve as nutrients for a second biological system.
- The integration of fish and plants results in a polyculture that increases diversity and yields multiple products.
- Water is re-used through biological filtration and recirculation.
- Local food production provides access to healthy foods and enhances the local economy.

Invasive aquatic flora species such as Hyacinth and Water Fern will be harvested in the estuary at Perseverance to be re-used within the facility in an integrated hydroponic fish-farming system.

Figure 4.84: Integrated hydroponic fish farm

Figure 4.85: Water hyacinth in Swartkops River
2.4 PUBLIC INTEGRATION

The facility will integrate the public to a certain degree in order to promote conservation and sustainable industry first hand through observation and education of the various processes involved in the production of algae and fish. This is also an effective method to promote eco-tourism in the region whilst obtaining additional funds for the project. The privatized nature of the activities within the facility demands carefull planning of public circulation so as not to intrude on these activities. Guided tours will be offered that will allow for the public to obtain knowledge first hand through the direct observation of the various processes involved and benefits of an integrated production system. A pre-determined circulation route and efficient privacy layering should be implemented in the planning of the design so as not to intrude on ongoing research and production. Tour groups will be limited to 20 people for effective control. Interactive exhibition rooms as well as lecture rooms can be implemented in the design to allow for futher education in the various fields of study.
2.5 SUMMARY OF ACTIVITIES

Field research
- Wet labs
- Dry labs

Laboratory research
Service

Cultivation
- Sample collection
- Production process: Harvest, extract, drying, pressing, refine

Export
- Process and package
- Harvest
- Export

Spaces should provide for:

Field research
- Boat storage
- Equipment storage
- Maintenance and repair workshops
- Wash-up space
- Docking bays and jetties

Lab research
- Adequate service supply (water, gasses, air supply etc.)
- Access for maintenance
- Equipment storage
- Flexible floorspace for ease of expansion and change in use
- Secure storage of hazardous materials

Spaces should provide for:

Production
- Flexible floorspace for changes in technology and production methods
- Ease of access for maintenance and exporting
- Visual and physical connection to laboratory facilities for effective monitoring, sample analysis and quality control
- Sufficient storage space to house services and equipment
- Security (public interference; possible patented technology)
- Adequate ventilation

Spaces should provide for:

Cultivation
- Adequate exposure to natural and/or artificial lighting
- Storage to house generators, pumps and CO2 supply
- Large open floorspace for maximum growth area coverage

Spaces should provide for:

Production
- Sufficient flexible floorspace for a variety of tank sizes
- Effective distribution of oxygen and fish feed as well as effective removal of waste.
- Waste treatment rooms and water purification (bio- and mechanical filtration)
- Effective temperature control via good architectural thermal design.
- Water header tanks storage
Part 3 : ARCHITECTURAL INVESTIGATION

The following architectural typologies related to the activities has been identified to form a single building type:

Research spaces: Laboratory typology
Fish/algae culture production : Factory/shed type

The **building type** will thus be classified as an **hybrid** of these architectural building typologies. The combination of these two typologies into a single building will promote faster and more effective translation of laboratory discoveries into products and processes for commercialisation of algae-based biofuel.

3.1 Defining Algae Architecture
3.2 Laboratory typology
3.1 DEFINING ALGAE ARCHITECTURE

Algae has been utilised in a variety of ways in buildings and urban landscapes that stretches its use past conventional methods of producing bio-products. An increasing awareness of the economical and environmental benefits of integrated algae systems in buildings are starting to be realised and designers and engineers are beginning to emerge with innovative biomimetic interventions to be used in existing and new buildings alike. The concept of ‘living buildings’ can be seen as a restorative response to the environmentally degrading effect of traditional industrial practices. The adaptability of algae and the environmental benefits it holds presents the opportunity for architecture to enter a new realm of sustainability.

Through my investigation into this relatively undefined and exciting field of architecture, I have concluded 3 predominant types that currently exist. These include:

**Type 1**: Algae production and research development facilities

**Type 2**: Integrated algae building systems

**Type 3**: Public urban landscapes
3.1 DEFINING ALGAE IN ARCHITECTURE

Type 1: Algae production and research development

Characteristics:
- Secure premises for the testing of technology
- Operates in privatised manner, disconnected from public
- Primarily concerned with production yields and profitability
- Variety of cultivation methods and algae strains utilised to develop technology and production efficiency

Figure 5.2: Alltech algae, Kentucky

Figure 5.3: Algae Parc, Wageningen

Type 2: Integrated algae building systems

Characteristics:
- Algae used as integrated component within the building envelope.
- Primarily concerned with renewable energy utilisation and sustainability in buildings.
- Has interaction with private occupant as well as a limited connection with public.
- Has a positive response towards the user and the environment.

Figure 5.4: Marina towers, Chicago

Figure 5.5: CO2 scrubbers on top of towers

- Algae used as sustainable technology for retrofitting of existing building and revitalisation of context.
- Use of scrubbers to extract CO2 out of the air.
- Integrated sustainable technology to create renewable energy.
- Used in context of high carbon emissions.
Algae can be integrated into the building envelope as a bio-adaptive facade providing shading and noise insulation for internal spaces.

- Integrated algae systems can be utilised on facades to generate solar heat and biomass for re-use within the building substituting additional heating expenses.

Type 3: Algae urban landscapes

Characteristics:
- Used for restoring ecological and social value of degraded areas.
- Interactive system within public realm.
- Perceived as integrated with - or object in the landscape.
As stated earlier, the project will predominantly be concerned with the production and development of algae production for biofuel application (Type 1). The public nature of the site and objective to increase awareness in the public realm will require an integrated public response that can be achieved through combining the three types listed.

- Re-adaption of existing architectural technologies to accommodate micro-algae culture.
- Algae used as photosynthetic machine to produce O2, reduce CO2 and provide shelter.
- Interactive, bio-adaptive, space-defining element in public realm

Figure 5.12: Milan expo rendering, Ecologic studios

Figure 5.13: Prototype technology exhibition, Milan, Ecologic studios

Figure 5.14: Bio-adaptive canopy
3.2 LABORATORY TYPOLOGY

The laboratory typology has been identified as one of the established building types that make up the programme. This section of research will look at various design components that make up a successful 21st century lab such as spatial arrangement, service distribution, flexibility, communication and environmental sustainability.

Laboratory buildings are technically and organisationally highly sophisticated, as they have to efficiently serve specialised work processes. They provide a controlled environment to prevent contamination of the test and research results. Programmes of these type of buildings are usually made up out of office spaces for theoretical research, laboratories for experimental work, support spaces and building services, all of which are functionally linked and optimised in their spatial organisation. (Stephen A. Kliment, 2001) The following sections have been identified as key components in the spatial organisation and physical expression of modern labs.

KEY DESIGN COMPONENTS:

A) Communication
B) Flexibility
C) Sustainability
D) Expression
E) Finishes
F) Services
A) Communication

SOCIAL SPACES
The idea of communication is a vital element in the planning of laboratory-type buildings. Spaces of interaction within and without the building should be created in order to provide a platform that encourages the production and exchange of knowledge between scientists. These spaces should allow for interaction between inter-related fields of research and shouldn’t be isolated from surrounding research programmes within the building. The design of these spaces should be approached with care so as not to take priority above design of research space. (Stephen A. Kliment, 2001)

Such spaces include:
Atriums, bridges, lobbies, courtyards, break rooms, meeting rooms, conference halls
OPEN VS CLOSED LABS

Open and closed labs are substantially different from one another with both containing their own benefits and disadvantages.

Open lab layouts favour collaborative team-based research with floorspace, benchspace, equipment and support staff being shared between the team members. This type of layout improves communication between scientists and is also a flexible mode of space making to accommodate future changes that may occur.

Closed labs are favourable when specific type of research and equipment is needed for the effective performance of work. Individual dedicated labs are still relevant in today’s society as it may become distracting to perform certain tasks effectively in a lab that is open to everyone.

It is therefore recommended that a combination of the two exists. Depending on the nature of the research, closed labs can be directly linked to open labs in order for effective teamwork as well as privatised research.
3.2 LABORATORY TYPOLOGY

B) Flexibility

Flexibility in research buildings entails the ability of expansion with ease and re-configuration of spaces as a result of change in use or technological developments. It is important that flexibility should be considered early in the design phase to save costs on future expansion and renovation costs.

FLEXIBILITY OF ENGINEERING SYSTEMS
These systems provide a means to distribute water, electricity, exhaust air, vacuum systems and natural gas and are essential in a laboratory building. Overhead service carriers are used to connect utility services within the ceiling with the work benches through the use of docking stations.

DESIGN CONSIDERATION
- Maximum number of fumehoods.
- Duct work sized to allow for future change.
- Ease of connection and disconnection at walls and ceilings
- Space for utility corridors, ceilings, heating, ventilation, airconditioning, plumbing, electrical needs.

FLEXIBILITY OF INTERNAL SPACES
- Use of equipment zones
- Modular spatial lab arrangements

Figure 5.22: Fixed and movable equipment zones

EQUIPMENT ZONES
It is recommended to allocate approximately 25% of the space in most labs for equipment zones. This provides space for the researchers to come in and move casework and equipment around as well as add case work and/or equipment where necessary.
MODULAR SPATIAL ARRANGEMENTS

The use of established modular lab spatial arrangements in the design of a laboratory enables the effective co-ordination of architectural and engineering systems as well as providing an flexible platform for future changes and developments in technology and research methods. Attention should be given towards the coordination of vertical risers such as elevators, utility closets, exaust and supply shafts, fire stairs and restrooms.

Figure 5.26: Three dimensional lab module concept

Figure 5.27: Lab module flexibility

Figure 5.28: Typical lab module

Figure 5.29: Typical lab module section

Figure 5.30: Bench arrangements
3.2 LABORATORY TYPOLOGY

B) Flexibility

CORRIDORS

Predominantly three types of corridor arrangements from which combinations and variations could be made to design the most effective combination for the programme. These include:
- Single corridor
- Double corridor
- Triple corridor

Single corridor arrangements

DESIGN CONSIDERATIONS
- Glazed interior walls or breaks in corridors to allow for natural light penetration.
- Inclusion of lounges with views to exterior to allow for user orientation and natural light penetration.

Double corridor arrangements

DESIGN CONSIDERATIONS
- Use of ghost corridors to directly link adjacent labs.
- Ghost corridors only to be used in open - or/and low security risk labs.

Triple corridor arrangements

DESIGN CONSIDERATIONS
- Central corridor can be used as a shared equipment corridor.
- Central corridor can also be exclusively used for maintenance access.
WRITE UP AREAS

DESIGN CONSIDERATIONS
- Distance to hazardous fume hoods.
- Proximity to labs.
- Access to views of exterior.
- Low traffic areas for minimal disturbance.

OFFICE SPACE
- Offices must be located along exterior edge of building to allow for natural light penetration and views.
- Scientist offices should be within close proximity of research labs.
- Office groupings that are disconnected from the labs should be avoided.
- Clustered groupings encourage interaction.

These spaces (lab, office, write-up, corridors) should be designed in an integrated manner for ease and efficiency of research, circulation and maintenance.

Figure 5.32: Write-up spatial arrangements

Figure 5.33: Office views towards exterior and labs
C) Sustainability

“A typical laboratory currently uses five times as much energy and water per square foot as a typical office building." (Perkins & Will, 2001: 27) This can be attributed to the following reasons:

- A large numbers of containment and exhaust devices.
- They house a great deal of heat-generating equipment.
- Scientists require 24-hour access.
- Irreplaceable experiments require fail-safe redundant backup systems and uninterrupted power supply (UPS) or emergency power.

OVERHANGS
Sun control and shading devices provide natural light, reduces heat gain and reduces cooling energy consumption in laboratory buildings. Shading devices which are integrated in building facades also presents the opportunity for distinguished aesthetics and should be considered early on in the design process.

GLAZING
Windows should be selected bearing in mind the energy costs and indoor quality of the environment. Wood or fibreglass frames should be used above aluminium for improved thermal performance. Low-E windows with the insulation value of at least R-3 should be used.

ROOF AND WALLS
The use of light-coloured roofing with a high-albedo coating to reflect light and heat is recommended. Photovoltaic panels can be integrated into the building envelope as metal roofing, spandrel glazing, or semi-transparent vision glazing.

VENTILATION
Ventilation systems are one of the essential services within a research facility and plays an important role in providing efficient and safe air quality within lab spaces. Chilled beams is an example of efficient and economical technology that could be considered to be used within the building. This device is efficient in the reduction of air change rates in a safe and efficient manner.
ENGINEERING
Civil engineering issues to consider include the use of pervious materials and light colored wherever possible. In preparing a site for new construction, designers should consider transplanting existing trees instead of removing them. Stormwater management is also an area that should be carefully considered to avoid erosion.

ARTIFICIAL LIGHTING
Sustainable lighting design reduces energy use while enhancing employee comfort and productivity. Sustainable lighting strategies include the use of compact fluorescents (CFLs) rather than incandescent lamps, maximising natural daylighting throughout a facility, and employing various photosensing technologies to conserve energy. Where functional requirements permit, lighting design should combine task and ambient lighting to reduce the high overall light levels. Good task lighting lessens glare and eyestrain. LED lighting works well for task lighting.

DAY LIGHT
Availability of natural daylight should be maximised within the building to reduce energy use, increase comfort and improve productivity within the workspace. Users of the building should be able to look outside of the building at any point. This also provides an effective means of orientating users to the time of day. Wherever possible, daylighting should be used as the primary source of illumination; artificial lighting should be thought of as a supplement to, rather than a replacement for, daylighting. Daylighting control systems should be utilised to limit the amount of active artificial lights within spaces. The following design methods of natural light utilisation should be used:

- Light shelves
- Clerestorey windows
- Skylights
- Daylighting control systems
D) Expression

In laboratory buildings there are two main factors that determine the exterior image of the building. These include:
- Organisation and design of offices, labs, and mechanical spaces
- Size, number and expression of exhaust stacks

EXHAUST STACKS

Exhaust stacks give research buildings a distinctive machine expression and could be approached in different ways to create a specific desired image. These stacks present the opportunity for an unique expressive articulation and response to the skyline. The type of lab which they serve should determine the type of system used. They should always clear a height minimum of 3m for safe distribution of exhaust air. The two main types include:
- Individual stacks
- Bundled stacks

Figure 5.41: Manifold exhaust system creates landmark in context, Stevenson Center Complex Chemistry building, Vanderbilt University, Nashville, Tennessee. Payette and Associates inc.

Figure 5.42: Exhaust air shafts must clear a minimum of 3m above walkable surface

Figure 5.43: Dedicated exhaust system, School of Medicine, Northwestern University, Evanston, Illinois, Perkins and Will

Figure 5.44: Unique building elevation through the use of individual exhaust stacks, Molecular Science Center, University of California, Anshen and Allen
3.2 LABORATORY TYPOLOGY

E) Finishes

WALLS
Walls are typically made out of gypsum with coated epoxy layers. Bumper guards and metal/timber corner guards could be used in areas of movable equipment.

CEILINGS
Ceilings within lab buildings can be either:
- Exposed revealing mechanical works and structure. Acoustic liners or paint should be utilised for noise reduction where mechanical piping systems are revealed.
- Closed with ceiling tiles

LAB FLOOR FINISHES
The floor must be a one piece non-pervious and with covings to the wall. Tiles and wooden planks are not appropriate because liquids can seep through the small gaps between them.

DESIGN CONSIDERATIONS
- Durability
- Cost
- Chemical resistance
- Aesthetics
- Ease of cleaning

Resilient sheet vinyl
Exposed concrete
Troweled Epoxy
Carpet

Advantages: Integrates all lab services
Adaptability
Suitable for all lab types
Ease of installation
F) SERVICE

A laboratory contains a large number of engineering systems that should be considered in initial planning for effective coordination and operation of the facility. These systems should be coordinated with lab modules for efficient and safe service delivery and easy maintenance.

STRUCTURAL

Structural grid is determined after lab modules has been estimated and is generally based on a two lab module grid. Materials include either concrete, steel or a combination of both.

Structural columns can be located either within labs, within corridors or in the centre of lab partition wall. Flexibility of lab spaces and interior image of corridor should be considered.

SHAFTS AND DUCTS

Economical and functional advantages and disadvantages should be considered when deciding on duct placement. Cost and access should be the factors to determine the placement as well as ease of maintenance without disrupting lab work. Location should also be informed by the structural system and lab modules of the building.

DESIGN CONSIDERATIONS

- Minimise overlapping of supply and exhaust ducts.
- Ease of access for maintenance and additions.
- Running and initial costs
- Image
- Building height
- Separation from lab spaces for minimal maintenance disturbance
3.2 LABORATORY TYPOLOGY

F) SERVICE

SHAFT LOCATION OPTIONS

A) At the end of the building
Advantages:
- Cost effective
- Labs unobstructed
Disadvantages:
- Research activity disruption

B) Middle of building
Advantages:
- Short efficient distribution
- Very cost effective
- Centralised mechanical roof equipment
Disadvantages:
- Limits future flexibility
- Research activity disruption

C) Shafts at end and supply in middle
Advantages:
- Cost effective
- Short efficient distribution
Disadvantages:
- Research activity disruption
- Central supply shaft limits plan layouts.

D) Multiple internal shafts
Advantages:
- Lower floor to floor height
- Short efficient distribution
- Ease of renovation outside lab
- Good for dedicated shafts
Disadvantages:
- More floor space required
- Shafts limit flexibility of spaces
- Fewer opportunities for interior glazing

E) Shafts on exterior of building
Advantages:
- Shorter horizontal runs
- Maximum flexibility of internal space
Disadvantages:
- Difficulty of access
- Research disruptions
- Limited views and glazing
- More floor area required
- Ducts will require insulation

Figure 5.53 : Shafts at end of building

Figure 5.54 : Shafts in middle of building

Figure 5.55 : Shafts at end and supply in middle

Figure 5.56 : Multiple internal shafts

Figure 5.57 : Shafts on exterior
INTERSTITIAL SPACE

Interstitial spaces are separate floors used to contain services that will then be fed into the laboratory spaces below. This is an effective way of hiding services with easy access for maintenance and renovations that is separated from the lab areas. There is no ductwork constricting laboratory floor space and the building enjoys a longer lifetime. It is, however, not economically recommended as the initial construction costs are substantially high.

MECHANICAL SYSTEMS

1. Primary systems : Centralised equipment used for the purpose of generating utility sources such as steam and chilled water. eg boilers, chillers, cooling towers, air compressors.

DESIGN CONSIDERATION:
Whether or not these systems are located in a central plant facility or included within the building as a separate facility.

A central plant facility has been chosen as it is more effective in terms of long term cost, maintenance and reliability.

Equipment to be contained within central plant:
2. Secondary systems: These are large systems utilised for the distribution of supply and exhaust air.

**DESIGN CONSIDERATION:**
Location of air supply grilles, secondary containment, noise control; ventilation.

**AIR SUPPLY AND INTAKE**
The location of air intake systems and exhaust stack requires careful consideration so as to avoid contamination through surrounding buildings or activities.

**FUME HOODS**
The placement of single or multiple fume hoods within a laboratory is critical to their safe and efficient operation. They are designed, constructed and maintained so as to draw air inward by means of mechanical ventilation to remove hazardous gasses that may be emitted during practical experiments.

**DESIGN CONSIDERATION**
- Located outside of walls
- Should be separated from write-up areas
- Should not be located near air supply sources
- A minimum distance of 1.2 meter to doors
- A minimum distance of 2.4 from doors across the fume hood should be maintained.

([https://www.ehs.washington.edu/fsodesignrev/1c-rwdi.pdf](https://www.ehs.washington.edu/fsodesignrev/1c-rwdi.pdf))

**Laboratory issues established**
- Designing flexible research space which caters for expansion
- Creating spaces of interaction for the sharing of knowledge and ideas between interrelated fields.
- Designing a safe and sustainable research facility.
3.3 PROGRAMMATIC ISSUES ESTABLISHED

- Designing flexible research space which caters for future changes and technological developments.
- Creating spaces of interaction for the sharing of knowledge and ideas between the various inter-related study fields.
- Designing a sustainable building in terms of energy usage and natural resource utilisation.
- Integration of public within the programme for increased awareness and education without inflicting on private activities.
- Incorporating nature directly and indirectly in the building.
- Designing an integrated production process which has zero waste.
3.4 PRECEDENT STUDIES

**SALK INSTITUTE OF BIOLOGICAL SCIENCES**  
**SAN DIEGO, CALIFORNIA, LOUIS KHAN, 1965**

investigating: flexibility, concept of served and servant spaces

*Figure 6.1: View of courtyard*

*Figure 6.2: Served and servant spaces*

*Figure 6.3: Unobstructed flexible laboratory space*

*Figure 6.4: Staircase detached*

*Figure 6.5: Mechanical spaces*

*Figure 6.6: Offices detached and facing view of ocean*

*Figure 6.7: Interstitial service floors*
- Offices located within close proximity of lab space which allows a good connection between types of research activities
- Circulation detached from labs and offices.
- Office spaces detached to utilise and frame exterior views
- Structural columns on outside of lab space to allow for flexible, uninterrupted floor space.
- Dignified use of water in public space
- Transparent lab walls to allow for daylight penetration and visual connection to exterior.
- Eastern service towers provides effective distribution of services without hindering research activities through possible maintenance.
- Interstitial floors allow for effective maintenance and service distribution without disrupting research activity in lab spaces.

**INFORMANTS TAKEN FROM PRECEDENT STUDY**

**SALK INSTITUTE**

- Offices located within close proximity of lab space which allows a good connection between types of research activities
- Circulation detached from labs and offices.
- Office spaces detached to utilise and frame exterior views
- Structural columns on outside of lab space to allow for flexible, uninterrupted floor space.
- Dignified use of water in public space
- Transparent lab walls to allow for daylight penetration and visual connection to exterior.
- Eastern service towers provides effective distribution of services without hindering research activities through possible maintenance.
- Interstitial floors allow for effective maintenance and service distribution without disrupting research activity in lab spaces.
PRECEDEENT STUDY

CENTER FOR URBAN WATERS
TACOMA, PERKINS AND WILL ARCHITECTS, 2009

Investigating: environmental sustainability, ecological restoration

MATERIALS

Figure 6.16: Recycled wood from municipal docks.

Figure 6.17: Recovered granite curbs.

WATER CONSERVATION

Encourages smarter use of water through the use of efficient appliances and fixtures and water-wise landscaping. The building uses 46% less water than a conventional facility, saving about 400,000 gallons per year. (http://www.urbanwaters.org/)

Figure 6.10: Exterior of Center for urban waters

Figure 6.11: Cistern catches green roof rainwater as well as excess lab water to be re-used for toilet flushing and plant irrigation.

Figure 6.12: Green roofs absorb and filter rainwater whilst aiding in heating and cooling.

Figure 6.13: Raingarden collects and filters excess water from parking lot.

Figure 6.14: LED lighting on water tanks indicates water-levels to evoke awareness within and without the building.

Figure 6.15: Use of pervious paving in parking lot and esplanade eliminates need for surface water elimination system.
ECOLOGICAL RESTORATION

Figure 6.18: Sustainably harvested snags provide staging, feeding and nesting habitat for birds and small animals.

Figure 6.19: Use of native vegetation for landscaping and ecological restoration.

Figure 6.20: Use of light shelves for reflected daylight into workareas.

Figure 6.21: Daylight strategy.

Figure 6.22: Solar shades provide users with daylight whilst keeping the building cool.

Figure 6.23: Diagram of water strategies.

Figure 6.24: Diagram of building systems.

NATURAL LIGHT

Promotes strategies that improve indoor air quality and provide access to views and natural light.

DIAGRAMS
The following sustainable strategies has been applied in the design to an LEED platinium award.

**Natural strategies:**
- Through maximising permeable surfaces stormwater retention and polluted run-off into the river is minimised whilst water is re-used.  
- Greenroofs act as rainwater catchment areas where water is transported to catch basins and storage tanks for flow rate measurement and re-use. 
- Permeable paving is used in parking areas and walkways and directs water to raingardens at times of high rainfall. 
- Use of sustainably harvested and salvaged materials in design and construction of building.

**Technological strategies:**
- Interactive digital screens to inform public and staff of water usage quantities in order to heighten awareness of conservation. 
- Water collected in cisterns re-used for flushing of toilets and irrigation of natural landscape. 
- Wood debris and tree snags added to increase population of fish and bird species.  
- Automated exterior shading devices and high performance glazing reduces glazed glare and heat gain.  
- Natural ventilation together with geo-thermal heating technology reduces considerable cooling and heating costs.
ZALGEN INNOVENTON
PORT ELIZABETH, SOUTH AFRICA
TYPE 1 ALGAE ARCHITECTURE

investigating: algae production in local climate, spatial- and physical requirements of integrated production and research

Figure 6.25 : Front view of research facility

Figure 6.26 : Separation of functions

Figure 6.27 : Raceway and bioreactor combination housed in greenhouse

Figure 6.28 : Kilo plant

Figure 6.29 : Spray dryer

Figure 6.30 : Open lab
Service and store

Figure 6.31: Accessible service areas

Figure 6.32: Supply components separated for ease of maintenance

Figure 6.33: Air controlled storage facilities

Figure 6.34: Water conservation strategies for re-use

INFORMANTS TAKEN FROM PRECEDENT STUDY

- Cultivation stage can be both integrated within the building facade or separated. If separated it should be handled in a controlled secure environment and be within close proximity of research facilities.
- Adequate space and access for service and store must be provided.
- Research and production process can be accommodated within a single building for ease of monitoring and testing.
- Storage facilities should be strictly regulated i.t.o. air temperatures and access.
- Rainwater should be efficiently captured and stored for reuse within and without the building.
Conclusion

**Programmatic issues**

- Designing flexible research space which caters for future changes and technological developments.

- Creating spaces of interaction for the sharing of knowledge and ideas between the various inter-related study fields.

- Designing a sustainable building in terms of energy usage and natural resource utilisation.

- Integration of public within the programme for increased awareness and education without inflicting on private activities.

- Incorporating nature directly and indirectly in the building.

- Designing an integrated production process which has zero waste.

**Site issues**

- Responding to different water edge conditions

- Responding to existing residential and recreational buildings and activities on site.

- Responding to existing landscape and vegetation

- Responding to estuarine climatic conditions

- Responding to industrial vernacular

**DESIGN OBJECTIVES**

- Restoration of recreational and natural value of the harbor and surrounding natural structures.

- Development of research in the production of renewable energy.

- Integrating the general public to voice awareness of the importance of natural conservation and sustainable industry in the region.

**DESIGN STRATEGIES**

- Reuse of air- and water pollutants to rehabilitate environment and produce renewable energy.

- Development of integrated public algae park for environmental awareness and education.

- Designing collaborative spaces for interaction and sharing of knowledge.

- Revitalisation of existing harbour infrastructure such as jetties, docks, pedestrian walkways and stormwater management.

- Integration of nature directly or indirectly for enhanced human-nature relationships.

- Designing an integrated production process which leaves zero wastes.
Chapter 4 : Design

4.1) Stakeholders

4.2) Accommodation schedule

4.3) Design development
4.1 STAKEHOLDERS

For this project to realize will require a substantial amount of financial input especially in the start-up phases and will require the support of a variety of concerning parties.

The project deals with social, economical and ecological management within the Swartkops River Catchment as well should thus appeal to the following parties:

GOVERNMENT PARTIES
A) Department of Forestries, Fisheries and Agriculture (DAFF)

The aim of this department is “to provide public support and essential services to the aquaculture industry.” (http://www.daff.gov.za/daffweb3/About-Us/Vision-and-Mission)

CORPORATIONS
B) SASOL

The production of biofuels in South Africa has been identified as a key and high profile initiative and companies like SASOL will reap the economic benefits as well as become the forerunners in renewable biofuel production in South Africa
4.2 ACCOMODATION SCHEDULE

### Scientific research

**Water ; ecological ; biotechnological research**
- Wet lab x3 - 600 m²
- Dry lab x3 - 360 m²
- Equipment store x3 - 60 m²
- Cold sample store x3 - 45 m²
- Dry store x3 - 45 m²
- Maceration room x3 - 36 m²
- Microscopic room x3 - 36 m²
- Computer lab - 50 m²
- Analytical lab - 30 m²

**Field research**
- Boat store - 50 m²
- Equipment store - 16 m²
- Repair workshop - 70 m²
- Washing bay - 70 m²
- Docking area

**General**
- Ablutions (male/female) - 20 m²
- Cleanstore - 4 m²
- Discussion area - 32 m²
- Research offices - 64 m²

**Service**
- Waste collection room - 9 m²
- Air supply plant - 16 m²
- Chemical gas storage - 4 m²
- Water storage - 10 m²
- Generator room - 12 m²

### Micro-Algae production

**Cultivation**
- Indoor grow rooms - 48 m²
- Outdoor growing - 500 m²

**Process (harvest and extraction)**
- Pilot plant - 600 m²
- Control room - 40 m²
- Equipment store - 16 m²
- Generator room - 12 m²
- Mechanical room - 20 m²
- Service yard

**Biofuel refining**
- Pre-treatment lab - 36 m²
- Fermentation lab - 42 m²
- Biotech lab - 42 m²
- Biomass conversion lab - 36 m²
- Microbiology conversion lab - 36 m²
- Support lab - 42 m²
- Biochemical conversion lab - 36 m²
- Imaging lab - 24 m²
- Cold store - 9 m²
- Quality control lab - 16 m²
- Analytical lab - 24 m²

### Macro-algae (seaweed) production

- Unloading area - 16 m²
- Washing bays - 40 m²
- Sorting and packaging area - 100 m²
- Cold store - 16 m²

1751 m²
## Fish farm

### Production
- Broodstockholding: 24 m²
- Hatching: 24 m²
- Nursing: 32 m²
- Grow-out: 200 m²
- Process and package: 100 m²

### Service
- Pump room: 25 m²
- Generator room: 12 m²
- Mechanical filtration room: 25 m²
- Bio filtration room: 25 m²
- Sludge collection: 12 m²
- Water storage: 4 m²
- Control room: 20 m²
- Air handling room: 12 m²

### General
- Foyer: 25 m²
- Secretary office: 12 m²
- Admin offices: 50 m²
- Manager office: 48 m²
- Ablutions: 20 m²
- Change rooms: 18 m²
- Clean store: 4 m²
- Conference rooms: 50 m²
- Kitchen: 20 m²
- General store: 12 m²

### Public
- Lecture hall: 64 m²
- Exibition space: 100 m²
- Library/study area: 24 m²

---

### Total area

Total area: 4643 m² + 20% circulation = 5571 m²
4.3 DESIGN DEVELOPMENT - Programme diagram

- Control room
- Refining labs
- Pilot plant
  - Separators
  - Mechanical pressers
- Cultivation
  - Wet lab
  - Dry lab
- Storage
  - Header tanks
  - Control room
  - Pump house
- Grow out
  - Hatchery
  - Nursery
- Process and package
  - Cold store
- Loading bay
- Quality control
- Bio filtration
- Mechanical filtration
- Sludge tanks
- Biowaste
- For feed
- Feed vessel
- Purified water
- Oxygenated water
- Bio-oils
- Bio-fuel
- Water tanks
- Pump house
- Control room
4.3 DESIGN DEVELOPMENT - Contextual model
4.3 DESIGN DEVELOPMENT - Approach

Towards an environmentally restorative solution

Restorative design objectives:

1. Minimise ecological footprint: - Low environmental impact design
   - Cyclical production process

2. Promote man-nature relationships: - Biophillic design (direct and indirect user contact with nature)

It has become evident that only by viewing human industry and practices as parts to a whole can man begin to work towards a sustainable future and with the rapid increase in population, the need to live in harmony with our natural counterpart becomes more stressed than ever. The design of the building forms the final chapter in the holistic design approach that has been exhibited throughout the course of this project.

The building not only seeks to minimise detrimental construction practice though sustainable construction and technology but also attempts to produce renewable energy and promote human-nature relationships. This is achieved by utilising natural processes of photosynthesis and bioremediation not only for production and purification but also to promote natural contact with the user. Algae, water and seaweed are used as interconnected systems which orientates the user within the linear confinement of the building. The building responds to the environment by utilising pollutants to purify and rehabilitate the surrounding natural eco-systems, restoring the value of the immediate context. The concept of parts-to-a-whole is emphasized and exhibited in the physical expression of interlinked components. Natural light is maximised through maintaining a shallow building depth, which also promotes views over the estuary from almost anywhere in the building.
4.3 DESIGN DEVELOPMENT

**Economical**
- Building will act as destination node attracting and encouraging eco-tourism in the region.
- The building along with the harbor premise development and revitalisation will improve economical value of Swartkops Village and provide a safe resource for local fish markets.
- The project provides an platform for surrounding industries to utilise and develop algae as renewable energy resource that can be sold for profit.

**Social**
- The building provides job opportunities through the seaweed initiative for the many poorer residents of nearby informal settlements (Motherwell, Zwide).
- Fish farming project provides a safe food source and offers food security to surrounding townships.

**Environmental**
- The building utilises water to restore natural habitats that has become degraded by illegal and irresponsible human activities.
- The cultivation of algae extracts CO2 out of the air and through the process of photosynthesis and bioremidiation produces O2, purified water and heat energy.
- Closed loop production line produces waste products as resources for various agriculture applications.
The production process is based on the natural closed loop processes seen in nature as opposed to the linear production processes seen in traditional factories. This process is designed to utilise environmental pollutants, such as CO2 in the air and polluted river water, and through the biomimetic processes of bioremediation and photosynthesis create renewable energy. As seen in nature, this cyclical process views waste products as valuable inputs to another process ending up with a production process that leaves zero waste and potentially produces more energy than it consumes.

4.3 DESIGN DEVELOPMENT

The cyclical integrated production process

The production process is based on the natural closed loop processes seen in nature as opposed to the linear production processes seen in traditional factories. This process is designed to utilise environmental pollutants, such as CO2 in the air and polluted river water, and through the biomimetic processes of bioremediation and photosynthesis create renewable energy. As seen in nature, this cyclical process views waste products as valuable inputs to another process ending up with a production process that leaves zero waste and potentially produces more energy than it consumes.

Pollutants
- CO2
- Water (trace metals, waste nutrients)
- Biofuel
- Bio-oil

Algae production
- Biomass
- Purified water
- Heat energy for re-use in building

Fish farm
- Food security
- Specie conservation
- Local markets

Sunlight
4.3 DESIGN DEVELOPMENT

River water polluted by surrounding industry and waste water overflows

- Seaweed farm 1 established in Swark-tops River: First stage of biofiltration
- Seaweed farm 2 established in Cooling channel: Second stage of biofiltration

- Mechanical filtration
- Micro-algae cultivation: Third stage of bio-filtration
- Algae production process:
  - Harvest and separation
  - Extraction and refining

- Recovered heat energy
- Fish farm:
  - Fish feed
  - Purified water
  - Export

- Dissolved waste

- Mechanical filtration
- Waste

- Sludge used for local agriculture

- Bio-mass
- Bio-oils
- Bio-fuel

Export
4.3 DESIGN DEVELOPMENT - Site development

The following strategies have been implemented to restore the recreational- and ecological value of the Tiger Bay harbor premises.

- Under-utilised viewpoints
- Degraded natural land
- Under-utilised green space
- Inactive buildings
- Lack of water management infrastructure
- Inactive hostile man-made infrastructure
- Privatised existing buildings

Re-use of channel for irrigation of degraded natural land, and establishment of fisherman’s walkway
Viewing decks to utilise natural viewing points
Removed dirt road with established vehicular limit points to elevate pedestrian
Establishment of central boat launch point
Upgrade of existing harbour jetties and docks
**Building as biofilter**

The building acts as a biofilter on the site. Orientated along the strong linear axis implied by the cooling channel, the building extracts water and then through a series of mechanical- and natural filters re-distributes water into a series of interlinked constructed wetlands eventually ending up in the recreational harbour. Water is continuously pumped from the cooling channel resulting in a permanent re-establishment of natural biodiversity. Dissolved waste water from surrounding buildings on the site is utilised for nutrient enrichment of algae farm.
Approach

- The design seeks to create a visual dialog between the old- (environmental pollution) and new industry (environmental restoration).
- Expression seeks to create an re-interpretation of traditional industrial vernacular through the expression of components that form part of the system.
- Forms gateway into Swartkops village

Figure: Driving down Grahamstown road, the main entrance to Swartkops Village

Wetland construction

- A series of artificial wetlands will be constructed around the site that will constantly be active either through storm-water inlets or pumped water from the channel.
- These wetlands will serve as ecological infrastructure that will purify water through a series of layers in the form of sub-wetlands before releasing the purified water into the harbor.
- Use of existing gravel and stones as well as indigenous vegetation will be used in the construction to enhance characteristics of place, and provide a habitat for local bird species.

Figure: Stones available on site
1. Biophillic design for the occupants

This theory is based on the notion that man has a natural affinity for nature and seeks to foster beneficial relationships with the natural world in order to achieve mental wellbeing. It has been implemented in various mundane work settings to improve productivity and mental- as well as physical health.

Three kinds of experiences of nature represent the basic categories of a biophilic design framework.

1. Direct experience of nature:
   Actual contact with environmental features in the built environment.
   eg. Light; Air; Water; Plants; Animals; Weather; Natural landscapes and ecosystems.

2. Indirect experience of nature:
   Contact with the representation or image of nature, the transformation of nature from its original condition, or exposure to particular patterns and processes characteristic of the natural world.
   eg. Images of nature; Natural materials; Natural colors; Simulating natural light and air; Naturalistic shapes and forms; Evoking nature; Information richness; Age, change, and the patina of time; Natural geometries; Biomimicry

3. The experience of sense of place:
   Spatial features characteristic of the natural environment that have advanced human health and wellbeing.
   eg. Prospect and refuge; Organised complexity; Integration of parts to wholes; Transitional spaces; Mobility and wayfinding; Cultural and ecological attachment to place.

4.3 DESIGN DEVELOPMENT

Responding to cooling channel

The on-site cooling channel will be utilised for the cultivation of seaweed. Seaweed will be cultivated, washed and then attached to an automated drying system that will form part of the facade of the building. Partially detached from the building, the seaweed wall will utilise climatic conditions for optimal drying. Once the seaweed is dried it will then be packaged and transported to nearest export points. The wall will act as an bio-adaptive interactive public feature whilst hiding service activities from residential views.

Figure : Seaweed wall concept sketch
Responding to rivers edge

The functional requirement of the research section of the programme demands easy access to water for field research to commence. The building will extrude partially into the river to allow for easy and quick boat based research and seaweed farm monitoring. A jetty equipped with a pulley system will provide for samples to be brought back and directly transported to wet labs for efficient research.

The design responds to the existing movement occurring on-site through lifting the building close to the water edge. By doing this the building frames the existing viewing corridor as well as remove itself from the existing public fishing activity.

Figure: Enhanced viewing corridor
Figure: Positioned according to existing circulation and linearity implied through existing cooling channel
Figure: Integrated with waters edge
4.3 DESIGN DEVELOPMENT

An integrated algae landscape

The building serves as an central hub for a variety of algae cultivation technologies distributed over the premises. This creates an public interactive landscape that sparks curiosiuty to the casual pedestrian. Designing the systems to accomodate public interaction further promotes education and awareness.

Awareness through observation and interaction

Algae as public landscape mediator

The design of a bio-adaptive algae-canopy will be utilised to layer public activity as well as break down the scale of the building. These triangulated algae panels adapts to the availability of sunlight, growing denser in condition of intense sunlight and thus providing more shade for the user beneath. This system grows algae by pumping algae medium, made up out of water, and co2, through the panels to end up with biomass that can be collected for futher processing within the building awell as purified water drinking points for the general public

Algae as landmark in the context

The design of the algae-bioreactor growing tower will act a an landmark and regional icon of sustainability in the context. Functional optimised in its opera-" operation, the living tower extracts CO2 with scrubbers from the surrounding pollut-ed air and distributes it through the algae cultivating tubes. Water is extracted from the river and then in turn pumped and purified through the process. This system will be a major feature of the building and spark interest in surrounding industries.

Bio tower concept
4.3 DESIGN DEVELOPMENT

Programmatic development

1. Primary water circulation:
This water is extracted from the river and distributed to various algae culture tanks with the aim of providing purified water for fish farming as well as drinking water within the building.

2. Secondary water circulation:
This water is extracted from the river and filtered mechanically. This relatively raw state of the water is then utilised for cooling of equipment, toilet flushing and wash-up of field research equipment. The water then enters the algae waste water treatment facility which is specifically designed for water treatment of this calibre.

- Water is used as organising element, functionally linking spaces
- Algae purification systems
- Roof space utilised for optimal algae production
- Algae integrated in facades as biomimetic insulating envelope
4.3 DESIGN DEVELOPMENT - Plan development

Layering of privacy thresholds

Centralised factory control room for effective monitoring and control over production processes

Concept of served and servant spaces. Lab offices provided with views towards estuary as well as towards ongoing lab research

Served and servant spaces. Compartmentalisation of factory spaces for ease of maintenance and safety
4.3 DESIGN DEVELOPMENT - Plan development
4.3 DESIGN DEVELOPMENT - Spatial development
4.3 DESIGN DEVELOPMENT - Form development

Towards a bio-mimetic approach
Design concept 1:
- Linear orientation for a sensitive response to existing circulation routes on site and framing of
- Using the old cooling channel for water-based transport to link the building with the existing truck depot in order to cut out additional export transportation costs.
- Vertical bioreactors risers contained within shell of building, attempting to relate to traditional factory expression of Swartkops Powerplant.

Design concept 2:
- Use of linear algae-growing wall as continuous green spine. Spine utilised as spatial organising element indicating primary circulation and providing orientation within building.

Design concept 3:
- Expressive use of functional components in order to highlight the concept of parts to a whole.
- Cultivation systems extruded into landscape for increased public interaction and awareness.
4.3 DESIGN DEVELOPMENT - Model development

Design concept 4:
- Establishment of central node in landscape perceived as mass anchoring lightweight skeletal structure
- Use of algae bio-adaptive canopy as interactive public mediator
- Expressive display of functional components
- This response to attempts to provide a better integration within the landscape and public realm as opposed to previous versions
Chapter 5 : Final design
River approach perspective
Visitors walkway
Algae public pavilion
Seaweed wall perspective

Automated seaweed wall with rotating louvres are detached from building for optimal drying

South western summer winds

North Eastern winter winds

Building as central collecting point for seaweed farming and processing

Traditional drying rack louvres
Model photos
REFERENCES

All diagrams are done—or adapted by the author unless otherwise indicated

BOOKS :


PUBLICATIONS :


HARNEY, P; AIA; NCARB; LEED AP BD+C. 2014. BETWEEN LAB-ORATORY AND FACTORY: A British Model for Innovation in Manufacturing and Applied Technologies

WEBSITES :


Annual reports (AR) and strategic plans (start plan) | Department of Environmental Affairs. 2015. Annual reports (AR) and strategic plans (start plan) | Department of Environmental Affairs. [ONLINE] Available at: https://www.environment.gov.za/documents/reports. [Accessed 10 October 2015]


INTERVIEWS :

Karla Kampman, Innoventon, Port Elizabeth

Paul Steyn, Micro-biology lecturer, N.M.M.U. Port Elizabeth, South Campus

Nadine Strydom, Marine biologist, N.M.M.U. Port Elizabeth, South Campus

ARTICLES :

(http://www.heraldlive.co.za/save-swartkops-river/)


REPORTS :


ENVIRO-FISH AFRICA DEPARTMENT OF ICHTHYOLOGY AND FISHERIES SCIENCE. 2011

LIST OF FIGURES

Figure A: Artist’s depiction of the effects of industrialism upon mother earth (http://www.deviantart.com/tag/globalwarming)
Figure B: The Swartkops River; Photo Prof Nadine Strydom
Figure 1.1: View from the Swartkops River towards Swartkops Powerplant (http://wikivillage.co.za/visit-amsterdam-hook)
Figure 1.2: Port Elizabeth, South Africa (Author)
Figure 1.3: Nelson Mandela Bay metro scale (Author)
Figure 1.4: Panoramic view of sewerage input at Motherwell canal (Swartkops NMMU report 2014)
Figure 1.5: Motherwell canal major source of pollution
Figure 1.6: Stormwater flowing in a channel which was eroded through infill material in the wetland
Figure 1.7: Illegal dumping of litter on the northern bank of the Motherwell Canal (Swartkops NMMU report 2014)
Figure 1.8: Polluted wetland
Figure 1.9: Concrete lined stormwater channel discharging into the wetland
Figure 1.10: Rubble and litter at one of the stormwater outlet headwalls
Figure 1.11: Polluted wetland
Figure 1.12: Sewerage pump station with clear evidence of blockages and overflows
Figure 1.13: Aerial view of Swartkops River mouth
Figure 1.14: Phragmites australis at Redhouse
Figure 1.15: Invasive aquatic plants, water fern (Azolla filiculoides) and water hyacinth (Eichhornia crassipes), at Perseverance
Figure 1.16: Sarcocornia perennis
Figure 1.17: Chenolea diffusa
Figure 1.18: Rhus longisipma
Figure 1.19: Spartina Maritima (Cordgrass)
Figure 1.20: Wit Steenbras (lithognathus lithogathus)
Figure 1.21: Spotted grunter (Pomadasys commersonnii)
Figure 1.22: Leervis (Lichia amia)
Figure 1.23: Cape stumpnose (Rhabdosargus holubi)
Figure 1.24: Dusky kob (Argyrosmus)
Figure 1.25: Shad
Figure 1.26: Upogebia africana (Mud prawn)
Figure 1.27: Blood worm
Figure 1.28: Tape worm
Figure 1.29: Spheniscus demersus
Figure 1.30: Areza goslath
Figure 1.31: Ciconia Nigra
Figure 1.32: Phoenicopterus ruber
Figure 1.33: Hieraetus permata
Figure 1.34: Haliaeetus vocifer
Figure 1.35: Hydroprogne caspia
Figure 1.36: Mycteria ibis
Figure 1.37: Phoenicopterus minor
Figure 1.38: St. Lucia Estuary
Figure 1.39: Keurbooms Estuary
Figure 1.40: Knysna Estuary
Figure 1.41: Sundays Estuary
Figure 1.42: Diagram of issue

Figure 1.43: Hollistic sustainability diagram
Figure 1.44: Linear production and consumption process
Figure 1.45: Industrial air pollution
Figure 1.46: The natural food web
Figure 1.47: Cradle to cradle design
Figure 2: Aerial view of Swartkops River mouth
Figure 2.1: Natural structure
Figure 2.2: Primary routes
Figure 2.3: Industrial growth
Figure 2.4: Natural origins of Swartkops River
Figure 2.5: Urban Settlement along river
Figure 2.6: Groendal dam
Figure 2.7: Catchment topography
Figure 2.8: Catchment vegetation
Figure 2.9: Swartkops river near Uitenhage
Figure 2.10: Invasive Water Hyacinth
Figure 2.11: Natural vegetation
Figure 2.12: Landscape at Perseverance
Figure 2.13: Natural structure at estuarine-head
Figure 2.14: Marshlands at Swartkops Village
Figure 2.15: Swartkops Estuary
Figure 2.16: Degraded jetties along water front
Figure 2.17: Railroad station fenced from street activity and lacks public hierarchy.
Figure 2.18: Under-utilized green spaces
Figure 2.19: Under-celebrated viewing corridors leading from commercial road
Figure 2.20: Cooling channel acting as man-made barrier
Figure 2.21: Unmonitored sewage flow at Zwide
Figure 2.22: Stormwater ponding
Figure 2.23: Lack of thresholds promoting street
Figure 2.24: Street-side stormwater channel, 21st Street, Paso de Robles
Figure 2.25: 21st street, Paso de Robles
Figure 2.26: Spokane stormwater project
Figure 2.27: Use of stone and mortar in street side stormwater channels.
Figure 2.28: Natural water cycle
Figure 2.29: Urban water cycle
Figure 2.30: Towards a more sustainable water cycle
Figure 2.31: Constructed Wetland
Figure 2.32: Natural Wetland
Figure 2.33: Quintly National Urban Wetland, China
Figure 2.34: Urban Wetland park, Los Angeles
Figure 2.35: Algae based wastewater treatment
Figure 2.36: Treatment Plant Algae Wheel (Indiana Dunes)
Figure 2.37: Southeast wastewater treatment plant in San Francisco
Figure 2.38: Seaweed farming in Zanzibar
Figure 2.39: Seaweed drying
Figure 2.40: Seaweed farming China’s Fujian coast
Figure 2.41: Diagram of sub-metro strategy
Figure 2.42: Diagram of sub-metro intervention
Figure 2.43: Demarcated seaweed-farming zones
LIST OF FIGURES

Figure 2.44: Micro-algae urban intervention
Figure 2.45: Urban strategies at precinct scale
Figure 2.46: Intervention at precinct scale
Figure 2.47: Railstation design
Figure 3.1: Harbour entrance (Photo: Author)
Figure 3.2: View from N/E corner of harbor
Figure 3.3: Possible sites
Figure 3.4: Western view towards site
Figure 3.5: Natural view points
Figure 3.6: Existing vegetation
Figure 3.7: Under-utilised waterfront
Figure 3.8: Harbour water levels
Figure 3.9: Boating channel water levels
Figure 3.10: View towards harbour
Figure 3.11: View towards Estuary
Figure 3.12: View along walkway
Figure 3.13: Saccorhiza perennis
Figure 3.14: Spartina Maritima (Cordgrass)
Figure 3.15: Aloe perfoliata
Figure 3.16: Milkwood
Figure 3.17: Flooded marshlands
Figure 3.18: Water bodies
Figure 3.20: River water
Figure 3.21: Channel water
Figure 3.22: Stormwater collection
Figure 3.23: Harbour retaining wall
Figure 3.24: Degraded dirt pedestrian walkways
Figure 3.25: River retaining wall
Figure 3.26: Yacht club
Figure 3.27: Angling club
Figure 3.28: Environmental river control office
Figure 3.29: Cooling channel
Figure 3.30: Swartkops Powerplant, industrial vernacular
Figure 3.31: Noisy R102
Figure 3.32: Composite informants and constraints
Figure C: Abandoned factory (Photo: Neville Peterse)
Figure 4.1: Estimated gallons of oil yielded annually per acre of biofuel crop (Source: International Energy Agency; Department of Energy; UOP LLC)
Figure 4.2: Diagram of production process
Figure 4.3: Diagram of algae production process and fish farm relationship
Figure 4.4: Diagram of algae production and fish farm relationship
Figure 4.5: Chlorophyta
Figure 4.6: Scenedesmus
Figure 4.7: Spirulina
Figure 4.8: Ulva (sea lettuce)
Figure 4.9: Gracilaria (seaweed)
Figure 4.10: Production components
Figure 4.11: Production process spatial layout
Figure 4.12: Micro Algae Production stages
Figure 4.13: Seaweed cultivation, Zanzibar
Figure 4.14: Harvesting via rafts
Figure 4.15: Seaweed washing
Figure 4.16: Seaweed drying, Zanzibar
Figure 4.17: Package seaweed
Figure 4.18: Freight train transport
Figure 4.19: LED Lighting used in indoor growing facitlities
Figure 4.20: Sunlight used in outdoor open pond growing systems
Figure 4.21: Algae raceway ponds
Figure 4.22: Outdoor ponds
Figure 4.23: Flat plate photo-bioreactors
Figure 4.24: Vertical Tubular photo-bioreactors
Figure 4.25: Plastic bags
Figure 4.26: Flat panel
Figure 4.27: Horizontal Tubular photo-bioreactors
Figure 4.28: Re-circulating water systems
Figure 4.29: Centrifuge
Figure 4.30: Mechanical algae presser
Figure 4.31: Dusky kob
Figure 4.32: Spotted grunter
Figure 4.33: Extensive pond system
Figure 4.34: Intensive tank culture
Figure 4.35: Raceways
Figure 4.36: Ponds
Figure 4.37: Recirculating systems

Figure 4.10: Diving expeditions
Figure 4.11: Wet lab
Figure 4.12: Dry lab
Figure 4.13: Production process
Figure 4.14: Diagram of algae production process and research relationship
Figure 4.15: Diagram of algae production and fish farm relationship
Figure 4.16: Water research
Figure 4.17: Tagging
Figure 4.18: Water sample collecting
Figure 4.19: Diving expeditions
Figure 4.20: Wet lab
Figure 4.21: Dry lab
Figure 4.22: Production process
Figure 4.23: Diagram of algae production process and research relationship
Figure 4.24: Diagram of algae production and fish farm relationship
Figure 4.25: Water research
Figure 4.26: Tagging
Figure 4.27: Water sample collecting

Figure 4.44: Micro-algae urban intervention
Figure 4.45: Urban strategies at precinct scale
Figure 4.46: Intervention at precinct scale
Figure 4.47: Railstation design
Figure 3.1: Harbour entrance (Photo: Author)
Figure 3.2: View from N/E corner of harbor
Figure 3.3: Possible sites
Figure 3.4: Western view towards site
Figure 3.5: Natural view points
Figure 3.6: Existing vegetation
Figure 3.7: Under-utilised waterfront
Figure 3.8: Harbour water levels
Figure 3.9: Boating channel water levels
Figure 3.10: View towards harbour
Figure 3.11: View towards Estuary
Figure 3.12: View along walkway
Figure 3.13: Saccorhiza perennis
Figure 3.14: Spartina Maritima (Cordgrass)
Figure 3.15: Aloe perfoliata
Figure 3.16: Milkwood
Figure 3.17: Flooded marshlands
Figure 3.18: Water bodies
Figure 3.20: River water
Figure 3.21: Channel water
Figure 3.22: Stormwater collection
Figure 3.23: Harbour retaining wall
Figure 3.24: Degraded dirt pedestrian walkways
Figure 3.25: River retaining wall
Figure 3.26: Yacht club
Figure 3.27: Angling club
Figure 3.28: Environmental river control office
Figure 3.29: Cooling channel
Figure 3.30: Swartkops Powerplant, industrial vernacular
Figure 3.31: Noisy R102
Figure 3.32: Composite informants and constraints
Figure C: Abandoned factory (Photo: Neville Peterse)
Figure 4.1: Estimated gallons of oil yielded annually per acre of biofuel crop (Source: International Energy Agency; Department of Energy; UOP LLC)
Figure 4.2: Diagram of production process
Figure 4.3: Diagram of algae production process and fish farm relationship
Figure 4.4: Diagram of algae production and fish farm relationship
Figure 4.5: Chlorophyta
Figure 4.6: Scenedesmus
Figure 4.7: Spirulina
Figure 4.8: Ulva (sea lettuce)
Figure 4.9: Gracilaria (seaweed)
Figure 4.10: Production components
Figure 4.11: Production process spatial layout
Figure 4.12: Micro Algae Production stages
Figure 4.13: Seaweed cultivation, Zanzibar
Figure 4.14: Harvesting via rafts
Figure 4.15: Seaweed washing
Figure 4.16: Seaweed drying, Zanzibar
Figure 4.17: Package seaweed
Figure 4.18: Freight train transport
Figure 4.19: LED Lighting used in indoor growing facilities
Figure 4.20: Sunlight used in outdoor open pond growing systems
Figure 4.21: Algae raceway ponds
Figure 4.22: Outdoor ponds
Figure 4.23: Flat plate photo-bioreactors
Figure 4.24: Vertical Tubular photo-bioreactors
Figure 4.25: Plastic bags
Figure 4.26: Flat panel
Figure 4.27: Horizontal Tubular photo-bioreactors
Figure 4.28: Re-circulating water systems
Figure 4.29: Centrifuge
Figure 4.30: Mechanical algae presser
Figure 4.31: Dusky kob
Figure 4.32: Spotted grunter
Figure 4.33: Extensive pond system
Figure 4.34: Intensive tank culture
Figure 4.35: Raceways
Figure 4.36: Ponds
Figure 4.37: Recirculating systems