Cape Peninsula
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A Biomimicry and sustainable product-service systems (S.PSS) approach to Design for Sustainability: A study in higher education in Industrial Design

by

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DECLARATION

I, Corbin Edlin Raymond, declare that the contents of this dissertation/thesis represent my own unaided work, and that the dissertation/thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

Signed Date: November 2019

ABSTRACT

In this research study Biomimicry and sustainable product-service systems (S.PSS) are explored in order to examine the Design for Sustainability (DfS) paradigm through a set of eight guidelines. It is argued that Biomimicry holds the blueprint to a design strategy that is more environmentally sustainable. This research study demonstrates that sustainability's triple bottom line can be achieved by combining Biomimicry's potential for environmental sustainability with S.PSS's potential to foster social and economic sustainability.

The study describes a behavioural change towards sustainability and proposes design education as a strategy to nurture sustainable design praxis. It is shown that the sustainable design praxis of student groups leads to behavioural shifts towards sustainability through design education. Industrial design students at the Cape Peninsula University of Technology in South Africa engaged in a short course on DfS and their design outcomes provided the data sets that have been analysed through inductive thematic analysis. The course was used as a case study from which theory was built. This specific research approach is called *theory building from case studies*. The appendices are included to supply additional evidence of where and how the data collection happened, and provides depth and insight into the projects. The richness and scope of the research study is supported by the appendices - it is for this reason that the rather sizable addition was included. It is through the thematic analysis that a set of eight guidelines were developed from the data and measured against a framework of critical citizenship in order to evaluate the societal behavioural shift to a more holistic approach to DfS. This thesis draws on existing fields of study within the DfS paradigm and integrates several fields of study in order to contribute to the discourse of a holistic approach to DfS.

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DEDICATION

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GLOSSARY

Terms/Acronyms/Abbreviations	Definition/Explanation
AHO	Oslo school of architecture and design
Bioflux	An industrial design student group's methane digester design project
CAD	Computer aided design
CC	Climate change
CPUT	Cape Peninsula University of Technology
C-SAN-Futures	Climate South Africa, Norway – Futures
DE	Distributed economies
DfS	Design for Sustainability
DfS1	Design for Sustainability with a focus on a technical approach to deliver goods with a good ecological impact.
DfS2	Design for Sustainability with a focus on a theoretical approach to impose sustainable actions and behavioural change by the end user
DfS3	Design for Sustainability with a focus on future orientated product-service systems solutions that could encourage societal changes and shifts towards sustainability
DRE	Distributed renewable energy
EDF	Electricite de France
EU	European Union
FID	Faculty of Informatics and Design
HEI	Higher Education Institution
ID	Industrial Design
Kunye	An Industrial Design student group's bio-gas cooking stove design project
LeNS	The research project: Learning network
LeNSes	The research project: Learning network on energy systems

MDG	Millennium development goal
NRC	Norwegian research council
NRF	National research foundation
PLA	Product lifecycle analysis
ProtoHype	A research project which explores sustainable futures scenarios through making, enactment and design
PSS	Product-service systems
SDG	Sustainable development goal
S.PSS	Sustainable product-service systems
TA	Thematic Analysis

CHAPTER ONE
RESEARCH BACKGROUND

1.1 Introduction
This thesis is an explorative study of design methods that inform a holistic approach to Design for Sustainability (DfS). I view DfS as a design paradigm which consists of design methods, design tools, design techniques, and design praxis. I examined the theoretical underpinnings of DfS through a systems theory approach in order to highlight the indicators of sustainable design praxis.

However, “sustainability” is somewhat ambiguous in its meaning, and in this Chapter, I clarify what sustainability means, how it relates to design, and how discrepancies in design methods blur the understanding of holistic sustainability, where holistic sustainability focuses on the three pillars of sustainability: economic-, social -, and environmental sustainability.

I describe these discrepancies through a research problem, and I present a research question to challenge a holistic approach to DfS. I make a case for using Sustainable Product-Service Systems and Biomimicry as a mixed-method approach to answering the research question. A brief overview of the research methodology demonstrates how I generated and presented the data needed for my design inquiry, followed by a set of design limitations and a brief outline of the thesis structure.

1.2 Research background
Before understanding the role that DfS plays in the practice as well as the research of design, I presented a historical account of how sustainability and development have been understood, interpreted, and developed. A comprehensive historical account of DfS can be seen in the work of Ceschin and Gaziulusoy (2016: 139) where they present several approaches to DfS and their main characteristics. I make use of these historical accounts to view Sustainable Development from an outsider’s perspective, where an outsider’s perspective frames sustainability outside of design praxis. Then ‘Sustainability’ is presented in relation to ‘Design’ to establish the overarching research theme of Design for Sustainability. The thesis is contextualised through a lens of sustainability, while at the same time, limiting the scope of this design inquiry to Design for Sustainability and its practices. These practices draw on design education, through which Design for Sustainability methods, tools, and techniques can be approached, presented, assessed, and discussed.

Ultimately the background to this study departs from acknowledging the sustainable development goals as an outsider’s understanding of sustainability and positions this thesis towards the sustainable development goals from an insider’s positioning. Thus, an insider’s perspective frames this study as a design inquiry towards DfS and aims to moves it from theory into practice.

1.2.1 Background to sustainable development

Designing for basic human needs is challenging in the face of sustaining human development. Sustainable development "requires basic human needs to be met in the present, without comprising the ability for future generations to meet their own needs" (Kates, Parris & Leiserowitz, 2016: 1). This definition of sustainable development by Kates, Parris and Leiserowitz (2016: 1) is a widely-accepted definition of the highly ambiguous concept of sustainable development. The origin of the phrase lies within the commissioned research on international concerns for the General Assembly of the United Nations in 1982, reported as *Our Common Future*, and published in 1987 (WCED, 1987). During this time there was momentum to push the collective concerns and aspirations of people from a local to a more global focus – where peace, freedom, development and the environment became the key focus areas for national and international laws (NRC, 1999: 9).

The term 'Sustainable Development' has been criticized for its ambiguity, resulting in conflicts between the needs of environmental sustainment and human development (Adams, 1990: 361). Since coining the term 'Sustainable Development,' attempts have been made to include 'environment' with 'development' as shown in the Brundtland Commission report:

> "But the 'environment' is where we live, and 'development' is what we all do in attempting to improve our lot within that abode. The two are inseparable" (WCED, 1987).

This report was followed by the 'Earth Summit', or rather, the United Nations Conference on Environmental Development (UNCED), in Rio de Janeiro 1992 (Kates, Parris & Leiserowitz, 2016: 2) and a decade later in Johannesburg, South Africa at the World Summit on Sustainable Development, where the views and objectives of sustainable development were reaffirmed (Kates, Parris & Leiserowitz, 2016: 3). Since then, sustainable development represents a goal, benchmark, a concept and a movement which has rapidly spread and is now a central mission of international organizations, institutions, and cities (Kesavan & Swaminathan, 2014: 495; Kemp, Parto & Gibson, 2015: 4; Kates, Parris & Leiserowitz, 2016: 2).

Notably, the three pillars of sustainability were introduced at the World Summit on Sustainable Development in Johannesburg to further clarify the meaning on the definition. The three pillars of sustainability focus on economic, social, and environmental development. The summit called for a collective responsibility to advance and strengthen the three pillars at local, regional, national, and global levels (Kates, Parris & Leiserowitz, 2016: 3)

This collective responsibility called for a sustainability transition - away from 'business as usual '- in respect to technological and social requirements - without changing lifestyles, values or the economic systems which have stabilized over the years (Raskin, 2002: 99). The shift away from business as usual concept is made plausible and possible through the Global Scenario Group's vision (Raskin, 2002: 99) to have "a rich quality of life, strong human ties and a resonant connection with nature."

The Global Scenario Group introduces four concepts that are necessary for sustainable development, such as:

1. quality of human knowledge,
2. creativity,
3. self-realization that represents development, and
4. quality (over quantity) of goods and services.

Furthermore, this transitional agenda focuses on the rejection of material consumption and then questions what is needed for a “good life” (Kates, Parris & Leiserowitz, 2016: 8).

The United Nation’s Sustainable Development Goals (SDG’s) have been developed to ease into such transitions by proposing goals and targets that question the sustainability of existing patterns of resource consumption. The SDG’s targets climate change, sustainable production and consumption, food waste, renewable energy and conserving oceans and forests (to be expanded on later in this thesis). They also speak to the duty we have towards taking care of nature and the importance of living in harmony with “Mother Earth” (Benoît-Norris, Vickery-Niederman, Valdivia & Franze, 2011: 686).

1.2.2 From sustainable development to Design for Sustainability: Theoretical underpinnings

Designers are entangled in the uncomfortable and complex relationship with the ecological crisis (Clune, 2010a: 3) and that to design with the best interest of “Mother Earth” in mind is like a double-edged sword. In the profession of Industrial Design, designers are concerned about the consumerist society, and at the same time, Industrial Designers are at the forefront of encouraging it, be it directly or indirectly (Papanek, 1984: 68; Clune, 2010a: 3). The Product Lifecycle Analysis (PLA) approach and design strategy were developed in the early 2000s as an attempt to re-orientate the ecological crisis through designing products with a reduced ecological impact over time (Vezzoli, 2013: 276). PLA is a technical design approach where designers analyse the product’s lifecycle which informs the best strategic design intervention with the least environmental footprint (Vezzoli, 2003: 2; Vezzoli, 2013: 278) and affirmed this as a position of Ecodesign (Clune, 2010a: 3). Fletcher and Dewberry (2001: 213) recognized Ecodesign as the first of three positions within Design for Sustainability [DfS1].

The second position of DfS [DfS2] is more theoretical and speaks to the impact of design on unsustainable human behaviours. The renowned design thinker and educator, Ezio Manzini’s, earlier research focused on (societal) behaviour change by addressing the unsustainable human behaviours. This societal behavioural change Ezio presents from Elizabeth Shove’s work into habitual consumption (Shove, 2003: 395; Vezzoli, 2003: 2). Shove (2003: 395) argues that goods and resources are consumed to maintain a standard of comfort, well-being, and convenience in every-day life. DfS addresses the relational impact of design on unsustainable behaviour and proposes that design can be an agent in reducing the ecological footprint of people’s actions (Vezzoli, 2003: 2).

It encourages designers to utilize their design skills to make every-day activities more sustainable (Clune, 2010a: 3). Fletcher and Dewberry (2001: 215) argue:

> "the most common approaches to Design for Sustainability tends to focus on pollution reduction, and resource efficiency [DfS1] rather than rational choices and actions [DfS2]. Design for Sustainability with a focus on people considers ways of satisfying fundamental human needs".

The third position of DfS [DfS3] takes a more literal approach to nurture a sustainable society towards making a positive and real change. Clune (2010b: 69) describes this as a future-orientated-change-focused approach to DfS. Ezio Manzini introduces Product Service Systems (PSS) as a method to elevate design on a community level and to challenge the habits of individuals owning products (Manzini, 2006: 10). A PSS, as described by Morelli (2002: 5), shifts the designers' capabilities from a 'product-focused' approach, to a 'result-focused' orientation towards design. This dispositional shift debunks the idea that an individual should, for instance, own a lawnmower (product-focused), when the result they require is a tidy lawn (result-focused). From this result-focused orientation, there is more scope for a sustainable service-orientated design solution, which addresses the unsustainable consumer behaviour to own products. Furthermore, Mont (2002: 238) clarifies and describes a PSS as:

> "a system of products, services, supporting networks, and infrastructure that is designed to be competitive, satisfy customers' needs, and have a lower environmental impact than traditional business models."

Fletcher and Dewberry (2001: 215) argue that DfS theoretical underpinnings suggest that there is a requirement to progress from 'product'-focused [technical] to 'need'-focused [behavioural] to 'result'-focused [social]. Table 1.1 summarises the critical positions of DfS:

Table 1.1: Three categories of DfS

	Design for Sustainability		
Positions	DfS1	DfS2	DfS3
Approaches	Technical	Theoretical	Future orientated (literal)
Change Catalysts	Ecological Impact	Behavioural change	Societal Change
Focus areas	Product-focused	Need-focused	Result-focused
Design Indicators	Ecodesign	Sustainable actions and behaviours	Product Service Systems
Key Influencers	Hanz Brezet	Elizabeth Shove; Ezio Manzini	Ezio Manzini; Toni Fry; Carlos Vezzoli

1.2.3 Design education: An approach to societal change through DfS

Vezzoli (2003: 3) and Shove (2003: 395) prompt us to acknowledge that the everyday actions we take as a society are unsustainable, arguing that the existing systems and designs which are already in place in our everyday lives are unsustainable over the mid to long-term. Clune (2010b: 74) argues that designers should understand the role design has historically played in contributing to 'unsustainability' before they engage with DfS – further arguing the importance design education plays in engaging students with the subject matter of DfS.

Based on an international study of 211 universities teaching Industrial Design, Mariano Ramirez investigated tools and strategies used to teach DfS and found a significant concern with the interpretation of Sustainable Design by the staff teaching these modules (Ramirez, 2007: 5). Ramirez explains that staff seem to interpret Sustainable Design in the same category as ecological/green design, which focuses on the 'minimization of environmental impacts' (Ramirez, 2007: 3). The concern this holds for DfS is that 'how we define is how we design' (Clune, 2010a: 1) in that how a problem is defined correlates directly to the designed outcome. By focusing on Ecodesign in design education, design educators address personal consumption, while negating the possibility of social solutions to address the over-consumption of natural resources.

Clune's work identifies key constructs to DfS within design education for the discipline of Industrial Design. His work is situated within a module unit called "Sustainable Design: Sustainable Futures" at the Centre for Design, Melbourne, Australia. He states that through all interventions he had with students on in-depth learning strategies, that there was no strategy in place to combine knowledge and understanding through the personal experiences of the students (Clune, 2010a: 3). Warburton (2003: 44) underlines the importance of combining student's personal experiences and prior knowledge in order to tackle wicked problems – in this case, unsustainability. In order for students to shift from the ecological impact of sustainable design (DfS1) to sustainable design through societal change (DfS3), students need to engage with the subject matter through education for sustainability, and not education about sustainability (Fien, 2002: 154; Tilbury, 2004: 103). The art of this shift lies within recognizing that DfS is not purely a technical problem, but it is more socially orientated and capable of addressing everyday consumption (Clune, 2010a: 1).

1.2.4 Situating my research within design education for DfS

This thesis is situated within the scope of two research projects. The first project is the Learning Network on Sustainable energy systems (LeNSes), which was funded by the European Union (EU). The second project, jointly funded by the Norwegian Research Council (NRC) and the South African Nation Research Foundation (NRF), studied the effects of Climate Change through design – this project was called Climate South Africa Norway Futures (C-SAN-Futures). Both projects investigate DfS3 through activating societal change through design education.

1.2.4.1 The LeNSes and C-SAN-Futures projects

The LeNSes project required that the Cape Peninsula University of Technology conducts a specific course on S.PSS in relation to distributed renewable energy. This course introduced S.PSS tools and techniques to students, and I co-facilitated it. I present this course as a case study in Chapter 4.3 and the data from this course in Chapter 5.2. The C-SAN-Futures project influenced the design approach to the course, which was futures-orientated and strategically aligned to DfS3.

The two projects ran independently from one another at the Cape Peninsula University of Technology (CPUT) in Cape Town, South Africa. The international project partners, significantly the Polytechnic di Milano in Italy and AHO School of Architecture and Design in Norway, were actively engaged in supporting and managing the projects. Both projects embodied societal agency through the use of learning tools and strategies for students as well as facilitators to combat the effects of climate change on our everyday lives. The Lenses projects focused on delivering clean and safe energy for all, whereas C-SAN-Futures looks to future scenarios where methods and techniques for a sustainable future can be realized.

Both projects are directed to DfS3's needs-focused approach to problem-solving for future scenarios. Table 1.2 briefly summarises:

Table 1.2: Brief overview of the LeNSes and C-SAN-Futures projects

Project name	LeNSes;	C-SAN-Futures
Project name (Expanded)	The learning network on sustainable energy systems;	Climate South Africa Norway Futures
Key activities	Pilot courses, Seminars, Conferences, Formal research contributions	ProtoHype, Conferences, Formal research contributions
Aims and Objectives and design indicators	Clean and Sustainable Energy for all, Distributed Renewable Energy (DRE), Distributed Economy (DE), Sustainable Product Service Systems (S.PSS)	Forecasting sustainable scenarios for future societies, Life's Principles, Biomimicry.
Methods and focus areas	S.PSS, DRE and PSS's as research methods to: Design for basic human needs through sustainable consumption and production methods. Developing and Implementing DfS tools	Participatory Design, Anticipation, Co-Design, Transposition research methods to: Design for the basic human needs of future societies. Anticipation strategies, design foresight methods through transposition.
Approaches	Theoretical, Emergent, Sustainability-Orientated, Practice Based	Theoretical, Future-Orientated, Practice Based

Underpinning these two projects' aims and objectives are the Millennium Development Goals (MDGs) and Sustainable Development Goals (SDGs). As an attempt to ensure an attainable and plausible scenario-driven education for DfS3 in Higher Education. These projects draw on international partnerships between several Higher Educational Institutes, as well as provide a discourse in Sustainable Development through sustainable design education. The more prominent MDGs and SDGs addressed through these projects are:

- MDG 7: To ensure environmental sustainability; and
- MDG 8: To develop global partnerships for development.

It is essential to highlight that the SDGs were developed from the successes and identified challenge areas of the MDGs. The SDGs are projected towards 2030 and described as a forecasting strategy to guide sustainable development. The 17 SDGs were introduced in June 2014 by the first United Nations Environment Assembly by 163-member states of the United Nations in Nairobi, Kenya. Both of these design research projects draw on the following SDGs:

- SDG 7: Ensure sustainable energy for all;
- SDG 9: Promote sustainable infrastructure and industrialization and faster innovation;
- SDG 12: Promote sustainable consumption and production patterns;
- SDG 13: Tackle climate change and its impacts; and
- SDG 17: Strengthen the means of implementation and the global partnership for sustainable development.

This thesis hones in on Sustainable Development and tightens around key concepts such as:

- The SDGs and MDGs as indicators of Sustainable Development (from an outsider's perspective).
- Viewing DfS3 as a methodological strategy for approaching sustainable societal change; and
- Viewing sustainable design education as a design technique (from an insider's perspective).

The basic access to clean energy is arguably the catalyst of attaining all these goals. In my previous role within the LeNSes project as a researcher and design educator, I focus on Distributed Renewable Energy (DRE). I will draw from previous knowledge and refer to Renewable Energy from the belief that it mainly supports and directs sustainable development in its products, systems and user behaviour.

1.3 Statement of the research problem

1.3.1 A brief overview of approaches to DfS

Since the early 2000s, several approaches to DfS have been practiced and implemented (Knot & Van der Wel, 2001: 65) with various succession projects funded by the EU as well as the United Nations Environment Program (UNEP). These methods and techniques have gone from discourses related to the reliance upon end-of-pipe pollution control to cleaner production to eco-design and Product Life Cycle Design (Vezzoli, Ceschin, Diehl & Kohtala, 2015: 2). Examples of these approaches to DfS can be seen in the project titles below:

- SusHouse (Strategies towards the Sustainable Household),
- ProSecCo (Product-Service Co-design),
- HiCS (Highly Customized Solutions),
- MEPSS (Methodology for Product Service System development),
- SusProNet (Sustainable Product-Service co-design Network), and
- D4S (Design for Sustainability): A step-by-step approach.

The previously mentioned LeNSes Project originated from the LeNs project, which in turn explored a range of methodologies focusing on Product Lifecycle Analysis (PLA), DfS1, and is now focusing on methods pertaining to S.PSS, DfS3. These include Distributed Economies, Distributed Renewable Energy, Distributed Information as well as Distributed Manufacturing. All of these methods address key focus areas of Sustainable Development. The LeNs project explore these methods through a series of design tools and apply them as course material for projects in Higher Education Institutions. However, the project provides few prescribed pedagogical strategies with which to implement these tools. The task then falls on the educators and researchers to design programs and courses.

1.3.2 Introducing a DfS strategy for sustainable product-service systems and DRE

Generally speaking, Sustainable Development is defined by the triple bottom line: Economic, Social, and Environmental Development. As previously eemphasised, environmental development is of significant importance to sustain the environment in which we live (WCED, 1987). A key point of interest relating to S.PSS is that it is an innovative and disruptive method, which challenges the Business as Usual exchange of goods for profit. Vezzoli describes S.PSS in relation to economic and social development as:

> "…at the end of the of the product's life, the producer has the potential economic interest to re- use or re-manufacture components to save on landfill costs and new component manufacturing" (Vezzoli et al, 2015: 2).

or alternatively:

> "…in a S.PSS approach it is in the economic and competitive interest of the producer/provider to foster continuous innovation in reducing the environmental impacts and improving social equity and cohesion" (Vezzoli et al, 2015: 2).

and further:

> "the benefits that occur are not only economic, but also more widely socio-ethical, as S.PSS's can broaden access to useful goods and services to lower income strata" (Vezzoli et al, 2015: 2).

The LeNSes project arguably shows potential within the socio-ethical, economic, and environmental systems approaches to design (Kolk & Van Tulder, 2010: 120). However, not all S.PSS projects have shown environmentally sustainable results in past research projects (Vezzoli et al., 2015: 5). An example explains how previous S.PSS solutions that are dependent on vehicle delivery services are in turn promoting the increase in carbon emissions due to the fuel consumption of the vehicles, despite the project's viability as a sustainable solution (Vezzoli et al., 2015: 9). Therefore, the concept of S.PSS seems to be a valuable and promising concept with which to tackle sustainable issues, but it does not represent the perfect sustainable design strategy (Kolk & Van Tulder, 2010: 120). The implementation of P.SS's and S.PSS's do not always hit the triple-bottom-line in their structure or outcomes (Ceschin & Gaziulusoy, 2016: 140). These S.PSS tools are used to test the economic and socio-ethical benefit of the context it is used within (Mathews, Tang & Tan, 2011: 463). By applying these tools to energy systems as advocated by S.PSS's, the environmental benefits are intrinsic. As a result, the environmental benefits are not seen as the primary focus of the S.PSS. At the heart of this research problem, I am therefore stating that S.PSS's, as a design method, needs a more in-depth, more robust, study into an holistic understanding of sustainability. Through this I recognize the studies proving the sustainability *of* S.PSS's, however I draw a focus on the environmental benefits, as well as the social, and economic benefits.

For these reasons, I propose that Biomimetics is introduced to complement the S.PSS methods of a LeNSes S.PSS course at CPUT's Industrial Design department. Biomimicry prompts designers to learn and abduct knowledge from nature's inherently sustainable methods and strategies.

1.4 Research questions

The LeNSes project provides the scope to couple S.PSS with DRE, yet this project is not restrictive to the addition of Biomimicry as another method to DfS. As explained in Chapter 1.3.2, LeNSes applies these design methods, with their corresponding tools, in a structured course that informs the praxis of DfS3. One of the most significant assumptions prior to the research is that: *by introducing Biomimicry as a research method to S.PSS methods, applied to DRE, it would yield positive results for DfS3 with specific interest on environmental development*. This assumption grounds and describes the research hypothesis. Therefore, to purposefully address this assumption and research hypothesis, I am reverting to a set of research questions. The research questions comprise one main research question, which is supported by what, how, and why sub-questions.

In the research question I refer to a holistic approach as an approach to design, which integrates DfS methods that set out to achieve the triple-bottom-line of sustainability: environmental, social, and economic sustainability. The DfS methods comprise of specific design tools and techniques, and I refer to the development and implementation of this as an holistic approach to design by exploring and integrating these tools and techniques. With an in-depth praxis of DfS, I refer to the praxis of Industrial Design students, and this is due to the nature of the LeNSes project which tests design approaches, design methods, design tools, and design techniques through short courses at HEI's. An in-depth praxis of DfS also refers to a strong correlation of a DfS-design process to the ideology of DfS3.

Therefore, the main research question explores how DfS approaches may generate societal change (DfS3). The research question further implies that there is a limitation within my research scope of Design for Sustainability. Based on prior understanding into the research area, S.PSS as previously coupled with DRE in the LeNSes projects is not restrictive nor classifies a limitation on introducing Biomimicry as a contributing method in achieving DfS.

Additionally, a research assumption is that Biomimicry and S.PSS have constraints, as well as enablers. The main question alludes to methods, tools, and techniques, which implies that the hypothesis needs to be tested for its viability as an enabler, and its limitations within constraints. I propose a set of guidelines to respond to how to develop and implement a holistic approach to design by integrating Biomimetics as a mixed-method approach to S.PSS.

1.4.1 Main research question

The main research question asks:

How can a holistic approach to Design for Sustainability be developed and implemented in a Higher Educational Institute to inform an in-depth design praxis for Industrial Design students?

1.4.2 Sub-questions

The sub-questions aim at clarifying the main research question. These sub-questions are:

1) What are the benefits and challenges of developing and implementing an integrated Biomimicry and S.PSS approach to design?
2) How would a set of DfS guidelines inform the integration of Biomimetics and S.PSS?
3) Why should such a set of guidelines be taken into account within the DfS paradigm?

1.5 Research objectives

The problem statement identifies issues related to the environmental sustainability of S.PSS's and recognizes mixed-method approaches to address this (as seen with the LeNSes project when S.PSS is coupled with DRE). The research hypothesis introduces Biomimicry as another method, which is intrinsically rooted within an environmental inquiry of research through design. Therefore, the objective is to view the nature of this study through systems theory to examine, understand, and answer the main research question throughout this thesis. I am doing this by analyzing academic literature underpinning DfS, Biomimicry, and S.PSS. By tapping into the design activities of the current research projects I have engaged in, I see myself as a participant within the study.

My role is to inquire about the theory of DfS through analysis and critique in order to understand DfS as the paradigm of the research. I investigate literature related to design methods, in order to theoretically understand the design(ed) tools and techniques of which they are comprised. I present these tools in a structured course and draw on several design research techniques to generate data needed for this study. The data was collected through qualitative modes of inquiry and consists of questionnaires, semi-structured interviews, and several observations, video documentation as well as images.

The purpose of the mixed data collection methods is to inform a set of design guidelines – which draw on thematic data analysis techniques. The secondary objective of this study is to align the research work with the research output of the C-SAN-Futures and LeNSes design research project and to view the relevance of the research work by aligning them with the SDGs and MDGs.

1.6 Chapter overviews

The outlining of my research chapters aims to provide a brief overview of the study into DfS, through a mixed-method approach of viewing design methods, such as Biomimicry, S.PSS, and DRE, in relation to their tools and techniques of implementation. Through this, data will be generated, presented, and discussed. I present a breakdown of this research in the following sections.

1.6.1 Chapter 1

A study into Sustainable Development is presented as a means of understanding Design for Sustainability. Sustainability is presented as a design lens through which to view this study. I present three phenomena in Design for Sustainability, where designing for societal behavioural change presents a key focus area for the study. I refer to this societal behavioural change to sustainability as DfS3. A specific design project conducted at CPUT with Industrial Design students is presented. I introduce the research background, problem statement, research questions, limitations, objectives, and a brief overview of the methodology in which data is generated, and presented.

1.6.2 Chapter 2

In Chapter two I present theoretical perspectives suited to the study in order to examine, discuss, and challenge ideas from formal design literature. I triangulate the theoretical understandings of authors in the specific fields of DfS, S.PSS, Biomimicry, and Design Education. I inquire about the changing climatic factors as a stimulus to call design into action, specifically through formal higher education in design. I state which concepts I aim to work with and find connections in design discourse across these research fields. I also make a case to prioritize sustainability's triple-bottom-line as environmental (planet), social (people), and economic (profit).

1.6.3 Chapter 3

I introduce a holistic approach to the study of DfS through Systems Theory, where I use elements of reductionism to isolate S.PSS and Biomimicry as functioning units with the system of DfS, and Environmental, Social and Economic sustainability as functioning sub-units within DfS, while not excluding the complexities the units and sub-units have concerning each other. Here I aim to make a case for an in-depth inquiry into DfS. I do this by recognizing DfS as a design paradigm, and I draw on systems theory to make sense of the paradigm's complexities. I position my gaze into this study of DfS more holistically from a systemic approach, and I look into the interrelatedness of DfS, Biomimicry, S.PSS, sustainability's triple-bottom-line, and systems innovation.

1.6.4 Chapter 4

This is a contextualising chapter where I introduce my role as researcher and my influence on the study. Here I introduce an external research observer into the study whose aim is to document the design techniques I have used to implement design tools pertaining to the research methods of Biomimicry, S.PSS, and DRE. This section focuses on the implementation of the specifically structured course, which forms part of the LeNSes project requirements. I present how I anticipate the participation of the actors in my research through qualitative modes of inquiry as a means to generate data from the formal outcomes of students' work, as well as pictures and video documentation of key activities of the course. This chapter highlights the research framework and the methodological approaches of acquired knowledge through the research study.

1.6.5 Chapter 5

In this chapter, I present the data sets which comprised of three main categories: Design Techniques, Design Tools, and Ways of Making, which draw on the research framework presented in Chapter 4. A case is presented where I describe the key activities of the design course on Biomimicry and S.PSS. I introduce the data which informs specific design techniques and the design tools which the facilitators and the students generated. The combination of the design tools and techniques are presented as "ways of making." These ways of making inform a mixed method approach that underpins the design process and the "making" of the data, which draws on fundamental observation techniques, images, and documents.

1.6.6 Chapter 6

I present the data, and I discuss it formatively and contextually in relation to DfS, in particular to DfS3. Therefore, I draw on my ability as a design researcher, practitioner and educator to relate design practice with design theory as a means of presenting a set of design guidelines for a mixed-method approach to DfS. I measure these guidelines against critical citizenship, and I make a case for why critical citizenship is an evaluation for DfS3. This chapter aims to correlate the research outset with the research activities and to review it to the research questions. Here I set out to answer the three sub-questions which inform this research inquiry.

1.6.7 Chapter 7

In Chapter seven I draw a set of conclusions and implications of the research, with brief reflections on why I chose this research topic, as well as how the research was designed and undertaken. Factual and interpretive conclusions are presented in this chapter on how this study contributes to the field of research. I present a specifically structured course through a set of guidelines as a means through which I test, present and prove my research. I acknowledge the dissemination of knowledge and suggest areas where the research can be improved and I also highlight areas of the research that are worth investigating further.

1.7 Summary

From the nature of this study, it should be clear that my focus is to examine the rigidity of what constitutes the three pillars of sustainability. By presenting S.PSS as a method through which to achieve DfS3, I highlight the discrepancies of environmental sustainability in S.PSS. I use this to make a case for the research problem area, which drives the research questions. I then set out to innovatively address this by incorporating Biomimicry in a mixed-method approach to S.PSS. This chapter briefly outlines the scope of my research and provides a catalyst for the research.

CHAPTER TWO
LITERATURE REVIEW: THEORETICAL PERSPECTIVES

2.1 Introduction
In chapter two, I present and unpack the key themes of Design for Sustainability through a lens of DfS3. I investigate literature about behavioural change within the scope of this study. By drawing on the previously established understanding of sustainable development (See Chapter 1.2), I inquire about the changing climatic factors as a stimulus to call design into action, specifically through formal design education. This type of design education is facilitated at Higher Education Institutions, i.e. Universities. This inquiry briefly presents S.PSS and Biomimicry research and design methods, where I make use of a thematic analysis technique to present similarities and differences between these methods through my literature analysis.

2.2 Climate change: A call to action
According to Karen O'Brien, there are "increasing calls from the global environmental change research community for new strategies for translating knowledge into action" (O'Brien, 2013: 587). When addressing a problem with a magnitude such as Climate Change, a transition from knowledge into action is arguably the most significant challenge for researchers and practitioners. This challenge goes with delays, and there are harsh and unfair consequences awaiting the 80% of the global population that hardly contribute to the change in climate (Chisin, Van Niekerk & M'Rithaa, 2014: 183). Based on scientific Figures, the global population has tripled since WW2 and currently stands at 7,2 billion citizens - this Figure is expected to grow with 2-3 billion people by 2050 (Vezzoli, Ceschin & M'Rithaa, 2009: 2).

The seemingly obvious challenge would be to provide all these people with sustenance without stressing and disrupting the natural environment (Rockström, Steffen, Noone & Persson, 2009: 13). However, the burning of fossil fuel resources is a growing concern when it is applied to provide these global citizens with food (Vezzoli, Ceschin & M'Rithaa, 2009: 3). Such concerns have motivated climate researchers to explore alternative energy resources. Jolley (2006: 2) argues that immediate action should be taken to develop cleaner and more sustainable energy resources instead of using fossil fuels. Climate researchers have also projected potential in renewable energy to contribute to a near 50% of global energy consumption (Jolley, 2006: 15). There is a seemingly direct relationship between fuels, resources used, and the dependence on the natural environment (Smith, 1968). At the same time, climate scientists argue that the remaining fossil fuels should be left underground in order to avoid a climate disaster (Rockström et al., 2009: 13).

Dyer (2008: 18), Leggewie and Welzer (2010: 1) argue that these drastic changes to "Business as Usual" (BaU) will be disruptive and that a more global society will adopt action when implemented incrementally. However, the call for action is immediate and requires implementation from a global community (Leggewie & Welzer, 2010: 1). The United Nations has recognized the effects of climate change and the potential stress the use of fossil fuels might have on the natural environment (Vezzoli, Ceschin, Osanjo & M'Rithaa, 2018: 13). Therefore, the United Nations has developed its Sustainable Development Goals (SDGs) as well as its Millennium Development Goals (MDGs) as a call for action towards Climate Change. Some of these SDGs and MDGs are:

- SDG 7: Ensure sustainable energy for all;
- SDG 9: Promote sustainable infrastructure and industrialization and faster innovation;
- SDG 12: Promote sustainable consumption and production patterns;
- SDG 13: Tackle climate change and its impacts;
- SDG 17: Strengthen the means of implementation and the global partnership for sustainability
- MDG 7: To ensure environmental sustainability; and
- MDG 8: To develop global partnerships for development.

2.3 DfS in formal design education

Kerry Shepard's (2008: 89) paper on Higher Education for Sustainability, "Seeking effective learning outcomes," draws on the interpretation of education for sustainability in relation to educational theories. It identifies fundamental sustainable educational theories that do and do not, support affective or effective outcomes, values, attitudes, and behaviours (Shephard, 2008: 90). Nathan Stegall (2006: 56), the writer of *Designing for Sustainability: a Philosophy for Ecologically Intentional Design*, argues that it is essential to realize that behavioural change is a critical point in the practice of sustainability. Stegall (2006: 58) further explains how the consciousness of design practice should steer away from poorly designed "sustainable products" to a point where designers envision products, services, and systems that can encourage "sustainable behaviour" through the use of a product. Therefore, sustainability in education should adopt "approaches" where good design outcomes should encapsulate fundamental values, behaviour, products, services, and systems (Orr, 1992: 78; Stegall, 2006: 56). These approaches draw on the theoretical underpinnings that result in effective sustainable course material in design education (Shephard, 2008: 91). These theoretical underpinnings are to assist the educator's aspirations for legitimate learning outcomes (Shephard, 2008: 91).

The learning outcomes of students in Higher Education Institutions reflect in two domains of education (Stegall, 2006: 56). These two domains are the cognitive domain and the affective domain (Krathwohl, Bloom & Masia, 1973: 10). It is fair to say that in Higher Education Institutions, educators have practiced and focused much more on a traditional cognitive method of learning (Bloom, 1956: 24); which includes what is known, what is understood, how it is described, comprehended, applied, analysed, synthesized and evaluated from knowledge to understanding (Bloom, 1956: 20; Krathwohl, Bloom & Masia, 1973: 10; Stegall, 2006: 58). However, within the affective domain practice within Higher Education Institutions, educators have focused on developing values, attitudes, and behaviour (Vygotsky, 1978: 40). They have also placed emphasis on students to be attuned to their ability to listen, to respond in interactions that include larger groups of individuals, to develop attitudes and values appropriate to very specific situations and to demonstrate balance and consideration (Bloom, 1956: 20; Krathwohl, Bloom & Masia, 1973: 12; Stegall, 2006: 58).

Therefore, the theoretical underpinnings that will assist the educator's aspirations of sustainable design outcomes in Higher Education Institutions would be best placed within an affective learning domain - as this domain focus on the development of values, attitudes and behaviour - which is a critical focus area of sustainable design and more so, DfS3 (Vygotsky, 1978: 40; Shephard, 2008: 89).

2.4 DfS through S.PSS

Since the early 2000s, research centers have identified Design for Sustainability through systems innovation. Researchers have made these identifications through analyzing the production and consumption patterns on environmental and social sustainability through, what they refer to as, systemic discontinuity (Manzini, 2006: 12). The significance of these studies has proven that radical changes in sustainable consumption seem to be widening the possibilities for innovation beyond the product (Brezet, Bijma, Ehrenfeld, & Silvester, 2001: 22). This radical change entails the sustainable innovation of a system that meets the demands of the customer through an integrated mix of the product and services together (Goedkoop, Van Halen, Te Riele & Rommens, 1999: 22). This integrated mix of product and services together can be defined as:

> "an offer model providing an integrated mix of products and services that are together able to fulfil a particular customer demand (to deliver a "unit of satisfaction"), based on innovative interactions between the stakeholders of the value production system (satisfaction system), where the economic and competitive interest of the providers continuously seeks environmentally and socio-ethically beneficial new solutions" (Vezzoli, 2015: 2).

This integrated mix of products and services to meet the demands of consumers through sustainable innovation and solutions within environmental and socio-ethical environments is known as a Sustainable Product-Service Systems (S.PSS) (Vezzoli et al., 2015: 13).

S.PSS has been studied since the 1990s and has set out to significantly reduce the lifecycle environmental load of current production systems by decoupling the value that is associated with consuming materials and energy (Vezzoli, 2013: 278). Consequently, companies are trying to increase production, yet this seems to be an insufficient approach to securing a competitive edge within industry practice and the desire to promote products is applying stress on available resources (Beuren, Ferreira & Miguel, 2013: 224). The development and implementation of a Product Service Systems (PSS) can provide alternative methods for companies to increase market shares as well as customer satisfaction by providing the consumer with more than mere product innovation (Beuren, Ferreira & Miguel, 2013: 224).

An S.PSS approach to delivering innovation to the consumer is through the identification of several partners (stakeholders) to secure a value within a co-production process (Morelli, 2006: 5). These co-production partnerships appear to be more innovative to improve efficiency in a competitive environment (Laperche, 2007: 24). Carlo Vezzoli explains that with S.PSS development,

> "companies have to shift their designing and selling products only, to support and accompany their usages and end-of-life management. So they have to take care of the lifecycle phase that are usually outside the traditional buyer-seller relationship"
> (Vezzoli et al., 2015: 9)

Sakao and Lindahl (2009: 215) and Cavalieri and Pezzotta (2012: 280) argue that when designing partnerships, it is essential to specify each partner's value and involvement throughout the product's life cycle. S.PSS, therefore, does not only identify the value within pure products (manufacturing), services and co-productive partnerships in lifecycle design, but it takes a holistic perspective of the triple bottom line in relation to sustainability to deliver the optimum mix of products and services together for the customer (Mathews, Tang & Tan, 2011: 463; Vezzoli, 2014: 105; Wuest & Wellsandt, 2016: 152).

S.PSS has its inherent qualities of design clemency, as it seeks ways through which to challenge design through sustainability and Design for Sustainability (Fiksel, 2003: 5330). As a model, it aims to shift, and direct customers' consumer decisions towards sustainable behaviour and practice, not to mention the challenge the model poses for manufacturers and designers to practice within its limitations (Bakker, Wever, Teoh, & De Clercq, 2010: 2). For this section of analyzing data, I will explore critical emergent themes of S.PSS – as this model aims to incorporate: transitional behavioural shifts, Systems Thinking, a disruption of the Business as Usual concept, transforming the landscape of potential and previously overlooked market sectors, as well as sustainable solution offerings.

S.PSS is a branch of the PSS model. At the heart of the PSS model, lies product ownership as well as consumer behaviour (Vezzoli, 2013: 278). A study into PSS shows its origin starts from the early papers of Vezzoli (2003) who questions the product lifecycle analysis. In the early 2000s, PSS draws on the idea that companies could adopt a cradle-to-cradle business strategy to decrease the environmental impact of the products they produce (Bakker et al., 2010: 3). The cradle-to-cradle conception fell under the umbrella of strategic activity to achieve long-term sustainability goals. The life cycle analysis of products stirred debates around societal systems, sustainability, ethics, and the importance society plays as a reflex towards climate change (Benoît-Norris et al., 2011: 686). Further debates about energy supply, energy usage, energy security, energy prices, and climate impacts are at the heart of socio- political issues, which, in turn, still creates a sense of urgency (Vezzoli, Ceschin & M'Rithaa, 2009: 6).

The transition from managing a product's manufacturing and disposal processes received a fresh take through the PSS model. PSS's objective is to oppose consumerist views and reframe product ownership models (Morelli, 2006: 1495). As seen in Figure 2.4 below, there are two examples of how a) consumerist behaviour demands product ownership from companies, and b) how companies retain product ownership to foster a consumer behaviour shift, where the owner is not responsible for tasks related to the product, i.e., maintenance, part checks, reselling or recycling (Morelli, 2006: 1495).

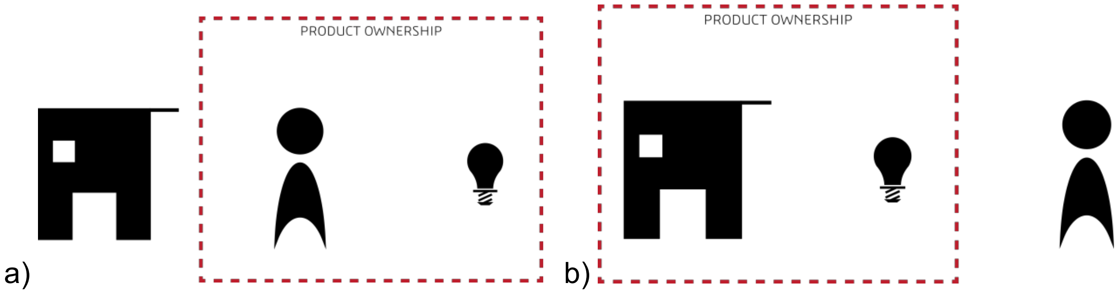


Figure 2.4: PSS model of product ownership

(Image by Corbin Raymond, 2019)

Example B shows how a PSS model works. The consumer does not own a product, yet still has access to the product through a provided service from the company. Products are rented instead of owned through additional offerings of services that are inexpensive at more affordable prices (Morelli, 2002: 5). A vital benefit of the PSS model is the ability to explore developing communities, the base of the pyramid (BoP) demographic living below the gross domestic product (GDP), through a business strategy of reduced service costs (Vezzoli, Ceschin & M'Rithaa, 2009: 6). While servicing the complex socio- political BoP community with affordable PSS solutions, a need for clean energy is of high demand to increase the standard of living as well as the quality of life. Therefore a shift towards sustainable product-service systems is essential, especially when introducing new and expensive technologies to communities (Vezzoli, Ceschin & M'Rithaa, 2009: 6). By incorporating these technologies that supplies energy to a demand is an example of how a PSS model can shift towards an S.PSS model (Vezzoli et al., 2015: 1).

Research on the adoption of S.PSS solutions identifies critical areas where significant challenges are met with the implementation of S.PSS solution offerings (Vezzoli et al., 2015). For example, the S.PSS model for different BoP demographics needs to be contextually appropriate for a successful S.PSS uptake (Vezzoli, Ceschin & M'Rithaa, 2009: 6). It calls for a social innovation where the designers need to work with and through communities and thus, designers and product developers are urged to cultivate products from the bottom up. It is important to understand the consumer's needs within these cultural contexts of the BoP demographics (Vezzoli, Ceschin & M'Rithaa, 2009: 5).

2.5 DfS through Biomimicry

Figure 2.5.1: Life's Principles

(Adapted from Baumeister, 2013)

According to Janine Benyus, the founder of Biomimicry, the word is made up of two words: Bios, meaning Life, and mimesis, meaning mimicking or imitating (Benyus, 1997; Baumeister, Tocke, Dwyer, Ritter & Benyus, 2013). Biomimicry, as a research method, presents key tools such as Life's Principles, as seen in Figure 2.5.1, and a Biomimicry Taxonomy that can be applied when nature is the source of inspiration (Rossin, 2010: 568; De Pauw, Karana, Kandachar & Poppelaars, 2014: 174).

Biomimicry calls for a careful approach to identifying nature as a source of inspiration instead of using nature (Rossin, 2010: 568). Biomimicry uses two different methodologies:

- challenge to biology or
- biology to design (Benyus, 1997).

Where the challenge to biology interrogates different or already existing design challenges and inquires nature for new innovative solutions (Rossin, 2010: 565). Within the methodology of biology to design, nature will produce its “champions” which use natural forms, processes, structures, and materials that can be abstracted and abducted into innovative design solutions (Benyus, 1997; Rossin, 2010: 564).

According to the Biomimicry Resource Handbook (Baumeister, 2013), when coupling these two design methodologies of Biomimicry with design, the biomimetic designer and practitioner encounter two sets of design ‘spirals’ as seen below inn Figure 2.5.2:

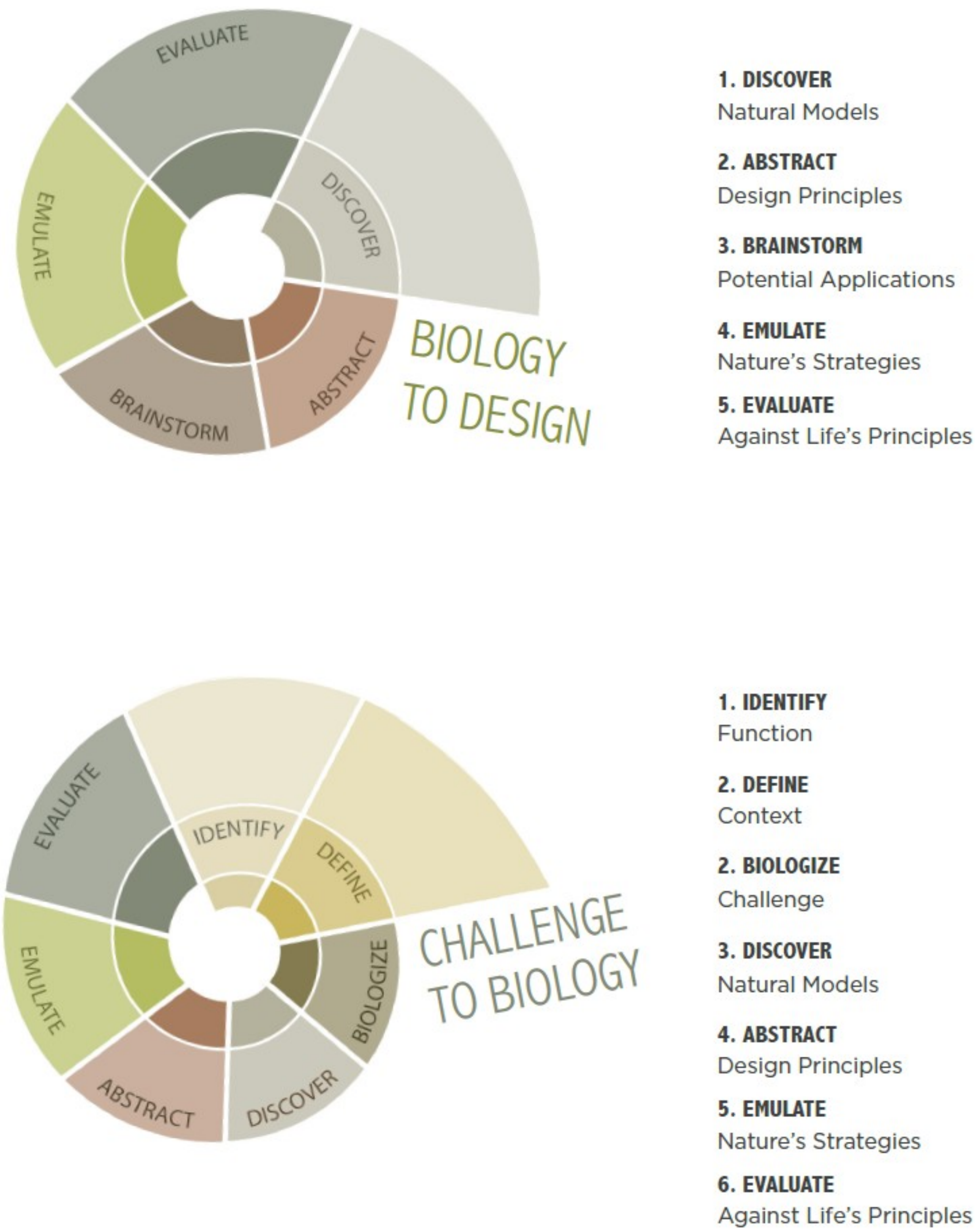


Figure 2.5.2: Design Spirals
(Baumeister et al., 2013)

Biomimicry is also defined as a designerly exploration and study of nature's "champions" when coupled with design research or research through design inquiries (Rossin, 2010: 564). These champions, found in the natural environment, produce the best ideas, models, systems, processes, and elements that inform the design process (Kennedy, Fecheyr-Lippens, Hsiung & Niewiarowski, 2015: 66). By exploring and studying nature's champions, designers can imitate and take inspiration in order to solve complex human problems on a product, service, or systemic level. Through this process of Biomimicry, designers can evolve and enhance human solutions (Kennedy et al., 2015: 67). Janine Benyus (1997), the author of "Biomimicry: Innovation inspired by nature" explains that if one identifies a leaf as a "champion," one can study the anatomy and structure of this champion to further better a solar cell. A further explanation is that this inquiry through nature creates a general understanding of Biomimicry through three main areas of biomimetic investigations (Baumeister, 2013).

A biomimetic approach to design can adopt either of the following processes: "Nature as a Model," "Nature as a Measure" or "Nature as a Mentor" (Panchuk, 2006: 5; Baumeister, 2013):

- Nature as a Model is described as: "a science that studies nature's models and emulates or takes inspiration from their design processes to solve human problems" (Baumeister, 2013).
- Nature as a Measure is described as an ecological standard - in which innovations and ideas need to be judged and measured against to determine whether they are (sustainably) correct or not (Baumeister, 2013). To support this, Panchuk (2006: 5) argues that the elements (plants, animals, microbes, etc.) in nature are the engineers of innovation today. After 3.8 billion years of existence, 'they' know what works, what is appropriate for the environment and its surroundings, and most importantly, what would last here on earth (Panchuk, 2006: 5).
- Nature as a Mentor is: "a holistic way of viewing and valuing nature. It introduces an era based on what we can learn from nature – and not on what we can extract from it" (Panchuk, 2006: 5). "The Biomimicry approach seeks nature's advice at all stages of design, from scoping to creation to evaluation" (Baumeister, 2013).

The way these three biomimetic principles have been applied has resulted in design solutions that have imitated shapes, processes, and materials from nature (Yiatros, Wadee & Hunt, 2007: 179). Professional practice within Architecture, Engineering, and Product Design has adopted these biomimetic approaches into contemporary design applications (Panchuk, 2006: 35). By imitating these biomimetic approaches, one can find alternative and sustainable solutions to design, which will ultimately reduce the amount of consumed energy, as well as wastage (Yiatros, Wadee & Hunt, 2007: 179).

By applying Biomimicry to the shape of a design, the manufacturing process and the materials chosen are indicators of these alternative and sustainable solutions (Yiatros, Wadee and Hunt, 2007: 178). New York City, for example, has incorporated a Biomimetic approach to sustainable innovation through an NYSERDA-funded program (New York State Energy Research and Development Authority). The main goal of the NYSERDA programs is to use Biomimicry for industrial innovations with regards to energy efficiency (Eggermont, 2007: 4; Peters, 2011: 46).

From the perspective of sustainable innovation, Biomimicry is argued to be an enacted design method, together with its tools, to improve efficient ways of making, in order to achieve a competitive advantage within the industry (Reed, Klumb, Koobatian & Viney, 2009: 1571). A Biomimicry tool, in this instance is Life’s Principles (Rossin, 2010: 564; De Pauw et al., 2014: 174). Life’s Principles acts as a guideline for sustainable innovation through various limits and boundaries, cyclic processes, dynamic equilibrium, and natural elements (Rossin, 2010: 564; De Pauw et al., 2014: 174).

The six main Life’s Principles (Peters, 2011: 46) are:

- Adapt to changing conditions,
- be locally attuned and responsive,
- use life-friendly chemistry,
- be resource efficient (material and energy),
- integrate development with growth, and
- evolve to survive.

2.6 Summary

The literature review highlights the importance of adopting an actioning attitude to towards mitigating the effects of climate change, and through a lens of DfS3 asks for societal behavioural change (Jolley, 2006: 15; Shephard, 2008: 91; Baumeister, 2013; Vezzoli, 2014: 105). Shepard (2008: 88) makes a case for behavioural change in HEI's through shifting towards an affective learning domain, where this domain focuses on the development of 'sustainable' values, attitudes, and behaviour. Vezzoli (2013: 278) presents the S.PSS model as a means of shifting product ownership and presents a value offer model where consumers are not necessarily the owners of the products, and thus shifts the behaviour of the consumer market to more sustainable ways of interacting with solution offerings on product, service and systemic levels. Benyus (1997) and Baumeister (2013) presents Biomimicry as a design method to inquire from nature how to measure the sustainability of products, materials, processes, and systems.

Biomimicry presents Life's Principles as a tool that draws on the understanding that 'Life creates conditions conducive to Life' (Peters, 2011: 46; Baumeister, 2013) and that nature has resolved issues of material processes and waste management through plants, organisms and microbes which add value to the ecosystems they operate in (Panchuk, 2006: 8). Similarly, S.PSS models are built from PSS understandings of Life Cycle Analysis as a tool that draws on Cradle-to-Cradle processes in ways materials are made, used, and discarded.

One of the most fundamental differences to the Business as Usual model which S.PSS and Biomimicry propose is in the prioritization of the triple bottom line. The Business as Usual (BaU) concept draws on a consumerist model, where a need or demand creates profit gains for goods and services. Through this buying culture, money circulates through economic structures and promotes financial prosperity on societal levels (Dyer, 2008: 18; Leggewie & Welzer, 2010: 1). Companies do not take responsibility for their goods and services, and the owners of these goods need to find ways of sustainable waste management (Vezzoli, 2014: 105). Therefore, the prioritization of the triple bottom line is Environmental, Social, Economic wellbeing.

A PSS, as well as S.PSS, models are need-focused and are aimed at sustainable behavioural change where socio-economic gains can be made through shifting the ownership of solution offerings to the companies which provide them (Mathews, Tang & Tan, 2011: 463; Vezzoli, 2014: 105). Drawing on the analysed literature, S.PSS models can be interpreted to have a prioritization of the triple bottom line, which is People, Profit, Planet.

Biomimicry presents a model that consults with nature when designing and researching into products, services, and systems for harmonious, sustainable gains for the environment and the aspirations of people through efficient, cost-effective solution offerings (Panchuk, 2006: 60; Baumeister, 2013) — therefore presenting a prioritization of sustainability's triple bottom line as Environment, Social, and Economic wellbeing.

CHAPTER THREE
DESIGN FOR SUSTAINABILITY: AS RESEARCH PARADIGM

3.1 Introduction
In Chapter three, I explore the paradigm of Design for Sustainability through a Systems Theory approach. I present reductionism in relation to Systems Theory because this presents a mode of inquiry into the study. The mechanics of DfS are viewed as an interrelated network of units concerning Systems Theory. These units are S.PSS (see Chapter 2.4) and Biomimicry (See Chapter 2.5), and sub-units comprising sustainability's triple bottom line: Environmental, Social, and Economic Sustainability. Thus, I present a systems approach in the research methodology in this chapter.

3.2 Reductionism
Reductionism, see Figure 3.2, draws on the ability to understand complex systems by reducing big problems into smaller units (Churchman & Churchman, 1968: 984; Flood, 2010: 270). These units are dissected to break the complex system down into smaller, more manageable and comprehensible units (Betts, 1992: 38; Jackson, 2003: 88). Reductionism has its place in systems approaches, mainly when applied to scientific problems, as its strengths lie within the ability to reassemble the small units to understand the more prominent structure of the bigger systemic problem (Wood & Caldas, 2001: 388; Jackson, 2003: 88).

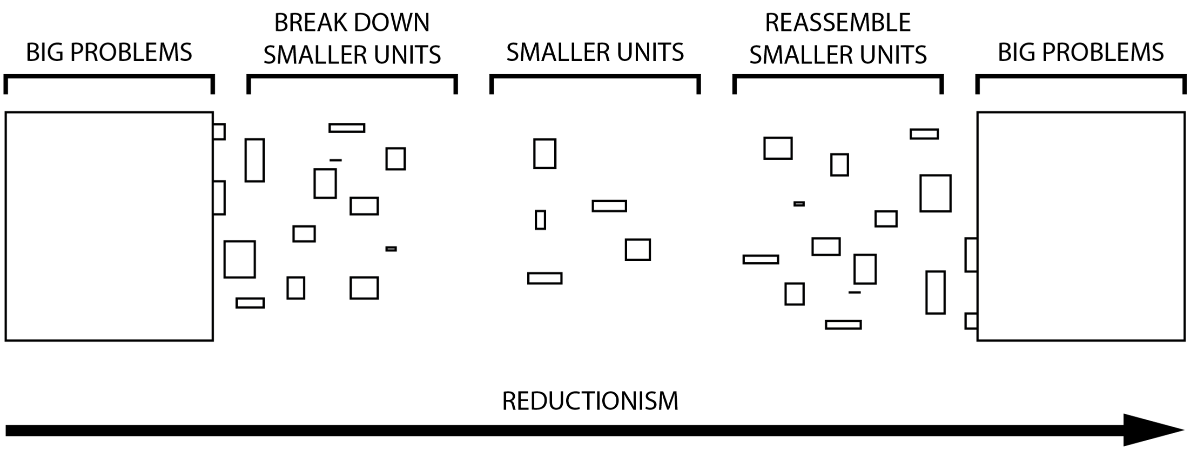


Figure 3.2: Reductionism
(Image by Corbin Raymond, 2019)

3.3 Systems theory

However, Reductionism falls short of the social systems approach found in Systems Theory (Ulrich, 1988: 137; Jackson, 2003: 88; Flood, 2010: 270). Systems Theory, see Figure 3.3, factors in human bias, which influences the way we understand sub-units through circumstances, values, and ethics (Flood, 2010: 270).

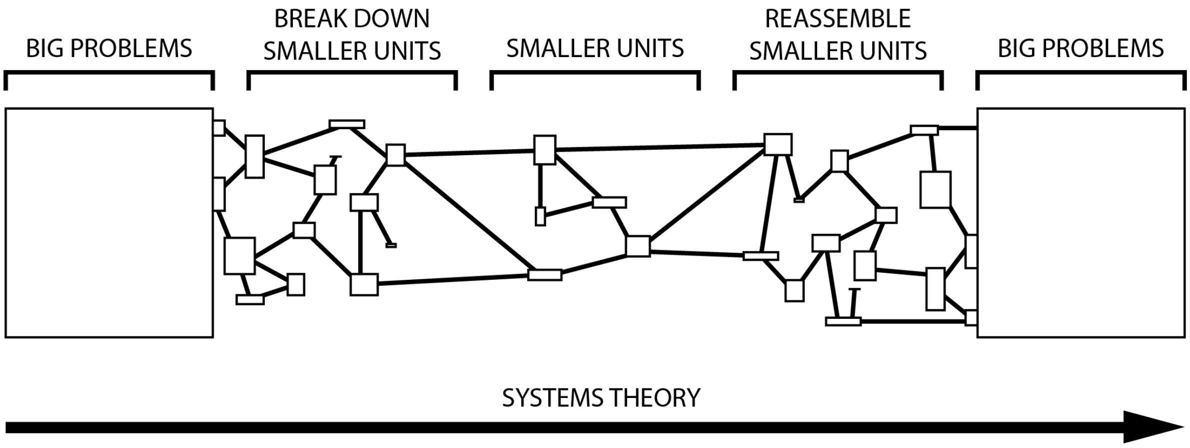


Figure 3.3: Systems theory
(Image by Corbin Raymond, 2019)

Systems theory is inherently reductionist; however, it deals with the relationship between units in order to understand the relationship between the parts making up a more extensive system (Walby, 2007: 451; Hammond, 2010: 17). Contrary to a reductionist approach, where the inquiry would yield in a breakdown of units without considering the interrelations between the units, systems theory draws from the understanding of interrelations to provide a conceptual framework for structuring sustainable assessment (Becht, 1974: 569; Jackson, 2003: 88; Hammond, 2010: 18). Ludwig von Bertalanffy (1968: 40), arguably the founder of general systems theory, defines it as “a set of elements standing in interrelations among themselves and the environment”.

The observer’s viewpoint of the system influences the way the system is delineated and defined more than how the system came into existence (Hammond, 2010: 57). Based on Ludwig’s definition, a system could act only upon itself, or it can interlace with other systems (Von Bertalanffy, 1968: 40). This systemic dualism is:

- a closed system – where the system only interacts with itself, or
- an open system – where the interactions within the system intertwine with external systems to itself.

Katz and Kahn (1978: 528) historically characterize the design application in open systems as:

- The import of energy information from the environment.
- The transformation of that energy into a form characteristic of the system.
- The release or export of products into the environment.
- The re-energizing of the system from sources in the environment.

Environmental sustainability comprises of open systems that depend on two rules:

- Inputs: where system must be limited to the capabilities of a more significant system for it to continue to supply the same inputs without degradation; and
- Outputs: where the emissions from the system must be confined to the limits of the more significant system to continue to integrate them without degradation (Bennetts, Radford & Williamson, 2003: 15).

The general aim of sustainable systems design is to progressively close up these open-systems in an attempt to create structures that reduce their dependence on their environment by:

- using fewer resources,
- feeding resources back into the environment, and
- reducing emissions back into the environment (Bennetts, Radford & Williamson, 2003: 1).

Sustainable systems design depends on the effort to regulate the input and output scope of the more significant system.

3.3.1 The triple bottom line (environment, society, economy) and Biomimicry

Sustainability can be viewed as a system that consists of three sub-systems, see Figure 3.3.1, otherwise known as the triple bottom line, and consists of environment, society, and economy. Within the paradigm of sustainability, these three sub-systems are referred to as a three-legged stool, where the failure of sustaining one of these sub-systems will result in a collapse of the entire system (Walby, 2007: 450; Hammond, 2010: 18). The triple bottom line shapes the S.PSS model to DfS and furthermore acts as a general guide to designing for sustainability within the natural system. However, designing within natural systems necessitates the inclusion of another model: Biomimicry.

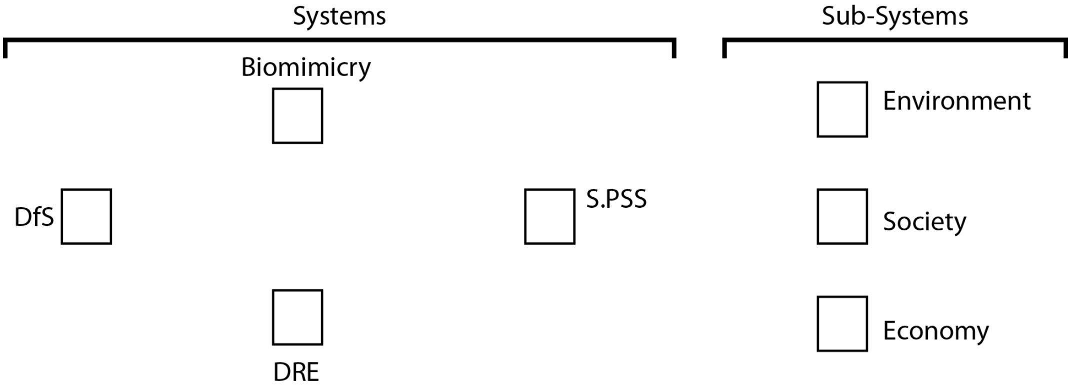


Figure 3.3.1: Systems and sub-systems
(Image by Corbin Raymond, 2019)

By drawing on systems theory, the interconnectedness of these sub-units is interdependent with each sub-unit. These interconnected sub-units, see Figure 3.3.2, consist of their systems comprising of their needs ascribed to it, which, in turn, determines its inputs and outputs. The relationships and connections between systems and sub-systems imply that a change in one sub-system often instigates a chain-reaction affecting other sub-systems as well as the more significant system (Walby, 2007: 458; Hammond, 2010: 18).

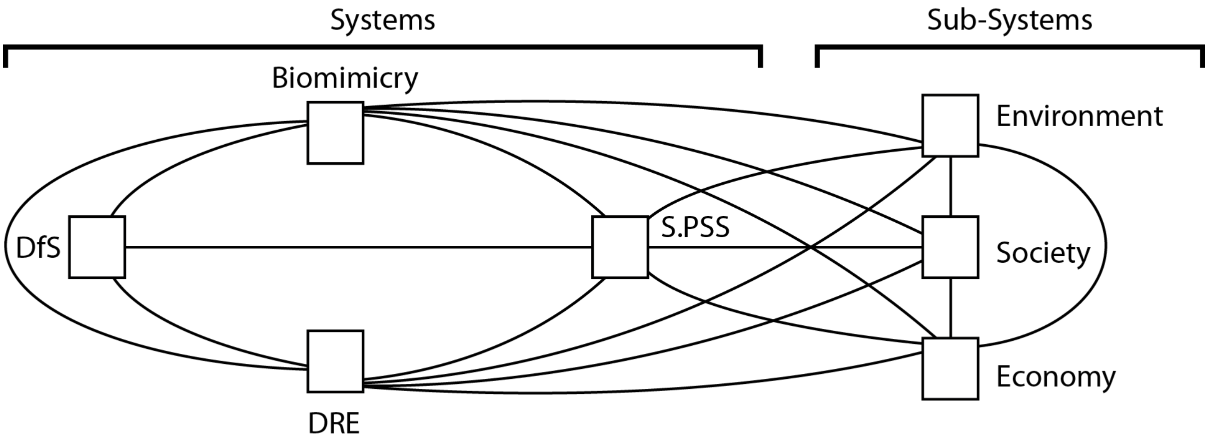


Figure 3.3.2: Interconnected systems and sub-systems
(Image by Corbin Raymond, 2019)

The systems approach to this study involves elements of theory and practice of Design for Sustainability as well as the approach described above as systems theory (Walby, 2007 451; Hammond, 2010: 18). The theory behind Systems Design for Sustainability denotes that the conceptualization of systems consists of products and services that will be jointly capable of satisfying specific user needs and desires (Margolin & Margolin, 2002: 25)

These product service systems needs are dependent upon innovative customer and stakeholder interactions through these relationships between units, while simultaneously leading towards eco-efficiency, as well as social equity and cohesion (Vezzoli, Ceschin & M'Rithaa, 2009: 3).

Conceptual evolution has taken place within sustainable design practice to enlarge its scope from the initial life-cycle design or eco-design products, to design for eco-efficient systems or product-service systems (PSS), to design for social equity and cohesion or sustainable product service systems (Vezzoli, Ceschin & M'Rithaa, 2009: 6).

The rationale behind using both DfS and systems theory is to take a holistic view of all the elements which makes up the system in which a product and/or service functions; how the product and/or service affects the dynamics of the system, and finally, the sustainability of the system as either an open or closed unit (Mathews, Tang & Tan, 2011: 463). This approach has the potential of becoming complex as more units and subunits are identified, but due to the limitations of the research (see page 94) the units within the system and sub-system has the potential to answer the research questions stated on page 11.

3.4 Environmental sustainability

Dobson (2012: 5) argues that environmental sustainability is a contested concept which implies that the meaning of this term is not stable enough as a stand-alone concept. He argues that environmental sustainability does not have the agency to be a pressing matter in society. In his speculative book, *Justice and the Environment: Concepts of Environmental Sustainability*, Dobson (1998: 191) explains how the inevitable fate of humanity will come to an end long before our sun dies out and further argues that therefore, sustainability has its limits. However, in the last days of humanity, the benefits and burdens of the quality of life will be spread across societies and matters of concern will be political, economic and cultural agendas – more so than the matter of environmental sustainability (Dobson, 1998: 11; Vezzoli, Ceschin & M'Rithaa, 2009: 6).

Based on this perspective on sustainability, the concept of nature's taxonomy informs the framework of environmental sustainability through its ability to create conditions conducive to life (Baumeister et al., 2013). It upholds political, economic, and cultural activities in the present through the ability to adapt to slow and radical changes in such contexts (Kennedy et al., 2015: 67). These contexts draw on the relations within the triple bottom line in order to meet the criteria of conditions conducive to life, by being locally attuned, responsive, and resource efficient while striving to evolve and survive (Benyus, 1997; Kennedy et al., 2015: 67).

Environmental sustainability is further underpinned by accepting and embracing diversity in its blueprint to maintain its integrity through variation, redundancy, decentralization, and self-renewal (Kennedy et al., 2015: 67). Design for Sustainability draws on its framework to leverage off cyclic processes and cultivate cooperative relationships between the sub-systems of DfS. The ability to integrate the unexpected becomes pertinent as it informs the ability of DfS to self-organize and reshuffle information in order to sustain the environment and its contexts (Jackson, 2003: 88; Dobson, 2012: 7).

3.5 Social and cultural sustainability

Cultural diversity is essential to create differentiation within a variety of circumstances experienced on a global scale (Bennetts, Radford & Williamson, 2003: 7). Sustaining this cultural diversity through preservation through design remains as a necessary process for a society's ability to develop, adapt, and innovate within its surroundings (Margolin & Margolin, 2002: 25). Culture as tradition draws on a system of transmitting social knowledge between generations that is, in itself, adaptive to changing circumstances. The ability of a society to adapt further draws on its interwoven relation with changes in the economic and environmental circumstances (Gabay & Ilcan, 2017: 338). By merely relating DfS to culture and society on a 'flat' level - where flat means superficial patterns of regional vernacular - the possibility of flexibility within socio-cultural circumstances might be missed as these circumstances are continually developing, adapting and evolving (Tilman, Fargione, Wolff & D'antonio, 2001: 282; Gabay & Ilcan, 2017: 339). Socio-cultural circumstances evolve inconsistently over time and space depending on the geographical or non-geographical entities which define the needs of different 'cultures' (Death & Gabay, 2015: 599). Therefore, different product solutions should address and meet the needs of that specific group in order to sustain it (Bennetts, Radford & Williamson, 2003: 7; Vezzoli, Ceschin and M'Rithaa, 2009: 6).

3.6 Economic sustainability

Market-based economies are undeniably dependent on capitalist societies where patterns of capital accumulation exist (Bennetts, Radford & Williamson, 2003: 3). Design projects draw on the ability to show a profit of some kind (Mager, 2008: 73). This ability to show continuous profit gains reflects economic sustainability within such societies (Mager, 2008: 73). A noticeable absence of a capitalist society underpins projects and its discourses concerning DfS. Arguably, the principle of capital accumulation fuels a societal system built on taxation, human resource development through employment endorsements, and capital investments (Kates, Parris & Leiserowitz, 2016: 3). This view on capitalism often results in societal and environmental problems as this economic system is based on the materialistic values of greed. Papanek (1984: ix) describes capitalism in design as:

> "Design persuades people to buy things they do not need, with money they do not have, in order to impress people that do not care."

Economists tend to favour one of two points of view when referring to economic sustainability. The first point of view is the neo-classical approach, where sustainable economic growth results from competitive markets, deregulation, and global economic integration. The second point of view is the abandoning of economic growth as a measure of a society's success, and instead, favours the stance of equity, reducing poverty, encouraging resource conservation, ecological limits, improved quality of life and regulation as the way to sustainability (Bennetts, Radford & Williamson, 2003: 3; Kates, Parris & Leiserowitz, 2016: 4).

3.7 System innovation

Vezzoli (2009: 6) introduces a serious and radical approach to sustainability when applied to the innovation in consumption and production patterns. He argues that system discontinuity is essential. In continuing his argument for systems innovation, Vezzoli (2009: 6) further states that given the scale and nature of this change, it is imperative to see the transition towards sustainability and sustainable ways of living as "a wide-reaching social learning process." According to Vezzoli (2009: 6), Manzini (2006: 10), and most authorities on design research agree that radical change in sustainable consumption will most likely evolve from an approach where the scope of innovation move beyond the product.

The products and services which make up the system should comprise of environmental, social, and economical components that are affected by - and effects - the products and services (Brown, 2008: 84; Clune, 2010b: 74). Therefore, sustainable product service systems and its innovations should be scrutinized for its pertinence, significance, and longevity (Brown, 2008: 84; Clune, 2010b: 74).

3.8 Summary

The transition towards sustainable ways of living alludes to DfS3, which asks for a "wide-reaching social learning process." This Chapter presents a futures-orientated approach through viewing Design for Sustainability through a lens of DfS3. A way of approaching DfS through Systems Theory is advanced, where I use elements of reductionism to isolate S.PSS and Biomimicry as functioning units with the system of DfS, and Environmental, Social and Economic sustainability as functioning sub-units within DfS, while not excluding the complexities the units and sub-units have concerning each other. The approach of Biomimicry and S.PSS function optimally within DfS when they are in harmony with the best practices of the triple bottom line.

CHAPTER FOUR
CONTEXTUALISING A METHODOLOGICAL APPROACH

4.1 Introduction

In Chapter four, I state influences on the research through a researcher's stance as well as how I approach generating and collecting data through the research methodology. I present the research activities which I have undertaken in order to address the research topic through a case study methodology. Furthermore, the structure of this chapter simplifies and contextualise key research activities, such as research methods, design tools, design techniques, and qualitative data sets as "sub-units" of a design inquiry into Design for Sustainability. This chapter provides a blueprint for the key research activities and data presentation of the following chapter.

4.2 Contextualising research perspectives

I have viewed this study from a position of Industrial Design, as an Industrial Design educator, as well as a design practitioner and design researcher. This informs my positioning within this inquiry into Biomimicry and S.PSS within the paradigm of DfS3. It is explained by Packer (2000: 228) that the ontological approach of the researcher influences the choice of methods that are used to collect and analyse data. Qualitative data which will be relevant to inform this study, as DfS3 is framed around societal behavioural change, and therefore to gain knowledge through the methods and techniques I use to collect data is based on my epistemic stances, as described in the following section.

4.2.1 A qualitative research approach from a relativist perspective

Packer and Goicoechea (2000: 228) explain two ontological stances in his work on research methodology: the one being realism and the other, Relativism. Realism couples with quantitative research, and according to Packer's theories, this means that as a researcher, I can find truth in a very objective way (Packer & Goicoechea, 2000: 234). Relativism, however, acknowledges the importance of context (Morgan & Smircich, 1980: 500; Packer & Goicoechea, 2000: 232). Hence, I acknowledge that the collected data is prone to change based on the context in which I explore the research in (Morgan & Smircich, 1980: 500). As argued by Packer and Goicoechea (2000: 228), the relativist stance, as opposed to realism, is most commonly used as a researcher's ontological stance in qualitative research.

4.2.2 Epistemological stance and assumptions

Ontology and epistemology are two paradigms in which the philosophy of knowledge creation and knowing happens (Morgan & Smircich, 1980: 502). Ontology refers to the subject of the research, and epistemology refers to the nature in which I gain knowledge. Realism and relativism allow me as the researcher to consciously conduct objective research with an epistemological stance grounded in etic as well as emic (Yin, 2017). Where an etic epistemology means that I will objectively collect data; and an emic epistemology means that I can interact and engage with this study to underline and bring forth meaning within a specific context (Packer & Goicoechea, 2000: 227; Yin, 2017).

4.2.3 Researcher's stance

As a researcher, I embody a relativist ontological and an emic epistemological stance in order to draw on, underline, and bring forth the meaning within this qualitative research study. This stance is appropriate for the case study methodology that I have used where key and common themes are analysed. The thematic analysis of research data from this case study informs the development of a set of guidelines - which is underpinned by objectively analyzing theoretical literature, as well as drawing on meaningful and contextually specific data underpinned by the case study.

I have aligned these ontological and epistemological stances to converge to inductive reasoning of this research study (Packer & Goicoechea, 2000: 228; Yin, 2017). Inductive reasoning takes a specific case, analyses it, and presents it as a set of general principles – which is what I do in my inquiry of a particular case presented as a structured course, from where I analyse data and recommend a set of general guidelines to DfS3 through Biomimicry and S.PSS.

4.2.4 Methodological considerations

As described previously in Chapter 3.3, I make use of a Systems Theory approach to inquire DfS. This approach helps me to identify sub-units of the study. One of these sub-units is a structured course, which I present as a particular case through which I generate data to be analysed. Therefore, a case study methodology informed me to identify, analyse, compare, and evaluate the collected data. I have considered the following aims (Mack, 2005: 3) of qualitative research:

- Seek answers to questions
- Systematically use a predefined set of procedures to answer the research question
- Collect evidence
- Produce findings that were not determined in advance
- Produce findings that are applicable beyond the immediate boundaries of the study
- Seek to understand a given research problem

4.3 Case study and data sampling methods

The case study methodology allows me to ask and answer “How” and “Why” questions (Miles, Huberman, Huberman & Huberman, 1994: 143). According to Yin (2017), and Baxter and Jack (2008: 544), these questions are essential when studying complex phenomena within their context. Yin and Baxter (2008: 544) further argue that qualitative modes of inquiry inform this contextual relevance in research. Baxter and Jack (2008: 545) describes how the case study research methodology supports a systems theory approach in order to understand the complex nature of phenomenological concepts (such as Designing for Sustainability).

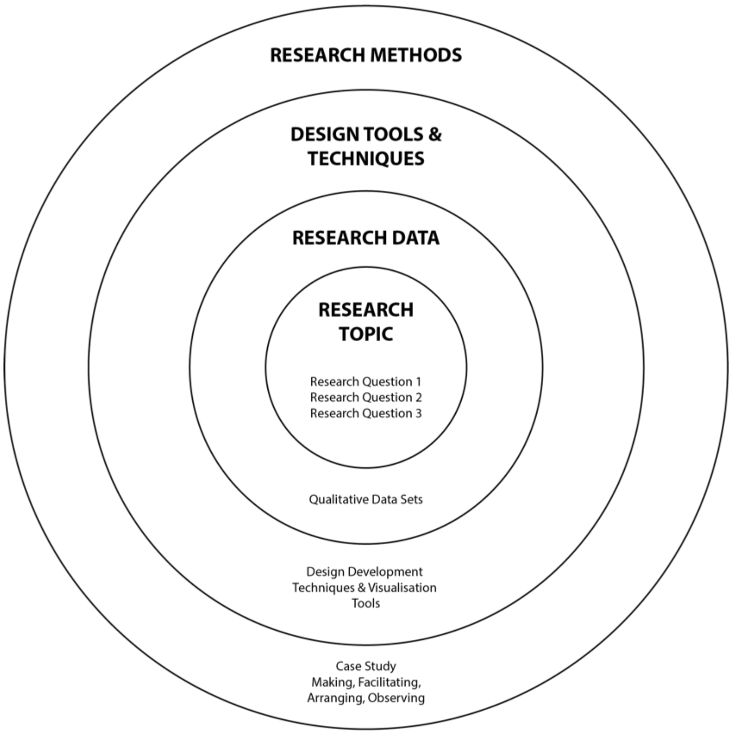


Figure 4.3: Research methodology
(Image by Corbin Raymond, 2019)

Drawing from this understanding, I have selected the structured course which has been outlined in the LeNSes project requirement as a case through which to generate data. I continue to present and thematically analyse this data. The objective of the case study, see Figure 4.3, is to extrapolate critical approaches to the praxis of design, specifically the praxis of S.PSS and Biomimicry when designing for sustainability.

I present the research subjects within this case study as the student projects from the structured course. The student projects are tangible and intangible artifacts that have been prototyped and presented within an undergraduate industrial design course. The reason why this is the research subjects is that the artifacts embody the design approaches students used, based on design tools and techniques which are informed by Biomimicry and S.PSS. Therefore, the data generated will draw on how these artifacts came to exist and what they embody.

I use a mixed-method approach to gather qualitative data sets (Baxter & Jack, 2008: 547). These data sets consist of:

- questionnaires (completed by the design students and course facilitators)
- document analysis comprising of reports (completed by students and an external observer)
- contemporary – and classical literature (relevant and supportive to the research context)
- mixed media observations (images and videos related to the course)
- semi-structured interviews (with the participating design students and design educators of the course)

The questionnaires and interviews were open-ended to ensure that the participants could freely contribute and express their opinions and answers. The consent form has been used in this regard to ensure that the participants were aware of their contributing role in my research. The challenge was to allow students to participate without them feeling pressured or fearful of their assessment marks being affected by my research. My research did not interfere with the assessment of student marks during the research, which alleviates concerns of the perceptions students might have. Therefore, I distributed the consent form to the selected students to ensure that they were aware of my research study and that they could freely decide on whether or not to contribute to the research.

The C-SAN-Futures and the LeNSes projects were the main drivers as mechanisms to ensure the active participation of participants. These projects researched Design for Sustainability and have already fostered good academic partnerships between the participating HEI's. This relationship was a leveraging mechanism that I have utilized to engage with the participants of the study.

4.3.1 Role of researcher

I am a facilitator of meaningful engagements with Industrial Design students, and I teach design approaches to S.PSS (applied to DRE) and Biomimicry as a way to achieve Design for Sustainability in the learning outcomes of an HEI. This engagement with the study allowed me to collect data through which I could identify and analyse critical themes of the case study and develop a set of guidelines from the collected data. As the researcher, I co-facilitate the structured course. Additionally, I was responsible for the primary collection of data and storing the collected data in a safe, and password-controlled data hard drive.

My role was to ensure that the aims of qualitative research are met in a clear, objective, and meaningful way (Mack, 2005: 4). I did the following:

- Selected the participants for the study and ensured that the mechanisms to ensure active participation were applied to finish the research without compromising the quality of the data in any way.
- Identified an external observer to assess the quality of design education on Designing for Sustainability during the course which I facilitated.
- Collected, documented and captured data through mixed-method techniques that included: questionnaires, document analysis, and semi-structured interviews.
- Support and contribute to the two significant research projects (C-SAN- Futures and LeNSes) with knowledge building and research outputs on Climate Change and Designing for Sustainability in the form of project reports, conference papers, journal publications, and this thesis research.

4.3.2 Selection criteria used for data collection of participants

I used specific criteria for selecting research participants, the observer, students and HEIs through a hand-picked selection process. Each participant was personally contacted and invited to participate by me through direct dialogue or through electronic messaging platforms where consent forms were either provided through print format or digital format. My research formed part of larger research projects and I had to meet the following selection criteria:

4.3.2.1 The selection criteria of the participating HEI were that:

- The HEI had to be located in Cape Town, Western Cape, South Africa.
- Offer design programs specifically in Industrial Design.
- Had given consent that the research would be conducted in their facilities.
- Had an interest in Research and Designing for Sustainability.

4.3.2.2 The selection criteria of the participating design students were that:

- Undergraduate students had to be registered as Industrial Design students within the academic year in which the data was collected.
- The students had to be from the identified HEI.
- The students had to give their consent.
- They had to be physically able to participate and not have any physical disability or mental impairment.

4.3.2.3 The selection criteria of the participating external observer are that:

- The observer should not be affiliated with the identified HEI.
- The observer has to have prior experience in content and pedagogy development.
- Have a personal interest in Sustainability and Designing for Sustainability.
- The observer had to give consent to be part of the research.
- The observer had to have the ability to observe, document, and compile an observer's report based on the way learning was facilitated as well as document the student's learning and design work.
- The person had to be physically able to participate and not have any physical disability or mental impairment.

4.3.2.4 The selection criteria of the participating HEI educators were that:

- The educator had to be employed by the identified HEI in a permanent lecturing position and teach in either of the undergraduate or post-graduate design courses.
- Have a personal interest in design research and design education about Designing for Sustainability.
- The educator had to be physically able to participate and not have any physical disability or mental impairment.

4.3.3 Research activities

The focus of this thesis is to investigate two design methods, Biomimicry and S.PSS into a more holistic and inclusive approach to DfS in order to be future-orientated with sustainable solution offerings as opposed to designing for DfS with these two methods in isolation (Irwin, Kossoff & Tonkinwise, 2015: 4). In order to achieve the integration of the two design methods into more holistic future orientated inclusive approach the following measures were put in place:

- Capturing, evaluating, and analyzing data from a growing body of literature on Design for Sustainability, Biomimicry, and S.PSS.
- Translation of the data into course material for Designing for Sustainability.
- Academic outputs in the form of research posters and conference papers.
- Facilitation of learning and studio contact time with the design students.
- Researching teaching tools and mechanisms for students to follow during their course work in Designing for Sustainability.
- Sourcing appropriate student participants.
- Development, distribution, and collection of research questionnaires.
- Sourcing an external observer to write an observational feedback report on the Design for Sustainability course.

These research activities ensure that the qualitative data sets are provided with content and contextually rich material. This draws thematic discussions forward in order to analyze the effectiveness of the methods used to gather data. Additionally, it allows me to answer the main research question – by answering the sub-questions – through inductive thematic analysis, as seen Chapter 6.4 on page 82.

4.4 Research activities and data collection methods

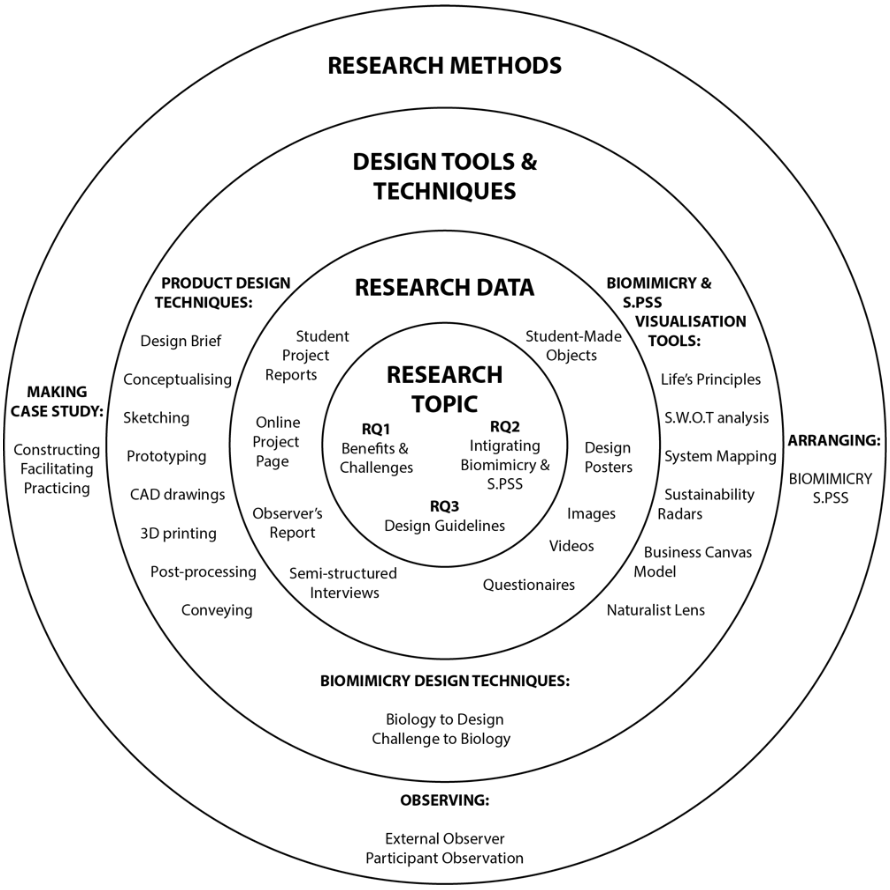


Figure 4.4: Research activities
(Image by Corbin Raymond, 2019)

Figure 4.4 shows the flow of how the research methods informed the design tools and techniques I used to inductively generate and collect relevant data which allowed me to address my research topic. This model framed my research so that each of these sub-units was viewed through a process of systems theory and thematic analysis, in order to make meaningful connections between key indicators and concepts of DfS3. These sub-units are examined in the following section in order to make sense of the way that the data was collected and presented.

4.4.1 Research methods: Theory building

I have developed a course that was used as a case study from which theory was built, which is a specific research approach called *theory building from case studies* (Eisenhardt & Graebner, 2007: 26). As mentioned in section 4.3, I presented a structured LeNSes course as a case study for my inquiry into DfS3. As researcher and co-facilitator of the industrial design course which was used as a case study, theory was developed from the findings of the mixed method data collection process (Eisenhardt & Graebner, 2007: 26). Another role was to identify and approach co-facilitators who met the criteria highlighted in section 4.3.2.4.

4.4.1.1 Structure of the course

The course drew on the expertise of the three main facilitators, who through meeting and planning, developed a programme for a structured course with formal assessment criteria for the Industrial Design undergraduate programme. A botanist was approached as an external facilitator to facilitate key learning events, such as a field trip with students to a botanical garden. See Chapter 5.3.3.

As my research project was situated within the LeNSes project an external observer was included to achieve an objective view with regard to the research activities related to the course. Table 4.4.1.1 shows the course structure, that was used as a case study from which to build theory using mixed data collection methods.

Table 4.4.1.1: Course structure

WEEKS 1-6	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
BRIEF	31 August	1 September	2 2pm Design Bldg. BRIEF Outlined – RF. Introduction to project, guideline for mapping work and activities. Intro to Biomimicry and Life's Principles evaluation. CR presents LeNSes SPSS by case studies. Rural, urban, peri- urban. Look at case studies. BJ observes. (2hrs)	3 ID THEORY	4 BREAK UP DAY
VAC WEEK Scoping Context, analysis of products,	7 Vac week: Scoping of Rural, urban, peri-urban energy-related products in context.	8	9	10	11
WEEK 1 GOAL Life's Principles evaluation and LeNSes tools,	14 Life's Principles evaluations – Teams look for obvious links between components, energy outputs, sources. Work on	15 Preparation of comparative analyses of chosen products – looking for linkages, similarities, differences,	16 Morning - drawing	17 THEORY	18 CR –-demonstrates further SPSS tools – Sustainability radars - a case study

design exercises	comparative analyses. Form teams CR – demonstrates SPSS tools – SWOT Analysis & system mapping on case studies provided.**BJ observes (9-3.30)** 4.5 hrs obs, 1hr writing up	SWOT analyses. (AB organises camera for capturing)	2pm: ID/MTech teams present product comparisons –		Business canvas exercise Project work in teams facilitated by RF, AB and CR BJ observes (4hrs??)
WEEK 2 GOAL Using LeNSes tools, Biomimicry , project work	21 9-12pm Kirstenbosch Naturalist lens – sight sounds smells taste touch. How does nature filter BJ observes Project work in teams facilitated by RF, AB and CR Wendy Hitchcock – botanist Observation mind-maps briefed – RF	22 • Show examples of previous • Presentations . • Biomimicry mini challenges • Teams prepare Observation mind-maps for tomorrow BJ observes	23 • 2pm: • ID teams present observation mind-maps • Project work in teams	24?? [Public holiday] ID THEORY?	25 CPUT closed Project work in teams Facilitated by CR, RF, AB BJ – interviews/ surveys with RF, CR, AB, students
WEEK 3 GOAL Design drawings, context scenarios to present to peers/ industry	28 • Guest speakers -TBC • Design drawings/ • Documentation prep	29 Design drawings/ Documentation prep	30 Design drawings – Mech Eng present?	1 October ID THEORY	2 Design drawings/ Documentation prep
WEEK 4 GOAL Fine tuning of products and system drawings	5 Design, system drawings/ Documentation prep	6 Design, system drawings/ Documentation prep	7 Design, system drawings/ Documentation prep	8 ID THEORY	9 Design, system drawings/ Documentation prep
WEEK 5 GOAL Final presentations marks, reports,	12 Plan final presentations, documentation, budgets for prototyping	13 Plan final presentations, documentation, prototyping	14 Plan final presentations, documentation, prototyping	15 ID THEORY	16 Present to outside stakeholders – Vimeo on youtube – CAD models, basic

budget recon.					prototyping Marks – panel/jury? BJ observes
	19	20	21	22	23
WEEK 6/7 GOAL Design, Prototypes, Manufacture – exhibit 2 November	Build final prototypes	Build final prototypes	Build final prototypes BJ – interviews/surveys with RF, CR, AB, students	ID THEORY	• Build final prototypes • - deadline 2 Nov. Posters, prototypes exhibit for moderation.

4.4.1.2 S.PSS and Biomimicry tools and techniques

The students used a set of S.PSS and Biomimicry design tools. The tools are aimed at understanding and visualizing system's complexities, with a specific focus on sustainability's triple bottom line. The S.PSS tools were presented during studio contact times by the facilitators.

These S.PSS tools consisted of the:

- Strength, Weakness, Opportunity and Threat (S.W.O.T.) analysis – a tool used during the identifying phase of the design process. This tool allows students to explore the Strengths, Weaknesses, Opportunities, and Threats to their design focus areas. See Chapter 5.4.2.
- Stakeholder Value Mapping – Which is a visualization tool used for identifying key stakeholders within systems design. The tool explores the ideal win-win scenarios between stakeholders within existing and possible contexts. See Chapter 5.4.4.
- Systems Mapping – another visualization tool which is best integrated with the stakeholder value mapping tool. This tool allows designers and design practitioners to identify the material, information, and monetary flows between the acting stakeholders with a system. This tool visualises closed loop systems and inherently challenges linear systems flows. See Chapter 5.4.5.
- Sustainability Radars – This is an evaluation tool to measure the sustainability impact of design(ed) interventions. It visually represents a scoring system for effectiveness in achieving sustainable, environmental, and economic sustainability. See Chapter 5.4.3.
- Business Model Canvas Tool – This is a mapping canvas tool that draws on the stakeholder value mapping and systems mapping tools to present innovative business value offerings to foster socio- economic development. This tool adds value to the evaluation process of design, where a business model exists around a solution offering. See Chapter 5.4.6.

Biomimetic design tools focused on an environmental lens of inquiry into the design areas the students had to identify in their course and consisted of the following:

- Life's Principles – An evaluation tool used to measure the environmental sustainability of design(ed) solutions, from a product, process, and systemic point of view. See Chapter 5.4.1.
- Naturalist Lens – A tool used to identify Natures Champions, in order to inform the design process through either Biology to Design, or Challenges to Biology, as explained in Chapter 2.5 DfS through Biomimicry. Also see Chapter 5.3.5 and Chapter 5.3.6.

4.4.1.3 Design techniques (the design process)

Due to the nature of the Industrial Design course and the structure through which the university offers the programme to students, the facilitators had to incorporate the generally practiced design techniques of the design process used in industrial design as follows:

- The Design Brief – a Scoping tool used to achieve a Memorandum of Understanding between the project facilitators and students. The design brief highlight, restrict, and challenge students to the contextual area of their work. See Appendix C4.
- Conceptualizing - An exploration technique that proves valuable to identify potential solution offerings. See Chapter 5.3.4.
- Sketching – A technique used to translate cognitive thinking into visualised ideas. Therefore, it is regarded as an ideation technique to explore, refine, and consolidate ideas. See Chapter 5.3.4.
- Prototyping – This technique used to test and evaluate consolidated ideas. See Chapter 5.5.2.
- CAD Drawings – A technique used to construct, edit, and refine consolidated ideas within computer-aided design software programs. The results of applying this technique are photorealistic visualizations of the designed solution. See Chapter 5.4.7.
- 3D Printing – A technique that uses 3D printing tools and machines to manifest digital CAD drawings into physical prototypes; these prototypes are evaluated, refined, and finalised. See Chapter 5.4.8.
- Post-Processing – This technique allows designers to refine their 3D printed artefacts for aesthetic and product communication purposes. See Chapter 5.5.2.
- Conveying – An evaluation technique that provides the scope for formal and informal presentations of designed solutions through oral, written, photo, and video mediums. See Chapter 5.3.3, Chapter 5.5.1, Chapter 5.5.3 and Chapter 5.5.4.

Therefore, the design tools used drew on the identification, exploration, visualization and evaluation tools of S.PSS and Biomimicry, while still drawing on the generally practiced design techniques of the design process used in the Industrial Design course programme.

4.4.2 Combined data collection methods

Using combined data collection methods helps to triangulate the data findings (Baxter & Jack, 2008: 556). Through facilitating the structured course, I managed to engage with students over a seven-week design project. The research data which has been presented is the student's work and formal outcomes of their design programme, as well as the external observer's report. The data collection also includes my personal photo documentation of the course, with a focus on key learning activities.

The combined data collection methods consisted of:

- 2 Student-Made Objects – These are 3D printed design artefacts that form part of the product component of an S.PSS solution offering.
- 1 Project Poster – A visualization artefact that demonstrates key components of the project through visual communication design.
- Photographs – A documentation tool to enhance the contextual relevance of crucial moments during the research activities.
- Questionnaires – Qualitative data collection technique which ensures objective participant opinions and ideas towards the research.
- Semi-Structured Interviews – Provides more informal qualitative dialogue to surface between the research participants.
- 1 Observer's Report – a formal observation document that draws on critical observations during the design course. The document holistically captures critical themes of the structured course, student projects, and presents rich qualitative data in an objective way.
- 2 Student Project Reports – A formal document that highlights the student's design process. It surfaces self-regulated documentation from the students during the course, as well as their relation, understanding, and interpretations of the design tools and techniques.
- 2 Online Project Pages – Self-regulated by the students to showcase their work, processes, and intricate relation between Biomimicry and S.PSS to a broader public domain.

These data sets are presented in:

- Appendix A (see page 101),
- Appendix B (see page 136) and
- Appendix C (see page 172),
- as well as in Chapter 5.

4.4.3 Data evaluation methods

The research questions and my research aim inform the evaluation of the qualitative data sets. The data should, therefore, meet a specific requirement in being able to provide me with critical insights that reflect on the “what, how, and why” questions. By using combined data collection methods enabled me to triangulate the findings when analysing and interpreting the data (Miles & Huberman, 2002: 7) The data should therefore be:

- Appropriate for a qualitative research inquiry.
- Thematically analysed (as discussed in my research approach).

The data sets should:

- Further address the units and sub-units of the theoretical inquiry (DfS3, Biomimicry, S.PSS, Sustainability’s triple bottom line) as well as the research methods, design tools and design techniques.
- Directly link to the structured course, and therefore, be generated by the research participants.

4.4.4 Ethical considerations

The affordances of qualitative case studies have the potential to yield opportunities that I could explore and describe in a specific context using a variety of data sources (Baxter & Jack, 2008: 556). It allowed me to explore individuals such as students and educators the identified HEI’s (Yin, 2017). The Case Study methodology, as well as a Systems Theory approach, allowed me to deconstruct the cases and subsequently reconstruct a set of design guidelines from it through analyzing various phenomena (Baxter & Jack, 2008: 544).

Therefore, appropriate and ethical procedures had to be taken to ensure that all participants were conscious of their involvement in the research project. Furthermore, the research posed no threat to the participants, as no person had to be medicated, exposed to harmful materials or gasses. There were no sensitive topics discussed, nor were there any procedures that were intrusive, invasive, or harmful to the participants. In addition ethical considerations and clearance was granted by the Faculty of Informatics and Design’s (FID) ethics committee and written consent by the Postgraduate Office was obtained, see Appendix D (page 217).

4.5 Summary

A brief description is provided on how the research methods highlighted in this chapter allowed me to use a structured course as a case, from which theory was built. Here I provide a breakdown of critical indicators of my research which include the criteria of participants, HEIs and the techniques and tools used to DfS3. All ethical clearance procedures of FID were adhered to.

CHAPTER FIVE
PRESENTING THE DATA

5.1 Introduction

In Chapter 5 the research data sets are presented in relation to the overall research objectives. The data sets comprise of three main categories, Design Techniques, Design Tools, and Ways of Making, which draws on the research framework presented in Chapter 4.4. The main research question reads: *"How can a holistic approach to Design for Sustainability be developed and implemented in a Higher Educational Institute to inform an in-depth design praxis for Industrial Design students?"* This chapter describes the data which has been generated through the guidelines of Chapter 4.

5.2 Presenting a case study

The data presented in this section draws from the observer's report, which gives an objective overview of the course: where Biomimicry, in relation to S.PSS and DRE, were introduced to undergraduate Industrial Design students at CPUT. The course took place over six weeks with key "research through design" activities. The course also had to meet the project requirements of the technology, product design and graphic design subject component within the existing industrial design curriculum of the HEI. There is a wide selection of various data sets that emphasise the different methods used to collect data. A short introduction to the techniques and tools used in this case study is described below, with an inductive thematic analysis of the data sets following in Chapter 6.

5.3 Design techniques

The design technique was introduced to inform a way of making. The design techniques required careful consideration, research and application and allowed for a reflective student to emerge (Mambrey, Mark & Pankoke-Babatz, 1998: 292). The belief is that the reflective design student has the capacity for a design praxis that reflects on theoretical issues and concepts (Sanders & Stappers, 2008: 15). This implies that the reflective student embodies conceptual and practical skillsets when dealing with complex design challenges (Sanders & Stappers, 2008: 16). The aim of using the techniques was to achieve this through a design praxis where the ways of making would contribute to a design process that builds on academic knowledge (Margolin & Margolin, 2002: 25).

5.3.1 The design brief: Delineating the scope of the design project

The brief was formulated and presented to the design class, by the facilitators. The brief is how the projects are scoped and presented at the design department, and both students and facilitators regard the document as a "memorandum of understanding." The brief sets guidelines for students to follow, gives an overview of the specific course's structure, as well as shedding light on critical activities, and design deliverables. The brief also gives contextual background to a specific problem area, which in this case is distributed renewable energy solutions in urban, peri-urban and rural communities. Moreover, the brief provides an overview of the course, which starts at the initial scoping of theoretical issues to the assessment criteria of the project, which can be seen in Appendix C4 (see page 208).

5.3.2 Constructing the course

The project weeks started after the vacation where the facilitators introduced the students to the design tools that aid in identifying and evaluating early concepts and ideas. This was followed by structured activities observing nature at the national Botanical Gardens at Kirstenbosch. At Kirstenbosch under the guidance of a botanist, students learnt from nature's strategies of energy resourcefulness, energy sharing systems, synergies, various processes and strategies, physical forms, and ecosystem operations.

The students then returned to the classroom where situated studio-based learning took place. Under the guidance of the facilitators students could now incorporate design strategies and techniques acquired from the various tools related to Biomimicry and S.PSS continuously reflect on the learning activities that took place at the botanical garden. The facilitators all had prior knowledge and experience on the implementation of these tools, see Chapter 4.4.1.2.

5.3.3 Facilitating the course

Figure 5.3.3.1: Situated and studio-based learning 1
(Image by Andrea Grant Broom, 2019)

The interactions between student groups and facilitators happened on a consultation basis. Students managed their own learning experiences with self-organized field trips and conveyed their findings during consultation sessions with the facilitator back in the studio, see Figure 5.3.3.1 and Figure 5.3.3.2.

Figure 5.3.3.2: Situated and studio-based learning 2
(Image by Andrea Grant Broom, 2019)

5.3.4 Design process

The students were assisted by the facilitators throughout their design processes. Each group of students had their own identified problem area, which resulted in some students leveraging more of the Biomimicry identification and evaluation tools or the S.PSS mapping and visualization tools. However, the most consistent process the students used was the design process taught at the department, which starts at:

- Step 1: problem identification,
- Step 2: communicating through dialogue and conveying this problem through presentations
- Step 3: concept ideation, see Figure 5.3.4.1 and Figure 5.3.4.2, and visualization (sketches, Illustrations, CAD designs, and prototypes)
- Step 4: conveying and evaluation (often repeating steps 1, 2, 3 and/or 4)

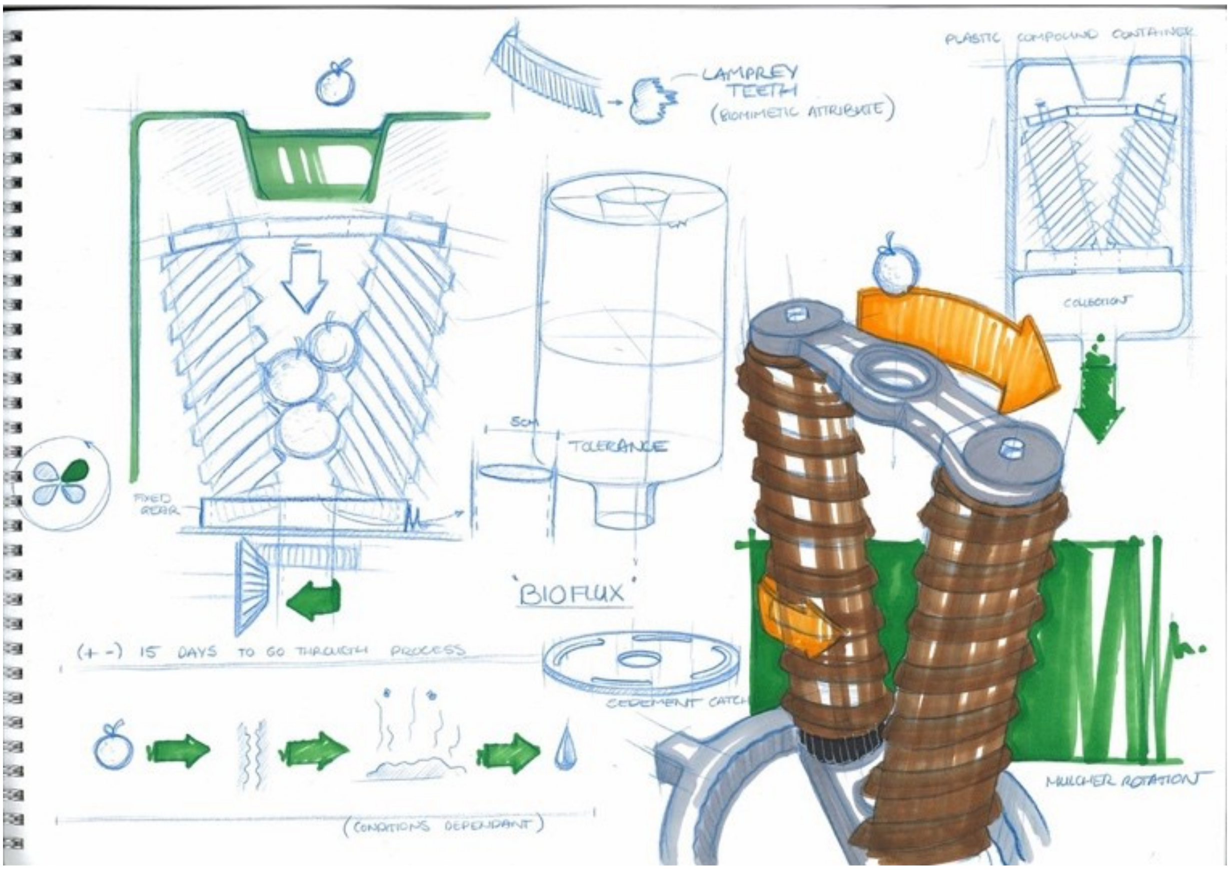


Figure 5.3.4.1: Bioflux design process, illustrations
(Image by Bioflux student group, 2019)

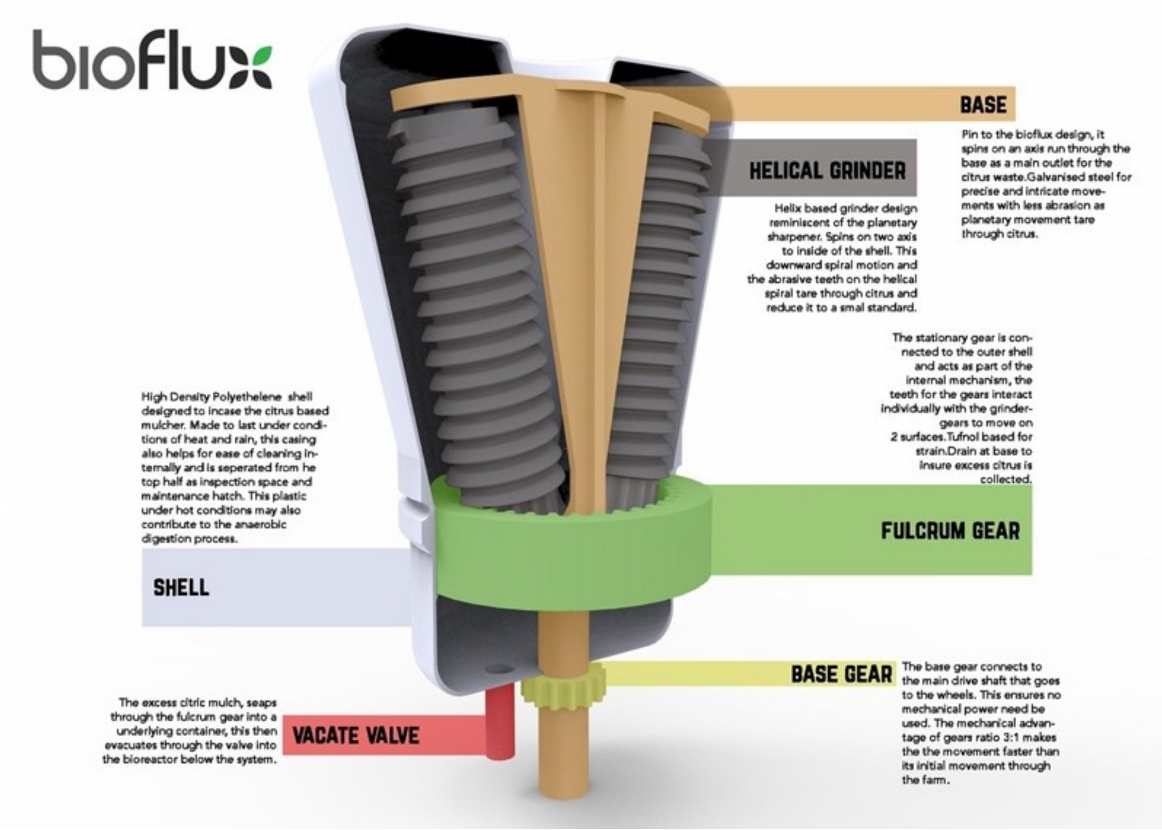


Figure 5.3.4.2: Bioflux design process, descriptive CAD render
(Image by Bioflux student group, 2019)

5.3.5 Biology to design

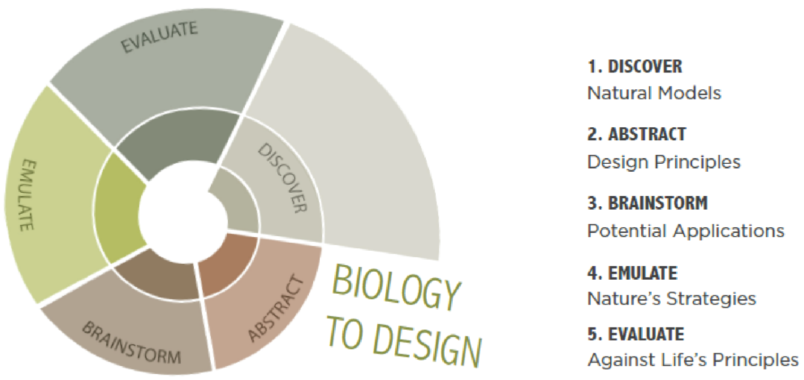


Figure 5.3.5.1: Design spiral, biology to design
(Baumeister et al., 2013)

One of the design techniques adopted from Biomimicry was Biology to Design, see Figure 5.3.5.1 (Baumeister et al., 2013). One group of students discovered natural occurrences of vortices that leverage from the gravitational pull, which allowed them to understand the energy requirements for the mulching of citrus fruit as a biofuel in rural areas. The students followed a process of abstracting fundamental design principles from natural phenomena as described Rossin (2010: 564) in the literature review (see section 2.5), which allowed the students could emulate these principles in a design application, see Figure 5.3.5.2. They went further to evaluate the design concept against Biomimicry's Life's Principles and pursued the development of their design. Peters (2011: 46) describes and highlights the six Life's Principles as:

- Adapt to changing conditions,
- be locally attuned and responsive,
- use life-friendly chemistry,
- be resource efficient (material and energy),
- integrate development with growth, and
- evolve to survive.

Figure 5.3.5.2: Bioflux, biology to design
(Adapted from Bioflux student group, 2019)

5.3.6 Challenge to biology

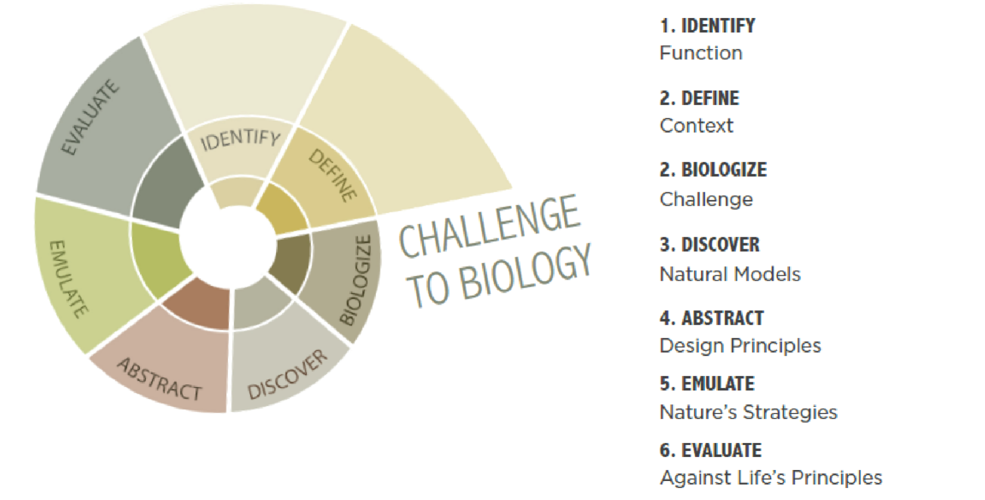


Figure 5.3.6.1: Design spiral, challenge to biology
(Baumeister et al., 2013)

Another group of students adopted the "Challenge to Biology" technique from Biomimicry (Baumeister et al., 2013). They identified fire prevention as a problem area in peri-urban spaces and discovered that the leading cause of shack fires are due to poorly supervised cooking practices. The group decided to work toward a safer cooking stove and challenged biology to deliver an organism which provides a model for form, processes or systems. The observed Strelitzia flower at the botanical gardens informs the functionality of a pressure system to expose pollen when birds land on a stem protruding from the flower. Students studied the functionality of a pressure system, whereby they emulated this natural process in a pressure-sensitive cooking stove. The design proposed a spring release valve for a biogas stove that shuts the flow of gas if the stove is accidentally knocked over.

Figure 5.3.6.2: Kunye, challenge to biology
(Image by Andrea Grant Broom, 2019)

5.4 Design tools

The design tools govern actions through which a way of making was achieved. It asks how an actor or participant can be engaged with a specific design technique and provides a series of tools that will allow participants; in this case, the students, to achieve specific design tasks. The tools call the students to practice design through various stages of the design process. Some tools are used to identify, observe, visualise, map, understand more considerable system complexities and relational flows, prototype, and communicate as well as evaluate.

5.4.1 Biomimicry: Life's Principles

Life's Principles (Baumeister et al., 2013) present a tool that functions as nature's sustainability indicators of ideas and final concepts. Life's Principles was introduced to students at the beginning of the course as a means to sensitize them to nature's way of evaluating sustainability.

Figure 5.4.1: Life's Principles sustainability checklist

(Adapted from Baumeister et al., 2013)

The Life's Principles checklist tool, see Figure 5.4.1, allows for an evaluation of processes and systems and material selection on a product- orientated level (Baumeister et al., 2013). The students used the tool to measure the Product, Service, and Systems offering of their S.PSS solutions. The tool does not have a ranking system, and students could check some of the boxes in each category Life's Principles. Some groups used this tool from the outset to navigate their entire design process towards active sustainability-orientated design decision making.

5.4.2 S.W.O.T. analysis

S.PSS draws on the S.W.O.T. analysis as a back-casting and forecasting tool that identifies strengths, weaknesses, opportunities, and threats. The tool was useful for early concept development and allowed them to analyse existing systems.

The students used the S.W.O.T. analysis tool twice during their project. The first S.W.O.T. analysis was on existing systems in rural, peri-urban, and urban settings. Student groups could focus their design approaches towards the various opportunities, weaknesses, or threats of existing energy systems and leverage their design intervention from these indicators. The second time this tool was made use of was before developing the business model canvas tool. The business model canvas tool requires a S.W.O.T. analysis of the new proposed design intervention. See Chapter 5.4.6.

5.4.3 Sustainability radars

The sustainability radar was introduced and used as a visualization tool for students to use. It functions as a measure of sustainability concerning sustainability's triple bottom line. The radar tool ranks the priority of sustainability indicators of the new proposed designs. The social, environmental, and economic radars function as the primary assemblages for the radar's indicators of sustainability.

5.4.4 Stakeholder map

When designing the service-end and systems operations and flow for their designs, the student groups used the stakeholder map tool (see Appendix B1, p171, and Table 5.4.4). It aided the students in identifying the key actors/stakeholders in their proposed S.PSS offerings concerning DRE. The function of this tool is to map out the interrelations between several actors, based on "gains" as an indicator. The students placed several actors on the grid tool and populated the various interrelated gains and benefits each actor would leverage from within their newly proposed systems. The tool functioned as an indicator for the main actors, as well as the secondary actors.

Table 5.4.4: Stakeholder Map

Stakeholder Map (A → B)	Actor 1	Actor 2	Actor 3	Actor 4	Actor 5
Actor 1	Maximum Gain				
Actor 2		Maximum Gain			
Actor 3			Maximum Gain		
Actor 4				Maximum Gain	
Actor 5					Maximum Gain

5.4.5 System mapping

System Mapping visualises the relations between the stakeholders of an S.PSS. It is a tool that can be informed by the stakeholder mapping tool. The Kunye project, for example, identified existing systems on waste management and gas stoves in Cape Town's peri-urban contexts. This student group mapped the existing systems and discovered that they are separated linear systems. They used the System Mapping tool to visualise the monetary, material, and information flows between stakeholders of their proposed solution offering, which is the biogas stove. Their designed system proposes a circular economy as well as integrating the waste management and gas stove systems. The tool makes use of indicators to understand the system's visualization. A line with arrows with two heads indicates a flow that moves back and forth between stakeholders. A line with a single arrow represents a flow that moves information, materials, or money from one stakeholder to the next. These arrows indicate feedback loops of the given system and visualise the landscape of the designed system, see Figure 5.4.5. As seen below, the students indicated the main actors with blue icons and secondary actors with orange icons.

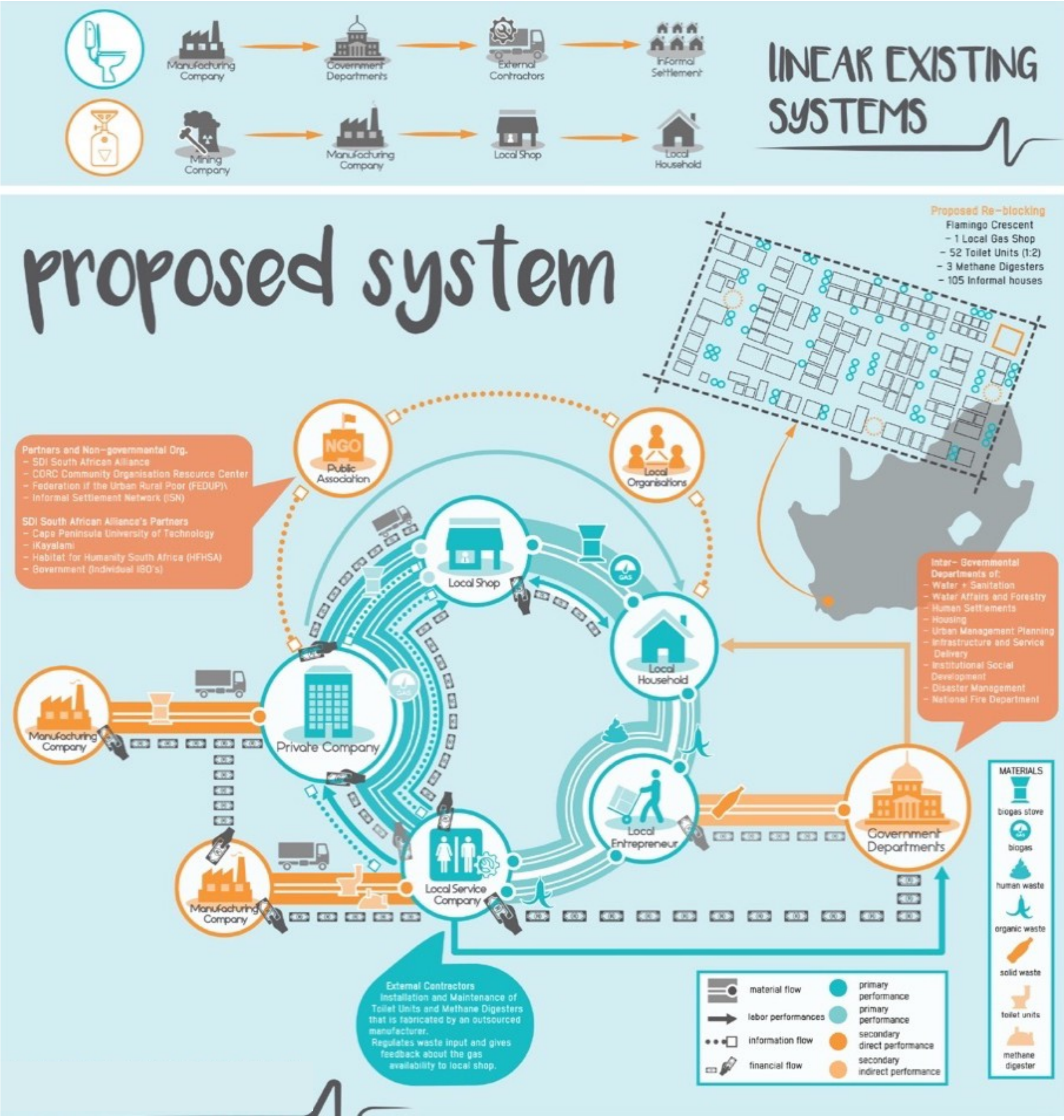


Figure 5.4.5: Kunye, system map
(Adapted from Kunye student group, 2019)

5.4.6 Business model canvas tool

Drawing on the S.W.O.T. analysis, Stakeholder Map, and System Mapping tools, the Business Model Canvas tool (Fritscher & Pigneur, 2014: 239) is used to develop the sustainability of the financial gains and strategic positioning of the student project.

The Business Canvas tool requires students to define and expand on indicators such as:

- the key partners (actors), their primary activities,
- the critical value propositions between actors,
- the resources needed for the S.PSS to exist,
- establishing customer relationships,
- distribution channels,
- customer segments,
- cost structures, and
- revenue streams.

The Bioflux project, for example, used the business canvas model to inform their business plan when they designed their S.PSS. Figure 5.4.6 illustrates their financial landscape:

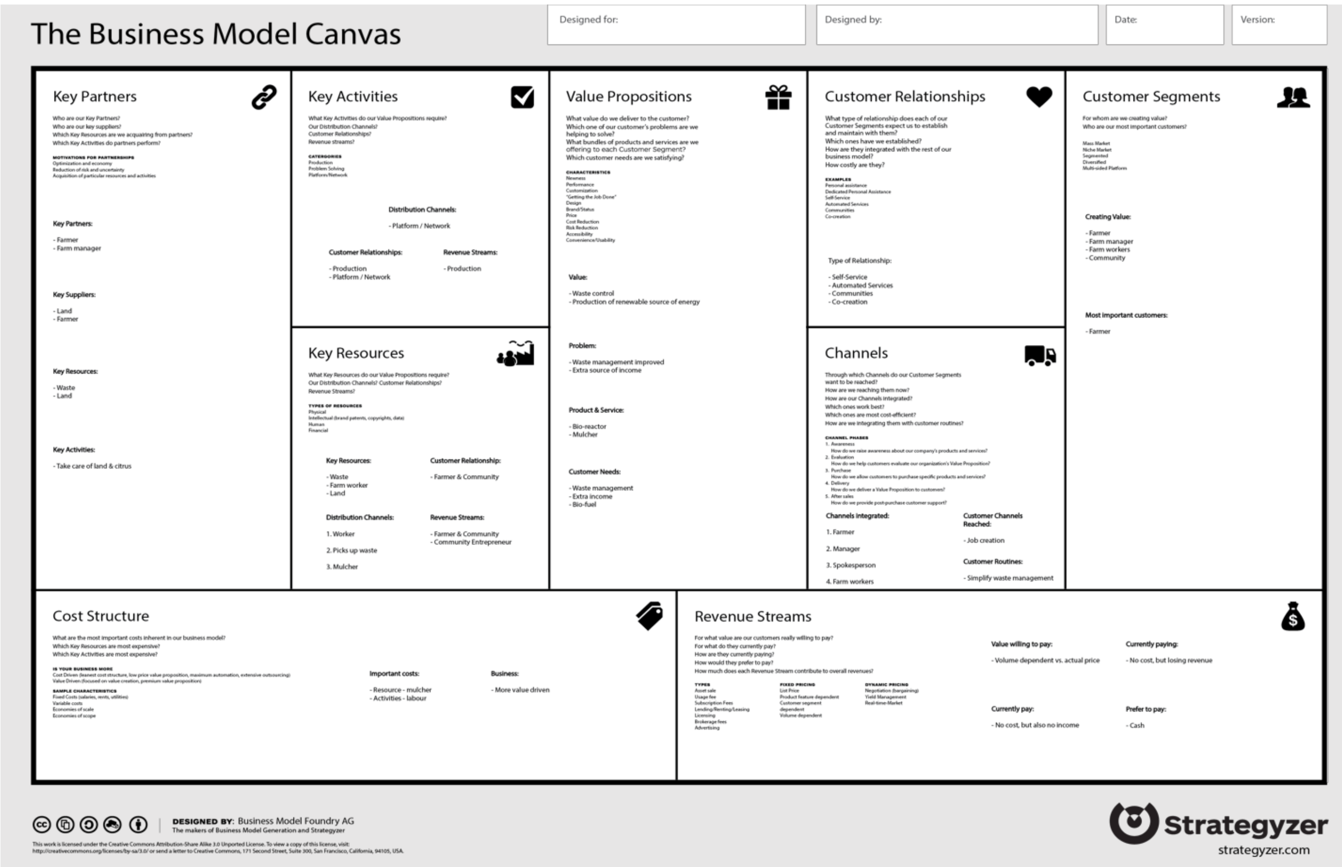


Figure 5.4.6: Business Model Canvas tool
(Fritscher & Pigneur, 2014: 239)

5.4.7 CAD: SolidWorks

Following the design process, described in Chapter 5.3.4, the computer-aided design software, SolidWorks, was used by the students to visualise the three-dimensional properties of their work. The tool allows them to model and sculpts in a digital software environment. The software allowed them to resolve part-designs and their complexities related to the product-end of their S.PSS solutions. Many CAD software tools allow industrial designers to visualise their concepts, see Figure 5.4.7.1, but the students used SolidWorks in their undergraduate years of study, and the department holds a license key for the software to allow students to use the tool.

Figure 5.4.7.1: Bioflux exploded view
(Bioflux student group, 2019)

One of the features this tool offers is its digital rendering function, which processes visual images of the designed products. The students used this function to display product graphics in the virtual photo studio in SolidWorks. The virtual photo studio allows them to add material properties to their designs, for example, plastics, ceramics, glass, paints, wood, liquids, metals, etc. The rendering tool also features manipulation of lighting environments, the direction of light as well as its intensity. Using SolidWorks provides the students with an added feature of producing technical drawings used for the manufacturing of parts, where material and manufacturing specifications can be listed, see Figure 5.4.7.2 and Figure 5.4.7.3.

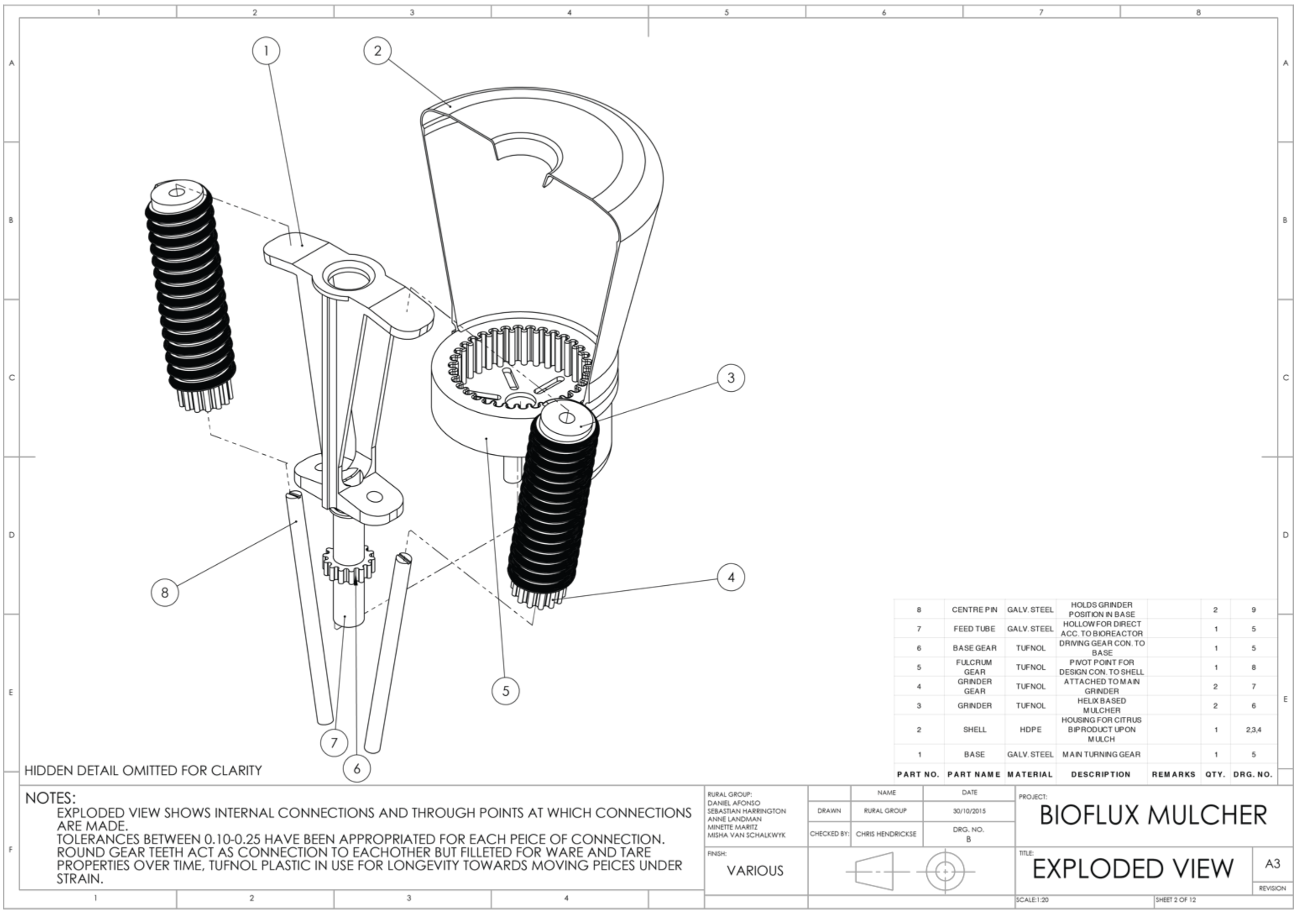


Figure 5.4.7.2: Bioflux technical drawing of exploded view
(Bioflux student group, 2019)

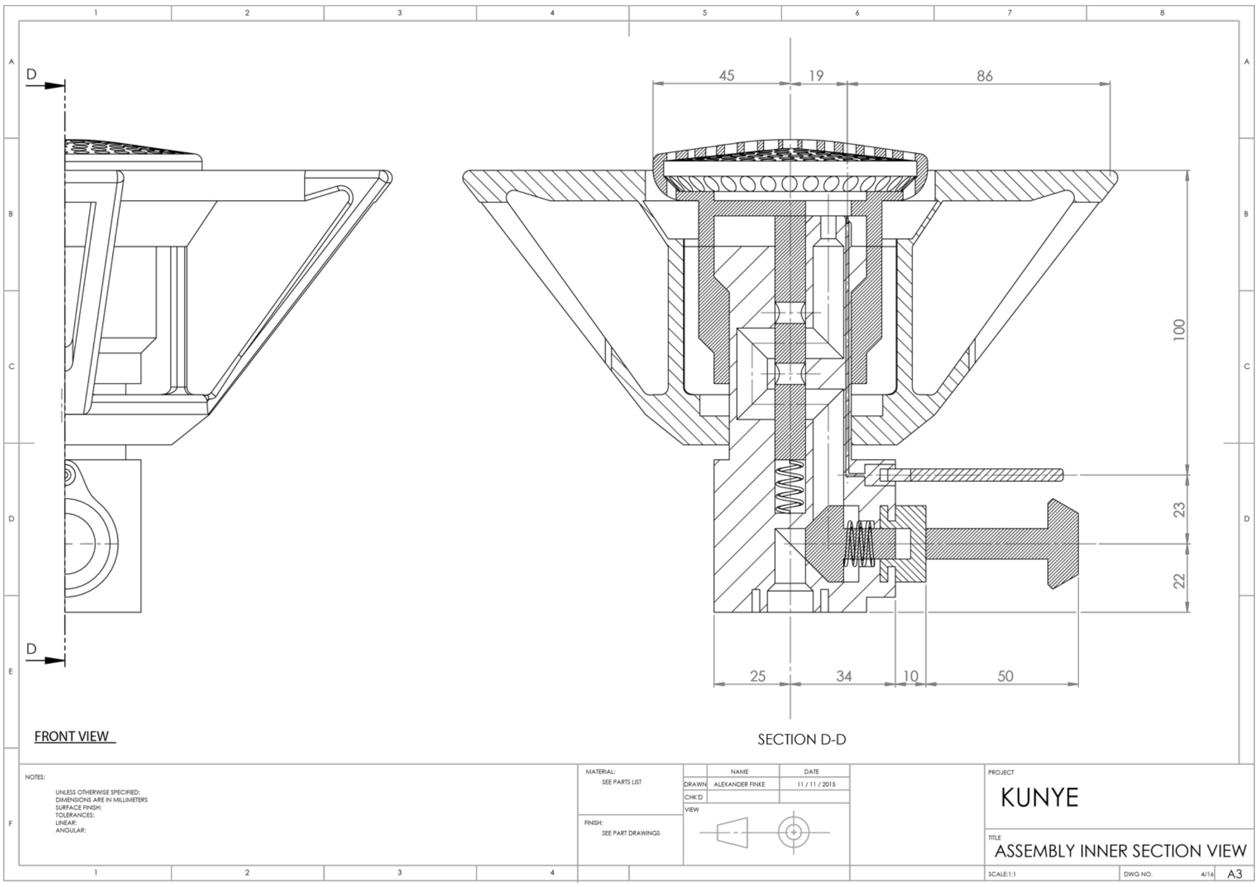


Figure 5.4.7.3: Kunye technical drawing of section view
(Kunye student group, 2019)

5.4.8 3D printing

A rapid manufacturing method that the students had access to in the Industrial Design department was 3D printers. This method of manufacturing uses a digital file from CAD software, which through a 3D-printer, is used to produce a manufactured part. The students had to prepare their CAD files for 3D printing. In the case of this project, the students working on the biogas stove used 3D printing as a tool to show a proof of concept. Their proof of concept visually and physically illustrates the mechanics of the designed part's movement when applying pressure on the stove's burner.

Parts could be printed to present a proof of concept that represents a smaller scaled model, as it was with the Bioflux project, or an actual life-size scale, as it was with the Kunye project, see Figure 5.4.8 below:

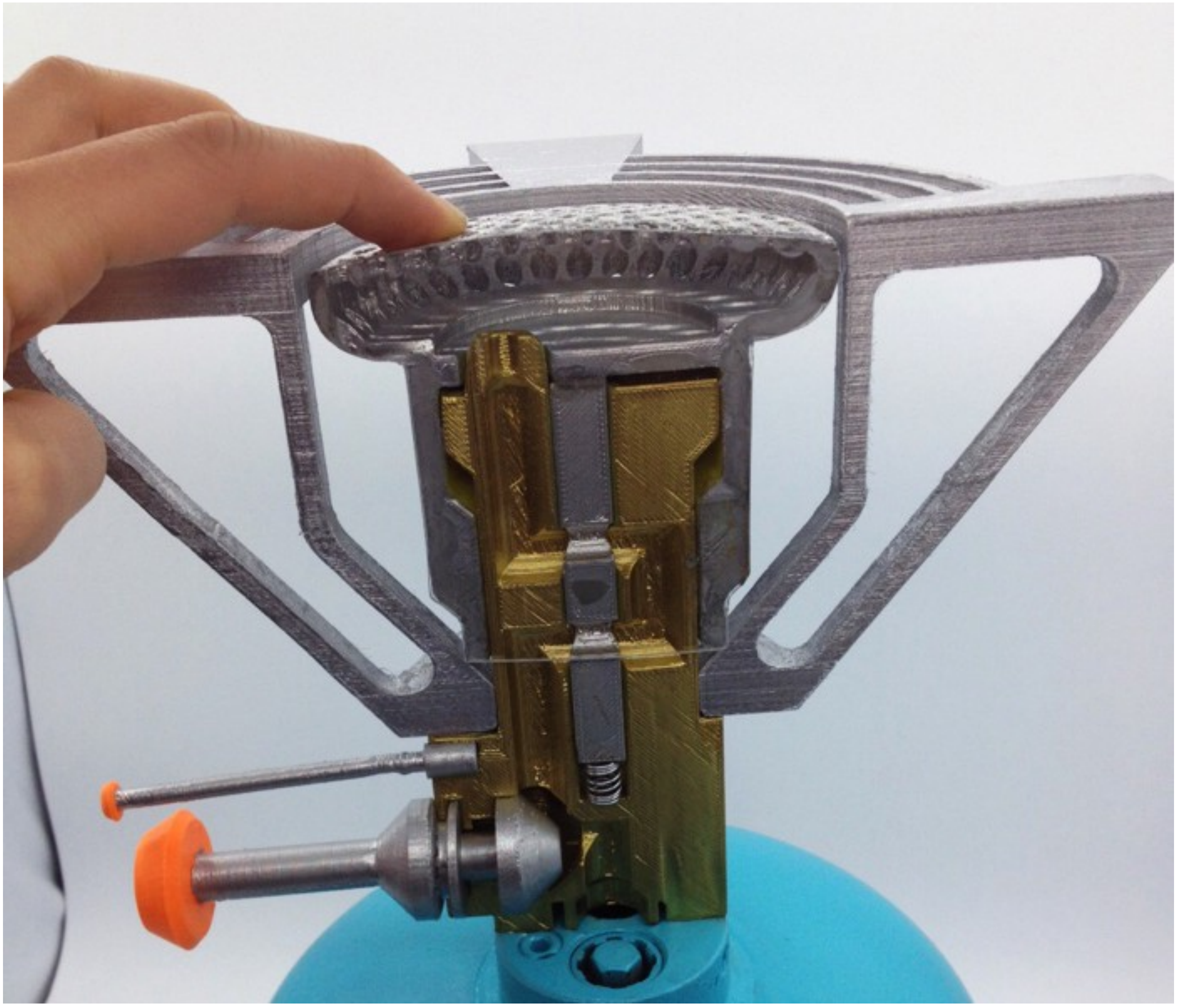


Figure 5.4.8: Kunye, 3D printed section view
(Kunye student group, 2019)

5.5 Ways of making

Ways of making is the combination of the design techniques together with the design tools. It aims to present and introduce specific data sets through student reports, posters, objects, online pages and the observer's report. These data sets represent what the students designed while commenting on how and why they designed what they did. I will present extracts from the student reports as well as the observer's report, which both appear in the Appendixes.

5.5.1 Student reports: Kunye and Bioflux

Student groups were given a guideline to follow when compiling the technology report, which was to conduct analysis relating to their design contexts. The student groups used included self-documented images in their reports, as well as digitally rendered images for their reports. The report requires students to use literature references to support their claims to their written work. Self-regulating student groups compiled these documents, where groups wrote these documents by sharing responsibilities and tasks. The reports indicate the design techniques and design tools which the students used and makes a case for how the students designed. See Appendix A (page 105) for Bioflux and Appendix B (page 136) for Kunye project reports.

This integration with the existing structure motivates for the technology report, which accompanies the designed project through a reflective document that is compiled by the students during each design project.

The technology report's structure for the two projects are listed in Table 5.5.1:

Table 5.5.1: Kunye and Bioflux project reports

Kunye	Bioflux
Introduction	Introduction
Design Analysis Project Synopsis Context and background to problem area Developed location as model Analysis of proposed location Analysing the current system according to Life's Principles System design concept Analysing Kunye's improved system according to Life's Principles Business model canvas	Design Analysis Rural context Citrus waste Smallholder farming How does the current system work? Biofuel The stakeholders The business model canvas Evaluation of existing system against Life's Principles How the product contributes to a renewed contextual S.PSS
Concept Analysis Persona Design process The Biomimicry champion selection and application The importance of aesthetics Final design	Concept Analysis S.W.O.T. analysis Evaluating product against Life's Principles Biomimicry
Ergonomic Analysis Gas canister 1kg Overall size Stability Switch	Ergonomic Analysis
Technical Analysis Materials and finish List of suppliers Manufacturing processes to be used	Technical Analysis Materials Main biofuel producing parts Manufacturing processes Technical Drawings List of Suppliers
	Prototype
Conclusion	Conclusion
List of References	List of References
Appendices Stakeholders Life's Principles Technical Drawings	Appendices Business model canvas Technical drawings Advert Brief Features & benefits

5.5.2 Student made objects

The objects which the students' designed developed from a combination of identifying, analyzing, mapping, and visualization tools. They represent the overarching design process which draws on biomimetic tools and design techniques as identifying and measuring indicators of DfS. The students used their design skills over weeks 5, 6, and 7 of the course structure to develop a proof of concept for their product designs. Where the product relies on a specific service model and functions within a self- regulated system – thus proposing an S.PSS product in relation to DRE application in urban, peri- urban, or rural contexts. These physical items encapsulate the design team's vision and aims.

Figure 5.5.2.1 and Figure 5.5.2.2 show how designs function as CAD renders (Bioflux) and a physical 3D printed part which interacts with an existing gas stove (Kunye).

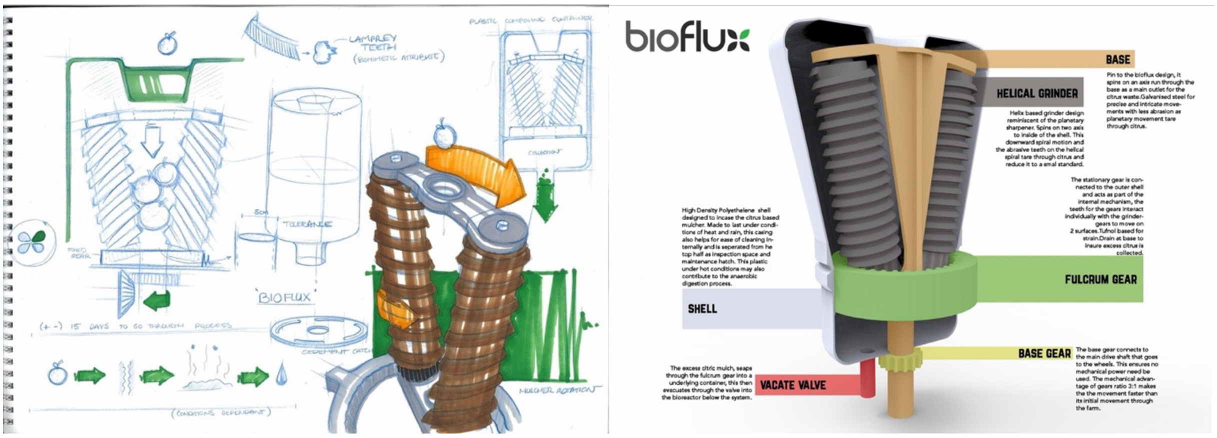


Figure 5.5.2.1: Bioflux, digital renders
(Bioflux student group, 2019)

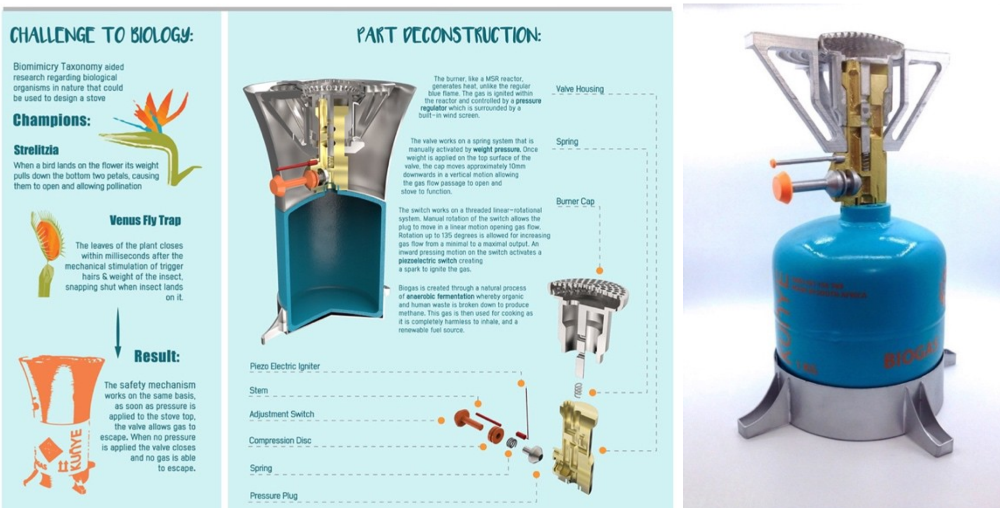
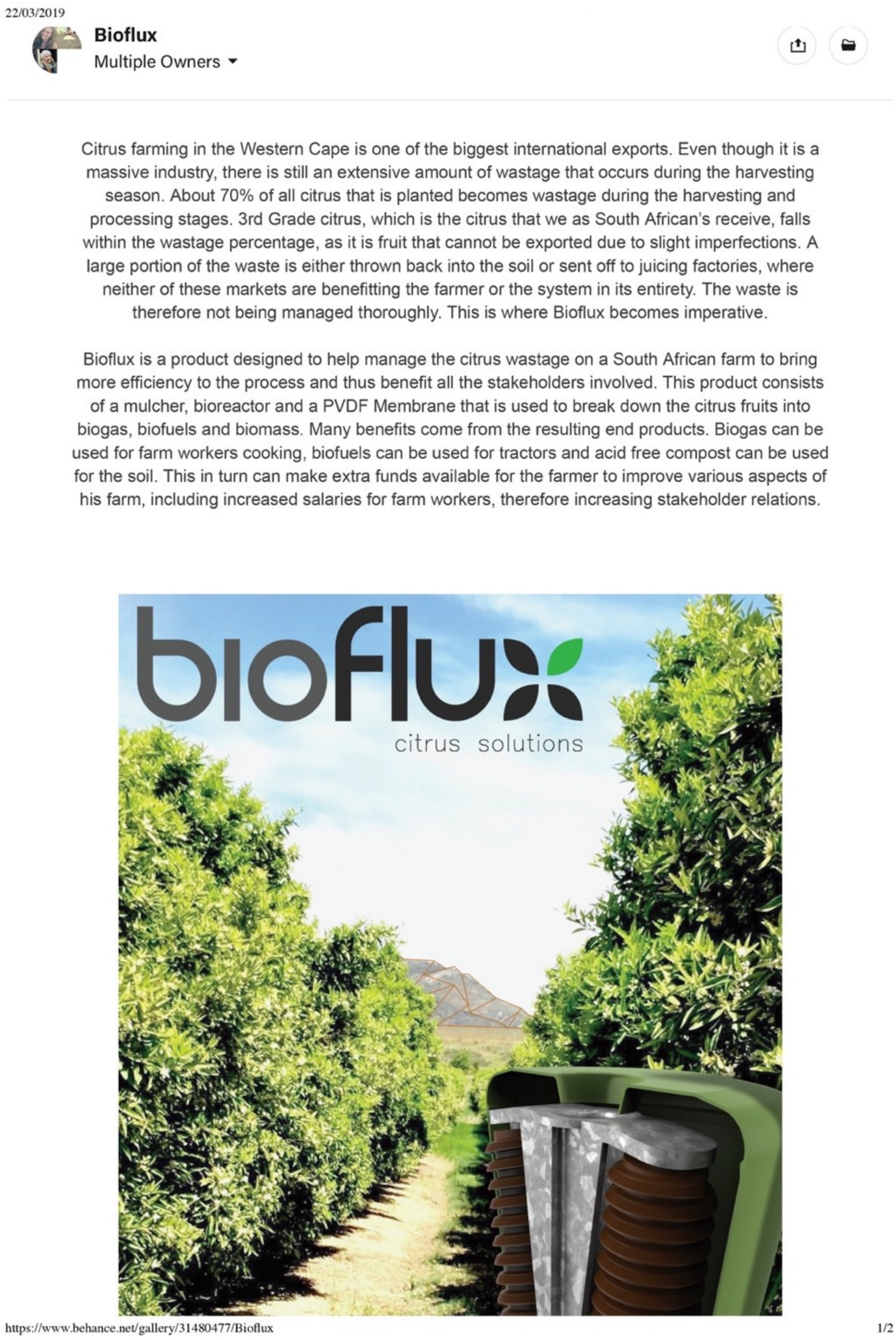


Figure 5.5.2.2: Kunye, student made object
(Kunye student group, 2019)

5.5.3 Online project pages

As part of the Industrial Design student's portfolio campaign, they were required to develop an online portfolio, see Figure 5.5.3.1 and Figure 5.5.3.2, to share and showcase their work. An online platform that was recommended to disseminate their student work was Behance, and so that the Bioflux and Kunye projects can be viewed and accessed online. The Behance website reflect the student projects as a summary of the Technology reports that the students had to complete. This online platform also illustrates the design process through various visualization tools that they have used during the course.


22/03/2019

Bioflux
Multiple Owners

Citrus farming in the Western Cape is one of the biggest international exports. Even though it is a massive industry, there is still an extensive amount of wastage that occurs during the harvesting season. About 70% of all citrus that is planted becomes wastage during the harvesting and processing stages. 3rd Grade citrus, which is the citrus that we as South African's receive, falls within the wastage percentage, as it is fruit that cannot be exported due to slight imperfections. A large portion of the waste is either thrown back into the soil or sent off to juicing factories, where neither of these markets are benefitting the farmer or the system in its entirety. The waste is therefore not being managed thoroughly. This is where Bioflux becomes imperative.

Bioflux is a product designed to help manage the citrus wastage on a South African farm to bring more efficiency to the process and thus benefit all the stakeholders involved. This product consists of a mulcher, bioreactor and a PVDF Membrane that is used to break down the citrus fruits into biogas, biofuels and biomass. Many benefits come from the resulting end products. Biogas can be used for farm workers cooking, biofuels can be used for tractors and acid free compost can be used for the soil. This in turn can make extra funds available for the farmer to improve various aspects of his farm, including increased salaries for farm workers, therefore increasing stakeholder relations.

https://www.behance.net/gallery/31480477/Bioflux 1/2

Figure 5.5.3.1: Bioflux online page
(Bioflux, 2019)

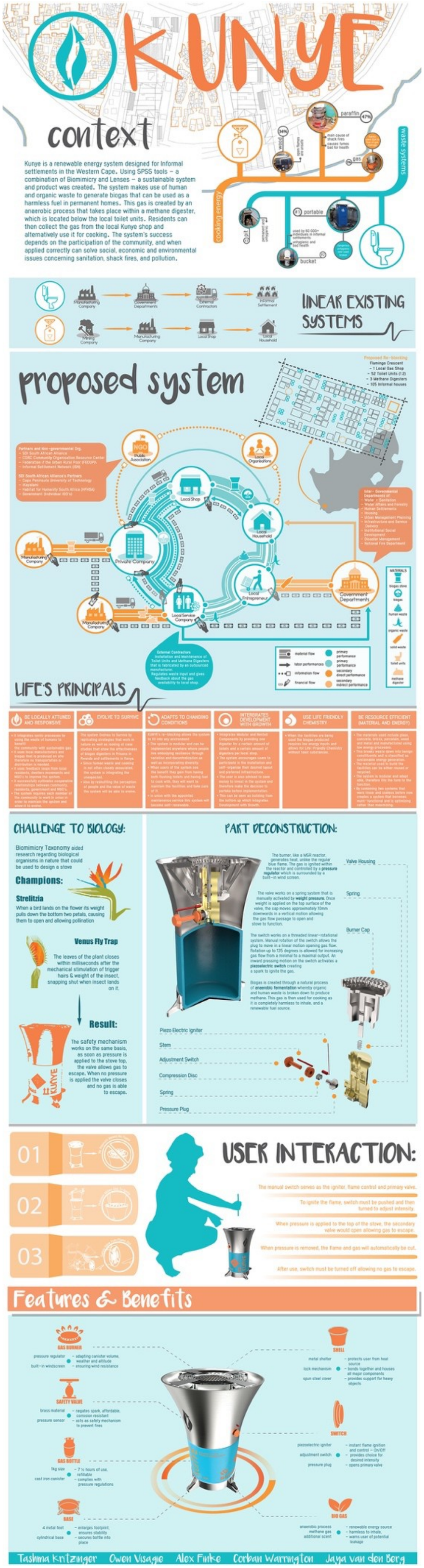


Figure 5.5.3.2: Kunye online page
(Kunye, 2019}

5.5.4 Design posters

The students designed the two posters on CAD software, which was a combination of Adobe Illustrator, Photoshop, and SolidWorks.

- The first poster was designed to visualise and contextualise the study. The Bioflux project focused in on citrus waste in rural farming contexts, and they aimed at adding value to the waste-goods through an S.PSS solution offering for the farm localities. The first poster visualized the problem area they investigated through an infographic poster as illustrated in Figure 5.5.4.1.

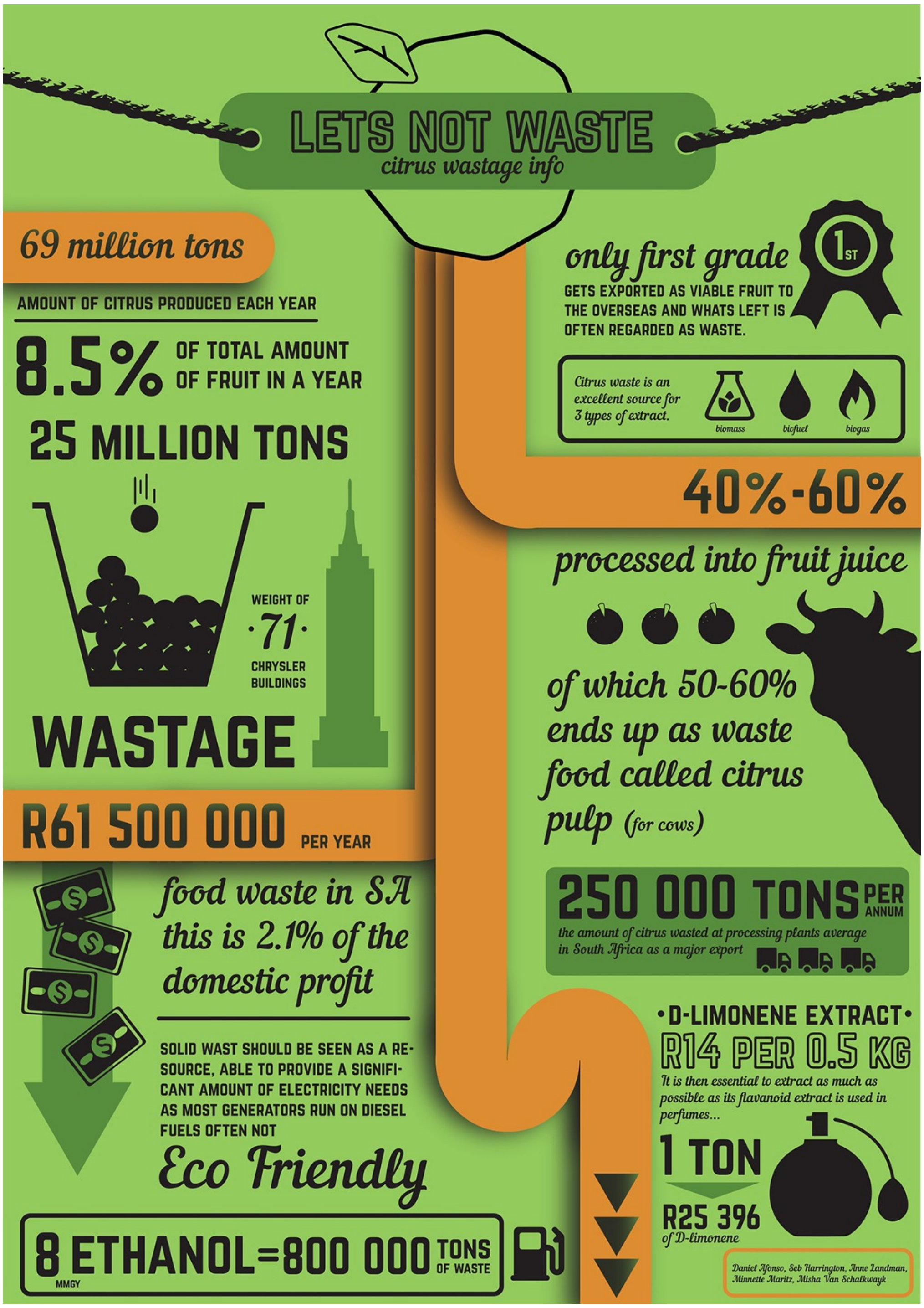


Figure 5.5.4.1: Bioflux infographic project poster
(Bioflux student group, 2019}

- The second project poster made use of the design visualization tools and functions similarly to the online webpages, which is a visual summary of the technology report. An example of the second poster, see Figure 5.5.4.2, features a system map which visualises material, monetary and information flows, the biology to design process, a visualised user experience, sustainability radars, Life's Principles, a digitally rendered images of the fundamental mechanism to mulch the citrus waste and the assembly of the mulcher, branding graphics, as well as the S.PSS's features and benefits.

Figure 5.5.4.2: Bioflux project poster
(Bioflux student group, 2019)

5.5.5 Observer's report

The observer's report was a prerequisite document for the LeNSes project, and while it was not specifically developed for this thesis research, it remains an objective and a critical data set for this study. The questions mainly focus on S.PSS and the triple bottom line of sustainability and can be seen in Appendix C. The report was compiled by an external observer who has extensive knowledge and experience in design education and as a sustainable design practitioner. The external observer acted as an observational participant within the study (Mack, 2005: 13) and compiled the report through specific guidelines that were set up through the LeNS project, as well as her own set of guidelines. The guidelines, see in Table 5.5.5, helped her navigate and make critical observations throughout the duration of the course.

Table 5.5.5: Guidelines for the observer's report

Date: Topic:	1 (poor)	2	3 (v. good)
Suitability of venue (s)			
Suitability of project/lecture staff			
Teaching methods and approaches			
presentations clear/concise or too text heavy			
Student-staff interaction			
Student-student interaction			
Group work			
Mech Eng-ID interaction			
Student responses			
Attention given to Mech Eng students			
Flexibility of lecturing staff to student needs			
Aims & objectives well explained			
Resources/tools sufficiently well explained			
Resources/tools sufficiently practiced			
Relevance of tools/resources to project			
Content: relevance/suitability of case studies			
Content: sufficient or too much			
Authentic learning?			

5.5.5.1 Semi-structured interviews

The observer had a set of guidelines which she used to conduct semi-structured interviews with the lecturers of the course. Semi-structured interviews provide the researcher with an opportunity to conduct qualitative and in-depth interviews, where a question is asked, and a series of follow up questions follow the responses of the interviewed individual (Mack, 2005: 116). The guidelines for the initial questions are seen in Appendix C6 (page 216) and ask questions directed towards the analytical and communicative functions of the design tools, the proposed course outcomes, as well as the overall project.

5.5.5.2 Questionnaires

Industrial Design staff, course facilitators and students were given questionnaires to complete. The questionnaires comprised of a series of questions aimed at evaluating and identifying key learning moments in the course. The questionnaires also focused on the indicators of sustainability methods, the triple bottom line, design tools, and design techniques. See Appendix C5 (page 211) for the questionnaire templates. The benefit of doing the questionnaires with the participants is to generate comparable data within the study (Mack, 2005: 3)

5.6 Summary

This chapter presented the study's data sets. Mixed method approaches underpin the design process and the "making" of the data, which draws on fundamental observation techniques, images, and documents. The design data consist of the design techniques, design tools, and ways in which research data is made, and reflects on the system's theory approach highlighted in Chapter 3.3. The presented data follows the model presented in Chapter 4.4, which echoes the research activities that took place between the facilitators, students, lecturers, and the external observer. The techniques and tools further draw from the "research through the design" objective highlighted in Chapter 1.5. These descriptions and visualizations of the data sets will inform the discussions and findings in the following chapter.

CHAPTER SIX

DATA ANALYSIS AND DISCUSSIONS

6.1 Introduction

DfS3 makes a case for future orientated societal change. In this chapter, I present and analyse key themes based on the research data, in order to find correlations between the research outset in Chapter 1.3 and the research questions in Chapter 1.4. I do this by using inductive thematic analysis and cross-referencing between the research data sets and formal literature. Through this thematic analysis of the data sets, I present a set of guidelines on how to use DfS3 with Biomimicry and S.PSS as an approach to DfS. A framework on critical citizenship (design) education functions as the measure for these guidelines. Critical citizenship (Johnson & Morris, 2012: 298) investigates the quality of higher education in Design and offers a measure of this specific course to other design educators who would want to test and implement a similar approach to DfS. There are indicators that describe each of the guidelines (Ten Dam & Volman, 2004: 359). Where after I restate this study's research questions and set out to answer the questions by discussing the findings of my research.

6.2 Thematic analysis: designer's perspective

Thematic analysis (TA) forms part of qualitative research inquiry, which complements content analysis. In this case, I make use of TA's ability to extract meaning from the data presented in Chapter 5, which will allow me to pinpoint, examine, and record patterns and themes (Javadi & Zarea, 2016: 34). The presented data may take the form of transcriptions from interviews, notes, documents, pictures, or videos for TA methods to be appropriate (Bowen, 2009: 27). The presented data becomes exciting when discovering themes and concepts from data and demands the researcher to understand the entirety of the data thoroughly.

It is, however, essential to understanding that themes are calculable in repetition, for instance every participant could use keywords or phrases such as "student protests" which might appear twenty times in transcriptions; even so, it is up to the researcher's discretion to determine if a theme involves a significant aspect in answering the research question (Boyatzis, 1998: 123; Javadi & Zarea, 2016: 34).

Themes may include rich or detailed descriptions which form part of theoretical or inductive thematic analysis. Theoretic analysis of themes is detailed and presented based on fundamental theories, which require the researcher to be familiar with texts beforehand (Guest, MacQueen & Namey, 2011: 92). The inductive method to TA recognizes strong relations between the presented data, which may have little relationship to the candid responses from research participants. Therefore, the inductive method recognizes underlying themes that are highly interpretive (Blomberg, Burrel & Guest, 2009: 54; Guest, MacQueen & Namey, 2011: 4). As TA's inductive method suggests: the level of my interpretation of themes will inform the conceptualization for framing the content of the data, as well as the efforts for detecting and testing of beliefs and presumptions (Boyatzis, 1998: 113; Bowen, 2009: 27). Moreover, it is my role as a researcher to make an effort to create theories based on the importance of the themes and a more comprehensive framework of meaning and connections, concerning my research questions.

6.2.1 Knowledge

Based on the research poster in Figure 5.5.4.2, the students give a visual account of all the design tools and techniques that they have used. This is indicative of an understanding and translated representation of them to gain a new understanding of DfS3 through examining, assessing, and evaluating Biomimicry and S.PSS. In Chapter 6.2.1.3 the students gain first-hand account understanding social behaviour related to unsustainability and DfS3. In Appendix C4 the observer's report provides detail of the course by presenting the design brief, which requires contextual and societal understanding through creative design methods as a basis. By viewing Chapter 5.3.3 together with Chapter 5.3.6 it becomes evident that the course requires active participation from the students to learn and use creative design tools in order to promote responsible, sustainable designs for local communities.

6.2.1.1 Course

The design course provides a procedural framework of the student's learning experience (see Appendix C2, p204). The course provides the design students with the project outlines, aims, opportunities, limitations, and assessment criteria. The brief as seen in Appendix C4 describes the activities of the project and acts as the memorandum of understanding (MoU) between students and facilitators. Also see page 183 for a detailed description of how the brief was discussed between facilitators and students. Through this observer's account on page 183-184 it can be understood that the brief facilitates an open-ended debate between the students and facilitators and should be rigid and flexible enough to adapt to verbal and written inputs from various actors.

The brief holistically frames the project around contextually rich learning spaces that connect various stakeholders to explore viable, sustainable product-service system solutions, see Appendix C4, p208. An inherent challenge is that the first draft of the project brief is drawn up by the facilitators of the course and is therefore limited to the facilitators' oversight of the project, which ranges between the cultural and contextual background, the theoretical underpinnings, design methods, the design techniques and design tools required to complete the project. In the presented case, the facilitators had to meet specific requirements that meet the appropriateness of their knowledge base and skill sets. An extract from the observer's report reflects on a semi-structured interview as seen on page 192, as:

> *Lecturer B reported (interview on 08/12/2015) that he had only ever observed the S.PSS tools being taught when he was an observer on a LeNSes pilot course at Makerere University, Uganda, and had never engaged with them himself. The context of Makerere University was also different from CPUT as the students were engineers, not designers, so they used the tools differently. Therefore, despite preparing himself as well as he could, he still found it difficult to explain some of the tools adequately and to answer all the students' questions. However, the course coordinator was much more experienced with the S.PSS tools so was able to assist with explanations to the groups when she was available.*

The course structure should require a phase of problem analysis, which is followed by a phase of making. Based on the observer's report, the brief delineates the aims of the students to:

- Analyse existing energy products within human and natural systems in rural, peri-urban and urban contexts;
- Consider all stakeholders in the system, using the S.PSS tools and methodologies, to ensure sustainable, stable, resource-efficient energy delivery;
- Apply Biomimicry as the primary lens for environmental sustainability with analysis and evaluation through Life's Principles;
- Apply Biomimicry design methodology and S.PSS tools and methods to improve and re-develop existing products within social systems and contexts;
- Become proficient in the relevant S.PSS tools and utilize these to design a Sustainable Product-Service System and produce and manufacture a prototype design (one product per group) for an identified energy-producing or energy-consuming product; for use in each of a rural, peri-urban and urban setting.

Therefore, a benefit of the brief is to expose students to various ways of making, which draws on DfS methods, and in this case, Biomimicry and S.PSS.

6.2.1.2 Identify DfS methods

The design brief suggests specific design methods that are appropriate for the completion of the project, and in the case of the structured course, the students can explore design methods related to DfS. These predetermined DfS methods are presented to the students by the facilitators. The responsibility to examine, assess, and contextualise the DfS methods to a specific project application shifts towards the students where they learn to unpack the theoretical underpinnings through self-study. This responsibility of self-study instills a sense of ownership and knowledge retention, which is relevant for the application of theory through design (practice). Through a phase of self-study during the vacation week of the course, the theoretical framing of DfS allowed students to explore complex theoretical discourses within systems thinking, design thinking, S.PSS, and Biomimicry. This exploration could be regarded as ideological and anthropocentric, as it excavates the histories, societies, systems, injustices, and power structures related to DfS. These theoretical discourses allowed students to discover more comprehensive knowledge of interconnectedness, and more collaborative, relations on the transformative ecology of meaning makers.

These discourses respond to Chapter 1.2.3, where Clune (2010a: 1) states that designers (students) should know the role of design in relation to DfS. Ramirez (2007: 3) responds to this and further explains that "how we define is how we design." The critical role of identifying appropriate DfS methods is to draw academic literature on DfS towards design practice, which in turn informs the enactment of a set of design tools. By coupling appropriate DfS methods and design tools with situated learning spaces, students can draw on intuitive design decision-making as a form of critical design skill.

6.2.1.3 Situated learning environments

In Chapter 2.4, I present the theoretical underpinning of DfS3 through S.PSS, where the literature suggests that designers need to work with communities (Vezzoli, Ceschin & M'Rithaa, 2009: 6). The literature stresses the importance of understanding the desired results consumer's seek within those cultural contexts. It was, therefore, a fundamental approach to change the learning environments of students into immersive real-world contexts. The aim of this is to develop a contextually relevant, sustainable product-service system over time. One example of this was the field trip to the Kirstenbosch botanical gardens as seen in Observation 5 in the observer's report on page 182. This field trip focused on the biomimetic way of learning through observation and experience.

Another example was by learning through observation and experiencing within the site visits to urban, peri-urban, and rural contexts. The student report in Appendix A, page 102, describes a site visit to the rural context in which their design had to exist. Here students could encounter the "field experts," for instance: In the peri-urban informal settlements in Cape Town, students interacted with the shack owners to determine the cause of shack fires (See Appendix B, page 139). The field experts explained the causalities of shack fires to the students as individuals losing balance and orientation due to the overconsumption of alcohol, which results in them knocking over the conventional kerosene cooking stoves. The accounts from the field experts informed the initial design outset of the students in the Kunye group to develop a safer cooking stove that prevents the shack fires through a safety valve for the safer release of cooking gas. The safety valve builds on the observations of the Strelitzia plant in the botanical garden. It is, therefore, clear that situated learning environments have a direct impact on the design process.

Figure 6.2.1.3: Situated learning
(Adapted from Bioflux student report, 2019)

Similarly, the Bioflux project team encountered critical indicators of a design intervention when they visited a citrus farm in a rural context, see Figure 6.2.1.3. The students observed that the discarded oranges which fell to the ground were considered biowaste. The conventional citrus production processes do not consider discarded biowaste. The students observed and documented discarded farming equipment such as the mulcher. The discarded mulcher inspired the students to identify citrus waste management as a potential solution space for a S.PSS offering for this rural context. Upon reflection, these interactions and observations within these "out of classroom" learning spaces, become critical drivers for the quintessential design decisions students had to make.

6.2.1.4 Error analysis

Through the identification of DfS methods, and observations within situated learning spaces, students were able to identify unsustainable social behaviour and social influences (See Appendix A, page 102-105 and Appendix B, page 139-143. The sensitization to these problem areas allowed students to analyse existing products, services, and systems within these contexts. By reviewing existing social behaviours and by asking the right questions within these spaces, students could experience what Ezio Manzini (2006: 10) explains in chapter 1.2.3 which is that the everyday actions we take as a society are unsustainable. Manzini (2006: 10) and Shove (2003: 395) also explain that existing systems and designs which are already in place in our everyday lives are unsustainable (Shove, 2003: 395; Manzini, 2006: 10). By introducing a phase of error analysis in the course, students could analyse unsustainable products, services, and systems within these contextualised settings. The student report of the Kunye project analyses the unsustainable waste management systems within peri-urban settings. Students evaluate and assess big centralized systems, by drawing up a S.W.O.T. analysis and measuring these unsustainable services and systems against Life's Principles (See Appendix A, page 113 and page 117-119. Students could question the status quo of the standard of living in these spaces.

Through error analysis, students could strategically position themselves to make critical design decisions that explore long term sustainable options. They could actively seek out alternative solutions that advocate for smaller distributed systems that oppose the concept of "design as usual." The aim here is to celebrate "quality of life" over "standard of living" through the restoration of societal equity and social justice. Based on the brief, students seek out a sustainable solution which has a declined energy dependency on natural resources. Error analysis allows for strategic design-positioning and design-intent. It is a critical phase in identifying the problem areas within a specific socio-geographic context. In this case, the contexts are: urban, peri-urban, and rural. It was important for students to do an initial S.W.O.T. analysis of the problem area and existing systems within these contextual settings.

Mack (2005: 3) states that how we identify, analyse and compare data forms part of qualitative studies, and this contextualisation allowed students to understand the composition of linear systems as well as strategically define "how they identify" and "what they identify as" problem areas that need a design intervention.

6.2.2 Skills

Students could develop their design skills by engaging with critical design thinking and active participation throughout the design process. An extract from the observer's report on page 195 read:

> *The course coordinator reported (pers. comm. 30/03/2016) that the students had been 'almost relieved' to have had a chance to apply the theoretical systems thinking they had been taught in the subject 'Professional Practice' and admitted that they had always thought of design purely as product development. They had said they would never be able to not consider product service systems in future design projects and that Biomimicry Life's Principles checklist was a very useful prompt for evaluating the sustainability of their designs.*

The design process requires the identification and solving of problems. The facilitators formulate a brief that aims at guiding students towards a specific problem area, where they can integrate DfS techniques and DfS tools in order to respond to the brief. Based on the student's reports, student groups could decide which tools would be more appropriate to visualise their new S.PSS concepts. Therefore, the techniques inform how the tools get put to use, which allows students to develop their own "voice" in order to achieve the goals of the brief.

6.2.2.1 DfS techniques

In Chapter 2.3, I identify Stegall's stance on DfS in formal design education where he explains how the consciousness of design practice should steer away from poorly designed "sustainable products" to a point where designers envision products, services, and systems that can encourage "sustainable behaviour" through the use of a product (Stegall, 2006: 56). This stance on the praxis of design is made stronger by the design techniques used to collaboratively explore and devise plans to develop new sustainable product-service systems. This is described inn the Concluding remarks in the observer's report on page 200 as:

> *… working in teams, to explore, design and develop sustainable renewable energy systems for a local context using selected LeNSes S.PSS tools together with Biomimicry methodologies, especially Life's Principles for evaluating the ecological sustainability of their designs.*

Design techniques introduce transdisciplinary actors to the foreground of the design process, which engages the actors of the situated learning environments: the facilitators of the course, the students, the guest speaker who facilitated the Biomimicry activities in Kirstenbosch garden to actively participate within the design process. The various actors' point of views, ideologies, and expectations enriches the diversity of design considerations (Sanders & Stappers, 2008: 15; Guest, MacQueen & Namey, 2011: 135). This collaborative process allowed for joint explorations into the problem area, as well as steer the student groups in developing appropriate product service systems that are contextually relevant (Vezzoli, Ceschin & M'Rithaa, 2009: 6).

6.2.2.2 DfS tools

These design tools, see Table 6.2.2.2, aim at providing students with a toolkit that could yield alternative product solutions. An extract from the observer's report on page 191 reads:

> *Biomimicry, however, focuses on nature and the alternatives nature offers to the traditional linear model of industrial design.*

In the observer's report, page 181, one of the facilitators describe the tools as a standardization for the design process of DfS. The tools mainly aim at communicating, visualizing, developing, making, and evaluating sustainable design. Chapter 5.3.4, 5.3.5, and 5.3.6 provided an informed DfS design process which the students coupled with various DfS tools. The table below shows which Biomimetic and S.PSS tools the students used during the course. Also, the tools are indicative of the triple bottom line, which is best represented by the aim of each tool's use (E – Environmental; S – Societal; F – Financial):

Table 6.2.2.2: DfS tools

	Identify and define	Biologize and Discover	Abstract and Emulate Visualise and Develop	Evaluate
Biomimicry and S.PSS tools	- S.W.O.T. analysis (E,S,F)	- Stakeholder Map (S,F)	- Systems Map (E,S,F) - CAD software - 3D printing - Business Canvas Model (S,F)	- Life's Principles (E) - Sustainability Radars (E,S,F) - S.W.O.T. analysis (E,S,F)

The tools do not follow a linear design process, but they are: remixed, repeated, or revisited based on the four steps below:

- Step 1: identifying and defining problems,
- Step 2: conveying and communicating problem areas,
- Step 3: concept ideation and visualization (sketches, Illustrations, CAD designs, prototypes, etc.),
- Step 4: conveying and evaluation (often repeating steps 1, 2, 3 and/or 4)

Based on the observer's report's questionnaires and interviews, page 185-188, the introduction of the tools seemed to be challenging to understand and apply. The challenge of using the tools was mainly due to the tools being new visualization techniques in the design process. The observer's report continues to highlight the student's willingness to learn the new design tools, and them gaining confidence through applying the tools throughout their design process, as seen on pages 189-192. These design tools used within the course allowed students to tap into the ideology of DfS3. An additional benefit of using the tools within the ideology of DfS3 is that the students adopt a "doing-thinker" and a "thinker-doer" mind-set when enacting DfS methods.

6.2.3 Values

Values tap into a set of critical ideological outcomes that address cultural and aesthetical sensitivity across a range of social contexts. The brevity of assessment and the contextualisation of theoretical methods act as the evaluators of values. As explained in Chapter 1.2, these ideologies towards DfS have closely aligned to the future orientated concept of DfS3. These ideologies draw on the collective design input from various stakeholders that yield a shared vision towards sustainability (Johnson & Morris, 2012: 294). The common ground in sharing these values came across through dialogues between actors during the course, from the development of a brief to testing the design solutions. The students have developed a deep understanding of the core values of DfS, which lead to informed, responsible, and ethical actions and reflections when making design decisions throughout the design process. The structured course facilitated the opportunity for free and open expressions of each participant within a project.

6.2.3.1 Alternative solutions

Drawing together the students' knowledge and skills, informed design praxis as "ways of making." Alternative solutions result from this way of designing, which oppose existing linear product (and) or systems solutions. A different way of making is introduced, which is guided by the informed, responsible, and ethical actions and reflections of the students.

The deliverables, such as the student posters, the student made objects, and the student reports suggest new, bio-inspired, product, service (and) or systems design (see Appendix A: 125; see Appendix B: 156). These solutions function on all three indicators of DfS. Each student project introduced a Sustainable Product-Service Systems (DfS3) design, which requires sustainable actions and behaviours to ensure sustainability is attained (DfS2) in the operations and profitability of the product-orientated designs (DfS1).

The system maps visualise the flow of these shifts towards social justice and safe and clean energy for all. The students showed that alternative solutions are committed to the quality of life and equity. These solution offerings are suggestive of a change in the societal consumer behaviour that is less dependent on unearthed natural resources, especially when coupled with DRE. Alternative solutions are underpinned by sustainability's triple bottom line: where a tool such as systems mapping introduces synergies between actors which can be conducive to a sense of equity. This sense of social equity is indicative of social sustainability. While working through a tool such as the business canvas model is indicative of financial sustainability and learning from nature's process, systems, and measuring new solutions against Life's Principles as a measure of environmental sustainability (Baumeister et al., 2013).

6.2.4 Disposition

The relation of knowledge, skills, and alternative solutions invokes a sense of social change towards sustainability. The mind-set of the students informs societal change, where the students actively participated with the project through mindful DfS practice. The outcomes of the student work are suggestive of a brief that is answered through a range of visualization tools, creative thinking, critical perspectives, autonomy, responsibility in thought, emotions and actions and a sense of forward-thinking which is in touch with reality. The student projects underline the benefit of working and learning with others through a design praxis, which requires social awareness. Through critically framing and questioning concerns within society and public affairs, futures-orientated design can address the political issues on urban, peri-urban, and rural areas. The two student projects highlight these indicators of disposition by addressing politicized and social issues on waste management in peri-urban environments, and by addressing access to renewable energy in rural areas.

6.2.4.1 Long term sustainability

The overarching theme for the projects draws from the SDG's which reflects a social and politicized orientated towards sustainability, which forecasts solution offerings towards 2030. This ability to forecast sustainability allowed students to design speculatively for potential and plausible scenarios. Through the development of critical perspectives on appropriate designs for local contexts and cultural settings, students could propose alternative solutions that reflect on future-orientated design thinking. To further emphasize the ability to design appropriately for various contexts and cultural settings, the observer's report describes that the student groups took ownership of their field trips to the peri-urban and rural contexts. This ownership of the learning experience reflects the students' mind-set and attitude towards the course and their projects and it indicates responsibility for decisions and actions.

Based on the above, the students could present new alternative designs and alternative scenarios that are in touch with reality, where their proposed S.PSS solution offerings rely on existing real-world actors and processes within the public sector. The S.PSS solutions are speculative and conceptual in their designs, yet only require financial capital investment to become appropriate for real-world applications. The designs speak to low impact interventions that work effectively towards sustainability over time, as opposed to high impact designs that seek sustainability with brief installations. The projects require stakeholder engagement to promote entrepreneurship and social justice within underdeveloped communities, with the potential of franchising the S.PSS solution in (near) similar contexts (Sanders & Stappers, 2008: 16).

6.3 Biomimetics and S.PSS - Presenting a set of guidelines

The thematic analysis (Chapter 6.2) presents a set of eight guidelines to DfS3 through Biomimicry and S.PSS design methods as seen in Table 6.3. These guidelines draw from the presented data in Chapter 5, and they present four central concepts: knowledge, skill, values, and disposition. The guidelines present a linear process, with key indicators that aid in the identification of these guidelines.

The indicators are short summarized versions of each of the subheading descriptors, which I describe in Chapter 6.2.

Table 6.3: Guidelines and indicators to DfS

	Guidelines	Indicators
KNOWLEDGE	1. Course	Project Outlines. Research and develop a creative brief. Assessment and evaluation criteria of the project in relation to sustainability. Ability to connect stakeholders to explore the contextually relevant sustainable product, service, and systems solutions.
	2. Identify DfS methods	Examine, assess, and contextualise the DfS Biomimicry and S.PSS.
	3. Situated Learning	Discovery of interconnected ecologies of meaning and design making towards sustainability. Transposed learning environments. Immersion and participation. Aims at delivering contextually relevant product solutions over time. Contextualised cultural sensibility.
	4. Error Analysis	Identifying societal behaviour, influences, and injustices. Assessing existing product, service and/or systems design. Assessing big centralized systems. Questioning the status quo: standard of living and consumption.
SKILLS	5. DfS techniques	Dialogue and cooperation between stakeholders: Students, facilitators, and external stakeholders. Capacity to think holistically and critically evaluate information and applying it in the real world. Active Participation, individually and collectively. Collaboratively explore and devise plans to develop new Sustainable Product-Service Systems.
	6. DfS	Generate, visualise, and convey new sustainable design solutions. Asking the right questions to develop new ideas. tools Adopting a "doing-thinker," and a "thinker-doer" mind-set to explore DfS methods through a DfS-orientated design process.
VALUES	7. Alternative Solutions	A new product, service and/or systems design. Distributed smaller systems. Informed, responsible, and ethical actions and reflections. A concern for social justice: safe and clean energy for all. Commitment to the quality of life & equity.
DISPOSITION	8. Long Term Sustainability	A critical perspective on appropriate for local contexts and cultural settings. Future-orientated design thinking. Presenting new alternative designs and alternative scenarios that are in touch with reality. Societal change. Responsibility for decisions and actions.

6.4 Biomimetics and S.PSS - Discussion of findings

A systems theory approach informs this research, where a big problem is addressed by breaking it down into smaller units, understanding the smaller units, finding and building the connections between these units in order to address the big problem again. This section of the discussion of findings aims at rebuilding a new understanding of DfS3 and the relation between Biomimicry and S.PSS. This new understanding forms the basis to answer the research questions and present new insights based on what I know.

6.4.1 Restating the research questions

This research study aims to answer a set of research questions, which acted as the catalyst for the research actions that took place. I aim to answer the main research questions throughout the discussion and findings chapter while addressing the sub-questions based on the knowledge acquired throughout the research activities. By doing so, I reflect a methodological process, see Figure 6.4.1, highlighted in Chapter 3.3. Through these discussions, I aim to reassemble the sub-units of DfS to gain new perspectives on DfS3.

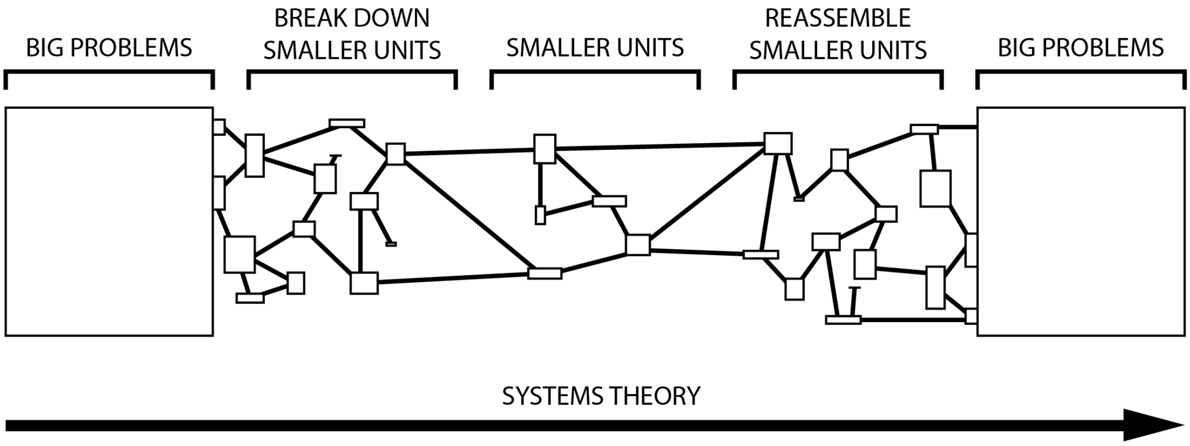


Figure 6.4.1: Systems theory
(Image by Corbin Raymond, 2019)

The main research question asks:

How can a holistic approach to Design for Sustainability be developed and implemented in a Higher Educational Institute to inform an in-depth design praxis for Industrial Design students?

The sub-questions ask:

- How would a set of DfS guidelines inform the integration of Biomimetics and S.PSS?
- What are the benefits and challenges of integrating Biomimetics and S.PSS?
- Why should such a set of guidelines be taken into account within the DfS paradigm?

6.4.2 How a set of guidelines informs the integration of Biomimicry and S.PSS

The guidelines reflect on the key data sets of the research. The data sets represent a set of student-made work, such as the student reports, posters, and online pages. My reflections also inform the guidelines on the course, as well as the observer's report. The observer's report gives a clear overview of the structured course, which presents a case within this research. Therefore, the guidelines represent a deductive process that draws on key activities in the integration of Biomimicry and S.PSS.

Additionally, the guidelines comment on the concept of critical citizenship education as an evaluator of societal change towards DfS3. I represent Johnson and Morris's (2012: 297) framework for critical citizenship education in Table 6.4.2, as well as indicate areas where the guidelines represent the integration of Biomimicry and S.PSS:

Table 6.4.2: Framework for critical citizenship education

	POLITICS/ ideology	SOCIAL/ collective	SELF/ subjective	PRAXIS/ engagement
KNOWLEDGE	Knowledge and understanding of histories, societies, systems, oppression and injustices, power structures and macrostructural relationships	Knowledge of interconnections between culture, power, and transformation; non-mainstream writings and ideas in addition to dominant discourses	Knowledge of own position, cultures, and context; a sense of identity	Knowledge of how collectively to effect systematic change; how behaviour influences society and injustice
SKILLS	Skills of critical and structural social analysis; capacity to politicize notions of culture, knowledge, and power; capacity to investigate deeper causalities	Skills in dialogue, cooperation, and interaction; skills in the critical interpretation of other's viewpoints; capacity to think holistically	Capacity to reflect critically on one's 'status' within communities and society; independent critical thinking; speaking with one's own voice	Skills of critical thinking and active participation; skills in collaborating to challenge the status quo; ability to imagine a better world
VALUES	Commitment to values against injustice and oppression	Inclusive dialogical relationship with others' identities and values	Concern for social justice and consideration of self-worth	Informed, responsible and ethical action and reaction
DISPOSITION	Actively questioning; critical interest in society and public affairs; seeking out and acting against injustice and oppression	Socially aware; cooperative; responsible towards self and others; willing to learn with others	Critical perspective; autonomous; responsible in thought, emotion and action; forward-thinking; in touch with reality	Commitment and motivation to change society; civic courage; responsibility for decisions and actions

Key to symbols

Elements present in the use of Biomimicry and S.PSS	(blue-green)
Represented elements (but not explicit) in the use of Biomimicry and S.PSS	(yellow-green)
Null (missing from the integration)	(red)

6.4.3 Benefits and challenges of integrating Biomimetics and S.PSS

One of the main benefits is the dispositional shift towards DfS. It comments on the student's ability to: actively question, be socially aware, autonomous, responsible in thought, emotions, and actions. The students are committed to changing society through active participation within the design process. The ability to integrate DfS methods, such as Biomimicry and S.PSS, allowed for a remixing of design tools that aim at visualizing alternative solutions. While at the same time, focus on the triple bottom line of sustainability. The students can design speculatively with a futures-orientated design process. This process measure against the targets set out by the sustainable development goals for 2030 (Gabay & Ilcan, 2017: 340). In this case, SDG7: "ensure sustainable and clean energy for all" was eemphasised, with goals such as SDG12: "Promote sustainable consumption and production patterns," SDG13: "Tackle climate change and its impacts" as supporting goals and ideologies for the projects the students developed.

The Global Scenario Group's vision (Raskin, 2002) of having "a rich quality of life, strong human ties and a resonant connection with nature" is realized through the integration of the DfS methods. This integration of DfS methods reflect four concepts of sustainable development, which underpins the eight guidelines:

- the quality of human knowledge,
- creativity,
- self-realization that represents development, and
- the quality (over quantity) of goods and services.

The guidelines represent the integration of Biomimicry and S.PSS and respond to "increasing calls from the global environmental change research community for new strategies on translating knowledge into action" (Adger, Barnett, Brown & Marshall, 2013: 112). This integration further supports the theoretical underpinnings that result in useful, sustainable course material in design education which yields legitimate learning outcomes (Shephard, 2008: 90; Johnson & Morris, 2012: 283).

The main challenge of the course, as emphasised in the observer's report is the introduction to the design tools and design techniques. Mostly due to poor case examples of how the tools can/should function in use, as well as poorly explained mechanics to the ideologies behind the design tools. Most of the student's critique was against the LeNSes online platform where the tools can be accessed. This student reflection, however, comments on the accessibility to the tools. The facilitators of the course introduced the tools to the students with limited experience of working with the design tools themselves. Therefore, the learning curve to trust the design process came with hesitant resistance from the students, which posed challenges to the overall participation of the course. Regardless of the accessibility and adaptation of a design process, which is informed by the integration of Biomimicry and S.PSS, the students could learn the tools and apply them to their various projects. One of the student's responses to the course was that "Biomimicry is inspiring" while another student's comment read: "Don't teach sustainability, rather just teach systems thinking. You require a full understanding of systems thinking before you can Design for Sustainability". This comment reflects on the weighted course content that the students had to work through, where they had to analyse, research and comprehend theoretical DfS paradigms (such as systems thinking) which supports the integration of DfS methods. Therefore, to critically understand DfS holistically, an understanding of DfS paradigms, as well as design methods, need to be addressed.

The external observer notes in the observer's report that:

> "The research and design process followed steps of analysis, synthesis, and evaluation, and required mastery of the S.PSS and Biomimicry tools and principles, which the groups seemed to achieve in the end. It was clear from the observations that, although aspects of the course could be improved, as must be expected from a pilot course, it enabled deep engagement in an authentic learning experience and this had significant value for the students."

6.4.4 Biomimicry and S.PSS in relation to DfS3

The research problem which I state in Chapter 1.2.2 shifts the primary focus of this study to seek out the environmental benefits of an S.PSS solution. This problem area acted as the catalyst for an in-depth and robust study into the holistic understanding of sustainability. The eight guidelines focus on the environmental benefits of DfS3 through Biomimicry. The implementation of these guidelines is suggestive of the social praxis and social relations found within S.PSS design methods. Life's Principles introduce a measure of sustainability, through reviewing nature's strategies on sustainability. Benyus (Baumeister et al., 2013) describes Biomimicry as an "approach (which) seeks nature's advice at all stages of design, from scoping to creation to evaluation." Therefore, the biomimetic approach to design informs the design process to be aligned to Life's Principles, such as:

Adapt to changing conditions, be locally attuned and responsive, use life-friendly chemistry, be resource efficient (material and energy), integrate development with growth, and evolve to survive (Baumeister et al., 2013).

Clune (2010b: 69) suggests that designers should know the role of design concerning DfS. DfS3 calls for a future's orientated societal change to the praxis, and status quo, of design (Clune, 2010a: 3). I identify students as the designers of the future, as well as the 'society' to adopt this ideology of DfS3 to shift DfS from the ecological impact of sustainable design (DfS1) to sustainable design through societal change (DfS3). Students actively participated with the subject matter through education for sustainability, and not education about sustainability (Fien, 2002: 154; Tilbury, 2004: 103). This ideology is aspirational and philanthropic and suggests that DfS is not purely a technical problem, but more socially orientated and capable of addressing everyday consumption and unsustainable societal behaviour.

The research hypothesis (Chapter 1.4) suggests that 'introducing Biomimicry as a research method to S.PSS applied to DRE would yield positive results for DfS3 with a specific interest in environmental development'. The eight guidelines evaluated against critical citizen (design) education responds to this hypothesis by proving the statement correct. It can, therefore, say that the course and the guidelines can address socio-ethical, economic, and environmental systems-approaches to design (Ten Dam & Volman, 2004: 359).

A significant discrepancy in the study of the DfS paradigm remains with the measure and evaluation of environmental sustainability. Life's Principles are steps in the right direction (Rossin, 2010: 568; De Pauw, Karana, Kandachar & Poppelaars, 2014: 174), and the integration of Biomimicry and S.PSS is a valuable learning experience. It is a promising concept to tackle sustainable issues, but it does not represent the perfect viable design strategy (Johnson & Morris, 2012: 289; Irwin, Kossoff & Tonkinwise, 2015: 4). However, Biomimetic and S.PSS tools can be integrated and closer aligned to address the triple-bottom-line in their structure or outcomes (Irwin, Kossoff and Tonkinwise, 2015: 3). Students could adopt the essential underpinning of experiencing DfS3 through integrating Biomimicry and S.PSS by developing a more profound and more holistic capacity of understanding on sustainability through knowledge, skills, values, and dispositions (Margolin & Margolin, 2002: 25; Sanders & Stappers, 2008: 15; Johnson & Morris, 2012: 289).

6.5 Summary

This chapter present a set of guidelines. The guidelines result from a process of inductive thematic analysis. The guidelines are based on key data sets as well as cross-referencing between literature sources. The themes consist of four primary segments: knowledge, skills, values, and disposition. Biomimicry and S.PSS informed the eight guidelines which present critical indicators that draw on the design methods used within the course. The evaluation of the guidelines against critical citizenship (design) education has revealed that there are areas that DfS does not take into account through this approach, such as the capacity to investigate deeper causalities and politicized notions of culture, knowledge, and power, related to DfS.

I readdress the systems theory approach which informs the process of understanding the more significant issue of DfS3 and restate the research questions, research problem statement as well as the research hypothesis. I present the discussions and finding from the data sets, as well as the eight guidelines, as an attempt to answer the three sub-questions of the research. By answering the sub-questions, I address the main research question: How can a holistic approach to Design for Sustainability be developed and implemented in a Higher Educational Institute to inform an in-depth design praxis for Industrial Design students?

CHAPTER SEVEN
CONCLUSIONS AND RECOMMENDATIONS

7.1 Introduction
This research study investigated Design for Sustainability through integrating Biomimicry and S.PSS as design methods in order to achieve sustainable societal behavioural change. In this case, a group of Industrial design students at the Cape Peninsula University of Technology (CPUT) functions as the indicators of “society.” These students actively participated in a design(ed) course, which aimed at integrating DfS methods, DfS techniques, and DfS tools. The main aim of the research was to present a set of guidelines that provides a strategy for DfS with a stronger representation of environmental sustainability. This guideline comes as a response to the research problem area, which calls for a stronger relationship between sustainable design praxis and environmental sustainability.

The research study explored literature themes which formally contextualises: climate change, DfS in formal education, DfS through S.PSS, DfS through Biomimicry, environmental sustainability, social and cultural sustainability, economic sustainability, as well as systems innovation. The intention of this was to provide a theoretical foundation to meet the main objective. My objective was to present a set of guidelines after analyzing key data sets by following a process of inductive thematic analysis. The guidelines have four categories: knowledge, skills, values, and dispositions. A framework on critical citizenship (design) education forms the measure of these guidelines. Where critical citizenship functions as a critical indicator of societal change. I came to know various aspects of my study and have disseminated the research at other HEI’s in Africa and abroad. I have also presented key findings of the research at a series of international platforms such as seminars, conferences as well as the Africa Design Talks, which was hosted by the World Design Organization.

In this concluding chapter, I also briefly describe the limitations of my research study and propose areas for future research, which aims at a deeper integration of Biomimicry and S.PSS as DfS methods. I continue to propose that it would seem viable to explore more integrated Biomimetic and S.PSS design techniques and design tools. I also propose a design framework that draws on the eight guidelines which I present. I also propose further investigation and potential design strategies towards DfS3 as a futures-orientated design strategy on sustainable societal change through forecasting long-term sustainability, which is in touch with reality.

7.2 Revisiting aims of the research

This research inquiry into the paradigm of DfS3 aims at shifting theory into practice through a mixed method approach that informed a design process that draws elements and solutions from nature for more environmentally sustainable solution offerings. The initial aims of the research responded to a research problem that called for a more environmental-orientated design inquiry towards DfS. With the research hypothesis, I introduce Biomimicry as a method that is intrinsically rooted in an environmental inquiry towards sustainability.

In response to the problem statement, systems theory was introduced as a research approach to unpack, understand and in turn used to answer the main research question. The research was delineated to design education, with a focus on Industrial Design at CPUT. Through analyzing the academic literature underpinning DfS, Biomimicry, and S.PSS, I could contextualise and formulate a design course for the students to meet the aim of shifting sustainability, which is futures-orientated and conducive to societal change (DfS3), from theory into practice. The course makes for a case that presents key qualitative data sets for me to analyse. I remained mindful to the methodological considerations, see section 4.2.4, where Mack (2005: 3) draws attention to the following aims of qualitative research:

- Seek answers to questions
- Systemically use a predetermined set of procedures to answer the research question
- Collect evidence
- Produce findings that were not determined in advance
- Produce findings that are applicable beyond the immediate boundaries of this study
- Seek to understand a given research problem

The qualitative data sets were analysed using inductive thematic analysis in order to inform a set of guidelines. The eight guidelines:

- defining a course
- identifying appropriate DfS methods
- Define and explore situated learning spaces
- working through error analysis
- Developing essential design skills through DfS techniques
- and DfS tools
- developing alternative solutions
- Seeking long term sustainability

The guidelines are embedded within the key data sets and key research activities which were described in Chapter 4 and 5, as well as the observer's report. The guidelines are measured against a framework on critical citizen education which comments on societal change: pertaining to students who actively participated in the course. Therefore, the first aim of the research study was to present a set of guidelines on the integration of Biomimicry and S.PSS in relation to DfS3, and this was achieved through the research.

The secondary aim of the study was achieved by aligning the research study with the two research projects presented in Chapter 1.2.4. In doing so, the relevance of the research study was enhanced by responding to the indicators of SDG's:

- SDG 7: Ensure sustainable energy for all
- SDG 9: Promote sustainable infrastructure and industrialization and foster innovation
- SDG 12: Promote sustainable consumption and production patterns
- SDG 13: Tackle climate change and its impacts
- SDG 17: Strengthen the means of implementation and the global partnership for sustainable development

7.3 Biomimicry and S.PSS design methods

This study was aimed at identifying how Biomimicry and S.PSS design methods could foster a more in-depth approach to DfS. A mixed method approach was adopted and specific design techniques was identified and design tools based on a case, represented as the structured course. These design tools and techniques inform a way of making which pulls design strategies towards environmental, social, and economic sustainability. The guidelines which emerged from the data are not prescriptive, they are dependent on contextualisation and should therefore intrinsically be adjusted, interpreted and reapplied to specific design applications. These guidelines aim to inform design education strategies towards DfS, and holds the potential of positioning students, with the capacity to DfS3, as critical citizens of design.

There are areas to improve when defining or implementing the guidelines, especially considering the replicability of the study. Firstly, the aim of the course needs to be predefined by the facilitators and can, therefore, be limited to the skillset and experience a facilitator might have towards S.PSS or Biomimetic design methods as well as the limited skillset to teach these DfS tools. The facilitators need a holistic overview of the entire course to determine when seamless transitions between modes of Biomimetic and S.PSS tools can be used.

Another area where the study could be improved is the development and design of specific design tools which hybridizes Biomimicry and S.PSS. The integration of the DfS methods calls for better-developed design tools that can function as a more integrated tool of the Biomimetic and S.PSS toolkits, and it is thus an area where this study can be improved. An area for further improvement is on the notion of integration. Within the case I presented, a *true* integration has not been achieved, since in the design exercise biomimicry has been used at a product design level and not at a product-service system design level. Although products have then been inserted in a PSS, biomimicry has not been used to define PSS design strategies. A valuable design tool from the Biomimetic toolkit is Life's Principles as an evaluation and indicative tool on environmental sustainability, while the S.PSS toolkit is more robust in developing social and economic sustainability through the business model canvas and the stakeholder mapping tools. In their current state, these tools are not overlapping and they would need remixing to help integrate Biomimicry and S.PSS even more.

The key outcomes of the projects which rely on active student participation represents a more holistic and in-depth approach to DfS. The eight guidelines can align with the four concepts of critical citizenship: Knowledge, Skills, Values, and Disposition. Based on this alignment with the guidelines and critical citizenship education, I propose a more robust way of framing and approaching alternative solutions as well as long term sustainability. This approach to framing long term sustainability should incorporate specific design methods, design techniques, and design tools which invokes critical perspectives on appropriateness for local contexts and cultural settings, explores future-orientated design thinking, and presents new alternative designs and alternative scenarios which are in touch with reality through DfS3 and societal change.

7.4 Contributions to knowledge and dissemination

My research work takes an innovative stance regarding DfS by emphasizing a futures-orientated design process through remixing design methods, design techniques, and design tools. This integration comments on the rigour and adaptability of design methods such as Biomimicry and S.PSS. The guidelines provide a reference point for a DfS philosophy which is fundamentally grounded within an advocacy approach for environmentally orientated design strategies pertaining to DfS. The study provides contextualised data which can function as referencing material for future projects which investigates this problem area of sustainable societal behaviour change through design education on DfS.

The secondary aim of the research was to nest this research inquiry within the two research projects: C-SAN-Futures, and LeNS. Contributing to the dissemination of knowledge created through these projects allowed me to test the rigour and replicability of the DfS methods, techniques, and tools which informed the eight guidelines (Chapter 6.4.2) in a variety of contexts. These contexts range from short pilot courses that focused on sustainable development through remixing S.PSS with methods of distributed renewable energy (DRE), distributed manufacturing (DM), and distributed economies (DE). Other short courses were aimed at DfS3's potential to change societal behaviour through futures-orientated design, such as the ProtoHype project. ProtoHype explored futures-orientated solutions through prototyping as a means of designer's commentating on unsustainable societal behaviour and actions. The key indicators of these learning moments were documented and formally shared within the LeNS and C-SAN-Futures communities, as well as with larger design communities such as the 4th annual Africa Design Talks which was hosted by the World Design Organization (WDO) in Rabat, Morocco. I have also attended and presented key data units and theoretical underpinnings of my research at international seminars, international conferences, as well as published an article which highlights key research activities of this study.

Table 7.4 provides a chronological order of my research activities and the dissemination of knowledge during the development of this thesis:

Table 7.4: Dissemination of work

Year	Dissemination Activity	Location	Host Organization	Description
2015	1. LeNS pilot course	Kampala, Uganda	Makerere University of Technology	Compiled an observer's report on critical teaching and learning outcomes. Presented on DfS, Sustainable Development and Distributed Renewable Energy (DRE) to Master's engineering students.
2016	2. ProtoHype project	Nairobi, Kenya	Oslo school of architecture and design (AHO)	Participate, co-facilitate, and present Biomimicry to Master's product and graphic design students.
	3. LeNS seminar	Stellenbosch, South Africa	Cape Peninsula University of Technology (CPUT)	Present key activities and findings on the mixed method design approaches and design techniques on DfS to an international group of design educators and design practitioners.
	4. LeNS conference on sustainable energy for all	Cape Town, South Africa	Politecnico di Milano, Cape Peninsula University of Technology (CPUT)	Present the Kunye and Bioflux projects, the principal research activities and findings on the mixed method design approaches and design techniques and design tools used on DfS, to an international group of design educators and design practitioners. Present a poster on the ProtoHype project.
	5. Cumulus conference	Hong Kong, China	Cumulus, Hong Kong Design Institute (HKDI)	Submitted and presented a short paper on future-orientated design strategies and presented on essential indicators of alternative design solutions.
2017	6. LeNS Pilot course	Stellenbosch, South Africa	University of Stellenbosch, Cape Peninsula University of Technology (CPUT)	Co-facilitated the course which focused on DfS methods: Biomimicry, S.PSS and Distributed Economies (DE) — presented and introduced Biomimicry and S.PSS design tools.

	7. Environment, Energy and Sustainable Development conference	Phuket, Thailand	EESD	Submitted and presented a paper on design techniques and design tools which focus on Biomimicry and S.PSS based on the structured course presented in this thesis.
	8. Published Article		DEStech Transcriptions on Environment, Energy and earth Sciences.	Published a paper on design techniques and design tools which focus on Biomimicry and S.PSS based on the structured course presented in this thesis. Raymond, C., Chisin, A. and Broom, A. 2017. Biomimicry, S.PSS and DRE: Designerly Strategies to Reduce the Knowledge Gap Between Design and Nature. DEStech Transcriptions on Environment, Energy and Earth Sciences.
	9. LeNS Short course	Beijing, China	Tsinghua University	Compiled an observer's report on critical teaching and learning outcomes. Presented on Sustainable Development and Distributed Renewable Energy (DRE) to Master's design students.
	10. Panellist at the Africa Design Talks	Rabat, Morocco	World Design Organization (WDO)	I discussed my research activities, design techniques, and my guideline's themes on Values and Disposition. The discussion focused on the facilitation of DfS education on sustainability in Africa, with a critical focus on SDG12: Sustainable consumption and production.
2017-2018	11. Internship	Paris, France	Electricite de France (EDF), Cape Peninsula University of Technology (CPUT)	Applying my research theory into practice. Actively participated in developing alternative solutions which are future-orientated within the Innovation Hub of Electricite de France (EDF)

7.5 Limitations of research

This Master's thesis, like any other study, is not entirely comprehensive. The design methods mainly focused on Biomimicry and S.PSS, and often mentioned DRE. I recognize that DRE is a design method, and the inclusion of DRE to the remixing of design methods could reframe the guidelines which I present in this study. The same goes for other DfS methods, such as distributed manufacturing and distributed economies. Therefore, specific limitations of this study are:

- It does not consider design methods other than Biomimicry and S.PSS to inform the guidelines.
- It is limited to one case of a structured course at CPUT; however, the developed methodology and guidelines could provide a framework for further research concerning DfS3 in different contexts.
- The study recognizes the different perceptions of DfS but mainly focused on DfS3 to inform societal change to sustainability.
- Resources are not available for further development of this research due to the timeframe of the LeNS and C-SAN-Futures projects which came to an end, but new funding cycles may lead to further research in this area.

7.6 Implications for further research

This thesis investigated the integration of Biomimicry and S.PSS design methods to DfS3. Based on my investigation, I present eight guidelines that draw on the process of inductive thematic analysis of key research data sets. A few identified areas for possible future research initiatives as a result of this study are:

- The manufacturing of a prototype based on these guidelines and studying user reactions and marketing difficulties related to the designed solution.
- Further optimization of the guidelines in order to develop a design framework on DfS3.
- Developing hybridized design tools focusing on Biomimicry and S.PSS specifically.
- Testing Biomimicry and S.PSS with other DfS methods, such as distributed manufacturing and distributed economies.
- Critical Citizenship presents a framework that has areas to explore concerning the role of alternative design solutions within the design praxis of DfS3, as well as the role it plays on the self, society, and politics.
- Critical Citizenship presents a framework that has areas to explore concerning the role of long term sustainability through futures-orientated design strategies that are conducive to sustainable societal change when Designing for Sustainability.

Life's Principles and Critical Citizenship provides a measure through which environmental and social sustainability of S.PSS's can be evaluated against. This proposes a further research direction for studies into the evaluation of DfS methods, praxis and the development of further design tools.

From a futures perspective, which has urgent current implications, Design for Sustainability is a notion that cannot be debated any longer, but a behavioural lifestyle that ought to be adopted by all; business as unusual.

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APPENDICES

APPENDIX A: BIOFLUX PROJECT REPORT

bioflux
citrus solutions

S.PSS Energy Product
Rural context - Lustigaan Citrus Farm Waste Management

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13 November 2015

Overview

This report is written by the group members and designers of BioFlux. It serves as a representation of all information used in the design process, from initial research to final design concept. The Design Analysis, Concept Analysis, Ergonomic Analysis, Technical Analysis and Prototype are the main headings discussed, each containing several sub-headings. The report allows the designers to make several conclusions, and identify which areas can be improved upon or further developed.

Introduction

The report is written on BioFlux in order to describe to the reader the design process leading up to the final design solution. The report also aims to identify the value offering of the product through analysing S.PSS and Biomimicry tools, as well as to prove the technical and ergonomic viability of the product. The production processes will also be described. The report thus enables the designers to identify and justify all decisions made in the design process.

The method of research was done through primary research, as well as secondary research. Primary research was obtained through field research on Lustigaan farm, including an informal interview with the farm manager. Secondary research was obtained through the use of published journal articles and online articles. The report will discuss the Design Analysis, Concept Analysis, Ergonomic Analysis, Technical Analysis and Prototype of BioFlux. Lastly, a conclusion will be made on the process and final product.

Design Analysis

In order to conceptualise a new design idea, various factors had to be analysed and knowledge had to be gained in several areas through thorough research. This included various contextual issues that would give rise to an innovative design. Only after this, the designers were able to start with the process of ideation and concept sketches.

Rural context

Understanding the definition of a rural area requires a clear overview of what an urban area is defined as. An Urbanized Area consists of a population of 50 000 or more. An Urbanized Cluster consists of a population between 2 500 and 50 000 (Reynnells, 2014).

A rural area is considered as any population, housing or territory that is not included in an urban area. This refers to any countryside that may or may not include farming or an agricultural structure or system (Cite, 2011). In South Africa, rural communities are defined as the slightly poorer communities as they rely more on subsistence farming, or need support from either their families or the government to maintain a living. Farming is considered to be the biggest rural area in South Africa. There is a great amount of unemployment within the rural communities, therefore job creation and development programs can be seen as a high priority when it comes to community growth (South Africa, 1997).

Figure 1: Lustigaan Farm

Image from: Van Schalkwyk, 2015. *Lustigaan Farm*. [Photograph]. In possession of Misha van Schalkwyk. Cape Town

Various farms within the Western Cape were researched in order to find a suitable farm that fits within the specific design brief. Rural areas researched included Klawer and Redelinghuys. Klawer farms with grapes and Redelinghuys farm with potatoes. For our context, we decided to focus on waste management and neither of the crops grown on these farms provides a large enough amount of waste. The farm that finally decided on is Lustigaan, situated in the Paarl. Lustigaan is one of three Cape Citrus farms, being the smallest at 50 hectares in size. Being a citrus farm, a high percentage of waste is produced on the farm.

Citrus waste

Within South Africa there is a big problem concerning the waste of valuable food. It is estimated that between 30%-50% of all food produced globally is wasted before getting to the consumer. People have started taking food for granted and sees it as a disposable commodity although it is not. Food waste has an immense impact on food security, meaning that resources used in food production and distribution is wasted. It also has a big impact on the environment through its supply chain (Oelofse, 2014).

Citrus produces the highest amount of wastage of all fruit. In the South African food industry, processing produces a large quantity of waste. Of all citrus produced, approximately 21% is processed, meaning canned and/or juiced. Approximately 50% of fruit produce end up as waste. The solid waste is the portion of the fruit that is often not utilised, which includes skins, pips and fibres. South Africa thus produces sufficient fruit-processing wastes, being solid and liquid, for the development of a bio-energy to be a viable option (Khan, et al, 2014).

Citrus is also chosen as focus area, as it is the biggest export in South Africa and has the highest value fruit crop in terms of international trade (Khan, et al, 2014).

Smallholder farming

Smallholder farmers are vulnerable to a variety of factors in their agricultural work. Vulnerability can arise from factors such as weather, pests, plant and livestock diseases, changes in prices for farm products and inputs. These can all seriously threaten the farm as a business and consequently the livelihoods of farmers and their families. If enterprises fail or yields are low and prices are not sufficiently high to cover production costs, farmers and their families find themselves in distress (Crossley, Chamen & Kienzle, 2009). To make an extra income, smallholder farmers can diversify their farming operations.

Figure 2: Citrus Market

Image from: Cape Citrus 2014. Our Markets. *Cape Citrus*. [Online]. Available: http://www.capecitrus.com/markets.htm [10 November 2015].

How does the current system work?
On Lustigaan farm, there are several systems in place for the different stages of recycling citrus waste. For the purpose of this report, two categories will be implemented to simplify the explanation of the different stages. The stages are dropped fruit waste and transport waste.

Dropped fruit waste

Figure 3: Current Mulcher

Image from: Afonso, D. 2015. *Current Mulcher*. [Photograph]. In possession of Daniel Afonso. Cape Town.

This category includes all the citrus that has dropped from the tree before the fruit are ready to harvest. In current practice, workers walk through the citrus orchards daily to gather the fallen fruits. This is done to prevent insects that infect the fallen fruit from infecting the citrus trees. Once all of the fruits are gathered, it is put in a mulcher. After being shredded, the waste in thrown into a hole in the ground, which returns nutrients to the ground.

Transport waste
This includes all the fruits that gets damaged in transport. These fruits are sold to fruit juicing companies. At the factory, the flesh and the peel are separated from each other. The flesh of the fruit is used to make fruit juice. The limonene in the peel is used to produce oil, having many uses, including fragrancing, flavouring or medicinal purposes.

Biofuel

What is Biofuel?

Anaerobic digestion is a sustainable and economically feasible waste management technology, which lowers the emission of greenhouse gases (GHGs), decreases the soil and water.

A biofuel is a hydrocarbon that is made by or from a living organism that humans use to power something. In practical consideration, any hydrocarbon fuel that is produced from organic matter (living or once living material) in a short period of time (days, weeks, or even months) is considered a biofuel (Biofuel.org.uk, 2015).

Biofuels does not need to be made by a living organism. Biofuels can also be made through chemical reactions, carried out in a laboratory or industrial setting, that use organic matter, called biomass, to make fuel. The only real requirements for a biofuel are that the starting material must be CO2 that was fixed (turned into another molecule) by a living organism and the final fuel product must be produced in a short amount of time (Biofuel.org.uk, 2015).

What is Biomass?

Biomass is simply organic matter; dead material that was once living. Biomass helps to produce energy more sustainably with less effort and time. Biofuel comes from biomass, which can be produced year after year through sustainable farming practices. Biofuel and biomass are therefore renewable, and can be replaced over a very short period of time (Biofuel.org.uk, 2015).

Advantages of biofuel

Cost benefit:

Biofuel currently cost the same amount as gasoline does, but the benefit of using it is substantially higher. The fuel is considered to be cleaner, which produces fewer emissions when burnt. Biofuel is able to adapt to current engine designs and operates very well in man conditions. The biofuel is able to keep the engines running for longer; it does not need as much maintenance and is also able to bring down the overall pollution emission. As it is high in demand, biofuel has a high potential for price drop.

Easy to source:

As biofuel are made from many different materials, this source of energy will not run out quickly. It can be sourced from manure, waste from crops and plants that are specifically grown to produce biofuel.

Renewable:

All the sources that are used to produce biofuel are considered renewable. The use of biofuel is therefore very efficient in nature, as the waste from crops or plants for biofuel can be obtained quite frequently without running out.

Reduce greenhouse gases:
Through various studies it has been proven that biofuel actually reduce greenhouse gasses by up to 65%, as the burning of coal, oil or any fossil fuels produces a high volume of greenhouses gasses.

Economic security:
For countries that do not have an unlimited supply of crude oil, having to import oil creates a huge dent in the economy. By increasing the amount of biofuels that a country uses, the reliance on fossil fuels will be reduced. It will also aid job creation with the growing biofuel industry.

Lower levels of pollution:
There is substantially less pollution created through biofuel as it is made from renewable resources. Biofuel also emit lower levels of carbon dioxide and other emissions when being burnt. It does however produce carbon dioxide as a by- product, but as biofuels is frequently used to grow plants which is eventually used for biofuel, a self-sustaining system is created.

Disadvantages of biofuel
High cost of production:
Even though biofuel is very beneficial to use, it is still very expensive to produce in the current market. The interest and capital investment in growing the biofuel industry in still very low at the moment. It currently matches the demand, but if the demand increases, supplying enough biofuel will have to be a long term operation, which will end up being very expensive.

Monoculture:
This means that the same crops are planted on the same soil every year. Although this can be beneficial for the farmer, it is not beneficial for the soil as nutrients required to grow the crops are depleted.

Use of fertilizers:
Biofuel are produced from crops, which need fertilizers to grow better. The downside of using fertilizers is the potential harmful effects on the surrounding environment, including water pollution. Fertilizers contain nitrogen and phosphorus, which can be washed away from soil to a nearby lake, river or pond.

Shortage of food:
Biofuel are extracted from plants and crops containing high levels of sugar. Most of these crops are also used as food crops. Even though waste material from plants can be used as raw material, the requirement for such food crops will still exist. It will take up agricultural space from other crops, which can create a number of problems. Even if it does not cause an acute shortage of food, it will definitely put pressure on the current growth of crops. The growing use of biofuel can thus potentially mean a rise in food prices.

Industrial pollution:

The carbon footprint of biofuel is less than that of fossil of fuel when burnt. The production process of biofuel does however depend on a high volume of water oil. Large scale industries meant for churning out biofuel are known to emit large amounts of emissions and cause small scale water pollution as well. Unless more efficient means of production are put into place, the overall carbon emission of biofuel is not drastically less.

Water use:

Large quantities of water is required to irrigate the biofuel crops, which may impose strain on local and regional water resources if not managed wisely.

Future rise in price:

Current technology being employed for the production of biofuel is not as efficient as it should be. Scientists are engaged in developing better means by which biofuel can be extracted. However, the cost of research and future installation means that the price of biofuel will undergo a significant rise. As of now, the prices are comparable with gasoline and are still feasible. Constantly rising prices may cause the use of biofuel to be as harsh on the economy as the current rising gas prices (Biogas Plant, 2011).

Why biofuel would work in a rural context

The rural area of Lustigaan farm relies heavily on fuel to perform their daily tasks. The use of biofuel would thus be ideal to be produced and utilised on the farm itself. Two potential applications for biofuel in South Africa are:

Biogas used as a fuel:

Air contains 21 % oxygen, meaning that the energy that is released consents biogas to be used as a fuel. Generally, biogas is a renewable fuel. Biogas can be used as a low cost fuel for cooking or heating purposes in any country.

Biogas used as a heat engine:

In modern waste management amenities, biogas can be used to run any type of heat engine in order to generate electrical or mechanical power. It can be compressed, like a natural gas, to control motor vehicles (Biogas Plant, 2011).

Types of Biofuel

The chemical structure of biofuels can differ. The table below compares various biofuels with their fossil fuel counterparts.

Biofuel	Fossil Fuel	Differences
Ethanol	Gasoline/Ethane	Ethanol has about half the energy per mass of gasoline, which means it takes twice as much ethanol to get the same energy. Ethanol burns cleaner than gasoline, however, producing less carbon monoxide. However, ethanol produces more ozone than gasoline and contributes substantially to smog. Engines must be modified to run on ethanol.
Biodiesel	Diesel	Has only slightly less energy than regular diesel. It is more corrosive to engine parts than standard diesel, which means engines have to be designed to take biodiesel. It burns cleaner than diesel, producing less particulate and fewer sulfur compounds.
Methanol	Methane	Methanol has about one third to one half as much energy as methane. Methanol is a liquid and easy to transport whereas methane is a gas that must be compressed for transportation.
Biobutanol	Gasoline/Butane	Biobutanol has slightly less energy than gasoline, but can run in any car that uses gasoline without the need for modification to engine components.

(Biofuel.org.uk, 2015)

Actions/Opportunities	Main Stakeholders
Transportation	Farm Manager
Delegation	
Picking	Farm Workers
Waste Management	
Packaging	Processors
Nursaries	Local Distributors
Juice factories	
Limonene Oil Companies	
	Potential stakeholders
Rules and regulations	Government
Funding	
International distribution	Exporters
External Income	

The Business Model Canvas - See Appendix A1

Evaluation of existing system against Life's

Principles Adapt to changing conditions
Incorporate Diversity

The current wastage system shreds the citrus waste, where after it is thrown into a hole in the ground, returning the nutrients to the ground. Although multiple processes are in place to re-use the the nutrients, the citrus wastage can be utilised more efficiently to meet a functional need.

Maintain Integrity Through Self-Renewal

The nutrients of the waste is returned to the ground, thus improving the system. Through utilising the citrus waste better than the current system, more energy can be gained from the waste.

Embody Resilience Through Variation, Redundancy, and Decentralization

The bags of citrus waste are collected by various workers walking on the farm, where after it is thrown into one hole in the ground.

Be locally attuned and responsive
Leverage Cyclic Processes
The hole in the ground has to be re-filled with ground after the waste is thrown in. This means the process of digging and re-filling the holes has to be repeated with every batch of waste, thus not being a smooth, cyclical process.

Use Readily Available Materials and Energy
The current system uses wire hooks and plastic bags to collect the citrus waste. The plastic bags are not readily available on the farm, and will only be thrown away after use.

Use Feedback Loops
Proper feedback loops are not in place in the current system.

Cultivate Cooperative Relationships
The relationships between stakeholders can be improved upon through better utilisation of the citrus waste to benefit the stakeholders.

Use Life-friendly chemistry
Break Down Products into Benign Constituents

The current waste management system does not create any harmful by-products. However, the plastic bags being used to collect the citrus are added waste, as it is thrown away afterwards.

Build Selectively with a Small Subset of Elements
Although the current system consists of only a few elements, the whole system can be improved upon to reduce the amount of elements and labour needed to manage the waste in a more effective manner.

Do Chemistry in Water
The current system does not require any solvents.

Be resource efficient
Use Low Energy Processes
The amount of labour and energy used to dig and refill the hole can be drastically minimized.

Use Multi-Functional Design
The current system does not make use of multi-functional design. A lot of labour is involved to solely discard the waste.

Recycle All Materials
The plastic bags and wire hooks being used currently can not be recycled. Fit Form to Function

The current products used in the system does not specially fit form to function, or can be improved upon.

Integrate development with growth
Self-Organize
The flow of the current system can be improved upon as components does not flow effortlessly into the next stage.

Build from the Bottom-Up
The current system consists of various products, mainly being the wire hooks and plastic bags. The components of these products are not necessarily assembled one unit at a time.

Combine Modular and Nested Components
Although the system consists of multiple components, these components are not combined very fluently.

Evolve to survive
Replicate Strategies that Work
It has been found that the previous mulcher used did not work properly, as the mulched fruit attracted pesticides and created a mess on the farm. Thus the farmer stopped using the mulcher, and currently only throws the whole fruit waste into the ground. This system can be improved upon to be more effective.

Integrate the Unexpected
The current system incorporates the citrus waste to be re-used as nutrients to the ground.

Reshuffle Information
The citrus waste is currently re-used as compost to the ground, thus providing nutrients.

How the product contributes to a renewed contextual S.PSS
In an attempt to improve the current waste management system used on Lustigaan farm, BioFlux has been created. BioFlux is developed within a sustainable product service system, ensuring that the product and the waste management system take the broader context into account. Using a biomimetic methodology, the product certifies that the deeper and complex needs of environmental systems are thoroughly understood and applied. Focusing specifically on a renewable energy solution in a rural context, BioFlux aims to promote the use of renewable energy.

Concept Analysis

Several promotional elements are relevant to the concept of BioFlux. These include the SWOT Analyses, Life Principles Analysis and the inspiration and influence of Biomimicry on the concept.

SWOT Analyses

SWOT

Strengths

- Improved waste management
- Production of Biofuel
- Utilises and promotes renewable energy
- Simple and easy to use
- Uplifts the community
- No electricity or fuel required to function
- Reduced labour in the system
- Reduced carbon footprint
- Materials blend with traditional farming equipment
- Provides a new product that has not been developed to South Africa
- Improved pest control

Weaknesses

- Possibly large in size
- Expensive product to initially implement in system
- Possible high maintenance
- Mobility as a requirement may be problematic
- May require more trained labour
- Should be weather resistant for outdoor usage
- Possibly not enough power generated through pulling of tractor

Opportunities

- Promotes job creation
- Sustainable energy creation
- Improved waste management
- Increased productivity of system
- Less labour intensive for farm workers
- More economic as an income is generated from the bio-fuel

Threats

- Farmer's trust to implement new product
- High cost of product
- Acceptance by the community
- Stakeholders would not feel that product benefits them

Drivers
*Importance Level: L - Low

M - Medium H - High

*Type of System: SS - Social System

NS - Natural System

ES - Economic/Built/Designed System

Minimize environmental impact
SS - Promotion of renewable energy

- Socially responsible & sustainable design - M ES - Promotes job creation
- Product produces bio-fuel, thus saving money - H NS - Nutrionts of fruit waste utilised properly - H

Facilitate innovation
SS - Education on renewable energy - L ES - Promotes job creation - H

NS - Production of biofuel / biomass - H

Improve relationship with end-user
SS - Improved relationship between farm manager and farm worker (money and labour intensity) - L

ES - More cost-efficient system - M

NS - Cleaner, more efficient method of taking care of the farm and waste – H

Increase end-user involvement
SS - Products promotes community upliftment and involvement - M

ES - Product being more labour efficient means that more income can be generated

- H

NS - End-users utilising bio-fuel instead of fossil fuels - H

Provide integrated and customised solutions
SS - More efficient process and system of waste management - H ES - Improved waste management at earlier stage - H

NS - Minimizing environmental footprint through waste reduction - H

Lifecycle perspectives
SS - Product promotes job creation

- Product promotes community involvement
- Education on sustainable and renewable energy generation - H ES - Improves the economic viability of the system - M

NS - Product gives back to environment though less greenhouse emission and renewable energy generation - M

Create added value throughout the value chain

SS - Product improves the knowledge of sustainable and renewable energy - L

ES - Product improves the productivity of the system, thus generating more income - H

NS - Less impact on the environmental footprint through utilising sustainable and renewable energy – M

Barriers

System complexity

SS - Simplifying the system / product / mechanism - M ES - Access to materials for product

- Possible difficulties with the transport of the machine
- Product might not be cost-effective - H

NS - Acidity of the citrus might be problematic in the system and product itself - M

Technical constraints in user-involvement

SS - User's / farm workers' difficulty with understanding the system - L ES - Educational tools needed to educate the farm workers - L

NS - Effect of the weather on the product and system

- Acidity of the citrus might be problematic in the system and product itself - M

End-user behaviour

SS - Rejection of stakeholders towards the product

- Lack of knowledge of the system - M

ES - Product might not be economically sustainable - M

NS - The effect of weather on the process of gathering waste - M

Scepticism

SS - Rejection of stakeholders towards the product - H ES - Stakeholders unwilling to pay for the product - H NS - Scepticism of the possible effects on the farm

- Uncertain if the amount of fuel required will be produced
- Scepticism towards the production and usage of bio-fuel itself - H Affordability

SS - Time needed to educate the users / farm workers - M ES - Possible high costs of the product and materials - H

NS - The resources availability vs. the cost of the resources - M

Government dependency

SS - Farmers might prefer to stick to traditions instead of accepting help from government - L

ES - Limitations due to the laws regarding the safety and labour - M NS - Limitations due to the laws regarding the environment - L

Poor infrastructure

SS - Communication and education between farm workers and farm manager - M ES - Infrastructure of the education of farm workers

- The time required to produce biofuel - L

NS - Uneven ground in South Africa might be problematic

- The Variety of materials required for the product

- Possible effect of pesticides in the system – L

Evaluating product against Life’s Principles

Figure 4: Life's Principles

Image from: Biomimicry Group 2014. Life's Principles. *Biomimicry Group*. [Online]. Available: http://biomimicry.net/about/biomimicry/biomimicry-designlens/lifes-principles/ [10 November 2015].

Adapt to changing conditions
Incorporate Diversity
It incorporates diversity by combining a traditional mulcher with a PVDF membrane and a bioreactor.

Maintain Integrity Through Self-Renewal
As farmers and farm workers become comfortable with the concept of the product, materials and technology can be improved to become more modernized.

Embody Resilience Through Variation, Redundancy, and Decentralization
It can be used on various citrus farms in South Africa or across the world if necessary. It is a simple product that can be understood by any person using it.

Be locally attuned and responsive
Leverage Cyclic Processes
Materials used to create the product can be reused for various other products if necessary. The product however is built to be long-lasting. The only component that is not fully renewable is the standard bioreactor that will be used within the product.

Use Readily Available Materials and Energy
Locally sourced materials will be used to build the product and will be built by locals except for the bioreactor which will be out sourced.

Use Feedback Loops
The workers work more efficiently by making use of the product. This improves the speed and productivity of the entire farms process.

Cultivate Cooperative Relationships
The main function of the product is waste management. Thus improving the flow of production and creating a cohesive interaction between the various stakeholders.

Use Life-friendly chemistry
Break Down Products into Benign Constituents
The product breaks down citrus fruits into all its various natural counterparts, creating biofuels that go back into natural without creating harmful gasses or greenhouse gasses.

Build Selectively with a Small Subset of Elements
The product only consists of all the fundamental elements needed for it to function efficiently.

Do Chemistry in Water
The product itself does not react with water. A rust protection will placed on the product.

Be resource efficient
Use Low Energy Processes
The product is handmade by the locals of the rural community and is not made by machines. Therefore it uses very little electrical energy.

Use Multi-Functional Design
It m k " " PVD M mb bioreactor.

Recycle All Materials
All materials will be able to be reused.

Fit Form to Function
The products outer shell will be built specifically for the functioning of the inner mechanisms.

Integrate development with growth
Self-Organize
There will be a natural flow within the system. Each component helps the produce flow effortlessly into the next stage.

Build from the Bottom-Up
The internal system will be laid out first where after an appropriate shell will be designed to incase it.

Combine Modular and Nested Components
There are various components within the shell of the product that combine fluently with one another in order to work sustainably.

Evolve to survive
Replicate Strategies that Work
Strategies in nature is used as inspiration for the mulcher design. The rasping effect of the Lamprey fish and stingray is used to destruct its prey. These strategies are used in the pulverising of the citrus fruit in the mulcher.

The sucking effect of the whirlpool is used to direct the citrus downwards, while cutting it simultaneously.

Integrate the Unexpected
The product incorporates citrus waste to fulfilling a new function through the production of biofuel.
The gravity feed and cone shape ensures that all waste is channeled down into mulcher, thus eliminating any clogging.

Reshuffle Information
To create a new intervention and unique solution, the product combines the mulcher, PVDF filter and bioreactor into one system.

Biomimicry

For the design, inspiration was found from numerous nature phenomena namely; the Spotted eagle stingray, the Lampre, Whirlpools and the Ant Lion Larva Pit.

Spotted eagle ray

The spotted eagle ray mainly feeds on all kinds of shellfish. To be able to crush the hard shells of its prey, it has a specialized chevron-shaped tooth structure. Another part of the stingray that has evolved to feed better is the jaws of the animal. The jaws have developed a calcified strut that allows them to break through the shells swiftly by supporting the jaws and preventing dents from hard prey.

This can be incorporated in the design in terms of the mulcher. The mulcher needs to shred the citrus efficiently in order to speed up the process of biomass to biofuel.

Figure 5: Spotted Eagle Ray

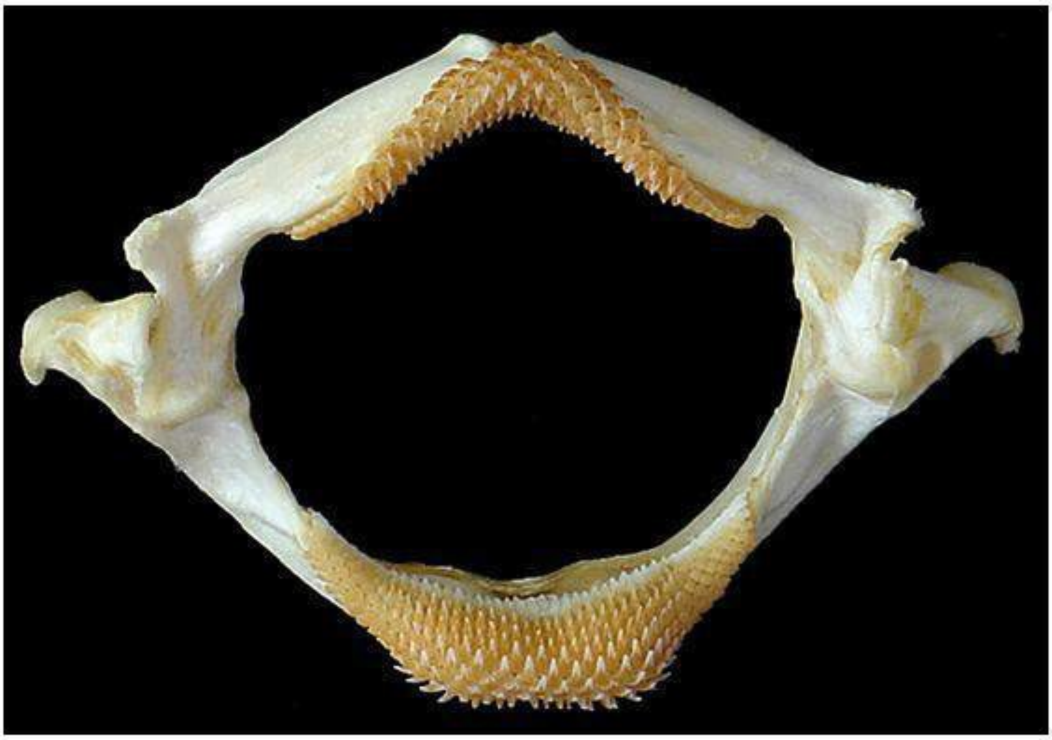

Image from: Clarke, L. 2015. Eagle Ray Tooth Plate. *Julian Rocks*. [Online]. Available: http://www.julianrocks.net/Sharks2/ElsPg/EaglerayTeethC.html [6 November 2015]

Lamprey

The lamprey uses a sucker-like jawless-mouth to cling to its prey, and has an abrasive tongue to gorge a hole in the prey's body. There it laps up the body fluids oozing from the wound.

The tongue of the Lampre is supported by a lingual cartilage, which can be moved slightly in a forward direction by paired basilariglossus muscles, originating in the basilaris and inserted on to the cartilage. The cutting lobes of the tongue are supported by an apical cartilage to which they are attached by tendons.

Figure 6: Lamprey

Image from: Wikipedia 2015. Lamprey. *Wikipedia*. [Online]. Available: https://en.wikipedia.org/wiki/Lamprey [6 November 2015].

Through a rocking motion of the apical part of the tongue, produced by the protractor and retractor systems. In addition to this rasping effect, the retraction of the tongue brings together the longitudinal laminae in a scissors-like action. This can also be incorporated in the design in terms of the mulcher. The mulcher needs to shred the citrus efficiently in order to speed up the process of biomass to biofuel.

Whirlpool

A whirlpool is a rotating current of water which creates a characteristic vortex. Most commonly, whirlpools are caused by the meeting of opposing currents and fast- flowing water through narrow openings. As the water passes through a narrow opening, it accelerates and forms a more powerful force. Being pulled into the opening by gravity, the water begins to spin, intensifies and forms a cavity in the centre of the drain. The cavity creates a vacuum into which objects are pulled (wiseGeek, 2015).

The vortex spiral shape can be adapted to the conical shape used for cutting and grinding blades as it spins. The cone shape assists in guiding the citrus waste into the intended mulching area of the blades, while the rotation of the blades also assisting in funnelling the citrus through the system ensuring maximum effectiveness.

Figure 7: Whirlpool

Image from: Admin 2015. Thinking like a Whirlpool. *Anne Dellenbaugh*. [Online]. Available: http://annedellenbaugh.com/blog [6 November 2015].

Antlion Larvaepit

The larvae of ant lions capture prey by building sand pits with the steepest possible slope (AskNature, 2015). Features like the slope and depth, influence the success in prey capture. A successful capture (i.e. prey consu mption) depends on both efficiency in trapping prey (an encounter) and on minimizing the probability that the prey escapes (retention). These two components should have selective consequences for the design of the trap. For example, augmenting the diameter of the trap increases the probability of encounter, while a steeper slope and a greater depth increase the probability of prey retention (Texas Master Gardener, 2006).

The slope of the Antilion Larvaepit funnel, being the central channel between the two chopping blades. The same way the Antlion Larvae designs its pit to trap and guide its prey directly into its mouth, the mulcher has been designed with the same principles as to guide the citrus waste directly into the Bioreactor.

Figure 8: Antlion Larvaepit

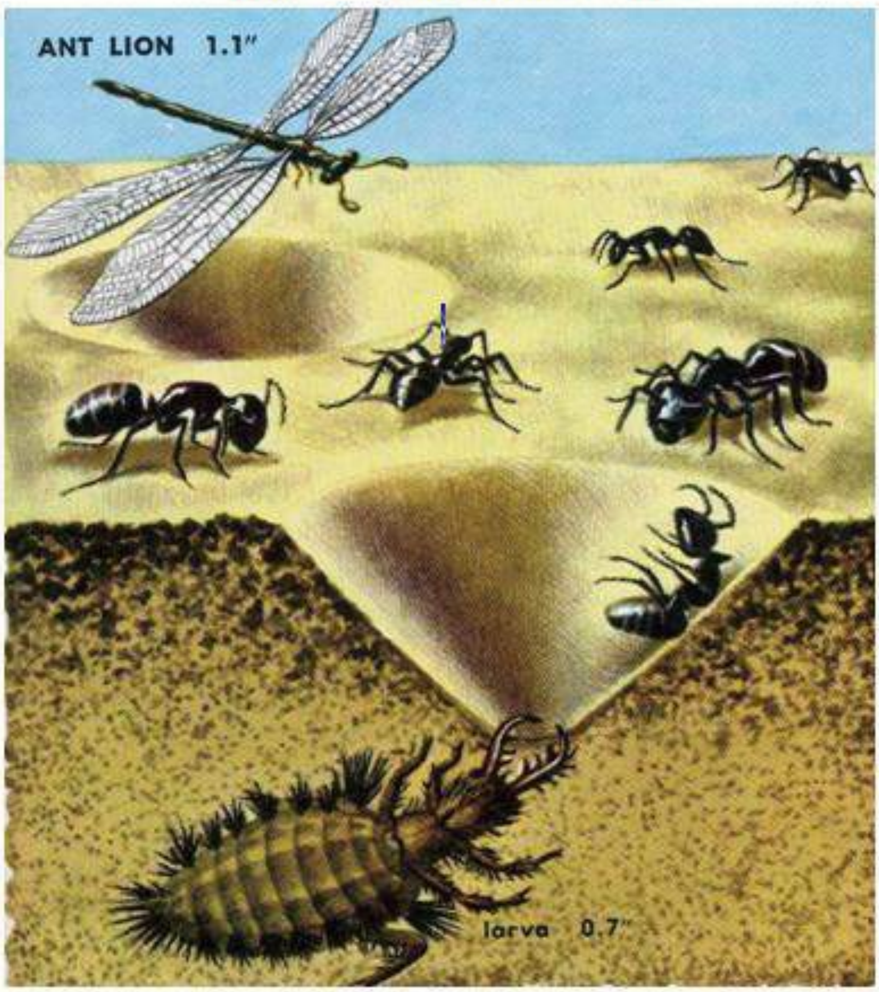

Image from: JohnDumont.com 2014. Neuroptera. *JohnDumont*. [Online]. Available: http://www.johndumont.com/insects/the-insect-orders/neuroptera [10 November 2015].

Ergonomic Analysis

In the current system, workers walk through the citrus orchards daily to collect the citrus waste. This waste is collected in plastic bags, with the aid of wire hooks. After the collection, the waste is thrown into a dug hole, where after the hole is filled with ground again. This process is very labour intensive. BioFlux is designed to reduce the amount of labour required to discard the citrus waste on the farm, as well as to utilise the waste more efficiently through the production of biofuel.

Several elements is taken into account to make sure that the product can be used in an ergonomically friendly manner. Bioflux is designed to be easily pushed through orchards by one worker. Thus, the overall size of the mulcher, bioreactor and trolley are kept compact and narrow enough to be transported with ease. BioFlux is also made of lightweight materials, having good strength-to-weight ratios.

The total height of BioFlux is designed to be low enough so that the opening of the mulcher can be easily accessed by the farm workers. The worker can thus comfortably throw the citrus waste in the mulcher, without adding extra strain to the body.

The use of three wheels enables the worker to push and control the trolley more easily than with only two wheels as well as adding less weight on each wheel. The use of one wheel ate the back and two wheels at the front of the trolley assures that the heaviest part, being the waste in the bioreactor, rests on two wheels.

Different parts of BioFlux are designed to ease the use of the product. The trolley is designed to firmly hold the bioreactor in the front. When full, the bioreactor can easily be removed and replaced with a new, empty vessel. The shell of the mulcher is manufactured in two halves that are assembled. This allows the mulcher to be easily accessed for maintenance by removing one of the halves. It also allows only one of the halves to be replaced if damage occurs.

Figure 9: Replacement of Bioreactor

Image from: Maritz, M. 2015. *Replacement of Bioreactor.* [Rendering]. In possession of Minette Maritz. Cape Town.

Figure 10: Throwing Waste in Mulcher

Image from: Maritz, M. 2015. *Throwing Waste in Mulcher*. [Rendering]. In possession of Minette Maritz. Cape Town.

Technical Analysis
Materials: Galvanised steel - framework
Galvanised steel will be used for the framework of the product, as well as parts of the mulcher. Galvanised steel is strong, tough and durable. Galvanising is lower in first cost than many other specified protective coatings for steel and requires less maintenance. The life expectancy of galvanised steel is more than 50 years in most rural environments. All areas of the galvanised product is protected, including sharp corners and inaccessible areas, making it better than any other coating (Galvanisers, 2011).

Acid can be corrosive to all types of steel, including galvanised steel. Galvanised steel performs best in solutions with a pH in the range of 5.5 to 12. Chemical environments with pH levels below 3 or above 13.5 are not recommended to galvanised steel due to the rapid corrosion of the galvanised coating. pH levels between 3 and 5.5 (acidic) or 12 and 13.5 (basic) are corrosive to galvanized steel, meaning that the corrosion protection will only last for a few years (AGA Update, 2014).

Figure 11: Steel Framework

Image from: Maritz, M. 2015. *Steel Framework.* [Rendering]. In possession of Minette Maritz. Cape Town.

The pH level of oranges is about 3.5. This means that galvanised steel can still be used for parts of the mulcher, although it will need to coated with an acid or base resistant paint or epoxy to ensure a longer service life (AGA Update, 2014).

Tufnol - Blades and gears

Synthetic Resin Bonded Fabric, often referred to as Tufnol, will be used for the mulcher. Tufnol is a proprietary brand of laminated plastic material, being one of the pioneering types of resin bonded plastic materials used for engineering components (Tufnol Godwin, 2014). Applications of Tufnol include bearings, gears, rotors, fuel pump gears, wear plates, chemical pumps and insulators (Barkston, 2011). This material is strong, hard and rigid, as well as resistant to chemicals.

Tufnol is also light in weight (about a fifth of the weight of steel) and weather resistant, making it more appropriate than steel. Tufnol is often used in outdoor and marine environments without corrod ing or degrading, as it has good wear resistance, good impact resistance, low water absorption and good dimensional stability (Barkston, 2011). Some grades are very resistant to wear in applications involving friction, being an ideal material for being used in a mulcher (Godwin, 2014).

High Density Polyethylene (HDPE) - shell

High Density Polyethylene (HDPE) will be used for the shell of the mulcher. HDPE is commonly used for water pipes, plastic bottles and hard hats. This plastic does not contain BPA (bisphenol A) or other commonly found toxic compounds, making it a much safer plastic in terms of health risks. HDPE will be especially ideal, as it has good chemical resistance and good impact strength, while being a fairly light material at the same time (Sustainable Baby Steps, 2015).

Main Bio-fuel Production Parts

Bioreactor

A bioreactor is a manufactured or engineered device or system that supports a biologically active environment. A bioreactor is a vessel in which a chemical process is carried, involving organisms or biochemically active substances derived from such organisms. A bioreactor is usually cylindrical, ranging in size from a few litres to thousands of litres. Whatever the size of the bioreactor, the conditions in the bioreactor have to be favourable so that living microorganisms can exhibit their activity under the defined conditions (Modak,2009).

Figure 13: Bioreactor

Image from: Maritz, M. 2015. *Bioreactor.* [Rendering]. In possession of Minette Maritz. Cape Town.

Polyvinylidene Difluoride (PVDF)

Rapid acidification and inhibition by D-limonene are major challenges of biogas production from citrus waste. As limonene is a hydrophobic chemical, this challenge is encountered using hydrophilic Polyvinylidine Difluoride (PVDF) membranes in the biogas reactor. Thus, the two-stage process can be conducted in one reactor (Wikandari et. al, 2014).

Manufacturing Processes Framework

The steel framework is designed to not be very complex to manufacture. The metal pieces is cut to size, where after it is shaped and welded to form the framework.

Once the frame is assembled, it is galvanised to make it resistant to rusting.

Blades and gears
The blades and gears are the more complex shapes of the design. Made of Tufnol, these parts are machined to precision with a CNC router. This manufacturing
process is very fast, making the parts and design more suitable for mass manufacturing.

Figure 14: Shell, Blades & Gears

Image from: Maritz, M. 2015. *Shell, Blades & Gears*. [Rendering]. In possession of Minette Maritz. Cape Town.

Shell
The HDPE plastic shell is manufactured through vacuum. This manufacturing process is also very fast, suitable for mass manufacturing and quite inexpensive. The two halves of the shell are vacuum formed and assembled. If the shell should get damaged on either sides, only one of the halves has to be replaced. This also allows easy access to the mulcher for maintenance, as one half can easily be taken off.

List of Suppliers

Steel:

- Macsteel Trading

Steelpark, Robert Sobukwe Road, Bellville South 021 950 5500

- SA Metal Group

14 Christian Avenue, Epping Industria 2, Cape Town 021 590 3900

Tufnol:

- Gartech Engineering Plastics

Unit 7, Swift Park 2, Benbow Avenue, Epping Industria 1, Cape Town 021 534 3388 / 021 534 3409
info@gartech.co.za

- Spex cc

10 Wallflower Str, Paarden Eiland, Cape Town 021 510 2136
priday@spex.co.za

High Density Polyethylene (HDPE):

- MBT South Africa

Unit 4 College House, Village Walk, Parklands, Cape Town 021 556 7787

- Polymer Trade Johannesburg, South Africa 011 888 5918
  sales@polymertrade.co.za

Prototype

A prototype is only made of the mulcher and the shell, as these are the most important parts of the product designed. The prototype is made to 1:4 scale, providing a clear idea of the final product. 3D printing and lasercutting were used to create the prototype.

The shell and mulcher are 3D printed. 3D printing provides a quick method to produce accurate prototypes. 3D printing is an additive manufacturing process that produces three dimensional solid objects from a digital file. The process starts with making a virtual design in a CAD (Computer Aided Design) file using a 3D modelling
program (creating a new object) or with the use of a 3D scanner (to copy an existing object). As a new object is created for our design, the design is created in a 3D modelling program. In this additive process, an object is created by laying down consecutive layers of material until the entire object is created (3D Printing.com, 2015).

The gears of the mulcer are laser cut. Lasercutting is a type of subtractive manufacturing that cuts a digital design file into a piece of sheet metal (Ponoko 2015). A computer directs a high-power laser at the material, which then melts, burns or vaporizes leaving an edge with a high-quality finish (Ponoko 2015). Thus this manufacturing method is ideal for the gears, which contains intricate details.

After the shell, mulcher and gears are created, the parts are spray painted. This creates a better understanding of the final product. Lastly, the parts are assembled.

Figure 15: 3D Printed Parts

Image from: Molenaar, D. 2015. *3D Printed Parts*. [Photograph]. In possession of Daryn Molenaar. Cape Town.

Conclusion

Through reading this report, the reader was able to gain a thorough understanding of the complete design process leading up to the final design of BioFlux. The report identified the value offering of the product through analysing S.PSS and Biomimicry tools, as well as proving the technical and ergonomic viability of the product. Through describing the Design Analysis, Concept Analysis, Ergonomic Analysis, Technical Analysis and Prototype of BioFlux, the designers were able to identify and justify all decisions made in the design process. BioFlux can be seen as a successful innovative product, as it reduces the amount of labour required to discard citrus waste on farms, while also utilising the waste more efficiently through the production of biofuel. The product thus also promotes the use of renewable energy. The design process also successfully applied the S.PSS tools to gain a thorough understanding of the design problem. Inspiration was also gained from several Biomimicry champions, providing a thorough understanding of the deeper and complex needs of environmental systems.

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APPENDIX B: KUNYE PROJECT REPORT

- Faculty of Informatics and Design

ND: Three-Dimensional Design

DESIGN / TECHNOLOGY REPORT - KUNYE

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Rael Futerman, Andrea Grant Broom & Corbin Raymond 10 November 2015

Overview

"KUNYE" is a product designed by Alex Finke, Corban Warrington, Jaya van den Berg, Owen Visagie and Tashma Kritzinger. All are 3rd year industrial design students studying at Cape Peninsula University of Technology. The goal of this report is to describe various elements of the design including context, product details, viability and manufacturing techniques. This will be done to prove the product's technical, ergonomic as well as contextual viability in its set environment. This report is a clearly stated document that separates information using numbers and headings. It allows readers to access sections with ease and is written using clear academic language. The report will thus give an overall understanding of the product by splitting the report into different sections namely Design Analysis, Concept Analysis, Ergonomic Analysis and Technical Analysis. The report comes to the conclusion that all aspects of design were taken into consideration creating a product that would not only work optimally but also fit its context.

Introduction

This report was requested by external S.PSS coordinators in conjunction with CPUT design lectures. The objective of this report is to give insight into all aspects surrounding the product "KUNYE". This report will describe to the reader the design process leading up to the final design solution, identify the value offering of "KUNYE" through analysing S.PSS and Biomimicry tools and also prove the technical, ergonomic and contextual viability of the product. The report will be able to describe to the reader the production specifications as well as processes taken in the design. There will be various topics under separate sections namely Design Analysis, Concept Analysis, Ergonomic Analysis and Technical Analysis. All of these sections will be discussed to prove viability through primary and secondary research done throughout the span of the project. The primary research conducted entailed interviewing persons closely living to the field of research analysed for the KUNYE stove and the system as a whole. The findings and some of the candidates interviewed are mentioned in the report, however for privacy reasons their names have been changed.

Design Analysis

This section of the report will discuss how we approached our design specifically focusing on contextual and background to issues that gave rise to our concept. The section also evaluates the existing system against Life's Principles and explains how our product contributes to a renewed contextual S.PSS. Furthermore the proposed system is analysed and its shown how it is implemented according to Life's Principles.

Project Synopsis

"KUNYE" Initially started as a project given to 3rd year students studying industrial design at Cape Peninsula University of Technology. The focus of brief was on "Sustainable Product Service Systems" with regards to "Energy Product Design".

The project aimed to analyse existing energy products within human and natural systems in urban, peri-urban and rural areas. In order to ensure sustainable resource-efficient energy delivery in various areas, all stakeholders in the system had to be considered using the S.PSS tools and methodology. The lens for environmental sustainability was to be Biomimicry with analysis through Life's Principles. Finally Biomimicry methodology and S.PSS was to be implemented to improve and redevelop existing products within social systems and contexts.

The final outcome had to be a developed product prototype, designed and demonstrated within a sustainable product service system, using deep social and environmental sustainability as a benchmark. Concentrating on energy efficiency, the type of energy source used for the design takes disassembly and cradle to cradle in mind. The product had to be the redesign of an existing part or product within the system with specific budget kept in mind.

Context and Background of Problem Area

Cooking Methods within Informal Settlements in South Africa

When considering the health and safety issues regarding the use of paraffin, it was discovered that the problem was immense. According to participants of our primary research gathered from Amahle and Nandi, the majority of the residents of Khayelitsha and Langa do not seem to care about the health effects of paraffin. Nandi states that people will continue to use paraffin due to its affordability and accessibility (Kritzinger & Amahle, 2015). Currently a 1litre bottle of paraffin costs approximately R12.00 at the local spaza shops in the townships. This amount of paraffin lasts about 2-4 days depending on the season and the daily chores done. It was found that the main reason for paraffin usage in the informal settlements is due to the fact that one can pay for it in small increments. Unexpectedly, a study done by the City Government showed that all stakeholders interviewed were afraid to use paraffin and did care about the health and safety issues surrounding it. As a result of this, studies found that the use of paraffin is gradually declining yet continues to be used in low-income households (Trait *et al*, 2010: 50).

Figure 1 : Cooking in Townships

Image from: Carnovale, M. 2014**.** Cape Town wine tasting and Langa, Khayelitsha and Gugulethu townships. [Online]. Available: http://www.marcocarnovale.com/2014/01/cape-town-wine-tasting- and-langa.html. [30 October 2015].

The participants, Amahle and Nandi also reasoned that there will be a continuing demand for paraffin due to families being familiar with it - they can predict the cooking time; they learnt to cook with it by their grandparents, and they believe that certain meals are cooked better with it (Kritzinger & Nandi, 2015). From a designer's point of view, the use of paraffin has major negative implications regarding the overall living standards of people in informal settlements. Not only is the fuel dangerous and expensive but it is remarkably unsustainable, environmentally and socially (Kritzinger & Amahle, 2015).

According to interviews the main reasons why most people do not use alternative methods of cooking such as the gas stoves is that there are bad experiences connected to using them leading to bad assumptions. These individuals are thus frightened to use gas stoves as they are seen as dangerous methods for them. The alternative cooking method used is electric stoves.

This is however an unreliable source of cooking as access to electricity is lacking in most households (Kritzinger & Amahle, 2015). Some individuals do have access to electricity, however their methods of gathering electricity are often illegal and result in an unreliable connection in winter months due to cold and wet weather conditions damaging the connection points (Kritzinger & Amahle, 2015)(Mthupha, 2014).

Water & Sanitation in Informal Settlements in South Africa

Another issue in informal settlements, which turned out larger than expected, is the poor access to water and sanitation. Since many of the shack settlements do not have piped water, it is almost impossible to, for example, extinguish a fire when necessary. There are also fewer fire hydrants in poor areas and the water that should be in the hydrants are often empty (Currie *et al*, 2013:9). This causes a problem when Fire Departments have to intervene on a situation of an uncontrolled fire, making it very unsafe for fire-fighters to assist a community. It was also found that fire-fighters subtract in case of emergency due to local residents cutting the water hose to extinguish the fires near their own houses (Kritzinger & Morrison, 2015). As a resort, residents have to find water taps closest to them to fill buckets and form chains extinguishing fire where their homes are burning or break down surrounding houses as to take away fuel for the fire to spread. The Cape Town municipality states that five water taps is enough for 8000 people. However it is not viable for any (large) community to use a tap running on low pressure far away from the flames to fight a fire, too often causing troops of community members to become homeless when a fire breaks out (Currie *et al*, 2013:28)(Times Media Group, 2013).

Figure 2: Bucket System

Image from: Brodie, M. 2013. Claim that no-one in Cape Town has to use ‘’bucket system’’ is wrong. [Online]. Available: https://africacheck.org/reports/claim-that-no-one-in-cape-town- has-to-use-bucket-toilets-is-wrong/. [30 October 2015].

Besides fires destroying many houses at once in communities, sanitation is another factor that plays a large role in lowering the quality of life in peri-urban informal settlements. It has been established that the lack of adequate sanitation in this environment can be blamed on: (i) lack of legal status of the settlement area; (ii) poor accessibility; and (iii) lack of interest by residents to invest in sanitation. According to the World Health Organization, adequate sanitation includes sanitation facilities that hygienically separate human excretion from human contact (Mels *et al*, 2009:336).

The City of Cape Town describes the requirements for basic sanitation Standards as the following: “The provision of a shared toilet (at a ratio of not more than 5 families per toilet) which is safe, reliable, environmentally sound, easy to keep clean, provides privacy and protection against the weather, well ventilated, keeps odours to a minimum and prevents the entry and exit of flies and other disease- carrying pests; and the provision of appropriate health and hygiene education.” (2008).

By reviewing studies made on local settlements, it is evident that this standard is not being reached. Communities like Enkanini, an illegal informal settlement in Stellenbosch 40 km west of City of Cape Town has the ratio 72 toilets to 8000 people of which 9 toilets are locked and 9 need to be repaired *(Figure 3)*. A study discovered that residents in some communities found toilets to be unfairly distributed and that crime and violence made 90% of participants frightened to use the toilets at night (Mels *et al*, 2009:333). A common yet inappropriate way of trying to solve this problem is making use of the bucket system. The Minister of Water and Sanitation states that the department spent R899 million in 2014/2015 to eliminate the bucket system (Currie *et al*, 2013:13). Nevertheless, General Director, Margaret Ann Diedrick, reveals that the current statistics of bucket utilisation in the Western Cape is close to 60 000. As a result more than two million people (mostly children) die each year from diseases associated with inadequate sanitation. Many different solutions have been explored ranging from compost toilets to the use of Ventilated Improved Pit latrines (VIP). Most successfully the focus has shifted to the use of pour flush toilets connected to a bio-gas digester at a ratio of five households per toilet (Mels *et al*, 2009:337).

Figure 3: Toilet Cubicles

Image from: Brodie, M. 2013. Claim that no-one in Cape Town has to use ‘’bucket system’’ is wrong. [Online]. Available: https://africacheck.org/reports/claim-that-no- one-in-cape-town-has-to-use-bucket-toilets-is-wrong/. [30 October 2015].

Developed Location as Model

For the purpose of the research, Flamingo Crescent *(Figure 4)* which is an informal settlement in Lansdowne holds 105 shacks and was chosen as a model for the purpose of this system. Now called Flamingo Heights, it is currently being re-blocked by an organisation named the SDI South African Alliance, which works with various NGO's and IGO's such as CORCA and CPUT. The incremental re-blocking aims to improve the spatial layout of the settlement and upgrading existing structures with fire-retardant materials. As well as the provision of basic services such as installation of water, sanitation, electricity and paved access roads throughout the settlement. As part of the product development of KUNYE', the desired layout of the proposed system was illustrated. The current areal map of Flamingo Crescent was re-block and the infrastructure was altered to include toilet units, biogas digesters and a local gas shop. The improved map includes 3 Bio-gas digesters, 52 Toilet units (ratio 1 unit: 2 households) and 1 local gas store. For further application of the system, Langa Cape Town will be re-blocked along with SDI the infrastructure improved.

Figure 4 : Current Map of Flamingo Crescent

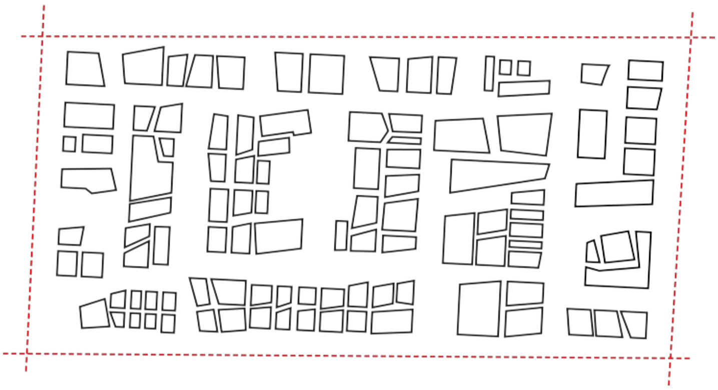


Image from: Kritzinger, T. 2015. *Current Map of Flamingo Crescent*. [Image]. In possession of Tashma Kritzinger. Cape Town

Image from: Kritzinger, T. 2015. *Reblocked Map of Flamingo Crescent*. [Image]. In possession of Tashma Kritzinger. Cape Town

Analysis of Proposed Location

Langa is an Informal Settlement located between Epping Industrial and Cape Town International Airport and consists of 52 401 people mainly living in shacks. Social problems such as crime, poverty and the lack of governmental support within the community results in poorly designed infrastructure and problematic resource utilisation. The sanitation consists of a bucket system that is implemented in concrete units alongside the outskirts of the settlement. At a certain time every day maintenance comes and collects the buckets and disposes the waste into a waste truck. Thereafter the workers rinse the buckets at the local taps which leaves the taps contaminated. Local residents make use of electricity for cooking and lighting during the hotter months of the year. During winter months, rainfall disrupts the source of energy and forces residents to make use of paraffin to do their chores as well as heat their homes.

Analysing the current system according to Life's Principles

The current system consists of two very linear systems 1. Sanitation and 2. Cooking. Sanitation is provided by Governmental Organisations and is part of human rights. It is not paid for, neither is it efficient. The second system relies on Paraffin provided by Private Companies and is a costly resource of energy. Neither the cooking system nor the toilet system *Adapts to Changing Conditions*. The stove is not resilient since it cannot recover after it has been exposed to a fire, knocked over or used wrongly. Yet the gas stove is diverse since it is able to be used for heating and lighting. The toilet system does not renew itself nor is it resilient. The toilets have to be maintained and cleaned every day. Considering all of the Life's Principles, the current system is definitely most *Locally Attuned and Responsive.* The stoves are manufactured locally and make use of paraffin that is provided by major companies like Sasol and Engen. Since toilet units are shared in the settlement, cooperative relationships are formed between residents for the upkeep of these units although they are not always successful.

Neither of the systems use life-friendly chemistry or evolve to survive and the current systems are doing the opposite. The popular Panda Stove is named 'The Time Bomb' since it is so dangerous and has killed so many people. The sanitation in the toilet systems creates issues that make a large amount of people sick. To *Integrate Development with growth* is not often applied to the current system, however, the current system is slightly *Resource Efficient* due to the form of the toilet unit and the stove fitting the function and national standards. In both cases no unnecessary material is used. The gas bottle is multi-functional but does not use low energy processes.

System Design Concept

After the problems in the system were identified, a new improved system was developed. The purpose was to create a closed loop system that uses the human waste and organic waste of the community to produce renewable energy which could be used for cooking. The system is reliant on the private company, KUNYE which outsources the manufacturing of the gas bottles and the stoves to an external company. After the stock is transported to KUNYE' it is distributed to the local shop which is located in the settlement. In return the local shop pays KUNYE for the stock and partnership fees. The local shop receives gas from the local service provider which produces gas via a biogas methane digester. The local shop then supplies the local household with the stove and gas which is used for cooking and the user (household) pays for the gas with cash. The waste from the household is distributed to two stakeholders. Firstly, the local service provider (digester/ toilet provider) directly receives the human waste from the local household. Secondly, the organic waste goes from the local household, to the local entrepreneur, then to the local service provider. In exchange for the organic waste the local service provider pays the local entrepreneur with slurry. Thirdly, the solid waste (e.g. glass and plastic bottles), is collected from the local household and sold to the government for recycling purposes. The local entrepreneur is an individual that registers with the local service company as an employee. The local service company is partially subsidised by the government for providing standard sanitation infrastructure and partially subsidised by the Private Company, KUNYE. The local shop also pays them for the gas that is received. The private company relies on NGO's and Dweller Movements to provide education and marketing to the community (local organization). The company also relies on them for constant feedback about the system and the product.

Analysing KUNYE's improved system according to Life's Principles

By aid of Biomimicry and the challenge to design tools, the re-design of KUNYE's system succeeded to use most of the Life's Principles. Most effectively the system is *Locally Attuned and Responsive*. It integrates cyclic processes by using the waste of humans to serve another function and benefit the community with sustainable gas. It uses readily available materials by using local manufacturers and biogas that is produced on site therefore no transportation or distribution is needed. It uses feedback loops from local residents, dwellers movements and NGO's to improve the product and system. It successfully cultivates cooperative relationships between community members, residents, government and NGO's. The system requires each member of the community to work in union in order to maintain the system and allow it to evolve.

Secondly, the system *Evolves to Survive* by replicating strategies that work in nature as well as looking at case studies that show the effectiveness of biogas digesters in Prisons in

Rwanda and settlements in Kenya. Since human waste and cooking is not often closely associated, the system is integrating the unexpected. Also by reshuffling the perception of people and the value of waste the system will be able to evolve. The KUNYE system *Adapts to Changing Conditions* by re-blocking settlements, allowing the system to fit into any environment. The system is modular and can be implemented anywhere where people live embodying resilience through variation and decentralisation as well as incorporating diversity. When users of the system see the benefit they gain from having both flushing toilets and having fuel to cook with, they will want to maintain the facilities and take care of it. In union with the appointed maintenance service this system will become self-renewable.

As previously mentioned the system does Integrate Modular and Nested Components by providing one digester for a certain amount of toilets and a certain amount of digesters per local shop. The system encourages users to participate in the installation and self-organise their desired layout and preferred infrastructure. The user is also advised to save money to invest in the system and therefore make the decision to partake before implementation. This can be seen as building from the bottom up which *Integrates Development with Growth.*

Throughout the lifecycle of the system it is *Resource Efficient*. The materials used to build the facilities include glass, concrete, bricks, porcelain, wood and metal. These materials can all be manufactured using low energy processes. When the facilities are being used the biogas produced requires low energy inputs and allows for *Life-Friendly Chemistry* without toxic substances. This breaks waste down into benign constituents and is classified as sustainable energy generation. This process can also be seen as recycling as well as the materials used to build the facilities has a very long lifespan and can be either reused or recycled. As mentioned before, the system is modular and adaptable, therefore fits the form to the function. And lastly, by combining two systems that were linear and useless before now creates a system that becomes multi-functional and is optimizing rather than maximizing.

The Business Model Canvas

The business model canvas gives a quick overview of all the partners, suppliers, costs, activities and so on involved in the designed system where the KUNYE stove fits in.

Key Partners

Key partners are:

- SDI South African Alliance
- CORC Community Organisation Resource Centre
- Federation of the Urban and Rural Poor (FEDUP)
- Informal Settlement Network (ISN)
- Cape Peninsula University of Technology
- iKayalami
- Habitat for Humanity South Africa (HFHSA)
- Government (Individual IGO's)

Key suppliers are:

- Presspin
- ADCENG
- Vulcan Steel
- Macsteel

Key resources from partners:

- Gas
- Toilets
- Stoves
- Gas canisters
- Methane digesters
- Infrastructure

Key activities performed by partners:

- Sales & distribution
- Marketing
- Installation
- Maintenance

Cost Structure
Most important costs:

- Installation of toilet units
- Installation of methane digester
- Infrastructure

Most expensive key resources:

- Materials for sanitation + methane digester

Most expensive key activities:

- Installation & maintenance
- Labour of local staff
- Marketing

Key Activities
Distribution channels:

- Local Integrated system
- Shop is close to homes

Revenue stream:

- Correct and strict control on money flow from one company to the other

Key Resources
Key resources:

- Gas
- Labour

Distribution channels:

- The company subcontracts to two other companies and outsources to manufacturers
- Local: the product is distributed to areas local

Customer relationship:

- The local households give feedback to the company via NGO's to ever improve the product/system

Revenue streams:

- The company relies on income from local shop (selling gas stoves and gas)
- The government funds local entrepreneurs

Value Propositions
Value to the customer:

- The value of health & safety providing a clean and fire-reduced environment

Problem solving for the customer:

- Solving the issues with the lack of sanitation/hygiene, electricity and health issues regarding the fumes of stoves

Bundles of products/services offered:

- The company is providing gas as renewable energy & clean toilets

Satisfying Customer need:

- The need to cook food without harming the customer's health & the environment
- Limits the amount of fires

Customer Relationships

Established relationships:

- Between community and company
- Between customer and local shop
- Between local shop and service business

Integration with the entire system

- The user's waste is key for the system to exist

Costs involved

- The customer's participation is priceless, the NGO's already work with these people and the company is strengthening that bond

Customer Segments

Creating value:

- For the people living in informal settlement & the government (& the country at large)

Most important customers:

- The individual families of the community

Revenue Streams

The value are customers are willing to pay:

- Cheap energy, which is easily collected, accessible and paid in increments

What they currently pay for:

- Paraffin
- Gas
- Electricity

How they are currently paying:

- With cash for paraffin; currently ZAR 12,-ZAR/L
- Electricity from the grid; sometimes stolen
- Refill gas ZAR 80,-

How they would prefer to pay:

- In small increments with cash

How much the revenue stream contributes to overall revenues:

- Paraffin is unsustainable and money goes towards large companies, which does not benefit communities

Concept Analysis

As soon as we were well educated with our context and how our products would fit into our system the next step could be taken where we chose the stove as a basis for our design. We set out to create a product that would utilize the Biogas produced in order to cook food in a sustainable manner. After primary and secondary research was conducted we were able to create a persona to add to our limitations.

Persona

Amahle is a middle aged female that lives with her husband and her one child in Langa, South Africa. In her shack-house in Langa she cooks approximately 3 times a day and uses a 2-plate electrical stove. The electricity she uses is borrowed from a neighbour which they pay for in small increments. Amahle also makes use of a paraffin stove during the winter months when the electricity is more unreliable due to rainy weather conditions. She owns a gas stove, however is too afraid to use it while living with other people she cannot fully trust to use this stove correctly. Amahle uses the local concrete bucket system toilet units that are provided by the government, however feels disgusted by using them due to it being unhygienic and smelly. Besides these disadvantages, the nearest working water tap available in her community are a decent 300 metres away from her home and is often filthy due to the toilet maintenance teams using these taps to clean the buckets. Amahle is fond of a clean environment and always ensures her house looks impeccable. Her day starts at 4 am and she leaves around 5am to work as a security guard in the city, from where she returns home around 6pm. In the mornings and evenings she boils water, fetched from the tap, to cook breakfast, lunch and dinner as well as to clean her son and herself. The filthy water created from these rituals are then always poured into a designated drain near the tap causing her to have to walk up and down multiple times a day with heavy buckets of water.

Design Process

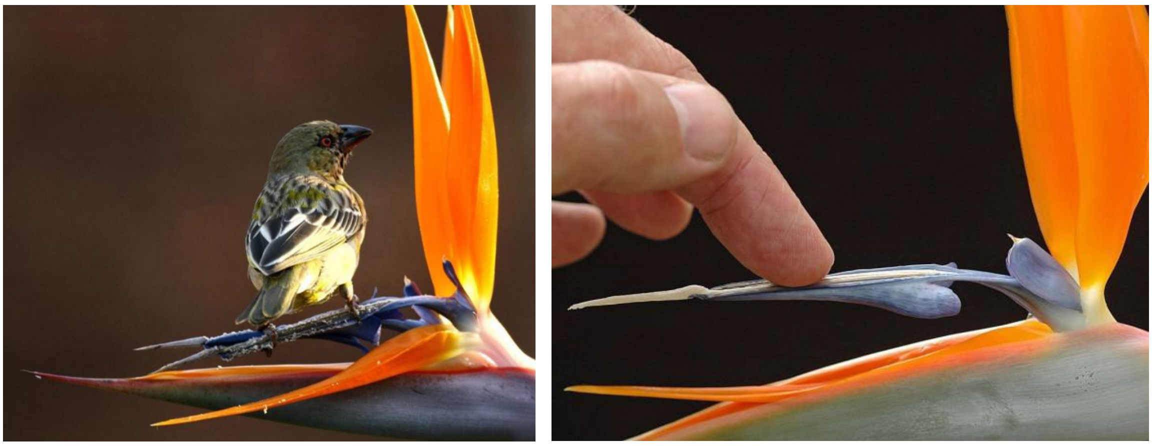
Now that our limitations were set we used an iterative design cycle where we came up with different concepts and discussed what we thought was true to our limitations in each. As each design cycle started a list of "Do's, Don't, Ideas and Concerns" were discussed. During each of these cycles, input from lectures were also taken into account. We followed this cycle until a final design concept was created.

The Biomimicry Champion selection and application

During these iterative cycles we identified key areas for development as well as areas in which we could potentially apply Biomimicry to solve design challenges. One of the main design challenges faced was preventing these stoves from becoming a fire hazard. We looked towards nature for inspiration and identified two key champions that could be used to develop a safety mechanism for our product. This safety feature was inspired by the "Mandela's Gold/" and "Venus Fly Trap".

The Mandela's Gold *(Figure 6)* is a flower that is able to bend and move without the use of hinges. These movements are reversible and work within the elastic/visco-elastic range of their materials. The "Mandela's Gold" relies on sunbirds to pollinate it. The flower is aligned perpendicular to the stalk, providing a perching spot for the birds. When a bird lands, its weight/pressure pulls down the bottom two petals causing them to open and reveal the anthers where the pollen is. The pollen covers the bird's feet while it's feeding on nectar and as it flies off to another flower it closes (Biomimicry Institute, 2011). Basically as soon as pressure is applied to the end of flower it opens and then closes if none is applied.

Figure 6: Pollination of the Strelitzia Reginae



Images from: Koorts, R. 2014. Strelitzia Reginae being pollinated by a Southern masked-weaver bird. [Online]. Available: http://www.trr141.de/index.php/research-areas-2/a04/. [24 October 2015].

The leaves of the "Venus Fly Trap" plant *(Figure 7)* closes within milliseconds after the mechanical stimulation of sensitive trigger hairs snapping shut when an insect lands on it. It can be done either with sensors or with the weight of the insect (Biomimicry Institute, 2005).

Figure 7: The Venus Fly Trap

Images from: Fun Guerilla 2010. Permalink to Venus Fly Trap: Very Hungry Plant. *Fun News.* [Online]. Available: http://beforeitsnews.com/fun-news/2010/06/venus-fly-trap-very-hungry-plant-79888.html. [24 October 2015].

This led to the development of a safety mechanism used within our stove. This safety mechanism works on the same basis as the "Mandela's Gold" and "Venus Fly Trap". It started out with the idea that as soon as pressure is placed on the top of the stove in the form of a pot etc, the valve would allow gas to escape. When no pressure is applied the valve would close and no gas would be able to escape *(Figure 8)*.

Figure 8: KUNYE valve system

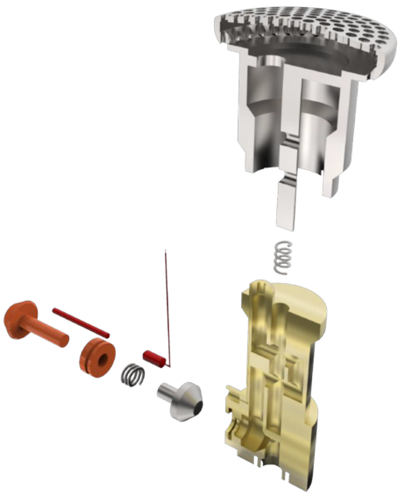


Image from: Finke, A. 2015. *KUNYE valve system*.
[CAD Design]. In possession of Alex Finke. Cape Town

The importance of aesthetics

Aesthetics is always somewhat important when it comes to design. As a starting point we looked at various stoves used by individuals in our context. These stoves included wood burning, gas, electric and paraffin stoves. What we found was that these stoves weren't the most aesthetically appealing. They had very basic features and was designed for function rather that visual appeal. We took this into consideration and created a stove that was very simple and easy to use while still being somewhat aesthetically appealing so that it can fit into any environment. The aim was to create a stove that would be seen as a status symbol as well as being adaptable to various environments. The overall prices of stove also needed to be kept to a minimum as the stove had to fall into the price range for individuals living in our context. This price limitation also had an effect on the overall design as materials and processes used to manufacture the stove needed to be kept to minimum cost. To add to the aesthetics of the stove a vibrant combination of colours and materials were chosen. The colour pallet we decided on was a combination of Teal, Orange and metal. This would give the design an attractive aesthetic appeal to the user.

Final Design

The final design decision as well design process took place on a CAD system where individual components could be created and ensure dimensioning and parts fitting together. This would ensure that components such as the safety valve would fit within the design as well as work optimally as a whole system. This allowed for rapid prototyping as well as final renders to take place.

Figure 9: Concept Sketching

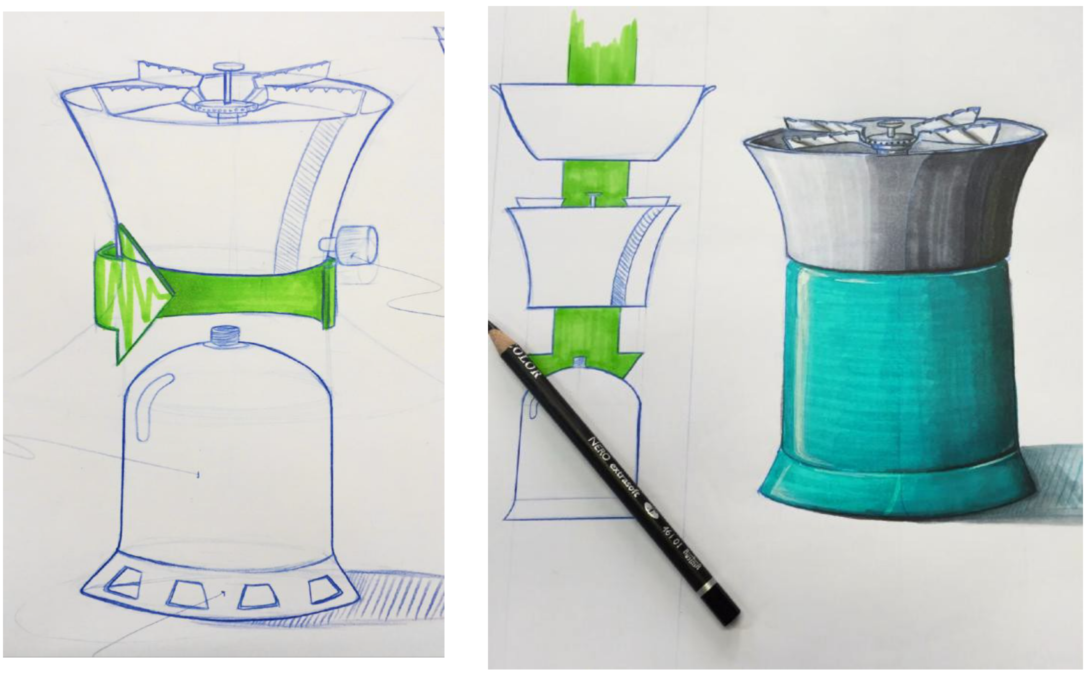


Image from: Warrington, C. 2015. *Concept Sketches KUNYE Stove*. [Drawing]. In possession of Corban Warrington. Cape Town

The final design *(Figure 10)* consists of three vital components being the gas canister, the stove top and the foot piece. The bottom section of the stove is the 1 kg cast iron canister containing the biogas that can be refilled once empty. Added support is given in the form of feet that would ensure stability on various terrain. These feet will also prevent the stove from falling over if a pot were to be placed off-centre. The feet are a simple added feature, welded onto a base where the canister fits into and creates more stability as well as minimises the use of unnecessary materials. The top section of the stove contains various components that makes the stove a new product. As a whole, the top section was designed to be screwed onto the gas canister by hand to create the whole stove system. The base of the cap section rests on the canister so that the weight is dispersed evenly when a heavy pot is placed on top of the stove. When the stove component is screwed into place the burner is essentially screwed into the canister directly allowing the gas to escape when needed.

Figure 10: Section view KUNYE stove

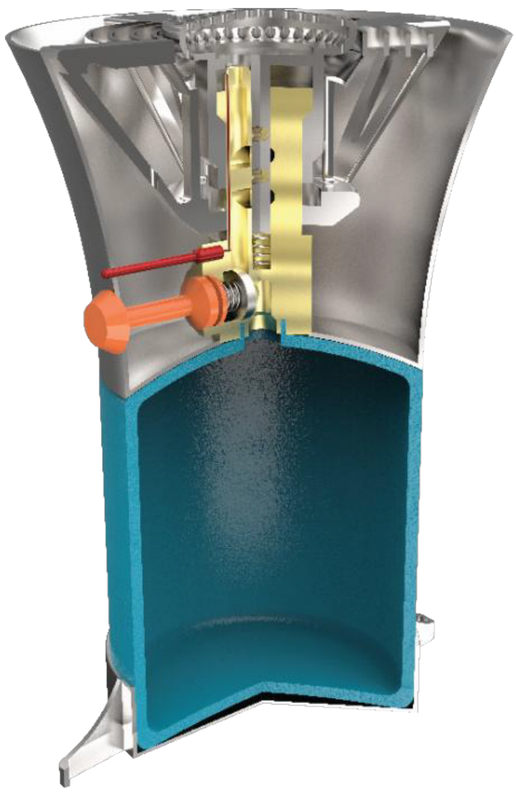
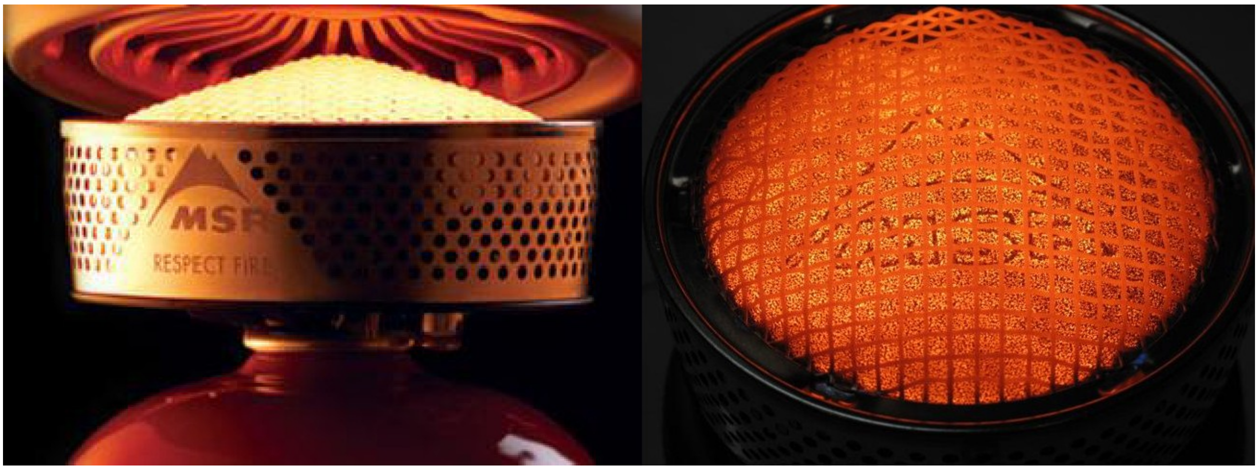


Image from: Finke, A. 2015. Section view *KUNYE stove*. [CAD Design]. In possession of Alex Finke. Cape Town

The top section consist of the following main components; Safety Valve, Switch and Burner. As mentioned in previous section the safety valves *(Figure 8)* works as follows; as soon as pressure is placed on the top of the stove in the form of a pot etc. the valve would allow gas to escape. When no pressure is applied the valve would close and no gas would be able to escape. This means that as soon as the stove is knocked over in some way the pot would fall off and no pressure would be applied to the stove top thus allowing no gas to escape and putting out the flame.

To allow gas to escape, the valve firstly needs to be opened so that the user will be able to ignite the flame by simply pushing the switch. The user can then adjust the intensity by simply turning the knob to the desired level. When the user is finished using the stove, they can simply turn the knob to the off position allowing no gas to escape. However due to the gas being odourless, as an extra safety measure a special odorant named Ethyl Mercaptan is added to the gas. Which is the most common odourising agent and is strongly associated with the smell of ‘’rotten eggs’’. It will allow users to detect leaking gas using their nose, and prevent gas build up, which can ultimately lead to a dangerous environment where a fire could break out (Georgia Public Service Commission 2004)(Hahn, 2015).

Figure 11: Gas Burner



Images from: MSR 2015. Reactor stove systems. *Cascade Designs Inc.* [Online]. Available: http://www.cascadedesigns.com/ie/msr/stoves/stove-systems/reactor-stove-systems/product. [25 October 2015].

The burner used is based on the MSR reactor which uses a unique way to generate heat. It's got a pressure regulator that keeps the gas flow in the same pressure in all terms regardless of how full the canister is or how cold it is outside. The gas is ignited within the reactor (the dome) and makes the whole burner red hot. This means that there are no regular flames that you see in other gas stoves (MSR, 2015).

This unique burner is built to work even in cases of strong wind. The burner itself is surrounded by a build-in wind shield. In addition, the bottom of the pot also prevents wind from blowing between the burner and the pot. It makes a structure that allows air to flow from beneath the burner to allow combustion. No wind will be able to blow between the burner and the pot. Most importantly this gas burner system is seen as the most fuel efficient at this moment in time making it the best choice for our product (MSR, 2015).

The biggest feature of our product is that the KUNYE stove makes use of Biogas, although it is not a physical feature, it is what makes our product stand out from the rest and can still therefore definitely be seen as a vital component of our design. Biogas is made up through a natural process of anaerobic fermentation whereby organic waste is broken down to produce methane. Biogas is naturally made up of 60-70% methane and up to 30-40% Carbon Dioxide with traces of Hydrogen Sulphide (World Bioenergy Associations, 2014). Waste that is used to produce biogas can consist of any type of manure produced by either livestock or humans. Organic waste also once broken down can produce efficient methane within an anaerobic digester (Last, 2008).

Once the biogas has been created and stored, it is used for cooking. It burns similar to normal gas, however biogas has more advantages than disadvantages (World Bioenergy Associations, 2014). Although the gas is made up from human- and animal waste, it is odourless and harmless to inhale unlike normal gas and paraffin. Biogas is also a renewable energy source making this a sustainable fuel source for our product and an appropriate substitute for non- renewable energy sources such as paraffin(C. Nelson, 2002)(Culhane, 2013).

Image from: Finke, A. 2015. *KUNYE Stove.* [CAD Design]. In possession of Alex Finke. Cape Town

Ergonomic Analysis

The stove was designed to meet the stringent SANS national standards and it even exceeds this standard as it produces less than half the amount of carbon monoxide required by law. The stove is able to cook food fast at high power using less gas than other stoves. All design decisions were made keeping ergonomic factors in mind to naturally suit its intended context.

Unlike the ergonomics of a chair this stove had far less dimensional guidelines to follow as a large variety of different sizes and shapes can be found. However certain elements of the stove had to be designed specifically to suit the peri-urban environment for the users to be able to interact with the product efficiently and safely. The contextual analysis will focus on these key elements and explain in depth how this was achieved.

Gas canister 1kg

One of the key components of our design was the choice of gas canister to be used in our design and the regulations connected to them. Various research was done into what would be a suitable choice for application in our design (See Technical Analysis). We found that gas used for cooking needed to be stored under high pressure and therefore we were required to choose a storage tank that complied with the regulations connected. This led us to using cast Iron gas canisters for the reason being that they come in various forms and sizes as well as complying with all the appropriate regulations. Currently individuals using Paraffin Stoves buy every 3 days or so which allows them to buy in small increments. We needed to take this into account so we used a 1kg gas canister which would allow individuals to work on the same basis and will need to be filled every 3 days. This size gas canister would reach a maximum mass of 2.8 kg when filled. Making it an acceptable portable weight for transporting to local refill stations. This weight would also keep centre of gravity low adding to overall stability. There was however a few things we needed to take into consideration when designing with such a gas canister in mind. This includes the following:

- Gas Cylinders need to be kept in an upright position within a well-ventilated area.
- Gas cylinders are not to be stored in damp areas near salt, corrosive chemicals, fumes, heat or exposed to the weather without a roof/housing.
- The regulator pressure control valve needs to be closed before attaching it to cylinders.
- Valves on gas cylinders need to be closed when a system is not in use.
- Never allow flames or concentrated heat sources to come in contact with a gas cylinder.
- Where compressed gas cylinders are connected to a manifold, the manifold and its related equipment such as regulators must be of proper design for the product they are to contain at the appropriate temperatures, pressures and flows.
- Use only approved valves, regulators, manifolds, piping, and other associated equipment in any system that requires compressed gas.

(IOWA State University, 2013)

Overall Size
The overall size of the stove as a whole had to be compact and allow for moving around while at the same time be structurally sound to handle large weights placed on top. The overall size of stove was thus based on average gas stoves found within households and adapted to fit within our design. We also looked at various other portable cooking systems to get a sense of what is accepted as the norm. The height of the stove had been determined through looking at other stoves and proved valid through interviews. The height was ideal as most people sit on the floor whilst cooking. The stove could also be placed on table tops and still be of acceptable height to work from. The stove top diameter was increased slightly to ensure various pots and pans used by individuals in our context would fit.

Stability
Stability with a product such as a stove is very important. To ensure that the stove would not be knocked over, a base with feet was created with a slightly larger footprint than the rest of the body. The centre of gravity and weight was low as the canister is the heaviest part. The feet also ensure stability so that if a pot was to be placed off-centre, the stove would not fall over.

Switch
As our switch combined a variety of functions it was quite an important part of the design. We were able to identify a few ergonomic aspects that we needed to take into consideration these include the following;

When looking at the push button switch used to ignite stove the following recommendations were made:

- The resistance of the push-button should increase gradually and then disappear suddenly to indicate that the button has been activated.
- The top of the button should have a high coefficient of friction to stop the fingers from slipping off. Where push-buttons are to be activated by the fingers, the concave form is preferable.
- To indicate that the button has been activated, a sound should be emitted if the workplace has low light levels.

(Karwowski, 2006)

The rotary part of the switch has recommendations made:

- In most applications rotary switches should have a fixed scale and moving pointer.
- The turning resistance should steadily increase and then suddenly decrease as the next position is approached.
- Cylindrical switches (knobs) should not be used if the resistance has to be high.
- Where only a few positions (2-5) are needed, they should be separated by 30-40 degrees.
- A sound should be made to denote that the switch has been activated. There should also be a definite stop position at beginning and end of the scale so that these positions can be counted out.
- The scale should always increase clockwise.
- The hand should not shield the scale.
- The surface of the switch should have a high coefficient of friction so that the hand does not slip.
- The distance between panel and the knob should be at least 3 mm.

(Karwowski, 2006)

All these guidelines were followed to create a switch that is ergonomically appropriate. Other things that needed to be taken into account when looking at our context was that the switch had to be easy to use, straightforward and very indicative. Colour was also used as indicator of importance and also how to use.

All elements of the KUNYE stove mentioned in the ergonomic analysis were well thought off and designed to best suit the users of the peri-urban environment and for them to be able to interact with the product efficiently and safely.

Technical Analysis

As the basic design was finalised we needed to decide on the different materials that could be locally sourced if this product was to be manufactured as well as the finish of each component. Another important aspect was the manufacturing processes that would be used.

Materials and Finish

Cast Iron Canister

Cast Iron gas canisters was chosen as these were designed for refilling and repeated use. These canisters are known for its long lifespan lasting up to 40 years. Most refillable gas canisters and in our case have an interior wall thickness of around ¼ inch and a reinforced neck and bottom. Reason being commonly used gases including Biogas are highly pressurized (between 1,500 psig and 2,500 psig) (Virginia Tech, 2011). These cylinders must be maintained in a good condition and protected from accidental damage at all times.

The finish of the gas canisters will be spray painted to desired colour. Finish is dependent on desired choice whether gloss, matt, metallic etc. which means various designs could potentially be applied. In our case however we decided that the canister will be spray painted teal with our logo also sprayed on the canister in orange.

Mild Steel Top Section

Mild steel will be used for the top section shell and various components as it is the most cost effective material for shell of this size and also components. Mild steel provides the strength required. The shell needs to be spun mild steel as it is the preferred choice as it's been used by companies such as Presspin for years. Steel is an extremely durable material and much harder than aluminium (Bewlay et al, 2006). Its strength makes it less prone to warping, deformation, and bending under high forces or heat stress. Moreover, steel is a very dense material. In fact, it is 2.5 times denser than aluminium. This ensures that steel spun parts will not dent or scratch easily (Bewlay et al, 2006). The finish of all mild steel component will simply be the brushed mild steel itself.

Brass Valve

We decided to choose brass as the material for our valve system reason being that brass is the preferred choice when it comes to gas systems. Brass is any alloy consisting of copper and zinc. Making it much cheaper than its rival Bronze. Combinations of iron, aluminium, silicon & manganese make brass corrosion resistant. Brass also negates spark which especially important when it comes to fittings around explosive gas (Diffen, 2015).

High heat resistant food grade Polypropylene plastic Switch

Polypropylenes offers a good balance of properties and are one of the most cost effective and widely used general purpose EPP's available. Polypropylene offers ease of processing with excellent chemical resistance and good mechanical properties. It is a stiff, lightweight and hard polyolefin with a high heat resistance and excellent chemical resistance at elevated temperatures. It has a high melting temperature of between 160 °C – 165 °C. It is also Scratch resistant and moisture resistant making it excellent for food and chemical applications (Maizey, 2015). The colour finish of switch itself will be orange with white indicators sticking to the overall aesthetic feel.

List of suppliers

One of our aims was to locally source all materials and processes for final product as this would uplift the community and mean that final product could be locally manufactured.

Macsteel - Cape Town

With a proud history spanning more than 100 years, Macsteel Service Centres SA has developed and expanded into the leading steel service centre and distributor in Africa. Macsteel will be used to supply the following:

- Mild Steel

Phone Number: +27 21 950 5800 / Fax Number: +27 21 950 5899 E-Mail: william.parkin@vrn.co.za /dave.watson@vrn.co.za
Physical Address: Steelpark, cnr Modderdam Road & Symphony Way, Belville South, Cape Town
Postal Address: P.O. Box 64, Sanlamhof, 7532

Vulcan Steel – Cape Town

Recognizing great challenges and opportunities for a specialist steel cutting service for the local engineering industry. The Laser Cutting section of Vulcan Steel was started in September 2004 to provide a quality, customer focused cutting service delivering flat metal parts on a daily basis throughout the Western Cape. They also offer metal bending services. What makes Vulcan Steel perfect is that Macsteel is the main supplier of Vulcan steel. Meaning that distribution costs will be kept minimum. Vulcan Steel will be used for the following:

- Profile Cutting and Bending

Tel: +27 (021) 528-8900 / +27 (021) 551-7894
Fax: 0866 22 7878 / +27 (021) 551-7878
Email: Information: info@vulcansteel.co.za / Laser: laser@vulcansteel.co.za / Debtors: debtors@vulcansteel.co.za
Physical Address: No.8 Longclaw Drive, Montague Gardens, Cape Town, Western Cape, South Africa

ADCENG - Cape Town

ADCENG Gas Equipment operates out of bases in Johannesburg, Durban and Cape Town. The company supplies and supports a comprehensive range of gas equipment in industrial, commercial and domestic applications. From the outset the company operated on the basis of providing the most appropriate gas products and solutions based on best practice standards. In addition to manufacturing its own products ADCENG's project and export division has a good working knowledge of international gas standards and is therefore well placed to advise and cooperate with its customers and suppliers on design work and safety standards of valves etc. ADCENG will be used to supply the following:

- Safety Valve/ Other Valve Components

Tel: 27 21 5512118 / Fax: 27 21 551 0527

Email: adcct@adceng.co.za

Physical Address: Units 1 & 7 Jarin Park Cnr. Dawn and Stella Rds Montague Gardens 7441 Postal Address: P O Box 37208 Chempet 7441

CADAC - Cape Town:

CADAC, the blue cylinder at the heart of every South African home for more than 60 years and a brand which has been woven into the fabric of South African lifestyle. CADAC is as much a part of South African culture as braais, biltong and boerewors. CADAC is constantly striving towards innovative thinking, continuous research and new product development, and as a result is at the forefront of developing solutions and products that meet changing expectations of the consumer globally. CADAC, is one of the most recognized and trusted brand names in South Africa. It is the leading marketer of a wide range of outdoor leisure and patio products, designed for unequalled durability, portability and convenience.

CADAC also supplies its own range of Gas Canisters that can be used for all applications ranging from small to large. CADAC will be used supply the following:

- 1 kg Gas Canister

Tel: 021 552 3125 / Fax 021 552 5137

Email: Maureen@cadac.co.za / evanob@cadac.co.za

Physical Address: Unit A1, Platinum Junction Business Park, No 4 School Road, Milnerton Postal Address: P.O. Box 211, Eppingdust, 7475

Presspin - Cape Town

Press Spinning specialises in metal pressings and metal spinning. Established in 1956, we work in brass, copper, stainless steel, mild steel and aluminium. Press Spinning is committed to supplying its customers with high quality metal pressing and metal spinning products at affordable prices. Presspin will be used for the following:

- Spinning of Shell

Tel: 27 21 511 0656/ Fax: +27 21 511 3583 / Cell: 082 803 1433
Email: info@presspin.co.za
Physical/Postal Address: 42 Lowestoft Street Paarden Eiland 7405

Manufacturing processes

Laser cutting

Various components such as feet, logo, base etc. will be profile cut using a process known as Laser Cutting. Laser cutting uses a high-powered beam to cut material based on computer- controlled parameters. As the laser guides its beam along the material, everything in its direct path is vaporized, burned or melted. One of the benefits of laser cutting technology is the cut product rarely needs any finishing work as this process ensures a high-quality surface finish.Laser cutting is also very accurate and profiles can be placed close together saving wastage of material (Thomas, 2015). It is able to achieve this using the following process. The laser machine uses stimulation and amplification techniques to convert electrical energy into a high-density beam of light.

Stimulation occurs as the electrons are excited by an external source, usually a flash lamp or electrical arc. The amplification occurs within the optical resonator in a cavity that is set between two mirrors. One mirror is reflective while the other mirror is partially trans missive, allowing the beam's energy to return back into the lasing medium where it stimulates more emissions. If a photon is not aligned with the resonator, the mirrors do not redirect it. This ensures that only the properly oriented photons are amplified, thus creating a coherent beam cutting material (Thomas, 2015).

Bending

Bending of sheet metal is a common and vital process in manufacturing industry. We will use this to bend feet into shape. Sheet metal bending is the deformation of the work over an axis in this case metal, creating a change in the part's geometry. Similar to other metal forming processes, bending changes the shape of the work piece, while the volume of material will remain the same (TLOM, 2013). In some cases bending may produce a small change in sheet thickness. For most operations, however, bending will produce essentially no change in the thickness of the sheet metal. In addition to creating a desired geometric form, bending is also used to improve strength and stiffness to sheet metal, to change cosmetic appearance and to eliminate sharp edges (TLOM, 2013).

Welding

We will be using a process known as welding to join our feet to the base cap as well as the spun shell section. Welding is the joining of metals. What welding does is join metals or other materials at their molecular level. What we know about welding is that there are four components to a weld. The four components are the metals themselves, a heat source, filler material, and some kind of shield from the air (Hashemite University, 2012). The welding process works as follows. The metal gets heated to its melting point, at the same time there is some sort of shielding from the air to protecting it, and then a filler metal is added to the area that needs to be joined ultimately producing a single piece of metal (Hashemite University, 2012).

We will specifically be using Shielded metal arc welding better known as Stick welding uses a rod or in the technical terms it is called an electrode that has a powder coating (technically a flux) on it that burns or melts to create a shield from oxygen and some rods have filler metal added to the coating to speed up the welding process. Afterwards, you chip off the slag to see the weld. Stick welding is the most common welding process. The flux shields the weld from oxygen and is exceptionally good for basic joining such as in our case (Hashemite University, 2012).

Metal Spinning

The metal spinning process consists of a tube or a disc of metal that is rotated at high-speed and machined into an axially symmetrical product using either a vertical or horizontal lathe. Force is delivered by a tool with a rounded end or a roller. A flat or possibly pre-formed, work piece is held between a mandrel and tail stock. As the apparatus rotates, the tool applies localized pressure to the work while it gradually moves up the mandrel (Bewlay et al, 2006). This causes the sheet metal work to be wrapped over the mandrel, thus taking its shape. Metal spinning is commonly performed cold but in some cases parts may be subject to warm or hot spinning. Spinning is capable of producing large parts. The advantage of spinning over other forming processes is its capacity to create seamless products from a single piece of material, with relatively low-cost tooling. Without seams, parts can withstand much higher internal and external pressures (Bewlay et al., 2006).

Plastic injection Moulding

The plastic switch used will be manufactured using injection moulding. The plastic injection moulding process produces large numbers of parts of high quality with great accuracy and minimum time. Plastic material in the form of granules is melted until soft enough to be injected under pressure to fill a mould. The molten plastic that has been melted from pellet form in the barrel of the moulding machine is injected under pressure into the mould (University of Obuda, 2013). After the molten plastic has been injected into the mould pressure is applied to ensure all cavities are filled. The moving and fixed platens of the injection moulding machine holds the mould tool together under pressure. The plastic parts are then allowed to solidify in the mould (University of Obuda, 2013). The moving platen moves away from the fixed platen separating the mould tool. Rods, a plate or air blast then aids ejection of the completed plastic moulding from the injection mould tool. The result is that the shape is exactly copied. The whole injection moulding process can then be repeated a large amount of times (University of Obuda, 2013).

Conclusion

This project analysed sustainable product service systems in peri-urban areas in Cape Town with the main focus on energy product design. To create a sustainable and resource-efficient product, all aspects of the system had to be considered, through the use of the S.PSS tools and methodology. Analysis through Life's Principles were applied stemming from the Biomimicry methodology in order to create KUNYE. These methods allowed for improving and redeveloping existing products/systems within the social system of the peri-urban context.

This report gave an in-depth analysis and description of the design analysis. Explaining how the Biomimicry and S.PSS tools were used as well as giving a thorough exploration background and context of the selected area and proving its viability. Furthermore the report analysed the KUNYE stove concept explaining step-by-step the design process and how Biomimicry has been applied to the stove. It also focused on the ergonomic analysis where key aspects were designed to perfectly slot in the peri-urban environment allowing its users to interact with the product safely and efficient. Lastly the report explores the technical aspects of the KUNYE stove and describing its manufacturing processes.

What makes this product so successful is the fact that the system it fits in is entirely sustainable. Human waste and the use of paraffin used to be two linear systems and are now integrated in a cradle-to-cradle system. The waste collected and used in a methane digester to generate gas is then used for cooking to make food, therefore producing waste again. This has a positive impact on the environment, therefore benefitting the government and the country at large. Other reasons why this product is successful is the integration of local entrepreneurs and businesses, creating more socially and economically sustainable communities. The KUNYE stove also aids to a safer and healthier environment for people to live and work in creating an overall feeling of upliftment.

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APPENDIX B1: STAKEHOLDERS

Direct contact with product:

- People in informal settlements (consumers)
- Distributors
- Manufacturers of the KUNYE stove and gas bottles
- Designers

Other:

- Raw materials suppliers of the product + other components
- Transport from manufacturer to distributor
- Project funding from bank or private
- company that disposes (recycling program)

Partners:

- SDI South African Alliance
- CORC Community Organisation Resource Centre
- Federation of the Urban and Rural Poor (FEDUP)
- Informal Settlement Network (ISN)

- Cape Peninsula University of Technology
- iKayalami
- Habitat for Humanity South Africa (HFHSA)
- Government (Individual IGO's)

IGO Stakeholders (Potential)

Department of:

- Water & SAnitation
- Water Affairs and Forestry (DWAF)
- Human Settlement's
- Housing
- Urban Management Planning,
- Infrastructure and Service Delivery
- Institutional Social Development.
- National Fire Department
- Disaster Management

Dwellers Movements- (improving the living conditions of poor people)

Poor People's Alliance:

- Abahlali baseMjondolo – (Western Cape)
- Western Cape Anti-Evicting Campaign (AEV) - (Western Cape)

Landless People's Movement – (Gauteng)

APPENDIX C: OBSERVER'S REPORT

the Learning Network on
Sustainable energy systems

Evaluation of the Pilot Structured Course
- S PSS with regard to DRE -
CPUT Industrial Design/Mechanical Engineering project as a pilot course within the new framework of Design for Sustainability

Implemented by
the ACP Group of
States Secretariat

EDULINK

Funded by the EU

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Glossary of terms

CPUT	Cape Peninsula University of Technology
GES	Global Environmental Studies
LeNses	Learning Network for Sustainable Energy Systems
OLEP	Online Learning E-platform
S.P SS	Sustainable Product Service System

Introduction

The Industrial Design Department in the Faculty of Informatics and Design at the Cape Peninsula University of Technology (CPUT), in Cape Town, South Africa, recognises the need for graduate design professionals to design for sustainable futures.

As elaborated by Tonkinwise, Irwin & Kossoff (2015: 1): Transition Design acknowledges that we are living in 'transitional times' and takes as a central premise the need for societal transitions to more sustainable futures. It argues that design has a key role to play in these transitions and applies an understanding of the interconnectedness of social, economic, political and natural systems to address problems at all levels of spatio-temporal scale in ways that improve quality of life. Transition Design advocates the reconception of entire lifestyles, with the aim of making them more place-based, convivial and participatory and harmonizing them with the natural environment. ... Everyday life is viewed as a potentially powerful, transformative space (Lefebvre 1984; Gardiner 2000) where transition designers explore ways in which basic human needs are satisfied locally, within economies that exist to meet those needs (Max-Neef 1992; Illich1987; Kamenetsky 1992).

In order to envisage such complex societal change, the authors cite Capra & Luisi 2014; Briggs & Peat 1999; Prigogine & Stengers 1994; and Wheatley 2006, as having proposed a Living Systems Theory which outlines general principles for how all living systems work. The theory explores phenomena in terms of dynamic patterns of the relationships between organisms and their environments. Self-organisation, emergence, resilience, symbiosis, holarchy and interdependence, among others, can serve as leverage points for initiating and catalysing change within complex systems (Irwin 2011).

In fulfilment of its mission to, among others, "build a university that is...sustainable and environmentally conscious" (http://www.cput.ac.za/about/vision), CPUT is a partner with the Learning Network for Sustainable Energy Systems (LeNSes) through its Industrial Design Department. LeNSes aims 'at the promotion of a new generation of designers (and design educators) capable to effectively contribute to the transition towards a sustainable energy for all society' and 'to promote a new shared and articulated disciplinary ground on System Design for Sustainable Energy for all focused on Sustainable Product, Service, System (S.PSS) and Distributed Renewable Energy (DRE) models...'. (http://www.lenses.polimi.it/index.php?M1=1&M=1&P=p_lensdesc.php)

The Industrial Design Department committed to this partnership with LeNSes by integrating S.PSS tools into a structured Industrial Design/Mechanical Engineering project as a pilot course within the new framework of Transition Design. The project, through the additional introduction of Biomimicry, aimed to demonstrate how design can '[frame] problems related to socio-material change within the context of complex ecosystems' (Tonkinwise, Irwin & Kossoff, 2015).

The course was conceptualised as a collaborative learning space for second-year students from the Global Environmental Studies (GES) course in the Dept of Mechanical Engineering and third-year Industrial Design students. Professionals in these disparate fields are frequently required to work together in their careers and this pilot course was designed to expose the students to such collaborative work.

Although the course was initially conceptualised more as a collaborative than specifically a transdisciplinary learning opportunity, it seemed that the course might provide interesting possibilities for transdisciplinary learning, and that the research should look for evidence of this. Transdisciplinary learning can be said to be the exploration of a relevant issue or authentic problem that integrates the perspectives of multiple disciplines in order to connect new knowledge and deeper understanding to real life experiences (www.greenwichschools.org/page.cfm?p=6695)[2]. Roberto Cuervo, an Industrial and Urban Designer and Associate Professor at the Pontificia Universidad Javerian, Colombia, an active researcher in design theory with an interest in interactive and trans-disciplinary design, maintains that '(t)he methodology of Design discipline demands Trans-Disciplinary work in order to have a holistic vision of the Human possibilities.' (Cuervo undated[3], 1). He makes the distinction between interdisciplinary work, where several disciplines work together around a problem or need, 'overlapping one from another but maintaining their own epistemological core,' and 'trans-disciplinary work where the core is precisely the overlapping disciplines, generating a new way of facing the problem or need, a more holistic vision in the boundaries of each disciplines offering a new territory of research where the knowledge core is blurring...' (sic) (ibid, 2). He goes on to say 'It is precisely on the boundaries between different disciplines where we can discover new challenges and fruitful territories to propose innovations in the field of Design' (ibid, 2).

The introduction of the S.PSS analytical and communication tools were to be used alongside Biomimicry's Life's Principles and the biomimetic design lens to inform all aspects of the course. These tools were to serve first to broaden (diverge) and then narrow (converge) the search for innovative product design by studying existing energy systems being used in rural, peri-urban and urban social contexts as well as energy systems in nature. Furthermore, it was hoped that indigenous wisdom, important to consider in transitional design, would be another aspect that students would draw on during their search for appropriate energy

[1] www.greenwichschools.org/page.cfm?p=6695 Accessed 31 March 2016
[2] www.greenwichschools.org/page.cfm?p=6695 Accessed 31 March 2016
[3] www.Icsid_Conf09_Roberto%20Cuervo%20(1).pdf Access 31 March 2016

systems design. It was envisaged that weaving knowledge from all these, rather disparate, knowledge bases would generate new and more holistic ways of conceptualising design and for innovative design for transition. The pilot course thus aimed to begin to radically shift the way engineering and industrial design students view the role of design in a world in need of radical re-design not only for sustainability, but for the thriving of all life.

Aims of the evaluation

The aims of the evaluation were to explore:

the structured Industrial Design pilot course as a method of facilitating integrated[4], transdisciplinary learning between engineering and design students at CPUT and possible lessons for fostering transdisciplinary learning among other disciplines and faculties;

the introduction of a Sustainable Product Service System (S.PSS) approach that ensures products and services take the broader environmental context - social, economic, political and ecological - into account;

- student perspectives on the usefulness of the S.PSS tools and methodologies and of the LeNSes website for facilitating access to these design resources;
- the use of Biomimicry as a lens and a methodology for designing sustainable solutions to particular problems; in this pilot course, for designing renewable energy solutions in formal, informal and rural contexts, taking the complex needs of the associated environmental systems into account;
- the final project prototypes, as design concepts arising from the collaboration process, in terms of their environmental and economic sustainability, innovation and practicality;
- the suitability of the pilot course for shifting the thinking of industrial design and engineering students from merely designing products towards seeking more holistic design solutions, within complex systems, for transition.

It was expected that the evaluation would make recommendations for

a) the transdisciplinary Industrial Design course
b) the GES course for Mechanical Engineering students
c) the integration of S.PSS and Biomimicry tools and approaches in design curricula
d) future cross-faculty and cross-departmental collaborations at CPUT.

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[4] holistic learning where knowledge, skills and values are brought to bear on an unfamiliar problem, in a real-life context, to propose possible solutions through reflexive learning.

Evaluation Methodology

Methodologically, the evaluation followed a case study approach, seeking to provide an in-depth qualitative analysis of the transdisciplinary Industrial Design course in line with the aims of the study described above, and of its value as a learning experience for the students participating. Analysis of the data focused on the following themes:

- the course as a means of facilitating and promoting transdisciplinary learning;
- the efficacy of Biomimicry and of S.PSS for facilitating sustainable design solutions in this learning and teaching context;
- the transdisciplinary course as a means of shifting students' thinking towards more holistic, sustainable design;
- challenges and successes experienced and what can be learned from these.

Data collection strategies and methods

Meetings:

The researcher attended meetings with the personnel involved in coordinating and teaching the pilot course, to gain an in-depth understanding of the course and its rationale.

Secondary data:

The course aims, outline, planned activities and content were studied to provide the context, the secondary data for the evaluation and for triangulation of the data.

Primary data from students:

This comprised six observations of the taught course and facilitated group work sessions, a field trip to Kirstenbosch Botanical Gardens, a questionnaire completed by students at the end of the taught course and observations of the final project presentations and prototypes. The moderated assessment of the projects formed part of the data for analysis.

The course observations were recorded on a template designed by the researcher (Appendix 1), incorporating some of the categories identified in the LeNSes *Questionnaire for Observers Evaluation Procedure* relating to pedagogy and curriculum; for example the learning content, the learning activities, and the modes of learning and teaching.

The researcher undertook the field trip to Kirstenbosch Botanical Gardens with the students to observe how they experienced learning about Biomimicry in an authentic, natural environment, facilitated by a specialist botany educator.

The intention was to attend the final student presentations of their projects, to hear what they had learned, how successful the project had been as a transdisciplinary learning experience, and how well they had understood and applied the particular Biomimicry methodology and S.PSS tools. However, because of student protests at CPUT which erupted at that time, the presentations were postponed and only took place at final moderation, where they were both marked and moderated by external examiners. For ethical reasons the researcher did not attend these presentations but did visit the exhibition of the projects and recorded certain observations as data. The feedback from the lecturers and course coordinator on the final projects also provided data for the analysis.

Finally, at the end of the taught component of the course and before they ventured into the design project, all the Industrial Design student participants completed a questionnaire to ascertain their perspectives on the following aspects of the course:

- S.PSS and Biomimicry as tools and methodologies for promoting and facilitating renewable energy design solutions in authentic contexts;
- The challenges and successes of the course in achieving its aims; and
- The usefulness of the LeNSes website and resources.

Primary data from key personnel:

The course coordinator, who also participated in and facilitated some of the class activities and discussions, and the two course lecturers (referred to as Lecturers A and B to protect their anonymity) were interviewed at the end of the course, to ascertain their perspectives on the challenges and successes of the course in achieving its aims.

Findings

Course structure

The course was conceptualised as a six-week, project-based, structured course[5] for third-year Industrial Design and second-year Mechanical Engineering students from the GES elective course. The Mechanical Engineering students were scheduled to attend every Wednesday afternoon session at the Cape Town campus, working in teams with the Industrial Design students. In addition, the teams were expected to work collaboratively off campus, in their own time, in order to complete their projects. The participation of the Mechanical Engineering students in the team designs was to form part of their GES course assessment.

The aims of the course were for the students to:

- Analyse existing energy products within human and natural systems in rural, peri-urban and urban contexts;
- Consider all stakeholders in the system, using the S.PSS tools and methodologies, to ensure sustainable, stable, resource-efficient energy delivery;
- Apply Biomimicry as the primary lens for environmental sustainability, with analysis and evaluation through Life's Principles;
- Apply Biomimicry design methodology and S.PSS tools and methods to improve and re-develop existing products within social systems and contexts;
- Become proficient in the relevant S.PSS tools and utilise these to design a Sustainable Product Service System and produce and manufacture a prototype proposal (one product per group) for an identified energy-producing or energy-consuming product; two for use in each of a rural, peri-urban and urban setting.

The structure of the six week course was planned in two week phases, as outlined in the course timetable:

Weeks 1 and 2:

- Introduction to LeNSes and S.PSS tools; three design exercises based on case studies presented. S.PSS tools to be introduced to the students:
  - Drivers and Barriers
  - SWOT analysis
  - Sustainability Radars
  - Stakeholder Mapping
  - System Mapping
  - Business Canvas Model
- Introduction to Biomimicry methodology – 'design to biology' and 'biology to design' challenges, Life's Principles (Appendix 3).
- Presentations and workshops, guest lectures on natural energy systems and renewable energy technologies.
- Primary context research through desktop research and using participatory design methods and activity theory where possible.

Weeks 3 and 4:

- Conceptualisation of S.PSS.
- Video presentations of ideas by students for evaluation.
- Documentation of process through a research report and visual diaries.

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5 See Appendix 2 for course outline and timetable

Weeks 5 and 6:
Prototyping and manufacturing of products for final presentation to a selected panel for evaluation.

Observations
Observation 1, September 2:

This was the first full afternoon lecture session of the course, an introduction to the course, and both Mechanical Engineering and Industrial Design students were present. The aims and objectives of the course were explained and the students were introduced to Biomimicry, to LeNSes and to Life's Principles, mainly through illustrative Powerpoint slides and discussion.

Lecturer A presented Biomimicry and Life's Principles, a holistic Biomimicry measure of the extent to which a product, process or system fulfils conditions that are conducive to life. Lecturer B focused on LeNSes and illustrated the discussion with his experiences as an observer at the pilot LeNSes course in Uganda in 2015, and with renewable energy case studies. This was followed by an introduction to activity theory, especially in relation to group work dynamics, as a way of motivating the students to work together effectively as teams and of appreciating the different strengths that each member brings.

It was decided that, as there were so few Mechanical Engineering students attending, there should be five and not six working teams, comprising between five and six Industrial Design students per team. The teams chose the contexts which they wanted to research and design for: two teams chose an urban setting, two a peri-urban setting, and one a rural setting. The teams were briefed to scope urban/peri-urban/rural energy-related products in their contexts to inform the next steps of S.PSS design. The four Mechanical Engineering students were not allocated to any particular team, but could 'float' among the groups, offering input and critical feedback as needed.

The Industrial Design students were briefed to choose a man-made product and to evaluate it in terms of PSS against Life's Principles. They were required to research how the product was used and present their findings a week later, at the beginning of the fourth university term. Life's Principles were deliberately not explained and each team had to work out for themselves how to use this methodology and apply it to their product.

Observations 2 and 3, September 14 (morning and afternoon observation sessions):
Only Industrial Design students were present as the Mechanical Engineering students were writing tests and would be able to attend only Wednesday afternoon sessions.

Products students chose for the Life's Principles evaluations were: a mascara brush, a toothbrush, an i-phone, a PVC water bottle, an incandescent light bulb and a leather and steel armchair. Most of the students presented their findings visually, in poster format, and these acted as focal points for feedback and discussion from the lecturers, the coordinator and from their fellow students. Discussions were lengthy and suggestions were made as to how to rethink the product designs in terms of more sustainable, biomimetic services and systems.

In the afternoon, Lecturer B introduced students to the concept of S.PSS in social (urban, peri-urban and rural), natural and economic (built, designed) systems. They were then taken through how to conduct a SWOT analysis for S.PSS, through case studies, with reference to the drivers/barriers in Table 1. These drivers/barriers accommodate social, economic and natural systems. For the following day, teams were told to identify an energy-related product that was relevant to their context, conduct an S.PSS SWOT analysis on it and then to market the product to the rest of the class.

Sustainable products, services systems

Drivers	Barriers
Minimise environmental impact	System complexity
Facilitate innovation	Technical constraints in user involvement
Improve relationship with end-user	End-user behaviour
Increase end-user involvement	Scepticism
Provide integrated and customised solutions	Affordability
Lifecycle perspectives	Government dependency
Create added value throughout the value chain	Poor infrastructure

Figure 1: Drivers and barriers to consider when conducting a SWOT analysis for S.PSS

Finally, a system mapping exercise was demonstrated through a case study. A comment on my observation sheet noted that I was finding all these tools quite confusing, but that maybe this was because I was not an industrial design student. 'What would really help would be some kind of pictorial 'road map' or diagram/model that shows how the various tools inform each other/the design process and what their different purposes are'.

The coordinator explained that the LeNSes tools help to standardise the design process for sustainability, and are useful communication tools; if designers structure their presentation around the tool then they have a good presentation.

Observation 4, September 18

The student teams had conducted a systems mapping exercise on their proposed design product as a way of learning how to use this tool. The Industrial Design students presented their findings which were interrogated and critiqued by their peers, the lecturers and the coordinator. This process was valuable for developing their understanding of how to use systems mapping and the depth of complexity that it could address.

In discussion with the coordinator, she explained that the tool provided a way of navigating through the complexity of stakeholder inter-relationships and of identifying contradictions and conflicts in the inter-related systems. It assists the identification of financial flows, material flows, administrative flows and information flows.

After the presentations, the students were introduced to more S.PSS tools - Sustainability Radars and Business Canvas.

Reflections from Lecturer B at the end of the afternoon were that the LeNSes platform is difficult to use and that good internet connectivity is a prerequisite, but that the connectivity is very poor in the Industrial Design Department, which is on the ground floor of the building. It was noted that the students had found it very difficult to identify a product to evaluate at this stage of the project, and said they would have preferred to have been allocated a specific product per group. They also commented that they needed more examples and case studies of how to use the different S.PSS tools first, before having to apply them, and that they had found the systems mapping process very difficult at this stage of the course.

Observation 5, Sept 21

The Industrial Design students were taken on a field trip to Kirstenbosch Botanical Gardens, to learn more about natural systems and nature's design genius, to see Life's Principles in action and to contextualise Biomimicry. The outing was facilitated by a botanist who took the students through several exercises based on deep observations of the ecology and organisms, using all their different senses. The students worked in pairs for the most part, appeared actively engaged in the learning activities and to be enthused by what they were discovering.

In the afternoon, on their return to CPUT, the students were taken through two design exercises that apply Biomimicry thinking, drawing on their inspiration that had been awakened from the field trip. These exercises are known as 'Biology to Design' and 'Design to Biology'. In the first exercise, participants explore and select a biological form or process of an organism, or a biological system, and propose how this 'recipe' can be emulated to address a problem in daily life; in the second, participants identify a problem in daily life, such as how renewable energy resources could be used in a particular socio-economic context, and look to nature for a possible solution. The website AskNature.org is the resource that participants can draw on for a scientific explanation of how nature solves the particular problem.

Students were briefed to select a ‘champion’ organism from nature, and put together a presentation for the following day on the challenges the organism faces in its context, the strategies it employs to meet these challenges, and to suggest how these strategies might inform how we as humans could respond to one or more of our own challenges.

Observation 6, Sept 22

The five groups of students presented their ‘champion’ from nature, its challenges, strategies and possible applications of these. The presentations were on the whole well researched and presented, demonstrating a sound understanding of Biomimicry principles and how to apply them.

Students were then given their design brief for the renewable energies project (Appendix 4). It was explained that they would need to observe a system and how people use and consume energy in that system, defining the social, economic and environmental aspects of their context in relation to energy usage. They would need to establish a relationship with a partner(s) in the community, drawing on their knowledge to describe the product space in detail and map the system and the energy flows using S.PSS. Questions to ask would be:

- Are there opportunities to harvest power from/in the system?
- Where does wastage happen in the system?
    - Can this be turned into a second income stream?
    - Where can one reduce waste or upcycle it?

Aspects of sustainability and their inter-relationship that would need to be mapped	
Social	Product usage Setting/context
Economic	Cost Maintenance Product failure
Environment	Product footprint – cradle to cradle

They would then need to develop a renewable energy solution that could be an adaptation of an existing product/system – leveraging off the existing system/products used - or a new product/ system. If the system is flawed, they could think of how the system could be improved/redesigned and design a component of the system that would bring about changes in the relationships in the system. They would need to describe the incremental change and relationship changes that would be brought about by the product design.

It was pointed out that a really simple product can be designed for even a very complex system, just by bringing about a change in perception. The students were reminded that sustainability is not only about using environmentally friendly materials and resources, but also about buy-in from stakeholders – i.e. social and economic sustainability. The LeNSes tools provide for systematic consideration of all components of the system to ensure a holistic solution and Biomimicry for evaluating the design against Life's Principles.

Students were to first present their concepts, and once they had received feedback on their concepts they could go ahead with prototyping their designs.

General observations

In addition to making comments on the checklist, to ensure reliability of the observation data, notes were also taken in each session attended of the learning content, the learning activities, and the modes of learning and teaching.

All in all, the following S.PSS tools were introduced to the students:

- Drivers and Barriers
- SWOT analysis
- Sustainability Radars
- Stakeholder Mapping
- System Mapping
- Business Canvas Model

General observations from the checklist were that the third-year Industrial Design classroom, as a large, flat space, lent itself to group design work but was not very well suited for lectures and presentations because the acoustics were poor and the student teams were very spread out in the space. However, no formal lectures were given – academic input from the lecturers took the form of short Powerpoint presentations illustrating Biomimicry principles, the use of Biomimicry and S.PSS tools and presenting case studies. As mentioned, several presentations were also given by each of the student teams. All these presentations served as discussion points for learning; the general atmosphere in these discussions was one of informality, with the students asking questions, responding and interacting freely and confidently with each other and with the lecturers.

The lecturing staff were very flexible to students' needs and they spent a great deal of time working with the teams – listening to them and advising them on their projects; explaining the S.PSS and Biomimicry tools in relation to their respective design projects; and facilitating the asking of probing questions of the design projects and the contexts to deepen the groups' understanding of holistic, sustainable design. However, the aims and objectives of each step of the project were not always well explained and foregrounding explicit objectives at the start could have avoided some of the initial confusion that was observed.

The Mechanical Engineering students were observed together with the Industrial Design students on only two occasions, but they appeared to interact well with each other and engaged in some lively group discussions.

From a non-designer perspective, the S.PSS tools could have been explained better, more examples / case studies could have been helpful in illustrating their relevance, and more practice with all the tools may have given the students greater confidence in applying them to their projects. Even though only a relatively small number of S.PSS tools were introduced, they were not easily understood and initially it seemed as if too much was being expected of the students in such a short time. In contrast it was noted that the students seemed to comprehend and be able to apply the Biomimicry tools and principles with relative ease. However, with time the teams were able to master the use of some of the S.PSS tools which were very important for anchoring the design process within their complex contexts.

The nature of the design project for renewable energy required the groups to be self-directed in their learning, compile their own design brief, and although support from the lecturers was available, they had to each take responsibility for their contribution to the project and undertake considerable theoretical and field research. The research and design process followed steps of analysis, synthesis and evaluation, and required mastery of the S.PSS and Biomimicry tools and principles, which the groups seemed to achieve in the end. It was clear from the observations that, although aspects of the course could be improved, as must be expected from a pilot course, it enabled deep engagement in an authentic learning experience and in this regard had significant value for the students.

Student questionnaire responses

The questionnaire that was drawn up[6], adapted from the LeNSes *Questionnaire for Observers Evaluation Procedure,* was completed in class on 25 September by 25 Industrial Design students. It consisted of six sections:

1. Evaluation of the teaching staff
2. General questions relating to the course
3. Use of the LeNSes online learning e-platform (OLEP), learning resources and website
4. Use of the OLEP interface
5. Recommendations for improving the course

In retrospect, the questionnaire was far too detailed and fewer categories and questions could have enabled a more meaningful evaluation of the pilot course. Therefore, only data that has significance for this course evaluation has been selected and presented here.

[6] See Appendix 4

With respect to the first section of the questionnaire, the students' responses reflected reasonable satisfaction with the quality of the teaching. Regarding the course, the students felt that it was adequately structured (question 2.3) (red); whereas they were less happy with the clarity of the course contents (question 2.2) (blue); and were not happy with the organisation and logistics (question 2.4) (green).

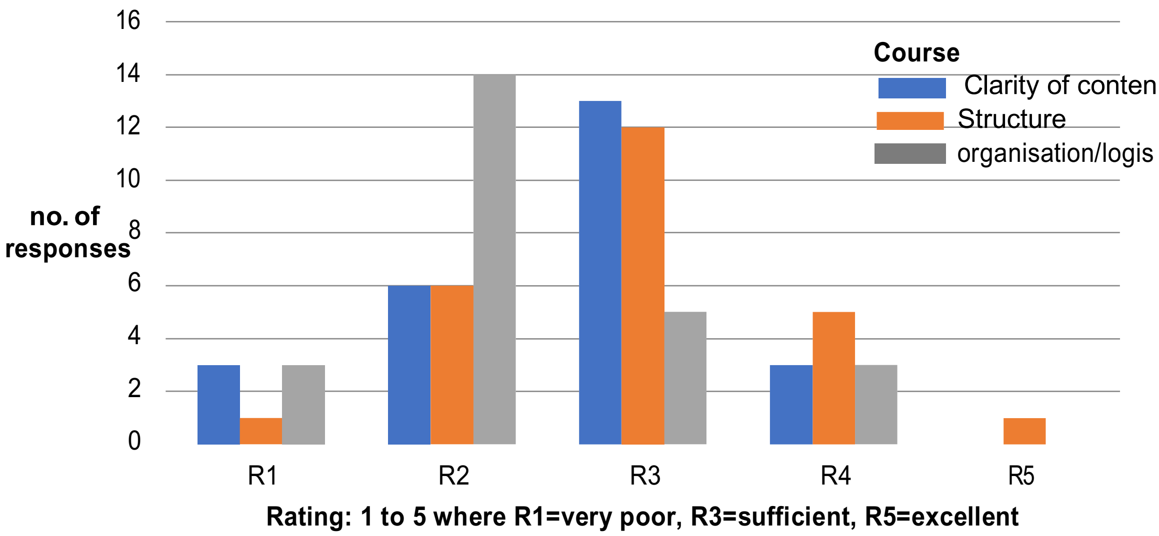

Figure 2: Student rating of the course

Their comments elaborated that the course objectives and process should have been more clearly explained from the outset, with explicit outputs and guidelines. The confusion that the students seemed to experience was exacerbated by what they described as miscommunication/conflicting communication among the lecturers. For example: 'Need clear guidelines and objectives from the start to avoid miscommunication'. This supports my observation as the researcher that I found the introduction of the S.PSS tools confusing and that a 'pictorial "road map" or diagram/model that shows how the various tools inform each other/the design process and what the purposes are' would have been useful in clarifying the objectives and the process (Comment in notes during Observation 3, 14 September).

Other comments about the course were that there was 'too much time spent on theory and not enough on the practical research of the design problem'; 'too many complex and vague aspects'; and 'explain activities more clearly'.

When asked the open question of which aspects of the course they had liked most and which they had liked least, by far the majority of students responded that they liked Biomimicry (red) the most and S.PSS (blue) the least (Figure 3).

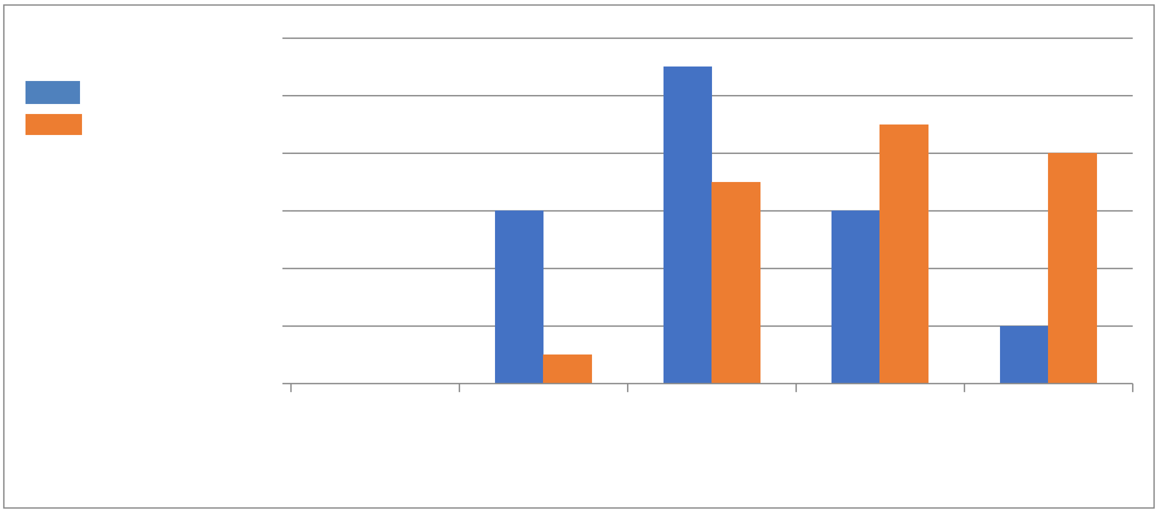

Figure 3: Compilation of student responses to Questions 2.21 & 2.22: ‘Please explain what aspects of the course you liked most/least?’)

In addition, the students found the Biomimicry materials much more useful than the LeNSes materials. These responses may be in part because they could relate to Biomimicry more readily than S.PSS – one response was that ‘Biomimicry is inspiring’. But also, at the time of completing this questionnaire they had not yet seriously engaged with the S.PSS tools in the design process. However, their negative experiences with the LeNSes website, which they found extremely difficult to navigate and to download resources, inevitably would have influenced their opinions. Only 3 responded that the website was adequate, 15 found the website poor to very poor and 7 reported that they did not even try to use it or gave up trying (N/a).

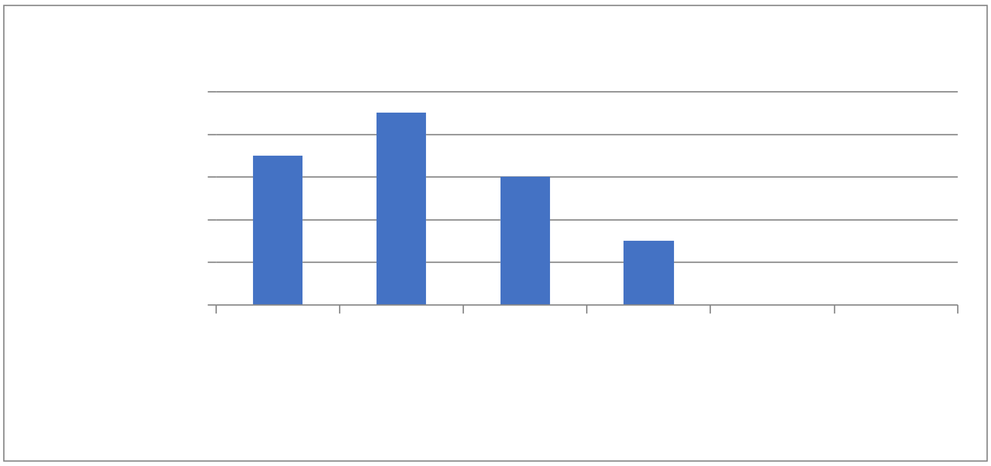

Figure 4: Student evaluation of LeNSes website. (Question 4.1 ‘To what extent is the website user-friendly?’)

Students’ evaluation of the online learning e-platform (OLEP) interface was also largely negative, as can be seen in Figure 5.

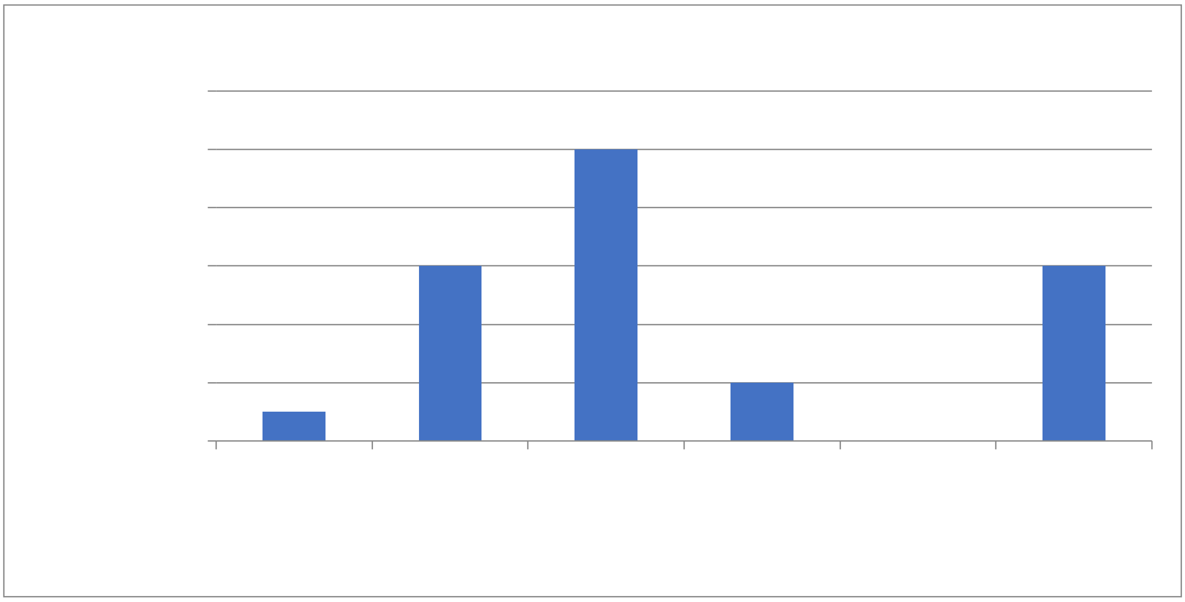

Figure 5: Responses to question 5.1: Learning resources can be searched using 3 different modalities: by ‘teacher/ course/ institution/year’, by ‘content/subject’, or through an ‘advanced search’. To what extent are these 3 modalities are useful?

Only 13 out of 25 students downloaded and used any of the LeNSes resources. Some comments were:

- ‘LeNSes course material was very difficult to navigate and access’
- ‘I don't understand how to use the website! So confusing’
- ‘Hard to use. Worst website ever’
- ‘Couldn't open the resources’

Those who did access the LeNSes website made use of the videos, Powerpoint presentations, text and systems mapping resources. There were requests for more case studies on the LeNSes website, especially of how S.PSS tools have been used successfully. A comment from one of the students was: 'Don't teach sustainability, rather just teach systems thinking. You require a full understanding of systems thinking before you can Design for Sustainability.'

These data indicate that, not only does the LeNSes website need to be re-designed to be more user-friendly and aesthetically enticing for designers, but the S.PSS tools could be designed to be easier to understand and apply. A very pertinent comment on one questionnaire was that ‘LeNSes tools need to be written for the local context’, and this is an avenue that could be pursued in South Africa, now that these tools are starting to be used here and local case studies are emerging.

An overview of the course

Interviews with key course personnel

The course co-ordinator and lecturers A and B were interviewed at the end of the course, once the design projects had been completed, so as to gain their impressions of the course as a whole. These took the form of semi-formal interviews and discussions; the guiding interview questions are attached as Appendix 6. In addition, after the projects had been formally assessed, brief discussions and email correspondence with them elicited their responses to the final project and prototype submissions.

These findings are addressed according to the following analytical themes:

- the course as a means of facilitating and promoting transdisciplinary learning;
- the efficacy of Biomimicry and of S.PSS for facilitating sustainable design solutions in this learning and teaching context;
- the transdisciplinary course as a means of shifting students' thinking towards more holistic, sustainable/transitional design;
- challenges, strengths and benefits experienced and what can be learned from these.

Facilitation of transdisciplinary learning

The rationale for the pilot structured Industrial Design/Mechanical Engineering course that integrated S.PSS and Biomimicry tools and approaches within the new framework of transition design, was not only to engender sustainable thinking and approaches to design for these students, but also to demonstrate the value of transdisciplinary collaboration in design problems and for learning in the problem space. This latter is particularly important for professional designers and engineers, whose work is by nature collaborative.

Initially the course had been planned for the third term, from July to September, but several factors prevented this from taking place and in the end it was held in the fourth term of the year. It had been anticipated that the GES Mechanical Engineering students would be able to attend every Wednesday afternoon for the six week duration of the course, working with the Industrial Design students and bringing their engineering knowledge to bear on the prototype designs for renewable energy solutions. However, the Mechanical Engineering students had to miss two of these meetings due to pre-scheduled tests as well as a third one due to a COSATU march that forced closures of the area around the CPUT Cape Town campus. Moreover, instead of the anticipated 20 or so Mechanical Engineering students registering for the GES course, there were initially only five and one of these dropped out, leaving four. Being fewer in number than the design teams, they were not allocated to particular teams but collaborated with the Industrial Design students in a loose, consultative fashion.

As a result, there was not much opportunity for transdisciplinary learning across the two faculties. However, it was stated by the course coordinator that the Mechanical Engineering students gave valuable feedback on the Industrial Design students' proposed renewable energy designs, resulting in two of the teams modifying their ideas substantially. In a separate evaluation of the GES course, these Mechanical Engineering students also emphasised that working on the project had been a highlight for them, and that it had been very exciting to see how differently and creatively Industrial Design students thought and approached a design problem. It seems, therefore, that even this limited collaborative learning opportunity was worthwhile, and it should be explored further in future courses.

A suggestion for facilitating future collaboration was that a venue be found that was midway between the two campuses, so that neither group of students would be unduly disadvantaged by having to travel too far. Moreover, one meeting a week is insufficient for the collaboration to be really meaningful, as the Industrial Design student teams worked together on their projects at least three times a week. It was suggested that the students from the two faculties should meet more frequently, at least twice a week if possible, as this would be much more fruitful.

Lecturer A emphasised that the language of S.PSS and of Biomimicry design was not specific to any particular knowledge discipline, so they become common languages for transdisciplinary design that people can learn together and in this way avoid hierarchical knowledge perceptions that may obstruct the collaboration – e.g. that one discipline is superior to another. In this way, S.PSS and Biomimicry can facilitate transdisciplinary collaborations and transitional design.

Moreoever, the Biomimicry methodology draws heavily on cutting-edge scientific research and the students had to engage with this scientific knowledge to abstract the design principles at work in their 'champion from nature', and apply this principle/these principles to their sustainable designs. It was clear, therefore, that S.PSS perspectives and the science of Biomimicry provided the Industrial Design students with a new, transdisciplinary way of conceptualising design and for providing innovative, sustainable solutions that were quite different to the traditional product design methodology of industrial design. Indeed, one of the students asserted in conversation that she could never conceptualise design in the 'old way' again, and it would be interesting to see how the impact of the pilot project continues to open 'new territories' (Cuervo undated, 2) of transdisciplinary design for these students in their fourth year of study.

Efficacy of Biomimicry and of S.PSS for facilitating sustainable design solutions

It was argued by both Lecturer A and the course coordinator that LeNSes focuses mainly on the economic and social aspects of sustainability, and does not address directly the environmental and ecological aspects except in relation to carbon reduction, i.e. a reduced carbon footprint. Biomimicry, however, focuses on nature and the alternatives nature offers to the traditional linear model of industrial design. For this reason, to overlay S.PSS analysis tools with Biomimicry design methodologies provides for a more holistic design approach that takes into consideration critical economic, social and environmental/ecological aspects. Biomimetic design surpasses sustainable design, as it goes much deeper into designing according to Life's Principles; such as for resilience, to adapt and evolve, to create conditions conducive to life, etc. Using the LeNSes tools it is S.PSS design: in combination with Biomimicry it is B.PSS design. A Biomimicry approach also deepens one's thinking about what is meant by sustainability.

It was explained that, traditionally, Industrial Design students at CPUT learn to design products in isolation from the broader social, economic and environmental context, especially in the first two years. In the third year they undertake some research of the product and the context before they embark on their design, but it is not necessarily sustainable design. One of the benefits of the S.PSS methodologies is that these can provide a much broader overview of the product and identify different areas where the product can benefit the user. As lecturer B commented:

'It has definitely shifted their thinking into being more responsible designers in terms of identifying their stakeholders – realising that a singular product will be affecting a number of different people at some time or another. Also because it is sustainable design it is a service you are providing, so it must be responsible design. There were a lot of benefits coming through from this project.' (Interview with lecturer B, 8/12/2015)

With regards to student difficulties in understanding the S.PSS tools compared to their ease of understanding and enjoyment of Biomimicry methodologies, Lecturer B suggested that this may have been because a Powerpoint presentation was used to explain the S.PSS tools, whereas there is usually very little formal lecturing in the Industrial Design Department. Student learning in the department is largely self-directed and the lecturers' role is to navigate and guide them in their learning and to facilitate learning through workshops and group projects. Biomimicry, on the other hand, was explored largely out of doors, at Kirstenbosch, which would have been more congruent with how the students are used to learning and could be partly why they responded more positively to it.

The S.PSS tool that the students seemed to be most comfortable using was systems mapping. Lecturer A remarked that it seemed to help them understand the system and the flows within the system better – such as the information and the energy flows. This was a new way of looking at a product for them and it opened their eyes to systems thinking. As Biomimicry is also about systems thinking, the two link together in a way that easily made sense to the students. Biomimicry's Life's Principles, however, took over some of the evaluative role of S.PSS, and to a deeper level. In discussion with Lecturers A and B they argued that in the same way as S.PSS does not specifically focus on ecological sustainability, so Biomimicry emphasises the genius of nature and 'has not yet developed the tools for the business, the social and the political aspects' of biomimetic design. So each methodology has its own strengths which complement each other and for this reason they are ideal to use in combination in designing for transition. As these methodologies develop and adapt with use it is possible that they may eventually merge.

Challenges

Lecturer B reported (interview on 08/12/2015) that he had only ever observed the S.PSS tools being taught when he was an observer on a LeNSes pilot course at Makerere University, Uganda, and had never engaged with them himself. The context of Makerere University was also different from CPUT as the students were engineers, not designers, so they used the tools differently. Therefore, despite preparing himself as well as he could, he still found it difficult to explain some of the tools adequately and to answer all the students' questions. However, the course coordinator was much more experienced with the S.PSS tools so was able to assist with explanations to the groups when she was available. Lecturer B asserted that, as a consequence, he had learned a great deal from facilitating the course and would be much more confident in teaching the application of the S.PSS tools in future.

Lecturer B explained (interview on 08/12/2015) that a lot of the Industrial Design students were resistant to the S.PSS tools initially as these challenged their thinking and their traditional approach to design. They also struggled with the terminology and with understanding the application of the tools. 'They felt that they were doing badly. At that point there was a lot of resistance from students for having to push out their old ideas.' Also the tools were introduced quite rapidly, one after the other, which caused some confusion. But this was because of time constraints, so that the students could get on with the design process and actually use the tools. He explained that this 'was a bit of a heritage from the pilot (Uganda) course', where they were similarly rapidly introduced to the tools in the first two weeks, but thereafter could select and apply the tools as they wanted to in their designs.

Another challenge, identified by Lecturer A, was bringing two design methodologies into one course, which could be quite overwhelming if not carefully managed. However, with time and practice the students seemed to gain confidence in applying them.

The course coordinator emphasised that some initial confusion in learning the Biomimicry and S.PSS methodologies is good, and that the students need to ‘go with the flow’. As Edwards (2014: 19) attests: ‘Achieving new understanding involves a reorganisation of our mental schema and of our relationships with the world. Its acquisition takes the learner through moments of ambiguity and uncertainty and there is always the risk of getting it wrong’. This may well explain the students’ resistance to the new methodologies at first.

A big challenge was that a strong, reliable internet connection is needed in order to access the LeNSes tools. However, the internet connectivity and signal strength in the Industrial Design Department was unreliable, and on quite a few occasions was not functioning when the students needed it. Lecturer B remarked that, because of this, he had had to print out the different tools for the students to use as there was no guarantee that he would be able to connect to the internet during the teaching session. This was very frustrating for the students as they could not access the tools online and, in addition, as designers, they reported that they had found the LeNSes website unappealing, very difficult to navigate, and the tools and terminology difficult to understand. These factors would have exacerbated any resistance they may have had to using the tools. The coordinator pointed out that the LeNSes tools should be used as visualisation tools to aid the design process – ‘to help them come up with the skeleton’ of their design. Non-designers might use them as they stand, but designers can adapt the design of the tools – such as the systems mapping and story board icons - for their own purposes. Ultimately, the tools are to be used as a check list, to ensure that all aspects of sustainability have been addressed.

Strengths

Lecturer B commented that the next natural step in designing a product is to design a service and a system, so the LeNSes tools allow the students to evolve in their design practice – it is a natural evolution of Industrial Design. Lecturer A explained that the pilot course has been designed to help bridge the gap between third year and the fourth, B Tech year. Third year project work takes a structured approach compared to the self-directed research and design that they do in fourth year. The third-year pilot course therefore scaffolds the learning process towards the fourth year, and the students learn to apply the theory of systems thinking to a design project for the first time. The course coordinator commented that: ‘It has also opened their eyes to more socio-economic issues in the country which they might not have engaged with before. It has exposed them to situations they have never encountered before. So if you want them to design something that is related to the real world, they are going to have to experience it’ (Course coordinator, 15/12/2015). The course has also highlighted their roles as designers in society, which ‘is not just about designing pretty things’ (Lecturer B, 15/12/2015) but about issues and responsibilities beyond this that require research and social engagement. It seems to have made them much more competent as designers and enabled them to design more holistically. Therefore it would seem that a strength of designing with S.PSS and Biomimicry has been to mentally prepare and mature the Industrial Design students for the fourth year, and it might be of value to monitor how they draw on these methodologies in their BTech (fourth) year.

The coordinator emphasised that for deep learning to take place, students need to be intrinsically motivated and to 'own' their learning. 'What we have noticed is that Biomimicry is so motivational. It really hits the spot of where students find meaning in what they are doing. It helps to drive that whole process.' (course coordinator, 04/12/2015). In addition, the introduction to activity theory in the first session of the course, and the team-building exercise that emphasised their individual strengths and roles and responsibilities within the team, were very motivational and dispelled any possible power play attitudes among the team members and especially between the Industrial Designers and Mechanical Engineers. Edwards (2014) notes that 'self-regulating' learners are needed 'to create the kind of society we would like to have' (p13). Self-regulation is 'the degree to which students are metacognitively, motivationally and behaviourally active participants in their own learning process' (Zimmerman 2008: 167) and as a consequence they are able to handle 'ambiguity and risk and can work with and on new knowledge' (Edwards 2014: 25).This course appeared to facilitate such learning processes, taking both the Industrial Design and Mechanical Engineering students beyond merely designing a product for its own sake, and engaging them with new, transdisciplinary knowledge.

The course coordinator pointed out that one of the strengths of using the two complementary methodologies was to demonstrate how design is intertwined with individuals and society, and at a very local level – the social ecology of design.

Benefits

One of the acknowledged benefits of the pilot course was that it has built capacity of the two lecturers as well as of the course coordinator. Lecturer A was knowledgeable about Biomimicry, but not about the LeNSes tools; Lecturer B had observed the LeNSes tools being used, but had never used them or taught them and had no knowledge of Biomimicry; the course coordinator had knowledge and experience of both the LeNSes tools and Biomimicry, but had never used them together for sustainable design – she maintained that to her knowledge it was the first time S.PSS and Biomimicry had been used together to teach sustainable design. Having planned and facilitated this course together, each drawing on their own strengths, they had learnt from each other and from the students as they went along and had filled in the gaps in their knowledge. They all commented that they were feeling much more confident about running the course again, and that it had opened up important possibilities for transitional design.

Shifts in student thinking shifted towards more holistic, sustainable/transitional design

The course coordinator reported (pers. comm. 30/03/2016) that the students had been 'almost relieved' to have had a chance to apply the theoretical systems thinking they had been taught in the subject 'Professional Practice' and admitted that they had always thought of design purely as product development. They had said they would never be able to not consider product service systems in future design projects and that Biomimicry Life's Principles checklist was a very useful prompt for evaluating the sustainability of their designs.

Lecturer A reflected (04/12/2015): 'I am very happy to see the mindshift, from the beginning to the end of the project; from a product focus to a systems-thinking approach – to understanding systems much better. ... If you are looking at lifelong learning, then they are better able now to tackle complex challenges than they were at the beginning of the project.' This was confirmed by the students who, at the end of the course, reflected that overall the course had helped them to understand a product within a system, and 'the interconnectedness of everything'. This indicates a clear shift towards transitional design thinking. Moreover, the course coordinator reported that the second year Industrial Design students had seen these third year projects and were making it clear that they too wanted this course in their third year. This points to a demand from the students themselves to experience transitional design thinking and practice, and that they see the relevance of this to their profession.

The course coordinator reflected that, if all learning could be project-based in Industrial Design, then the other subjects, such as business studies, professional practice, materials etc. could all focus on the sustainability of the final product. In this way, learning would automatically be a holistic process that could be geared towards transitional design.

Suggested adjustments to the course

It was acknowledged by all three personnel that a more thorough, well explicated introduction to the course would have made it much easier for the students to understand what was expected of them. 'I think we need a big systems thing first – what are we doing and why – in a whole day workshop. It would cover why Biomimicry, and so why LeNSes, and why are we doing it this way?' (course coordinator, 15/12/2015).

The course coordinator felt that, because the students had had to learn to use S.PSS analysis and communication tools in addition to Biomimicry methodologies, they had not engaged as deeply with Biomimicry on this course as students had on other Biomimicry projects. Therefore, in future the students should spend the first week immersed in the Biomimicry methodology, with a small outcome, and then conceptualise the project using the LeNSes tools in the second week.

The Biomimicry immersion would include field trips – maybe even the first weekend away in nature, to be able to really experience deep observation. Biomimicry would provide the framework for the project, and once the students' mind-sets had shifted into a biomimetic way of thinking then the LeNSes tools could be introduced. The course would start with discovering how nature works; then how society works like an ecosystem; and finally how S.PSS tools can be used to analyse and improve design for services, systems and cradle to cradle. 'Then they will really understand why they are doing it' (course coordinator, 15/12/ 2015).

The S.PSS component should include a field trip to an urban, peri-urban and rural setting, so that the students can observe and understand the distinctive characteristics of the context for which they are designing. To be able to use these tools well they need to engage with them intensely, which an immersive experience would provide. It was recognised that, arising from the findings of the GES course evaluation, the Mechanical Engineering students also would need to be trained in Biomimicry thinking so that when they collaborate with the Industrial Design students they have the same design understandings and goals.

For the transdisciplinary group work, it might be helpful for the students to agree on team roles, responsibilities and rules - such as how often and where they are to meet, individual responsibilities at each stage of the process, etc. This is especially important for people who do not know each other to be able to work effectively together towards a common goal and to do so within a very limited time frame.

Because of the unfamiliar Biomimicry and S.PSS terminology, it was suggested that a glossary of terms should be compiled for the students in future.

Evaluation of the final design projects

The aim of the pilot course was for each student team to develop a prototype for a renewable energy system, in a selected rural, peri-urban or urban context, that considers all stakeholders in the system through the application of S.PSS and Biomimicry design methodologies. The prototypes should ensure environmentally and economically sustainable, stable, resource-efficient energy delivery.

The course coordinator (pers. comms. 29-30/03/2016) emphasised that the final prototypes produced by the industrial Design student teams were merely conceptual models as this was all that was possible in such a short course. To develop these further, additional courses could focus on grappling more deeply with the original concepts and on ways of testing them before manufacturing the prototypes. However, the course coordinator's opinion was that all the projects were innovative in terms of their appropriateness for context, and that they had promise for further development (pers comm. 30/03/2016).

General use of S.PSS and Biomimicry methodologies in the design process

Lecturer A (22/02/2016) asserted that all the groups had used Biomimicry quite effectively in their design solutions. They had used S.PSS tools and Biomimicry methodologies to evaluate their systems and identify gaps in their solutions. However, the course coordinator pointed out that for the most part they did not apply Biomimicry principles to the materials and manufacture of the products; using Biomimicry to evaluate the concepts at a systems level could avoid the dangers of mere bio-inspiration and encourage a more cradle-to-cradle approach in future projects. With a bigger project and more time this could be explored.

Lecturer A (22/02/2016) argued that, in general, the better designs were those that followed a challenge to nature approach, translating an identified renewable energy need into a Biomimicry function. These teams came up with new products, rather than just adapting an existing product. The best designs were not necessarily the product, but the system that they designed from identifying a function in nature. Biomimicry reframes understanding of the function, by asking: 'how does nature...?'

As has been mentioned, S.PSS tools identify flows – human, financial, product, material – and show where a system may fail. All the relationships within a system must be considered in order to satisfy every user within a system – termed a 'unit of satisfaction'. All the projects used the Business Canvas as well as an analysis tool for researching context and possibilities, and some degree of systems mapping. Systems mapping is critically important and when it is not implemented thoroughly there is a breakdown in one of the critical relationships and the product will be ineffective. It was clear that the student teams had applied some of the S.PSS methodologies tools in the design of their prototypes, but not all of them. Had they done so it would have given more depth to their designs.

It was also noticed that indigenous knowledge did not appear to have been drawn on in the projects, as had been hoped, and this is an aspect that could perhaps be given more attention in future.

Analysis of the final projects prototypes and the design process

The five project prototypes and the marks awarded by the examination panel were as follows:

Project prototype	Mark
Safety biogas burner (peri-urban community) This portable gas bottle could be refilled with biogas from a community biodigester and was fitted with a safety valve mechanism, inspired by the design of the strelitzia flower for pollination, to mitigate fire accidents	85%
Compost water heater (peri-urban community) The idea was to pass water pipes through a large tank which could be continually filled with waste vegetable matter by the community to produce compost, and the heat produced in the composting process would heat the water for household use in the community	85%
Citrus biodigester (rural context) This design addressed the waste problem of spoiled citrus fruit on a farm, grinding up the fruit and producing biogas for fuel and citrus oil for the cosmetics industry as by-products	70%
Wifi on tour buses The design captured wind energy from the movement of the bus and converted it into an energy source for a wifi application that, among other things, provided information for tourists	65%
Emergency lighting in train carriages (urban context) This concept used the piezoelectric effect to operate emergency lights in suburban train carriages to alert other passengers – such as in muggings, a medical emergency etc.	60%

Figure 6: Summary of final project prototypes and assessment marks awarded

There were no remarks given by the examiners on the final projects but comments collated from lecturers A and B and the course coordinator are presented below.

Safety biogas burner

Sanitation challenges and the problems of devastating and frequent shack fires in informal settlements in Cape Town result in ongoing political and social tensions. Despite their limited capacity, this team researched both these social issues and their business model addressed the community's needs for toilets as well as for safe, renewable energy for cooking in informal settlements. In this way they merged two complex linear systems into a closed loop system.

This project was considered to be the most effective in its application of both S.PSS tools and Biomimicry for sustainable environmental, economic and social design solutions. The S.PSS systems mapping tool was used very effectively to address the socio-economic and environmental challenges of the particular context in the design concept. In terms of Biomimicry, the team incorporated Life's Principles effectively and made use of a highly appropriate biological 'champion', the strelitzia flower, in their challenge to design. The safety mechanism that mimicked the strelitzia pollination mechanism allowed the gas to flow, and therefore for the flame to be lit, only when a heavy enough pot was placed on the burner; should the burner overturn the flame would instantly extinguish.

The one shortcoming was that the materials from which the proposed biogas burner and gas tank were to be made were not ecologically sustainable, but this was equally he case with all the projects.

Compost water heater

This team researched the natural heating potential of the composting process and designed a simple prototype for an effective water heating solution based on this process.

However, the team did not research the social context and the needs of the people who might use the product. It was said that this team was the most resistant to using systems mapping and focused on the product rather than the product within a system, so the chances of it being used effectively within the community were doubtful. In addition, it was felt that the team could have spent more time developing the compost collection/storage device as this was not a strong design aspect of their project.

Citrus biodigester

This prototype was designed to reduce biological farming waste, addressing a social need in a local context.

S.P SS system mapping and environmental, social and economic radars were used very effectively in this project, in conjunction with Biomimicry's Life's Principles to address the environmental, social and economic issues. However, it was felt that the project was not very innovative in using design principles from nature, and this Biomimicry aspect could have been much more strongly developed.

Wifi on tour buses

Although an innovative concept, this project was considered not to have applied Biomimicry and S.PSS tools very effectively.

This team's challenge was to apply the sustainable product service system approach to an existing system which was, allegedly, already carbon neutral. This made it difficult to identify potential value within their solution and, as a result, the use of S.PSS tools to show the value of their renewable energy solution was not fully explored. That said, this group had trouble in understanding the S.PSS and Biomimicry tools. Although they worked through all the tools, there was resistance to using them to inform their design processes and their prototype had little relation to the Biomimicry 'champion' that they had identified.

Emergency lighting in train carriages
Although innovative, it was said that this project had no real economic or environmental benefits built into the system.

Conclusion

The course set out to introduce students in the Industrial Design and Mechanical Engineering Departments at CPUT to a radically different way of approaching design and of viewing their roles as designers; to design for societal transitions to more ecologically, economically and socio-politically sustainable futures. The course was designed and structured to be a collaboration between students from the two different academic disciplines, working in teams, to explore, design and develop sustainable renewable energy systems for a local context using selected LeNSes S.PSS tools together with Biomimicry methodologies, especially Life's Principles for evaluating the ecological sustainability of their designs.

The purpose of layering both S.PSS and Biomimicry in the design project was to ensure that three major aspects of sustainability were addressed: S.PSS tools are focused primarily on the economic and socio-political aspects of design; Biomimicry draws on inspirational examples in natural systems for how to design in ecologically sustainable ways. Where these approaches were diligently applied together in the design process they were very effective in addressing these three aspects of sustainability and in initiating innovative design solutions. However, the LeNses website needs to be re-designed to be much more user- friendly and aesthetically pleasing to encourage exploration and application of the resources. Similarly, the S.PSS tools can be difficult to understand for first-time users and the language and terminology is not necessarily familiar to users outside of a European context; more locally relevant case studies can be helpful in this regard.

The students had been introduced to systems thinking in their theory course and had been introduced to renewable energy designs earlier in the year. This pilot course built on this knowledge and stretched the students' capacity as sustainable product designers even further. As a result they could experience a deeper understanding of the impact their product, service and systems would have on the context of their problem area. Several of the projects' design solutions envisioned future concepts, systems and possible stakeholders, which indicated that the students were already transitioning into design for sustainable futures. The course has also prepared the students for the requirements of the fourth year, so this should be an easier transition for them.

Administrative and logistical difficulties along with other unforeseen factors unfortunately meant that the course did not fulfill all its aims as a transdisciplinary learning experience for the Mechanical Engineering and Industrial Design students. Despite the limited opportunities for their collaboration, the students nevertheless appeared to value the experience highly and it stimulated their thinking in new ways. Because of its potential as a transdisciplinary learning experience it is recommended that this collaboration be attempted again, but that the Mechanical Engineering students learn the necessary Biomimicry methodologies so that they can participate in the project more fully and can apply these methodologies in their future professional practice. The course facilitators/lecturers would need to be well trained in both the S.PSS analysis and communication tools and in Biomimicry. There would need to be strong commitment from both the academic departments involved for the initiative to succeed and all the planning, roles and responsibilities would need to be finalised ahead of time.

Finally, this pilot course has demonstrated the power of layering S.PSS and Biomimicry (B.PSS) to create innovative design solutions for transitions to sustainable futures. The discourses of sustainability vary across different sectors of society and emphasise their own particular interests – e.g. business discourses tend to focus on economic sustainability, environmental discourses on ecological sustainability. Biomimetic design deepens these understandings of sustainability, applying Life's Principles to design problems and, in so doing, attempting to create conditions conducive to life. The B.PSS approach frames design problems within the context of complex, interlinked systems, ensuring that all aspects of sustainability are addressed and that design solutions are **truly** sustainable.

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APPENDIX C1: OBSERVATION CHECK LIST FOR LENSES PROJECT

Date: Topic:	1 (poor)	2	3 (v. good)
Suitability of venue (s)			
Suitability of project/lecture staff			
Teaching methods and approaches			
presentations clear/concise or too text heavy			
Student-staff interaction			
Student-student interaction			
Group work			
Mech Eng-ID interaction			
Student responses			
Attention given to Mech Eng students			
Flexibility of lecturing staff to student needs			
Aims & objectives well explained			
Resources/tools sufficiently well explained			
Resources/tools sufficiently practiced			
Relevance of tools/resources to project			
Content: relevance/suitability of case studies			
Content: sufficient or too much			
Authentic learning?			

APPENDIX C2: COURSE OUTLINE & TIMETABLE

WEEKS 1-6	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
BRIEF	31 August	1 September	2 2pm Design Bldg. BRIEF Outlined – RF. Introduction to project, guideline for mapping work and activities. Intro to Biomimicry and Life's Principles evaluation. CR presents LeNSes SPSS by case studies. Rural, urban, peri-urban. Look at case studies. BJ observes. (2hrs)	3 ID THEORY	4 BREAK UP DAY
VAC WEEK Scoping Context, analysis of products,	7 Vac week: Scoping of Rural, urban, peri-urban energy-related products in context.	8	9	10	11
WEEK 1 GOAL Life's principles evaluation and LeNSes tools, design exercises	14 Life's Principles evaluations – Teams look for obvious links between components, energy outputs, sources. Work on comparative analyses. Form teams CR - demonstrates SPSS tools – SWOT analysis & system mapping on case studies provided.**BJ observes(9-3.30)** 4.5 hrs obs, 1hr writing up	15 Preparation of comparative analyses of chosen products – looking for linkages, similarities, differences, SWOT analyses. (AB organises camera for capturing)	16 Morning - drawing 2pm: ID/MTech teams present product comparisons –	17 THEORY	18 CR -– demonstrates further SPSS tools – Sustainability radars - a case study Business canvas exercise Project work in teams facilitated by RF, AB and CR BJ observes (4hrs??)
WEEK 2 GOAL Using LeNSes tools, Biomimicry, project work	21 9-12pm Kirstenbosch Naturalist lens – sight sounds smells taste touch. How does nature filter BJ observes Project work in	22 • Show examples of previous • Presentations. • Biomimicry mini	23 • 2pm: • ID teams present observation mind-maps • Project work in	24?? [Public holiday] ID THEORY?	25 CPUT closed Project work in teams Facilitated by CR, RF, AB

	teams facilitated by RF, AB and CR Wendy Hitchcock – botanist Observation mind-maps briefed – RF	challenges • Teams prepare Observation mind-maps for tomorrow BJ observes	teams		BJ – interviews/ surveys with RF, CR, AB, students
WEEK 3 GOAL Design drawings, context scenarios to present to peers/ industry	28 • Guest speakers - TBC • Design drawings/ • Documentation prep	29 Design drawings/ Documentation prep	30 Design drawings – Mech Eng present?	1 October ID THEORY	2 Design drawings/ Documentation prep
WEEK 4 GOAL Fine tuning of products and system drawings	5 Design, system drawings/ Documentation prep	6 Design, system drawings/ Documentation prep	7 Design, system drawings/ Documentation prep	8 ID THEORY	9 Design, system drawings/ Documentation prep
WEEK 5 GOAL Final presentations, marks, reports, budget recon.	12 Plan final presentations, documentation, budgets for prototyping	13 Plan final presentations, documentation, prototyping	14 Plan final presentations, documentation, prototyping	15 ID THEORY	16 Present to outside stakeholders – Vimeo on youtube – CAD models, basic prototyping Marks – panel/jury? BJ observes
WEEK 6/7 GOAL Design, Prototypes, Manufacture – exhibit 2 November	19 Build final prototypes	20 Build final prototypes	21 Build final prototypes BJ – interviews/surveys with RF, CR, AB, students	22 ID THEORY	23 • Build final prototypes • - deadline 2 Nov. Posters, prototypes exhibit for moderation.

APPENDIX C3: BIOMIMICRY

Life's Principles

EVOLVE TO SURVIVE

- replicate strategies that work
- integrate the unexpected
- reshuffle information

BE RESOURCE (MATERIAL AND ENERGY) EFFICIENT

- use multi-functional design
- use low-energy processes
- recycle all materials
- fit form to function

ADAPT TO CHANGING CONDITIONS

- maintain integrity through self-renewal
- embody resilience through variation, redundancy, and decentralization
- incorporate diversity

INTEGRATE DEVELOPMENT WITH GROWTH

- combine modular and nested components
- build from the bottom-up
- self-organize

BE LOCALLY ATTUNED AND RESPONSIVE

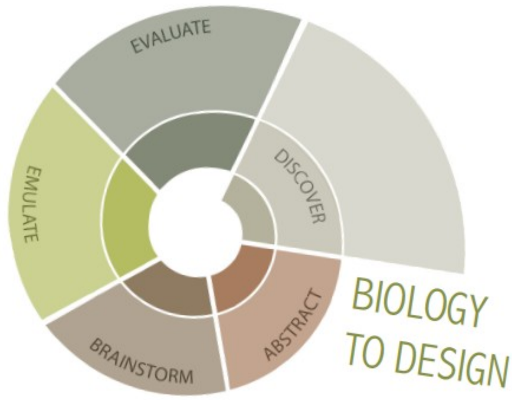
- use readily available materials and energy
- cultivate cooperative relationships
- leverage cyclic processes
- use feedback loops

USE LIFE-FRIENDLY CHEMISTRY

- build selectively with a small subset of elements
- break down products into benign constituents
- do chemistry in water

Biomimicry Design Methodologies

Design Spirals



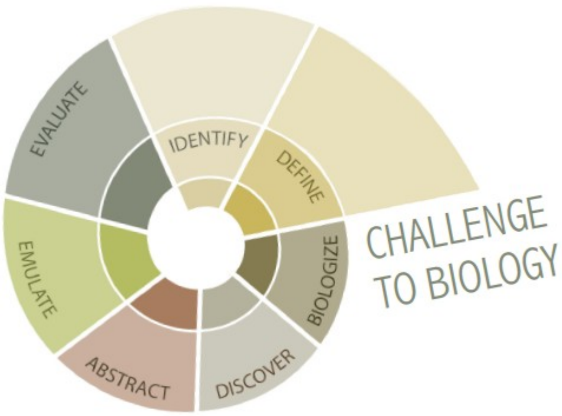
1. DISCOVER
Natural Models

2. ABSTRACT
Design Principles

3. BRAINSTORM
Potential Applications

4. EMULATE
Nature's Strategies

5. EVALUATE
Against Life's Principles



1. IDENTIFY
Function

2. DEFINE
Context

2. BIOLOGIZE
Challenge

3. DISCOVER
Natural Models

4. ABSTRACT
Design Principles

5. EMULATE
Nature's Strategies

6. EVALUATE
Against Life's Principles

APPENDIX C4: DESIGN BRIEF

LeNSes/Biomimicry Energy S.PSS Design

Student Groups	Lecturer(s)	Project Introduction	Final Presentation Dates
3rd Year Industrial Design 3rd Year Mechanical Engineering	XXXXXXXX	2nd September 2015	To Internal/External Panel: 15th October Final prototypes: 2 November
PROJECT: The project aims to analyse existing energy products within human and natural systems in Rural, Informal and Formal settings. To ensure sustainable, stable, resource-efficient energy delivery, all stakeholders in the system will be considered using the S.PSS tools and methodology. The lens for environmental sustainability is Biomimicry with analysis through Life's Principles. Biomimicry methodology and S.PSS will be implemented to improve and re-develop existing products within social systems and contexts.			

Project Title:	SPSS Energy Product design
The brief:	6 Teams comprising +-5 students in each, will begin by individually investigating currently-used energy-producing or energy-consuming devices in either urban, peri-urban or rural settings. Using Biomimetic and SPSS evaluations, the teams will collaboratively develop presentations based on a comparative overview of each of the products/devices within the group. Concentrating on energy-efficiency, type of energy source, design for disassembly, cradle to cradle. The product must either in manufacturing processes or use, rely on fossil fuel in some way. The final outcome is a fully developed product prototype, designed and demonstrated within a Sustainable Product Service System, using deep social and environmental sustainability a benchmark.
Using the SPSS tools, with Biomimicry as a lens	You will be introduced to Biomimicry as a lens for investigating more innovative approaches to designing products that utilise renewable energy. Life's Principles will be used as an evaluation tool, whilst the SPSS tools found on the LeNSEs platform will be demonstrated as a resource and mode for presenting solutions. LeNSes*: The introduction of a Sustainable Product Service System (S PSS) approach ensures that products and services take the broader context of each project into account. Incorporating Biomimetic methodology ensures that the deeper and complex needs of environmental systems is thoroughly understood. The project will look at Renewable Energy (RE) solutions in Informal, Formal and Rural contexts. The design proposals will be uploaded to the global LeNSes platform and the most successful entered into the LeNSes student award programme. * The Learning Network of Sustainable Energy Systems.

OBJECTIVES:

- To engage with theories and principles which pertain to Biomimicry and to use this as a lens and methodology with which to approach the project
- To engage with the tools found on the LeNSes platform and use these to demonstrate innovative, sustainable product service systems
- To translate research findings into cohesive research documents with appropriate accreditation of sources (reflective journal and report)
- To develop appropriate presentation methods to best communicate concepts and designs.
- To re-design existing product and develop prototypes within a specified budget (To be advised)

GENERAL TIMELINE AND DELIVERABLES:

Weeks	Activities	Deliverables
Weeks 1 – 2 BIOMIMICRY and S.PSS introduction and analysis	Receive training in Biomimicry and SPSS tools Life's Principles, Case studies:Mexico, Cameroon,Urban?	• Individual A3 poster- Present Life's Principles evaluation • Evaluate Rural, Urban and Peri-urban energy products and systems using LeNSes SPSS radar diagrams • Group presentation video of conceptual solutions.
Weeks 3 – 4 DESIGN PHASE	Weather station Swot analysis System mapping Sustainability radars Business canvas	• Group presentation video of conceptual solutions. • Group Report
Weeks 5 – 6 PROTOTYPING, SPSS infographics		• Prototype: model • 2 – 3 min video clip • Infographic on PSS

Please Note: All work (visual and textual) must be correctly referenced using Harvard referencing

DEADLINES:

- Presentation of comparative energy products: Wednesday 16 September 2015
- Presentation of Observation Mind-maps: Wednesday 23 September 2015
- Final presentation: Friday 16 October
- Prototypes for Moderation: Monday 2 November

MARKING:

- Marking of this project will be done in three ways:
    - Individual marks (individual projects during weeks 1-4) – *this is departmental specific*
    - A group mark (for Design Phase presentation & report, weeks 5-6) Peer mark
    - Prototype design
    - Infographics

PRESENTATION & REPORT MARKING RUBRIC

Names of Students:	

CATEGORY	Highly Proficient	Capable	Adequat e	Limited	Inadequate	MARK
INSPIRATION Demonstrate an understanding of and the ability to conduct primary- and secondary research; Demonstrate an understanding of Biomimicry as a lens for design Demonstrate an understanding of LeNSes SPSS tools						/20
IDEATION Demonstrate the ability to identify Key Issues; Demonstrate the ability to generate relevant strategic and innovative ideas based in Biomimicry and using SPSS tools						/25
IMPLEMENTATION Demonstrate the ability to develop viable and focused strategic insights and recommendations. Demonstrate the ability to develop appropriate level of prototype and design communication elements where necessary						/30
DOCUMENTATION Professionally presented (Attention to detail) Correct referencing; Demonstrate the effective use of Biomimicry methodology, Demonstrate the ability to substantiate reasoning in a clear and cohesive manner						/25
TOTAL MARK						/100
General Comments:						

APPENDIX C5: QUESTIONNAIRE, STUDENT EVALUATION OF COURSE

Questions to be answered by the students

1. EVALUATION OF THE TEACHING STAFF

Answer these questions based upon your general impression of all the teachers of either the host or the guest institution (you do not have to fill it in for each teacher one by one.)
A. Host institution
Please give an evaluation on the following different aspects of the teaching staff. Please tick the relevant boxes accordingly to following the scale: 1 = VERY POOR,
2 = POOR, 3 = SUFFICIENT, 4 = GOOD, 5 = VERY GOOD/EXCELLENT

	1	2	3	4	5
1.0 Is the lecturer's explanation style clear?					
1.1 To what extent does the lecturer show enthusiasm for his/her subject?	○	○	○	○	○
1. 2 Lecturer's preparation for the class	○	○	○	○	○
1.3 Students involvement during the class	○	○	○	○	○
1.4 Feedback to students	○	○	○	○	○
1.5 Lecturers' help inside or outside class	○	○	○	○	○

2. GENERAL QUESTIONS ON THE PILOT COURSE

2.1 What is the sustainability focus of the course?

Social Sustainability (People)	%
Environmental Sustainability (Planet)	%
Economical Sustainability (Profit)	%

What is the focus of the course regarding PSS and DRE?

Products Service System (PSS)	%
Distributed Renewable Energy (DRE)	%

Please evaluate the following aspects of the LS. Please tick the relevant boxes accordingly to following the scale: 1 = VERY POOR, 2 = POOR, 3 = SUFFICIENT, 4 = GOOD, 5 = VERY GOOD/EXCELLENT

	1	2	3	4	5
2.2 Are the contents of the course clear?	○	○	○	○	○
2.3 To what extent is the course well structured?	○	○	○	○	○
2.4 Are the organisation and logistics (classroom, timing, internet etc) of the course satisfactory?	○	○	○	○	○
2.5 Is the content of the course materials up-to-date (e.g. slides, books, papers, readers, etc.)?	○	○	○	○	○
2.6 Does the course provide sufficient theoretical background?	○	○	○	○	○
2.7 Do you consider this course useful for industrial design?	○	○	○	○	○
2.8 Does the course support motivation for learning?	○	○	○	○	○
2.9 Do the assessment and assessment criteria match the course content and course objectives?	○	○	○	○	○
2.10 Do the course assignments match the course content?	○	○	○	○	○
2.11 Does the course assignment motivate your learning?	○	○	○	○	○

2.12 Indicate your understanding of the topics.	○	○	○	○	○
2.13 Indicate the practicality of the content	○	○	○	○	○
2.14 How useful are the LeNSES materials?	○	○	○	○	○
2.15 How useful are the Biomimicry materials?	○	○	○	○	○
2.17 Student involvement: the course structure allowed students to learn from each other	○	○	○	○	○

2.18 Please evaluate the following aspects of the LS. Please tick the relevant boxes accordingly to following the scale: 1 = VERY POOR, 2 = POOR, 3 = SUFFICIENT, 4 = GOOD, 5 = VERY GOOD/EXCELLENT

Content in relation to Sustainability	○	○	○	○	○
Content in relation to Product Service Systems	○	○	○	○	○
Content in relation to Distributes Renewable Energy	○	○	○	○	○
Content in relation to the specific context of Africa	○	○	○	○	○
Content in relation to entrepreneurship and business models	○	○	○	○	○
Content in relation to human centred design	○	○	○	○	○
Content in relation to Product Life cycle design (or design for environmental sustainability)	○	○	○	○	○
Content in relation to Biomimicry applications	○	○	○	○	○
Content in relation to case studies and examples from practice	○	○	○	○	○
How was the balance between theory and practice?	○	○	○	○	○

2.19 Are there any topics related to Design for Sustainability, Product-Service Systems and Distributed Renewable Energy that you would add within this course?

Yes	○	Please explain:
No	○	

2.20 Please add comments, in particular if you have identified some aspects that you consider to be “poor” and “very poor”:

2.21 Please explain what aspects of the course you liked most?

2.22 Please explain what aspects of the course you liked least?

3. USE OF THE OPEN LEARNING E-PLATFORM (OLEP) AND ONLINE LEARNING RESOURCES (LRs) (http://lenses.polimi.it)

A. The use of Learning Resources:

3.1. Have you downloaded and used any of the LeNSES Learning Resources?

Yes	
No	

3.2. When during the course did you use these Learning Resources?

3.3. Have you used only the Learning Resources suggested by the teacher?

Yes	
No	

B. The usefulness of the Learning Resources:

3.4. Has the availability of the Learning Resources online facilitated the process of learning?

Yes	
No	

3.5. Which types of learning resources (ppt, text, video, etc) have been more useful for you?

4. USE OF THE WEBSITE

Please evaluate the following aspects of the LeNSes website (www.LeNSes.polimi.it). Please tick the relevant boxes accordingly to following the scale: 1 = VERY POOR, 2 = POOR, 3 = SUFFICIENT, 4 = GOOD, 5 = VERY GOOD/EXCELLENT

	1	2	3	4	5
4.1. To what extent is the website user-friendly?					
4.2 To what extent does the website activate your interest?					
4.3. How satisfactory is the interface?					
4.4. Are the menu and tool bars structured and organised in a functional way?					
4.5. Are the web pages structured in a coherent/adequate way?					
4.6 How easy is it to navigate the website?					
4.7 Is the information clearly organised?					
4.8. To what extent is the information useful?					
4.9. To what extent is the information accurate?					

4.10. How adequate are the size and colour of the textual elements?	○	○	○	○	○
4.11. Give an overall evaluation of the aesthetics of the website	○	○	○	○	○

4.12. Please add comments, in particular if you have identified some aspects listed above that you consider to be "poor" and "very poor":

.

4.13. Is there any information/part missing? Please list what is not available that you would like to find (and specify if technical or content related)

4.14. Is there any information/part overlapping that is not useful and you would leave out?

4.15 Which website features did you find most interesting?

4.16 Can you make any other suggestions for improving the website?

5. USE OF THE OLEP

Please evaluate the following aspects of the OLEP. Please tick the relevant boxes accordingly to the scale: 1 = VERY POOR, 2 = POOR, 3 = SUFFICIENT, 4 = GOOD, 5 = VERY GOOD/EXCELLENT

	1	2	3	4	5
5.1. Learning resources can be searched using 3 different modalities: by "teacher/ course/ institution/year", by "content/subject", or through an "advanced search". To what extent are these 3 modalities are useful?	○	○	○	○	○
5.2. To what extent is the procedure to search learning resources by "teacher/course/institution/year" user-friendly?	○	○	○	○	○
5.3. To what extent is the procedure to search learning resources by "content/subject" user-friendly?	○	○	○	○	○
5.4. To what extent is the procedure to search learning resources by "advanced search" user-friendly?	○	○	○	○	○

6. RECOMMENDATIONS FOR IMPROVING THE COURSE

Please make suggestions for improving the course

APPENDIX C6: GUIDING INTERVIEW QUESTIONS FOR LECTURERS

1. Lenses analytical and communication tools

- Is this the first time that the Industrial Design (ID) students have been are introduced to the idea of sustainable design? if not, in what way is this introduced at an earlier stage?
- Is this the first time that S.PSS & Biomimicry (BM)are being taught together?
- How proficient did the students become at using the S.PSS tools and BM, both separately and together, and in an integrated way?
- In what ways did these tools/methodologies help the students in innovative renewable energies design?
- Many of the students were unhappy with the LeNSes website and accessibility of the online resources. What could be done about improving this?

2. Questions relating to the proposed course outcomes

- To what **natural energy systems** were the students introduced?
- Were the students introduced to any **alternative energy systems** in rural, peri-urban and urban settings,or were they expected to research these themselves?
- What aspects of **indigenous Wisdom** did students draw on during their search for appropriate energy systems design?
- What **guest speakers** did they have on renewable energies? Were these helpful?
- As a research methodology, to what extent did the students use **Participatory Design** methods and, other than for understanding group dynamics, did they use **Activity theory** in any way?
- To what extent do the student projects reflect the **interconnectedne**ss of social, economic, political and natural systems?

3. Project overall

- Other than the inclusion of the (Mechanical Engineering) ME students, how was this project different from last year?
- What value did the ME students add? What were the main difficulties in implementing the transdisciplinary learning?
- What do you think were the strengths of the course?
- Weaknesses?
- What do you think of the final projects , especially in relation to the goals of the course?
- What would you do differently next time? [How do you think it could be better structured? Better coordinated? Better facilitated] [Time, planning, facilitation etc]

APPENDIX D: ETHICS APPROVAL AND CONSENT FORM

*please take note of the title change of this thesis from the original title which was approved on 6 June 2016.

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6 June 2016

Mr CE Raymond
Faculty of Informatics & Design
Cape Peninsula University of Technology

Dear Mr Raymond

RE: PERMISSION TO CONDUCT RESEARCH AT CPUT

The Faculty Research Ethics Committee received your application entitled "Biomimetic product service systems: A Design Model", together with the dossier of supporting documents.

Permission is herewith granted for you to do research at the Cape Peninsula University of Technology.

Wishing you the best in your study.

Sincerely

APPROVED
Chair Senate Ethics Committee
06 JUN 2016
Cape Peninsula University of Technology
Sign: ....

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