The Development of an Implementation Framework for Green Retrofitting of Existing Buildings in South Africa

by

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Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

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Abstract

The Development of an Implementation Framework for Green Retrofitting of Existing Buildings in South Africa.

In this study frameworks related to retrofitting were investigated in order to develop a holistic framework for the green retrofitting of existing buildings in South Africa. The developed framework consists of five phases: retrofit feasibility, pre-project planning, construction, post-retrofit activities, and finally operation and maintenance.

The framework was validated by means of a case study. The time required by the organisation involved to obtain the necessary funds for constructing the retrofit far exceeds the available time of this study. Therefore only the first two phases of the developed frameworks, retrofit feasibility and pre-project planning, were validated. The framework was developed to be a generic representation for South African retrofit projects, and as with the maintenance phase, many aspects were selected and adapted for the South African context.

One of the main barriers for green buildings in South Africa, identified from literature, is the high cost perception South Africans have regarding green buildings. In the case study it was demonstrated how internal resources and expertise of the organisation can be used to reduce the total retrofit cost. Combining a retrofit with maintenance actions can further reduce the additional amount needed to invest in a green retrofit. Fourteen retrofit features are suggested and grouped into seven smaller independent projects according to the types of skills that are required for each installation. This minimises the time, external expertise and resources needed for specific jobs. These sub-projects are generally not fixed to a pre-defined schedule and can be attempted at stages the organisation finds suitable.

Uittreksel

’n Implementeringsraamwerk vir die Groen Aanpassing van Bestaande Geboue in Suid-Afrika.

(“The Development of an Implementation Framework for Green Retrofitting of Existing Buildings in South Africa.”)

In hierdie studie word raamwerke vir die aanpassing van geboue ondersoek met die doel om ’n holistiese raamwerk vir die groen aanpassing van bestaande geboue in Suid-Afrika te ontwikkel. Die raamwerk wat ontwikkel is bestaan uit vyf fases: die uitvoerbaarheid van die aanpassing, voorafbeplanning van die projek, konstruksie, post-aanpassingsaktiwiteite en laastens inwerkstelling en instandhouding.

Die uitvoerbaarheid van die ontwikkelde raamwerk is deur middel van ’n gevalle studie getoets. Die tydperk wat die betrokke organisasie benodig om die nodige fondse vir die aanpassing te bekom is meer as die tyd wat beskikbaar is vir die studie. Daarom kon net die uitvoerbaarheid van die eerste twee fases van die ontwikkelde raamwerk, die uitvoerbaarheid van die aanpassing en die voorafbeplanning, getoets word. Die raamwerk is ontwikkel om verteenwoordigend te wees van Suid-Afrikaanse aanpassingsprojekte, en soos in die geval van die instandhoudingsfase, is baie aspekte gekies en aangepas met Suid-Afrikaanse toestande in gedagte.

Een van die hoofstruikelblokke vir groen geboue in Suid-Afrika is, soos in literatuur geïdentifiseer, die persepsie van hoë koste. In die gevalle studie word daar gedemonstreer dat die interne bronne en kennis in die organisasie self gebruik kan word om die totale kostes verbonde aan die aanpassing te verminder. Die kombinering van die aanpassing met instandhoudingsaksies kan die addisionele bedrag wat benodig word vir belegging in die aanpassing, verder verminder. Veertien aspekte van aanpassing word voorgestel en in sewe kleiner onafhanklike subprojekte volgens die tipes vaardighede wat vir elke installasie benodig word, groepeer. Dit verminder die tyd, eksterne bedrewendheid en bronne wat vir spesifieke take bekom moet word. Daar is gewoonlik nie ’n voorafskedule verbonde aan hierdie subprojekte nie en dit kan uitgevoer word op stadiums wat vir die organisasie gerieflik is.

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To my Creator, all the glory. Thank you for this amazing opportunity and I am proud to say, I gave it my best.

Professor Alan Brent and Mrs. Imke de Kock, thank you for your understanding, guidance, patience and sharing of knowledge during my research and I cherish the friendship you have built. I am truly grateful for the opportunity.

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I would also like to thank the Sustainability Institute that provided their main building as case study for my research. I hope that this thesis can add value to the Sustainability Institute main building.

My wife Joanie, you have given me remarkable encouragement and support during my research. You showed me unwavering love and patience. Thank you for being the same amazing person today as the day I married you.

My parents, Jacques and Lucresia Geldenhuys, you raised me to push through when life gets hard. You never stopped believing in both Joanie and me, and you have given me amazing support during tough times. I can't thank you enough.

My parents-in-law, Willem and Felicity Engelbrecht, thank you for your dedicated, daily prayers and support.

Mahish Rama, thank you for being an inspirational friend.

Thank you to friends and family who also offered their support and understanding.

"The plans of the diligent lead to profit as surely as haste leads to poverty."
Proverbs 21:5, 1000 BCE

Dedication

This thesis is dedicated to my wife, Joanie. Thank you for our wonderful time together as married students.

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Nomenclature

Abbreviations

AD	anno Domini
AHP	Analytical Hierarchy Process
AP	Accredited Professional
BAU	Business As Usual
BIM	Building Information Management
BCE	Before the Common Era
BPD	Building Performance Database
CBECC-COM	California Building Energy Code Compliance for Commercial
CBEI	Consortium for Building Energy Innovation
CBES	Commercial Building Energy Saver
CCT	Customized Calculation Tool
CEN	Comité Européen de Normalisation (French: European Committee for Standardization)
CIBSE	Chartered Institution of Building Services Engineers
CIDB	Construction Industry Development Board
CoC	Certificate of Compliance
COMBAT	Commercial Building Analysis Tool
COPRAS	Complex proportional assessment
D.C.	District of Columbia
DNI	Direct nominal irradiation
DME	Department of Minerals and Energy
DPW	Department of Public Works
ECM	Energy conservation measure
EMR	Experience modification rating
EWP	Energy Water Performance
FM	Facilities management
GBCSA	Green Building Council of South Africa

HVAC	Heating Ventilation Air Condition
HOQ	House of Quality
IEEE	Institute of Electrical and Electronics Engineers
IEQ	Indoor Environmental Quality
ISHVAC	International Symposium on Heating, Ventilating, and Air-Conditioning
ISO	International Organization for Standardization
IT	Information Technology
kL	Kilolitre
kW	Kilowatt
kWh	Kilowatt-hour
LED	Light emitting diode
LEED	Leadership in Energy and Environmental Design
MCDM	Multi-Criteria Decision Making
M&V	Measurement and verification
MMP	Maintenance Management Plan
MWh	Megawatt hour
NGO	Non-Governmental Organisation
OECD	Organisation for Economic Co-operation and Development
O&M	Operations and maintenance
OSHA	Occupational Safety and Housing Administration
PCP	Pre-construction planning
PMI	Project Management Institute
PPP	Pre-project planning
PV	Photovoltaic
RICS	Royal Institute of Chartered Surveyors
RRDS	Rich Room Data Schedule
S.A.	South Africa
SAW	Simple additive weighting
SBI	Sustainable Building Index
SBS	Sick Building Syndrome
SERDP	Strategic Environmental Research and Development Program
SETAC	Society for Environmental Toxicology and Chemistry
SI	Sustainability Institute
SWOT	Strengths, weaknesses, opportunities, threats

TARWR	Total actual renewable water resources
T&C	Test and commissioning
TOPSIS	Technique for order preference by similarity to ideal solution
U.K.	United Kingdom
U.S.	United States
USGBC	United States Green Building Council
WEC	World Energy Council
WGBC	World Green Building Council

Chapter 1

Introduction

1.1 Background to the Research Problem

In the 1950s up to 30 per cent of the world population lived in urban areas. Today the world average is 54 per cent and is projected to be 66 per cent by 2050 (UN-DESA, 2015). The African population in 2011 stood at 414 million urban and 632 million rural (UN-DESA, 2012). By 2050 the African population is estimated to increase to 1.265 billion urban and 927 million rural (UN-DESA, 2012). An increase of 72 per cent in world urban population is expected from 3.6 billion in 2011 to 6.3 billion in 2050 (UN-DESA, 2012). According to this estimate, Africa will host a fifth of the world's urban population by 2050. South Africa currently has nearly two thirds (62 per cent) of its population urbanised, projected to be 79.6 per cent by 2050 (UN-HABITAT, 2010), essentially one of the most urbanised among sub-Saharan Africa countries (Turok, 2012).

Cities are complex evolving systems that use vast amounts of resources (Batty, 2008). The unsustainability of cities lies in massive resource consumption and waste generation beyond the carrying capacity of the cities and the absence of waste-to-resource flow (Agudelo-Vera *et al.*, 2011; Batty, 2008). The Easter Island case is an example of how an entire civilisation can come to a fall due to unsustainable development. The earth's resources that sustain human life are limited and it is crucial that these resources should be managed strategically (Diamond, 2005; Ponting, 2007; Agudelo-Vera *et al.*, 2011).

Literature provides sufficient evidence that Africa is already stressed with urban poverty and unsustainable exploitation of resources like land and energy due to the current rate of urbanisation (Cobbinah *et al.*, 2015; UN-DESA, 2015; Millennium Ecosystem Assessment, 2005). Africa has large undeveloped renewable energy resources and there is a lack of access to electricity in households, which influences all aspects of living such as health, education and nutrition (Nakumuryango and Inglesi-Lotz, 2016). In a recent report published by the Royal Institute of Chartered Surveyors (RICS), Tim Kasten made a statement regarding Africa's rapid urbanisation. He stated that we cannot necessarily rely on solutions from the past to solve the problems that arise in the future (RICS MODUS, 2011). Achieving sustainable urban development in Africa is a daunting task (Cohen, 2006).

In South Africa there are few governmental incentives that promote sustainable development (Lombard, 2013). The South African economy is challenged by aged or inadequate infrastructure, inefficient regulatory processes, delaying investments and investor uncertainty due to lack of Government co-ordination (South Africa, Department of Communications, 2015), while energy security also plays an important role in the South African economy (Fawkes, 2005). Water resources in South Africa are adequate for the foreseeable future, but the country cannot be seen as a water secure country (Muller *et al.*, 2009). South Africa was ranked according to the total actual renewable water resources (TARWR) as the 29th driest out of 193 countries (UNESCO-WWAP, 2016).

South Africa had to introduce load shedding to help stabilise the electricity grid (South Africa, Department of Communications, 2015; Sebitosi, 2008). Coal, linked to emissions, is the source of 93 per cent of South Africa's electricity (Eberhard, 2011), which is high compared to the world average of around 40 per cent. However South Africa has among the highest annual solar direct nominal irradiation (DNI) in the world, meaning it has excellent solar energy potential. The government realised that it is important to create a sustainable energy mix through the development of renewable energy sources. A publication in 1998, The White Paper on Energy Policy, suggested that South Africa has substantial potential for improving energy efficiency (South Africa, Department of Minerals and Energy, 1998) and will have to do so in order to maintain economic competitiveness (Fawkes, 2005) as energy production plays an integral role in economic development worldwide (Davidson *et al.*, 2006). Twenty-five per cent of the South African population lack electricity. (World Energy Council (WEC), 2013). South Africa has set a national objective to have 30 per cent clean energy by 2025. (South Africa, Department of Energy, 2015). Compared to the world, South Africa showed the largest renewable energy asset growth and eighth largest renewable energy investments in 2014. (McCrone *et al.*, 2016).

According to De Villiers and Volschenk (2011) shortage of resources like water and electricity is a great threat to an economy, but Muller *et al.* (2009) suggest that it is not the determining factor of the success of a nation. It can be managed, mitigated and perceived as an opportunity to adapt or innovate. Singapore is a good example of this as they have rapid economic growth despite water scarcity. Their water management strategies place them at the forefront of that discipline and industry (Muller *et al.*, 2009).

1.1.1 Sustainable development and the construction industry

Litman and Burwell (2006) compare the application of sustainability planning to development to taking preventative medicine for health and wellness. In short, the aim is to anticipate or manage a problem rather than wait for the crisis. Sustainable development is about the integrated nature of human activities and the balance between economic, environmental and social objectives (Litman and Burwell, 2006). This is also referred to as the triple bottom line principle. Figure 1.1 illustrates the interaction of these aspects to ensure sustained human well-being.

The construction industry has a major impact on the environment, emissions, as well as human health and wellness (Zuo and Zhao, 2014). Buildings use various resources like raw materials, water and energy but they also produce waste and emissions that are potentially harmful. Research done by Levin *et al.* (1995) calculated the representative contribution of buildings to environmental impacts in the United States (U.S.). Levin *et al.* (1995) calculated this environmental burden as an estimate fraction for each building-related category based on U.S. national inventory flow data from 1993 to 1995 as research funded by the Strategic Environmental Research and Development Program (SERDP) to identify the building-related environmental impacts of greatest concern (Levin *et al.*, 1995; Levin, 2003). In Figure 1.2 results calculated in Levin *et al.* (1995) are shown, listed from the smallest to the largest contributions to environmental impact. These results were also discussed in Levin (1996) and Levin (1997).

A growing population and economy pose an interesting challenge to designers and builders to satisfy the need for new and renovated facilities that are productive, accessible, secure, healthy and that reduce environmental impact (Alnaser *et al.*, 2008). Green buildings offer numerous benefits on environmental, economic and social level (Zuo and Zhao, 2014).

1.1.2 Green buildings

The ultimate goal of being green according to Yudelson and Meyer (2013) is being sustainable. In Figure 1.2 there is evidence of the significant environmental impacts that buildings have. Although building stock is not the sole cause for environmental decay, designing new or adapting existing buildings can help to make cities sustainable.

De Villiers and Volschenk (2011) suggest a major obstacle of the South African green building industry could be the perception that green buildings are an added feature and add cost, compared to conventional buildings. Research was done by Coetzee and Brent (2015) on the perceptions in South Africa on green building life-cycle cost impacts. A survey with a sample size of 1192 perceived that the average green building cost premium perception

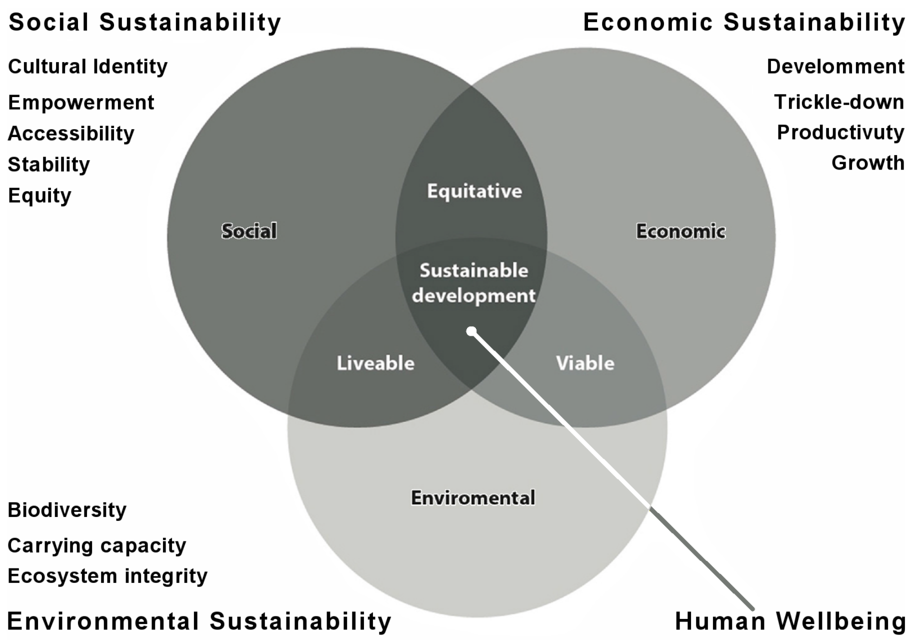


Figure 1.1: Sustainability as a balance between economic, environmental and social aspects. Adapted from Castellano *et al.* (2016) and Alnaser *et al.* (2008).

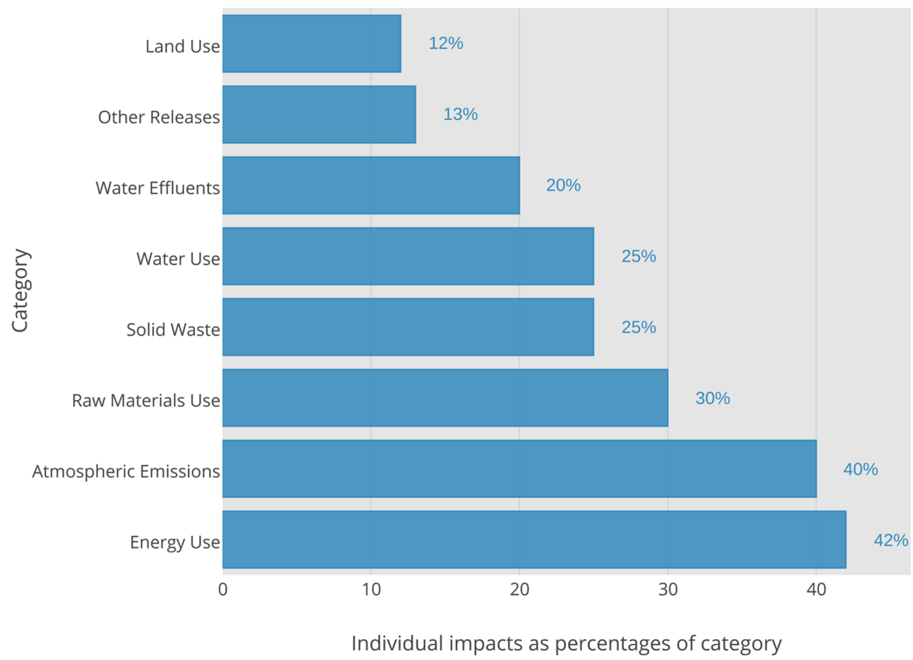


Figure 1.2: The environmental impacts attributed to buildings. Data in Levin *et al.* (1995).

was about 20 per cent, double the actual premiums, among professional practitioners and property developers in South Africa. Actual cost premiums were calculated from case studies of four- and five-star newly built green buildings in South Africa as less than 1 per cent and up to 10 per cent (Milne, 2012). The survey done by Coetzee and Brent (2015) showed that the perception of the average cost payback in South Africa is 7 years where in fact it is only 4.8 years.

Life in the urban environment is linked to non-communicable illnesses like cardio-vascular ailments and diabetes due to unhealthy habits like physical inactivity, bad diet patterns and obesity. Buildings play a significant role in some of the health and well-being problems in cities since people spend most of their time inside buildings (Balaban and de Oliveira, 2016). With green buildings the aim is also to provide optimal indoor environmental quality. By improving lighting, heating, cooling, airflow and air quality the health, well-being, comfort and productivity of occupants can be improved (Romm and Browning, 1998). Preller *et al.* (1990) determined that sick leave related to Sick Building Syndrome (SBS) symptoms could be reduced by 34 per cent if occupants have individual control over the temperature and airflow at their workstations. Sick leave was 35 per cent lower in offices with increased ventilation with outside air and the absence of humidification. This was found in the study by Milton *et al.* (2000). A mail sorting room of the Main Post Office in Reno, Nevada was fitted with a new ceiling to improve noise levels, lighting and temperature and led to a 6-8 per cent increase in productivity (Romm and Browning, 1998). These cases are a few examples of various instances found in literature about productivity and health benefits in buildings designed for optimal Indoor Environmental Quality (IEQ). An increase in productivity and a decrease in absenteeism linked to green buildings, together with reduced operation and maintenance costs (Nilashi *et al.*, 2015), can contribute significantly to financial savings.

The Green Building Council of South Africa (GBCSA) is a non-profit organisation formed in 2007 to encourage the sustainable property industry in South Africa through green building practices. GBCSA has worked towards developing assessment frameworks for green buildings in South Africa (GBCSA, 2014*a*,*b*, 2016*a*). Currently the GBCSA has seven ratings that a building can apply for (GBCSA, 2014*a*,*b*, 2016*c*):

- Existing Building Performance,
- Interiors,
- Office,
- Public & Education Building,
- Multi Unit Residential,

- Retail Centre, and
- Socio-Economic.

Green buildings have gained greater public awareness, but defining a green building in a single manner can be difficult. There have been many debates in this regard and can possibly prove to be a barrier to implementing and promoting green buildings (Zuo and Zhao, 2014). Yudelson and Meyer (2013) say that the ultimate goal is for a green building to be sustainable. Figure 1.1 is an illustration portraying sustainable development as a balanced mix of the three sustainability principles: environmental, economic and social sustainability. Human well-being depends on the adoption of sustainable development in a balanced manner. Love *et al.* (2011) believe green buildings should promote sustainable growth and offer an opportunity for decreased impact and increased output. The City of Cape Town (2012) suggests that the three principles of sustainability should also be applied in consideration of the context a building is situated in. The City of Cape Town (2012) believes that green buildings should:

- be appropriate to the local context;
- conserve the natural environment;
- use resources efficiently and effectively;
- be approached on a life-cycle basis;
- reduce waste;
- use resources that are renewable;
- incorporate sustainable procurement;
- use locally-sourced materials and skills;
- improve the health and well-being of users;
- have continuous monitoring and evaluation; and
- leave a positive legacy.

According to GBCSA (2014*a*) and GBCSA (2014*b*), a green building reduces or eliminates negative environmental, human and health impacts, strives towards resource efficiency and does this as part of its as-built or operational practices. The GBCSA assessment for Green Star rating evaluates the following categories (GBCSA, 2014*a*,*b*):

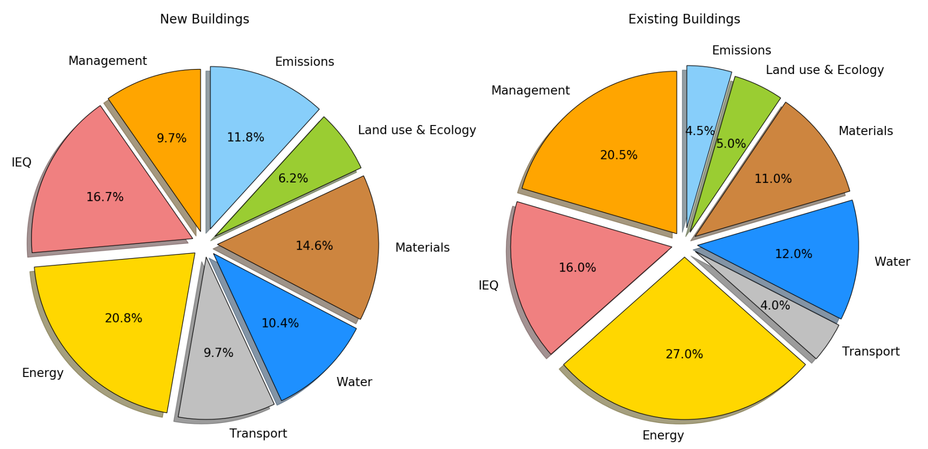


Figure 1.3: A comparison of the category weightings in the GBCSA new and existing building rating tools. Compiled from data in GBCSA (2014*a*) and GBCSA (2014*b*).

- Management,
- Indoor Environmental Quality (IEQ),
- Energy,
- Transport,
- Water,
- Materials,
- Land Use and Ecology,
- Emissions, and
- Innovation.

In Figure 1.3 a comparison is made with regard to the weighting assigned by the GBCSA to each of the eight environmental performance assessment categories in new green buildings and existing green buildings. The ninth category, not included in the pie charts, is the Innovation category which encourages new growth and the adoption of green building technology. Figure 1.3 shows that the energy consumption and management aspects are much more important when applying for an existing building rating. Emissions, materials and transport are prioritised more within new building ratings than with existing buildings.

A slight shift in focus from new green buildings to green-retrofitting is expected because demolition and rebuilding is not a financially viable option for the vast number of existing buildings (Jagarajan *et al.*, 2015; Miller and Buys, 2008). Buildings have long lifespans and to be able to adapt to rapid

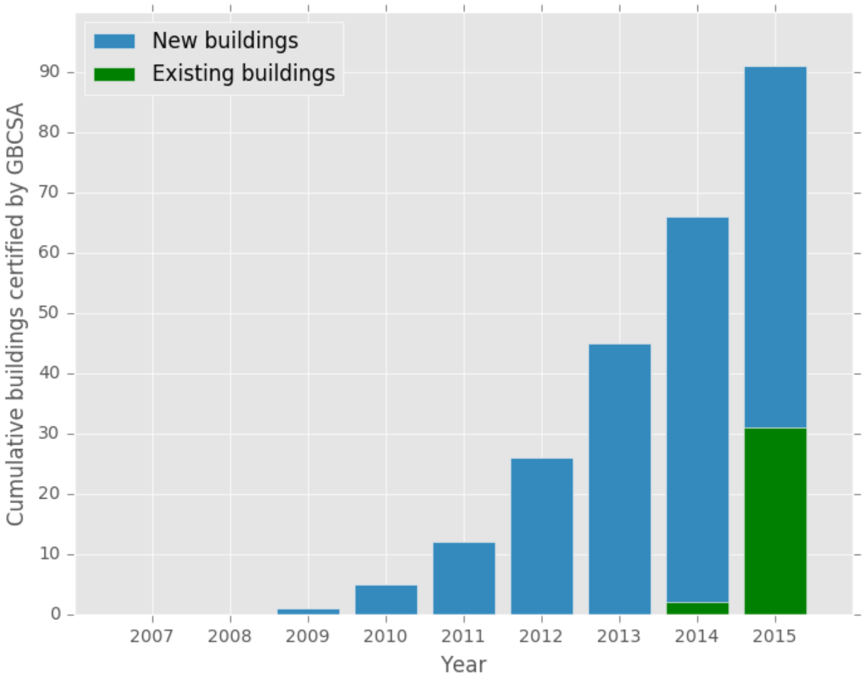


Figure 1.4: Cumulative plot of new and existing buildings certified by the GBCSA from 2007-2015. Compiled from data in GBCSA (2016*b*).

changes in the local and global context they would have to undergo retrofitting, upgrading and renovation.

Commissioning a retrofit project on an existing building is different to commissioning a new build in the sense that instead of focussing on initially designing for efficiency and performance, one has to identify existing defects or inefficiencies preventing optimal performance (Mills *et al.*, 2004). According to Amann and Mendelsohn (2005) it is financially better to be open minded, focus on the building as a whole and if possible apply the changes at a single point in time when involved in a retrofit project.

The primary benchmarking strategy adopted for green buildings in South Africa is the set of Green Star SA rating tools, administered by the GBCSA (City of Cape Town, 2012). Figure 1.4 shows the cumulative number of new and existing buildings rated by the GBCSA from 2007 to 2015. By the end of 2015, the total number of GBCSA certified projects in South Africa for all Green Star SA tools was 134 (GBCSA, 2016*b*). This correlates with what was stated by De Villiers and Volschenk (2011) namely that green building in South Africa is still at an early stage, but according to a report by DODGE Data & Analytics (2016), great growth is expected in the green building industry in South Africa. The green retrofitting of existing buildings is expected to be the largest sector of the green building industry in South Africa within the next three years (DODGE Data & Analytics, 2016).

1.1.3 Frameworks

The frameworks developed by the GBCSA are useful for the evaluation of a green building's environmental performance. The manuals are intended to aid a project in gaining compliance for certification as it will finally be assessed according to these criteria. It is therefore an assessment framework and not an implementation framework. Frameworks from literature that can be related to green retrofitting cover various aspects but the majority strongly focus on energy. A discussion follows.

Ma *et al.* (2012) present a framework for the selection and identification of energy retrofit options for existing buildings, which addresses the project phases and aspects that influence the success of the project in a holistic manner. Volvačiovas *et al.* (2013) developed nine feasible multi-attribute selection strategies to determine the best scheduling and associated scheduling cost approach for retrofitting a small public building in Lithuania that served as a kindergarten. McArthur (2015) developed a building information management (BIM) framework for existing building maintenance, operations and sustainability. The framework was tested on a complex university building. Menassa and Baer (2014) developed a House of Quality (HOQ) model that integrates the competing objectives of stakeholders and was tested on an existing US Navy building. The selection process of retrofit technologies for existing buildings was addressed by Si *et al.* (2016). Lee *et al.* (2015) evaluated 18 energy retrofit toolkits developed to analyse retrofit options in terms of cost and energy performance. These toolkits come from different contexts in terms of climate and building type. Styles *et al.* (2015) provided general water management guidelines for the hospitality industry in Europe through best practice, benchmarking and key performance indicators. Tsai *et al.* (2014) used mathematical programming to create an integrated decision model that can be used in the construction industry to select green building projects without sacrificing profit margins. A broad-spectrum risk management system that provides recommendations for energy retrofitting was developed by Wei *et al.* (2014) and can be applied to various building categories.

1.2 Research problem

Green buildings are necessary because they are a more sustainable and resource-efficient option in the construction industry, which is a large contributor to environmental impacts and challenged to address the problems linked to urbanisation. There are many old or existing buildings for which it is not a viable option to demolish and rebuild them as green buildings. Retrofitting offers a way to adapt these buildings so that they can also function in a sustainable and resource-efficient way as is intended with green buildings.

There is a scarcity of frameworks that provide a holistic approach to green retrofitting that incorporates all aspects in one framework. The frameworks that exist in literature mostly focus on one or two particular environmental and/or project management aspects such as water or energy and risk management or project scheduling. The types of buildings for which they are developed also differ from each other in purpose, size and the geographical regions or climates in which they are located. There is a lack of applicability of these frameworks to green retrofitting existing buildings in South Africa.

1.3 Research question

How can existing retrofitting frameworks be adapted and integrated into a holistic green-retrofitting framework that can be applied to existing buildings in South Africa?

1.4 Research objectives

The researcher aims to fulfil the following objectives:

- To gather and study literature about retrofit frameworks and approaches regarding various aspects that play a role in a green-retrofit project. To then evaluate these frameworks according to their context.
- To investigate and understand the context within which the green-retrofit framework for South African buildings will be applied.
- To determine what is required of the green-retrofit framework for South African buildings.
- To develop a holistic green-retrofit framework for the South African context.
- To evaluate and improve the applicability of the developed framework by applying it to a case study.

1.5 Scope and limitations

- The research is focussed on existing buildings. An existing building's location and orientation is fixed. This has a big influence on how the building is affected by climatic conditions.
- As a case study the green retrofit framework will be applied to one building, namely the Sustainability Institute main building just outside Stellenbosch. Limited data is available on the current technology and previous performance of the building.

- The scope of the research allows for only one case study to be performed, this might limit the generalisability from a research perspective.
- As this study has a limited time frame and the organisation involved required more time than available to obtain the funds to commence with the retrofit, it was not possible for some aspects of the framework to be tested.

1.6 Assumptions

The appropriateness of the official regulatory standards for buildings (e.g. SANS codes or ISO standards) will not be evaluated in this study. It is assumed that the building complies with these standards as they are legally mandatory.

1.7 Definitions of key terminology

Retrofitting is defined by Iselin and Lemer (1993) as work done to change the performance, function or capacity of a building, an upgrade to a building to adjust to new circumstances or requirements. The USGBC defines **green retrofitting** as an upgrade to a partially- or wholly-occupied existing building that improves environmental performance, reduces energy and water use, improves indoor comfort and quality of space through natural lighting, reduced noise levels and improved air quality, done in a financially beneficial manner (Kats *et al.*, 2003).

1.8 Brief overview of chapters

In Figure 1.5 a guide to the chapters of the thesis is provided. In the second chapter a literature study is provided whereafter the framework design and methodology is discussed in chapter three. In the fourth chapter the framework is applied to a case study for validation. In chapter five a summary of the research, the final adaptations of the framework, suggestions for future research and the conclusion are provided.

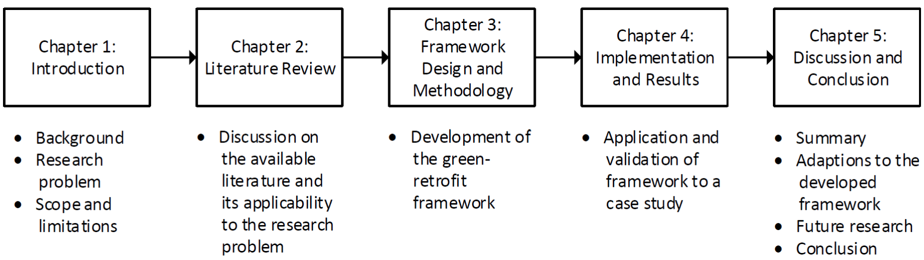


Figure 1.5: Brief overview of chapters.

Chapter 2

Literature Review

2.1 Introduction

In the literature review the focus is on frameworks that can be applied to a green building retrofit. Literature was selected to reflect the most applicable frameworks and approaches available on the topic of green retrofitting. From the literature certain themes and aspects stood out. The frameworks were then grouped under subheadings corresponding to these themes, namely success factors, project phases, stakeholders, scheduling, retrofit technologies, energy, water, information and operations management, maintenance, risk and uncertainty, cost and finally pre-project planning.

2.2 Factors which influence the success of a retrofit project

Six key influences on the success of a retrofit project were identified by Ma *et al.* (2012) and shown in Figure 2.1. These are: human factors, retrofit technologies, policies and regulations, client resource and expectations, building-specific information and finally, other uncertainty factors.

Human factors comprise of activity, comfort requirements, access to controls, occupant regimes, management and maintenance (CIBSE, 2004). Stephen Pearson stated in CIBSE (2015) that it is critical to understand human behaviour for a system to run optimally. Examples of human-based retrofit measures are responsible behaviours like turning off devices when not in use. A physical retrofit entails adaptations that alter the physical characteristics of a building such as adding insulation in order to improve its energy performance. In cases where physical retrofits are not feasible due to financial constraints, restrictions on modifying historic buildings' envelope or because all other retrofit measures are already implemented, human-based retrofits can further improve the performance of a building (Pisello and Asdrubali, 2014).

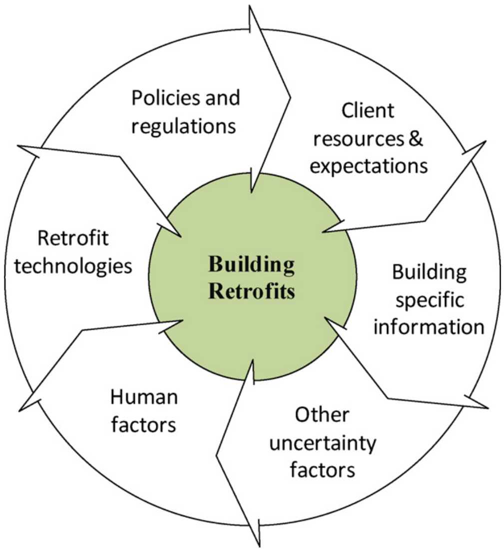


Figure 2.1: Six key factors that influence a retrofitting project. (Ma *et al.*, 2012).

Selecting appropriate retrofit technologies for existing buildings can be challenging, especially if multiple criteria exist and interrelate. Single-criterion decision making is still commonly based on criteria such as energy consumption or cost. Multi-Criteria Decision Making (MCDM) models can be used to investigate existing building limitations and opportunities at a early stage to help find the technologies that are best suited (Si *et al.*, 2016).

Ma *et al.* (2012) limit the scope of policies in their research to only energy policies set by the government. Policies and regulations that are included in the decision making process for holistic retrofitting projects should include all applicable government policies and regulations. According to the author's knowledge the available policies and regulations in South Africa are limited.

Client resources and expectations set the target and goals for the project and help to determine the required retrofitting technologies. Menassa and Baer (2014) describe the importance and means of managing the stakeholder objectives. Clients tend to struggle with energy-efficient investment decisions due to the complexity of the problem (Ma *et al.*, 2012). An example of client resource and expectations in an energy retrofit project is a case study on a two-storey educational facility discussed in Alajmi (2012). For a low or no cost investment, a non-retrofitting scenario comprising of scheduled equipment and lighting, and also reduction of infiltration (i.e. closing doors) presented an opportunity of reducing the building's annual energy consumption by 6.5 per cent. With a greater financial investment, the retrofitting scenario showed an annual energy consumption saving of 49.3 per cent. Together the savings potential increases to 52 per cent (Alajmi, 2012).

Building-specific information is important in order to achieve an effective optimal retrofit solution. Such information includes the building age, energy sources, fabric, geographic location, occupancy schedule, operation and maintenance, service systems, size, type and utility rate structure (Ma *et al.*, 2012).

Building projects face uncertainties due to the climate, building operation, occupant behaviour and the increased complexity of methods and tools to support design decisions. By reducing uncertainties and improving prediction of project decision outcomes, more optimal decisions can be made (Hopfe, 2009). Wei *et al.* (2014) presented a risk management system to determine the potential risk and reward related to various retrofit scenarios.

2.3 Phases of the retrofit project

The overall process of any retrofit project can be defined in Figure 2.2 as five main phases: project setup and pre-retrofit survey, energy auditing and performance assessment, identification of retrofit options, site implementation and commissioning and finally, validation and verification (Ma *et al.*, 2012)

In the first phase, project setup and pre-retrofit survey, the scope of work as well as project targets are defined by building owners or agents. The budget and work programme requires that available resources are determined. If it is necessary to understand operational problems and main occupant concerns better, a pre-retrofit survey should be performed as well.

Energy auditing and performance assessment are performed in the second phase. Building energy data from an energy audit is analysed to understand current consumption behaviours and to reduce energy wastage and recommend less expensive energy conservation measures (ECMs). The building performance is assessed by benchmarking the building energy usage, using green building rating systems or selecting performance indicators. Diagnostics is important for identifying operational building malfunctions, inefficient equipment and improper control schemes.

During the third phase different retrofit alternatives are identified. Performances of the retrofit alternatives can be assessed quantitatively using appropriate tools for economic analysis, energy models and risk assessment.

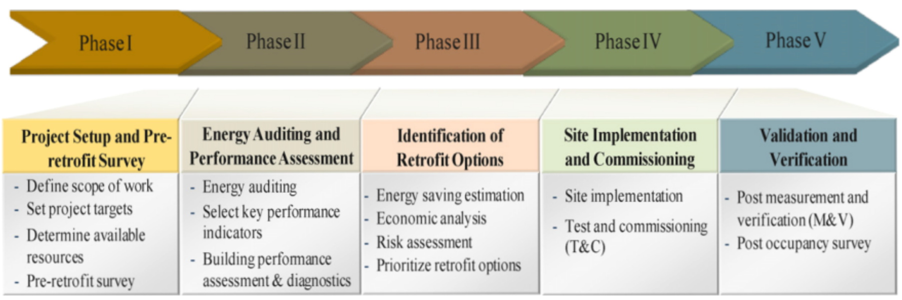


Figure 2.2: Key phases for retrofitting a sustainable building. (Ma *et al.*, 2012).

Energy- and non-energy-related factors are used for the prioritisation of the alternatives.

Site implementation and commissioning is described in the fourth phase, where the chosen retrofit measures will be implemented and finally fine-tuned when test and commissioning (T&C) is employed. T&C might cause some building occupant interruptions as also observed and addressed in the study by Volvačiovas *et al.* (2013).

The five key phases of a sustainable building retrofit (Figure 2.2) identified by Ma *et al.* (2012) was primarily intended for a building energy retrofit. Phase two, energy auditing and performance assessment, has a strong energy focus and should be expanded to include other performance aspects as well if this is to be used for a holistic green retrofit.

2.4 Stakeholders

In the study by Menassa and Baer (2014) a House of Quality (HOQ) model was developed that integrates the competing objectives of stakeholders. During the case study the model was tested by retrofitting a US Navy existing building.

The first step in developing the model is to construct a list consisting of the stakeholder requirements which serve as the independent variables when determining the most important items for the HOQ model. These requirements may be supported by economic, environmental, social or technical reasons. Each requirement is then given an importance rating between 1 and 5, 5 being the most important. In step two the decision alternatives (mechanical, electrical, plumbing and envelope retrofitting) are determined. These serve as dependent variables. During step three a relationship matrix ($i \times j$) is compiled involving the decision alternatives (indexed j) which are evaluated for their relationship with regard to each stakeholder requirement (indexed i). This is carried out in order to gain an insight into how the various stakeholders influence the selection or priority of certain retrofit options. The relationship is rated between 0 and 9, 9 being extremely strong. The technical importance matrix is obtained by applying Equation 2.4.1 to the relationship matrix.

$$\boldsymbol{TechnicalImportance}(i,j) = \boldsymbol{Importance}(i) \times \boldsymbol{Relationship}(i,j) \tag{2.4.1}$$

The fourth step involves using Equations 2.4.2 and 2.4.3 to obtain a prioritized relative weight for comparing retrofit options. The scale for relative weight is 1-5. The options with the lowest weights are the least important considerations from the integrated perspective of the stakeholders and vice versa.

$$\boldsymbol{Relative\ Weight}(j) = 5\left[\frac{\boldsymbol{Technical\ Importance}(j)}{Maximum\ Technical\ Importance}\right] \tag{2.4.2}$$

where,

$$\boldsymbol{Technical\ Importance}(j) = \sum \boldsymbol{Technical\ Importance}(i, j) \tag{2.4.3}$$

In step five the results of the HOQ are verified and validated. An occupant satisfaction survey of the current building occupants is carried out. This is done to identify the specific aspects and degrees of dissatisfaction with the current features and characteristics of the building. The survey results are then used to develop a benchmark to which the HOQ stakeholder results can be compared on a normalised scale. Significant differences are then investigated to uncover why certain aspects were overlooked or under-estimated by the stakeholders. Further detail on this approach can be found in Menassa and Baer (2014).

A more accurate perspective of stakeholder objectives can help to provide better design requirements according to the specific needs within the entire organisation. Ma *et al.* (2012) also addressed stakeholders in their framework and stakeholder objectives management is definitively a beneficial tool to apply within a green retrofitting framework not only for South African buildings but all buildings in general. An occupant satisfaction survey is also important as the occupants have a more realistic idea of the inefficiencies in the building spaces in which they function.

2.5 Scheduling

Volvačiovas *et al.* (2013) studied a small public building in Lithuania, a kindergarten, and developed nine feasible multi-attribute selection strategies for retrofitting. Their aim was to determine the best scheduling and associated scheduling cost approach for retrofitting the building. Retrofitting projects tend to cause discomfort to employees and visitors. School disruption caused by the construction can be problematic if the construction works cannot be completed during periods of recess. In general, state agencies prefer to use minimum cost as the only attribute in their procurement. This does not represent all the important aspects of retrofitting comprehensively or the true financial gain. Volvačiovas *et al.* (2013) identified five key attributes that reflect the true economic benefits and used them in their case study: construction cost, duration of works, payback time for renovation, energy saving throughout ten years and people's satisfaction.

According to Volvačiovas *et al.* (2013), it was found during many studies that for a multi-attribute decision making model several methods should be used to determine a near optimal solution. Therefore the authors assessed and ranked retrofitting alternatives using three alternative methods: simple additive weighting (SAW), complex proportional assessment (COPRAS) and the technique for order preference by similarity to ideal solution (TOPSIS). The SAW method is used to obtain a weighted sum for each alternative by multiplying the score function with a weighted importance for each attribute and summing all attribute products. This helps to determine each alternative degree of satisfying the requirements of the decision-maker. The COPRAS method adequately assumes its dependencies, direct and proportional, for investigated versions of a system of attributes in terms of the significance and degree of utility. For the TOPSIS method the benefit attribute is maximized and the cost attribute minimized. A negative ideal solution minimizes the benefit attribute and maximizes the cost attribute. The best alternative is farthest away from the negative solution and closest to the ideal solution.

The nine alternatives developed for retrofitting the building differed in the number of stages the work was divided into and worker count per stage. For the case study, it was determined that the best approach would be a one-stage retrofitting process with the largest workforce possible. Volvačiovas *et al.* (2013) also suggested that by quantifying energy savings in units (kWh) instead of using the cost, reduces uncertainty in calculations substantially.

While the method proposed by Volvačiovas *et al.* (2013) was used for determining the best schedule for retrofitting a small public building, this decision making model can be applied to various types of decisions in a retrofit project that involves multiple attributes.

2.6 Retrofit technologies

The selection and performance of retrofit technologies are subject to many uncertainties, such as climate volatilities, occupant behaviour and changes in government policies. Retrofit technology selection is a complex task and other challenges may include: limited finances, disruption of operations and long payback periods (Si *et al.*, 2016).

Si *et al.* (2016) reviewed Multi-Criteria Decision Making (MCDM) methods to find techniques for selecting technologies to retrofit existing buildings. To ensure a good and thorough selection of green technologies multiple criteria should be incorporated such as technical, economic, environmental and social criteria that can be represented as a weighting in decision support systems that influence the retrofit goals (Si *et al.*, 2016).

MCDM methods are mathematical models that weigh criteria, score alternatives and synthesize a final result. The following phases occur during the decision making process with multiple criteria (Gore *et al.*, 1992):

- objective identification,
- developing criteria,
- alternative generation, evaluation and selection, and
- implementation and monitoring.

In order to make a good criteria selection the following principles must be applied: systematic approach, consistency, independency, measurability, and comparability (Ye *et al.*, 2006, cited by Si *et al.*, 2016). Criteria can usually be organised in a hierarchical manner from general to detailed. Within each level the criteria must be mutually exclusive of each other but inclusive with regard to the upper levels. This can be a daunting task as the sustainability criteria: economic, environmental, social and technical aspects are interrelated. Overlapping should not occur as this could lead to double-counting (Si *et al.*, 2016).

After the criteria have been determined, criteria weighting is done by assigning weights to indicate their importance relative to each other. Thereafter alternative scoring is done using the Analytical Hierarchy Process (AHP) method. AHP is a widely used MCDM method and can simultaneously consider qualitative and quantitative criteria. There are three steps in the method (Si *et al.*, 2016):

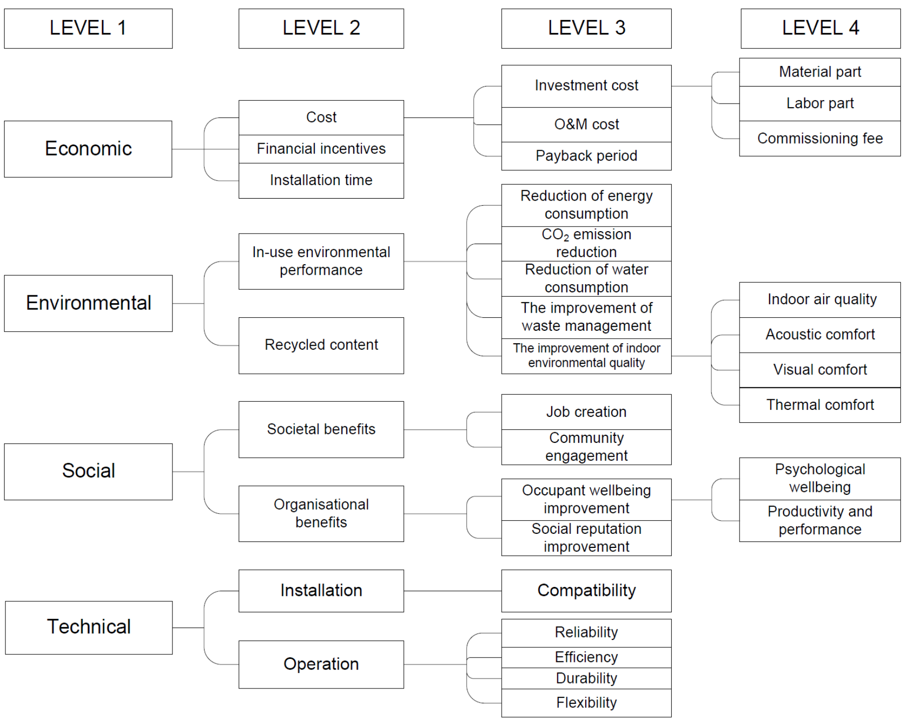


Figure 2.3: Integrated AHP structure with multiple criteria. (Si *et al.*, 2016).

- Structuring the hierarchy between criteria and alternatives.
- Compiling a pair-wise comparison matrix.
- Calculating weight values of criteria and scores of alternative performance.

The integrative AHP hierarchy with multiple criteria is presented in Figure 2.3. This criteria tree is suggested for the comprehensive evaluation of green alternatives. Depending on the data availability, constraints and objectives, decision makers might use fewer criteria and therefore a simplified model (Si *et al.*, 2016).

In the work by Yudelson (2009) the SWOT analysis is highly recommended for the analysis of green building technologies. This method identifies the strengths, weaknesses, opportunities and threats of the technology. SWOT analysis is also the preferred method for technology selection by the award winning green architect, Nathan Good.

2.7 Energy

Throughout the literature analysis it was clear that more attention is being paid to energy in new designs of green buildings and the retrofit of existing buildings. This might be because energy savings are generally quantified more easily in a building compared to other sustainable upgrades.

Ma *et al.* (2012) illustrated a systematic energy retrofitting approach (shown in Figure 2.4) that identifies, determines and implements the best existing building retrofit measures. This retrofitting approach can be applied to any building type requiring minor modifications. The retrofitting approach can be divided into two parts, firstly strategic planning and model/tool selection and secondly main retrofit activities in the entire building retrofit project. The second part consists of pre-retrofit, during-retrofit and post-retrofit activities.

The framework by Ma *et al.* (2012) in Figure 2.4 is well-structured for an energy retrofit. The potential exists to adapt this framework from energy retrofitting to green retrofitting existing buildings. There is still some work to be done before this will be possible with this framework.

The energy performance of an existing building is benchmarked by the Green Building Council of South Africa (GBCSA) using the four compliance paths shown in Figure 2.5. To benchmark energy performance for existing building a minimum of 12 months of energy data is required by the GBCSA. A building is allowed to use only a single applicable compliance path for benchmarking energy performance. The energy water performance (EWP) benchmarking tool forms part of the first compliance path and is intended for office buildings. EWP compares building energy usage against a national

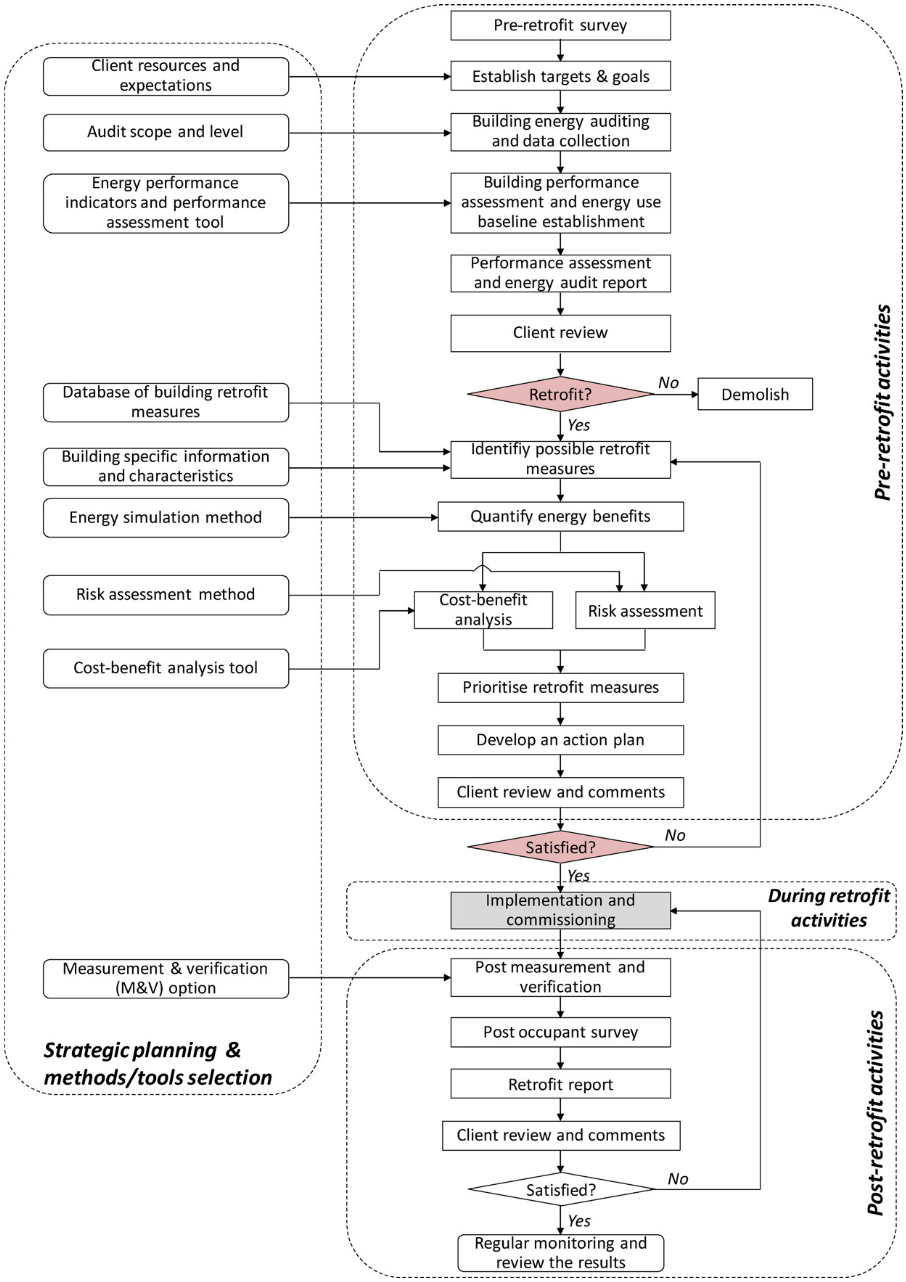


Figure 2.4: A systematic approach to identify, select and implement appropriate retrofit measures to existing buildings. (Ma *et al.*, 2012).

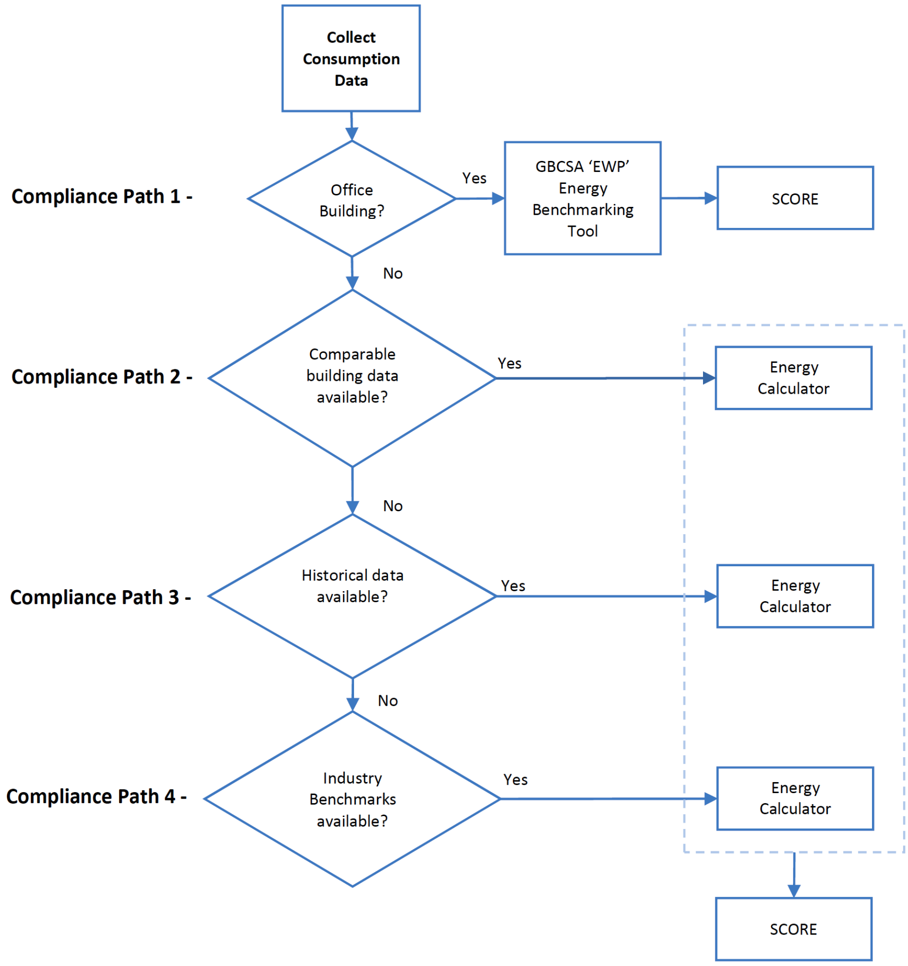


Figure 2.5: Different compliance paths for existing buildings energy performance. (GBCSA, 2014*a*).

normalised average benchmark. For the second compliance path a baseline of the building's energy usage within the last ten years is required to compare with the current energy usage data. The third compliance path uses historical energy usage data of at least two similar buildings in the same climatic zone and compares their data with the project being rated. Industry benchmarks are used for the fourth compliance path and this applies only to buildings that cannot use the EWP benchmarking tool, have no comparable building or historic data available and have to be motivated for a project. Once an energy benchmark score is obtained, the energy score is totalled with other category scores in the GBCSA existing building performance rating to calculate the star rating (GBCSA, 2014*a*). If the project does not comply to any of the four compliance paths the building will have to be adapted before benchmarking can take place.

The GBCSA existing building performance assessment, pertaining to energy, is focused on the South African context and therefore relevant.

However, in a study on next generation green buildings, Gou and Xie (2016) suggested that green building rating systems tend to encourage design solutions to focus on gaining a higher score by doing less harm, which is not necessarily the best way to strengthen the human-nature system. Gou and Xie (2016) found that rating systems generally assume sustainable design as a circle and cycle approach, while Gou and Xie (2016) believe the critical role of the resource flow of buildings should be in producing, using, recycling and replenishing in order to support and maintain the ecosystem functioning. The GBCSA energy performance assessment for existing building retrofits could still offer insight into achieving energy performance, especially in South Africa, but Gou and Xie (2016) still have a strong argument and therefore it is suggested that energy retrofit decisions should not just be governed by a rating system.

In research by Lee *et al.* (2015) 18 energy retrofit toolkits that were developed to analyse the cost and energy performance of retrofit options, were evaluated. These toolkits are divided into three categories, namely empirical data-driven methods, normative methods and physics-based energy modelling.

Empirical data-driven methods are based on statistical regression techniques. The challenges related to these methods are as follows: training data is required to develop the model, there is an absence of a physics-based evaluation of the building characteristics and performance, the model could be limited to a specific building type or location and they do not evaluate the dynamics resulting from integrating various retrofit measures. The tools that were discussed under this category were Building Performance Database (BPD), C3 Commercial, Agilis Energy, FirstFuel and SIMIEN (Lee *et al.*, 2015). Reduced-order models require simple input and output and perform a fast evaluation.

The normative method is one of these models and follows the standards of the European Committee for Standardization (CEN) and International Organization for Standardization (ISO). The method determines the energy usage at different levels of thermal energy demand, emissions, primary energy and delivered energy per carrier. The tools that were discussed under this category were Chicago Loop Energy Retrofit Tool, HELiOS Building Efficiency and Retroficiency. These models may not be as accurate as physics-based approaches but are computationally efficient (Lee *et al.*, 2015).

Physics-based energy modelling is a complex alternative but provides a more accurate outcome as it works with the dynamics of the physical system. The tools that were discussed under this category were Commercial Building Energy Asset Score, Simuwatt Energy Auditor, CBEI, CBECC-Com, EnCompass, The Energy Savings Benefits Evaluator for Enterprise Customers, Commercial Buildings Energy Saver (CBDES), Customised Calculation Tool (CCT), Commercial Building Analysis Tool (COMBAT) and EnergyIQ (Lee *et al.*, 2015).

Lee *et al.* (2015) identified the following shortcomings and challenges in current toolkits aimed at analysing cost and energy efficiency measures:

- New efficiency measures and technologies that become available in the market, but are not included or accurately evaluated by toolkits. Regular updates must become available to continually expand and adapt to changing technology and approaches.
- Analysis is limited by the extent and quality of database information.
- Some toolkits are developed for specific buildings types or a certain geographical region.
- It is important to take the integrated effect of different technologies and design parameters into account to improve the accuracy of analysis. An example would be the reduced cooling load as a result of a change to energy efficient lighting.
- Lack of model calibration methods.
- Pre-defined assumptions that lead to error between simulated and actual results. This can be addressed by developing measures to improve information acquisition and user input quality.
- Neglecting the influence that occupant density and behaviour have on the building's performance.

2.8 Water

The paper by Styles *et al.* (2015) provided guidelines for general water management in the European hospitality industry through best practice, benchmarking and key performance indicators. Some examples of best practice for water management are:

- Regular inspections of water network and water-using equipment at least every six months. This will aid in the identification of leaks and inefficiencies.
- Sub-metering will provide zone-specific usage data and simplifies the detection and location of leaks and inefficient use.
- Elimination of excess heating of water through pipe insulation and lower though acceptable hot water temperatures. Reducing heat loss across pipes will also reduce water use due to shorter lag time of hot water arrival.

The GBCSA existing building performance benchmarks building water performance in a similar manner as energy performance. Likewise, existing building water performance is measured using one of four compliance paths: EWP benchmarking tool, comparable building data, historical data or industry benchmarks. At least 12 current consecutive months of water usage data is required of a building intending to use these benchmarking paths. The first path applies to office buildings and makes use of the EWP benchmarking tool that compares the building being benchmarked to a South African national normalised average benchmark. A comparison to similar buildings' water usage data is done using the second path and requires comparison with at least two other comparable buildings within the same climatic zone. Benchmarking via the third path requires at least 12 months of historical water usage data of the building being benchmarked within the last ten years for comparison. Finally, the fourth path benchmarks building water performance against industry benchmarks and this path must be motivated if it is to be used (GBCSA, 2014*a*).

As motivated with the GBCSA energy benchmarking, the GBCSA existing building performance benchmarking for water is focussed on South Africa and therefore very relevant. The argument by Gou and Xie (2016) mentioned before still applies. Although a focus on gaining the best benchmarking score, as stated by Gou and Xie (2016), does not necessarily strengthen the human-nature system in the best way, the GBCSA benchmarking for existing building water performance does offer insight into achieving a better water performance. The benchmarking tool should not be the only consideration in a retrofitting project and perhaps in order to strength the human-nature system buildings there should be a focus on producing, using, recycling and replenishing to maintain the ecosystem (Gou and Xie, 2016).

2.9 Management of information and operations

McArthur (2015) developed a building information management (BIM) framework for existing building maintenance, operations and sustainability shown in Figure 2.6. The framework was tested on a complex university building during a case study.

BIM is a database generated for buildings that includes a wide variety of attribute information and the relationships that exist between building elements. Such a database is used for estimating cost, construction scheduling, multi-disciplinary coordination, integration of three-dimensional designs and analysis (McArthur, 2015).

During an investigation by McArthur (2015) BIM models in the post-occupancy period where it is possible to support facilities management (FM) and building operations were studied. BIM models also offer a

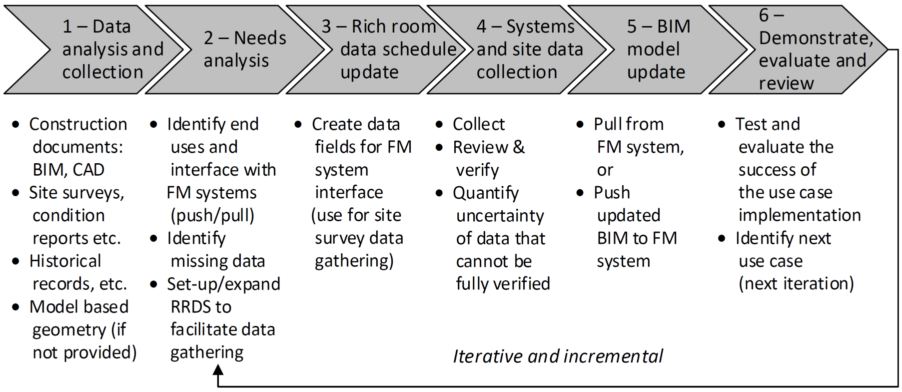


Figure 2.6: Development Framework for the management of facilities and/or operations. (McArthur, 2015).

consolidated interface for information on all aspects on building operational performance.

There are four key challenges to overcome when using BIM models for sustainable operations management:

- Identifying the critical information, used for improving the building's operational performance. Information used per project varies because of the model scope, specific user systems and organizational structure, but all relate roughly to one of three areas: activities for maintenance, front-of-house (sustainability, occupant comfort, etc.) and space planning.

- To manage the information transfer. Two modes of data transfer, "push" and "pull", are critical to the framework. The "push" mode refers to when the FM system is provided with updated data from the BIM model. "Pull" mode refers to when the BIM model is updated with data pulled from the FM system.

- The effort required to create a facilities operation and/or management BIM model must be controlled. Controlling the effort is generally associated with two complications. Firstly that the operations and maintenance (O&M) information required is not always available. Secondly the file size can become large and clumsy. To address the first, a shift of effort to the designer and the contractor can be achieved by using an organization standard BIM execution plan in the building renovation and construction procurement. For the second complication it is recommended that a stage modelling approach is used. During this approach two copies of the construction model are kept, one with all the data and another one containing only the data required.

- Uncertainty in existing building documentation will have to be addressed and will require a complete field inspection. McArthur (2015) suggests three approaches for handling uncertainty in a BIM model's data. Firstly verification, a low risk, but costly approach, to verify unknown or uncertain data with field-measured data. Secondly acceptance, to draw samples that are a percentage of each element and to verify these samples with field measured data. Thirdly, omit data from the model that is below a chosen certainty level. The third option can limit the model severely, although being the least expensive.

As shown in Figure 2.6, McArthur (2015) developed a BIM model framework for the management of facilities and/or operations. The initial step for developing a base model is data analysis and collection. Steps two to six are iterated for each identified use case.

When applying for GBCSA Existing Building certification, the building is mainly assessed in terms of its operational performance. As performance can change with time, re-certification is required every three years (GBCSA, 2014*a*). In the BIM framework shown in Figure 2.6, the focus is on the post-occupancy period after a retrofit has been completed. The aim is to monitor and help manage the building.

Since the BIM framework proposed by McArthur (2015) (Figure 2.6) is flexible and can be easily adapted, the framework can be applied to different building contexts in South Africa.

2.10 Maintenance

Horner *et al.* (1997) developed a decision diagram for building maintenance in Figure 2.7. The diagram is a logical process for the selection of a cost-effective and appropriate maintenance strategy for buildings. The first task is to develop a list of all the individual components of the building and its sub-systems. The type of failures and their consequences should be identified for each component. A significant item is an item the failure of which will affect building performance, health, safety or the environment. Non-significant items are therefore items the failure of which has no significant effect on building performance, health, safety or the environment. Horner *et al.* (1997) identified three stages of building maintenance: corrective, preventive and condition-based. Corrective maintenance, also referred to as unplanned or failure-based maintenance, is the simplest form of maintenance and is performed when an element of the building breaks down or does not perform its required task. Preventative maintenance, also known as time-based, planned or cyclic maintenance, overcomes the disadvantage of corrective maintenance by reducing the probability of failure or sudden failure. Condition-based maintenance recognises a change in the performance or condition of an item and is the principal reason for performing the maintenance (Horner *et al.*, 1997).

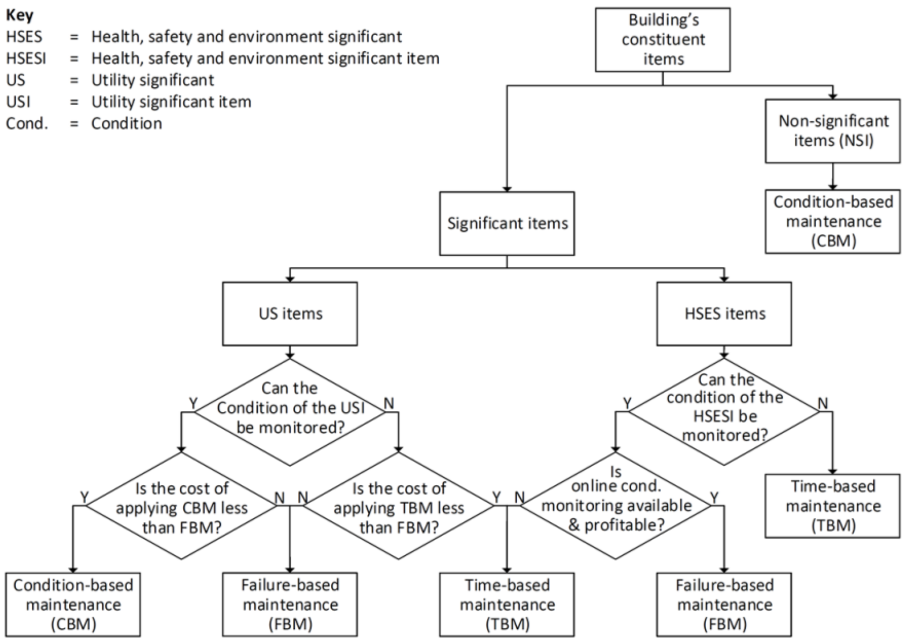


Figure 2.7: Decision diagram for building maintenance. (Horner *et al.*, 1997).

The maintenance planning process in Figure 2.8 was developed by the South African Department of Public Works (DPW) for new and existing buildings owned by the South African government to promote facility availability and ensure service delivery (CIDB, 2015*b*).

CIDB (2015*b*) highly recommends that all buildings, new or existing, have a Maintenance Management Plan (MMP). In Figure 2.8 a list of triggers were identified indicating when a building should develop a new MMP or update/review a pre-existing MMP. The identified triggers are (CIDB, 2015*b*):

- There exists no MMP for an existing building.
- The construction of a new or extra facility was recently completed.
- Existing facilities were recently renovated or refurbished.
- A review of the life-cycle and portfolio requirements against a pre-exisiting MMP.
- The facility performance requirements have changed.
- Failure impact consequences of components have changed.
- The maintenance budget has changed.

The framework in Figure 2.8 can be used to guide the process of developing a MMP at portfolio, facility and component levels. It was developed for the South African context and caters for most new and existing buildings (CIDB,

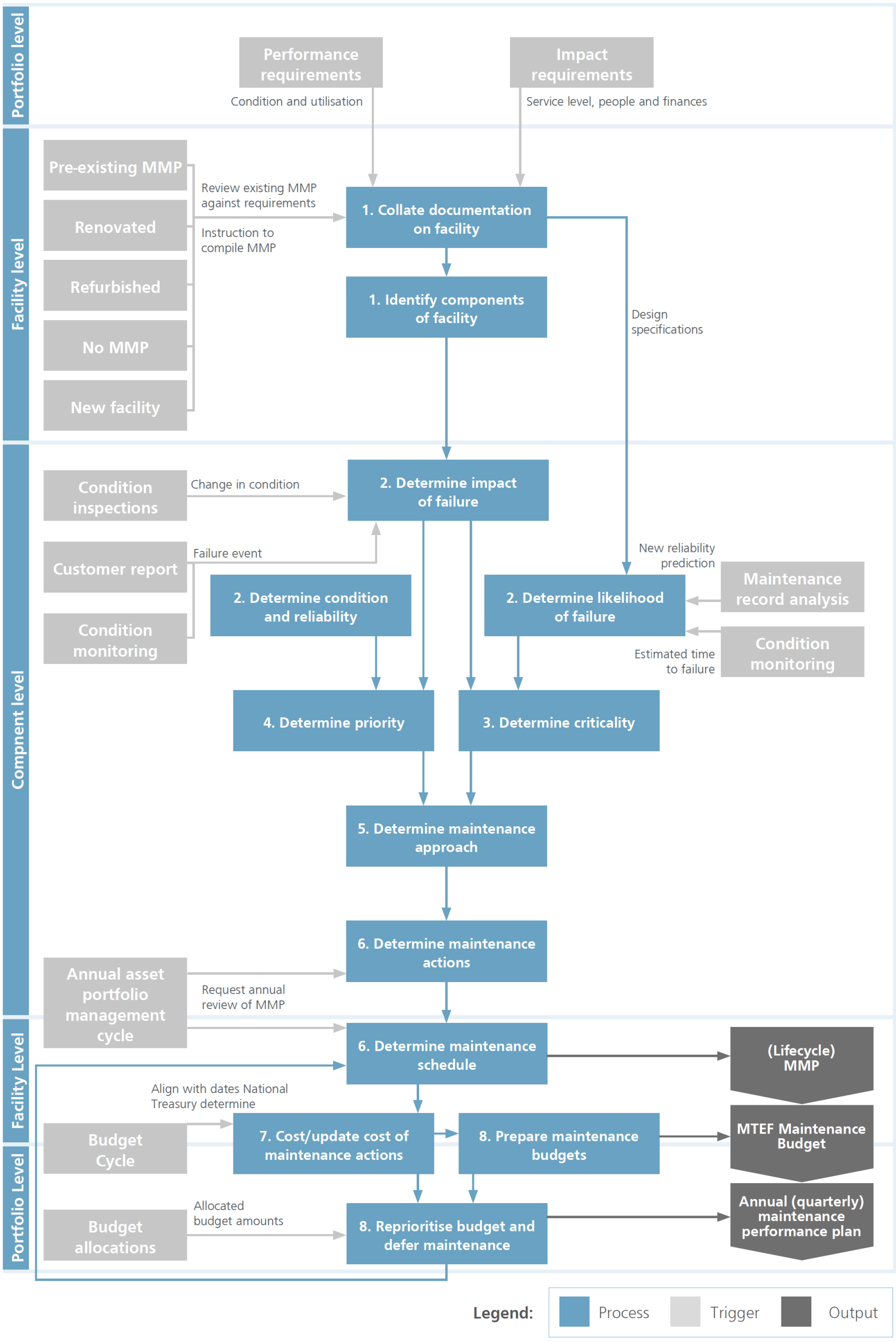


Figure 2.8: Portfolio, facility and component level of maintenance planning. (CIDB, 2015*b*).

2015*b*). This framework can be recommended for the retrofitting of existing buildings in South Africa. Maintenance plays an integrated role in ensuring the sustainability of green buildings and should be considered important.

2.11 Risk and uncertainty

2.11.1 Project risk management

Managing the risks involved during a project can be difficult and can result in a project not meeting its objectives. The areas of uncertainty are usually plentiful and can involve the following aspects (Chapman, 2001):

- Difficulty in identifying user requirements.
- Trouble with sequencing and transferring the required information during the iterative design process.
- Unpredictability and innovative nature of the environment.
- Uncertainty in estimating the required time and resources.
- Dependency on various sub-contractor skills and external consultant expertise.
- Diverse characteristics and complexity of each individual component or technology.
- Various different practices between disciplines.
- Progress estimation.

Traditionally the risk management process can be divided into four key phases namely risk identification, analysis, mitigation and follow-up, as indicated in Figure 2.9. During *risk identification* all risks, and their characteristics that could affect the project throughout its life-cycle must be determined and documented. A work breakdown structure can be used to guide risk identification for each project activity. Various techniques are

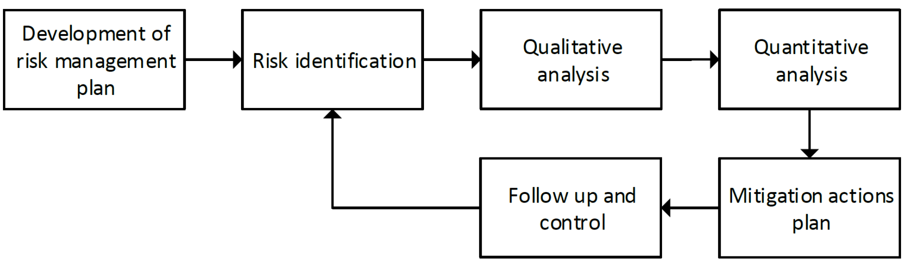


Figure 2.9: Risk management process (Leopoulos *et al.*, 2006).

available such as brainstorming, the Delphi and Nominal Group techniques, structured interviews, expert opinions, etc. The identified risks can be listed in a risk register or risk breakdown structure according to certain aspects or activities (Chapman, 2001). An example of a short risk register and risk analysis is provided in Table 2.1.

Table 2.1: A risk identification and analysis example amended from Leopoulos *et al.* (2006).

	Probability	Impact		Exposure	
Risks	(%)	Time[1]	Cost[2]	Time[1]	Cost[2]
External unpredictable:					
Interference of authorities since the building is a landmark	30	10	400	3	120
Natural disaster	30	10	860	3	258
Non-acceptance by customer	10	10	1750	1	175
External predictable:					
Absence of skills in region	30	5	5515	1.5	1654
Poor subcontractor productivity	80	10	285	8	228
Internal non-technical:					
Change in senior project management by top management	10	5	143	0.5	14
Vague project scheduling	50	20	570	10	285
Accident or sabotage	5	-	22857	-	1143
Cost overrun - payment negotiations	60	-	430	-	258
Technical:					
Design differs from implementation -blueprint lacks detail	50	20	570	10	285
Technical complexity of the project	80	15	429	12	343
Legal:					
Legal problems due to public disturbance	80	15	429	12	343
TOTAL:		120	34238	61	510

[1] Time in days.
[2] Cost in currency unit.

Table 2.2: An example of a risk probability and impact measurement interval table. Amended from Chapman (2001).

Scale	Probability	Impact		
	(%)	Time (weeks)	Cost (million R)	Performance
Very high	> 70	> 15	> 2	Objectives not reached
High	51 - 70	10 - 15	0.5 - 2	Major shortfall in brief
Medium	31 - 50	5 - 10	0.05 - 0.5	Minor shortfall in brief
Low	10 - 30	1 - 5	0.01 - 0.05	Specifications not met
Very low	< 10	< 1	< 0.01	Specification not met

Risk analysis prioritises the risks according to severity, also known as exposure. Exposure is calculated as the probability of occurrence multiplied by the expected impact (Wideman, 1992), as demonstrated with the example in Table 2.1. Risks that exceed a specific exposure threshold are prioritised for further investigation and mitigation planning (Leopoulos *et al.*, 2006). Table 2.2 is another example of how the risk probability and impact can be used to evaluate the severity of a risk by creating intervals. The impact is usually measured in time, cost, performance or a combination thereof.

Risk mitigation entails designing an appropriate response to the risks, prioritising them according to exposure; attending to high exposure risks as well as immediate risks first. General risk responses include avoidance, mitigation, transfer or retention. The risk control approach must be adjusted to be significantly less than the impact cost of the risk on the project if it were to occur (Leopoulos *et al.*, 2006). Lastly, risk *follow-up* is done to track the implementation and effectiveness of the defined risk actions. The risk assumptions and estimations are continually validated as the project progresses. The information in the risk register should be updated continually and can be kept to build up a risk history. By consulting the risk history the accuracy of risk estimation for similar or future projects can be improved.

2.11.2 Risk management systems

Few approaches take stochastic (random in nature) influences on the project, such as energy price fluctuations and variation in weather and future scenarios, into consideration. Excluding risk from the retrofit decision analysis reduces the optimality of the solution over the building's lifespan and therefore reduces the benefits. Due to a lack of convincing and significant financial benefits, property owners are reluctant to perform a retrofit. Determining the potential risk and rewards will improve decision making under uncertainty (Wei *et al.*, 2014).

Wei *et al.* (2014) present a broad-spectrum risk management system for energy retrofitting. This system provides a probabilistic view of the future associated with various scenarios resulting in recommendations that are robust against future uncertainties. It can be applied to various building categories and can be used by both retrofit service providers and clients. The overall design is shown in Figure 2.10 and is organised into roughly three columns. The first column from the left represents the inputs, the second column the computation and optimization and the third column the outputs.

The system considers both the deterministic and stochastic factors as inputs. The deterministic factors include the known/fixed attributes and characteristics and are represented by the building properties block in the first column. This includes and is not limited to factors like building location, orientation, architecture, lighting characteristics and HVAC (Heating Ventilation Air Condition) system. The stochastic factors are represented by the uncertainties block which can include weather prediction error, fluctuations in energy price and varying usage patterns. The variables to be optimised for the retrofit are specified by the contract block and can include reward/penalty factors for specific uncertainties influencing the return of the project. The goals of the client and provider (performing the retrofit) can be expressed in terms of return and risk tolerances for certain aspects. Historical data contains existing information regarding costs of energy and material, learned models of other buildings, weather predictions, status of other projects and any relevant knowledge (Wei *et al.*, 2014).

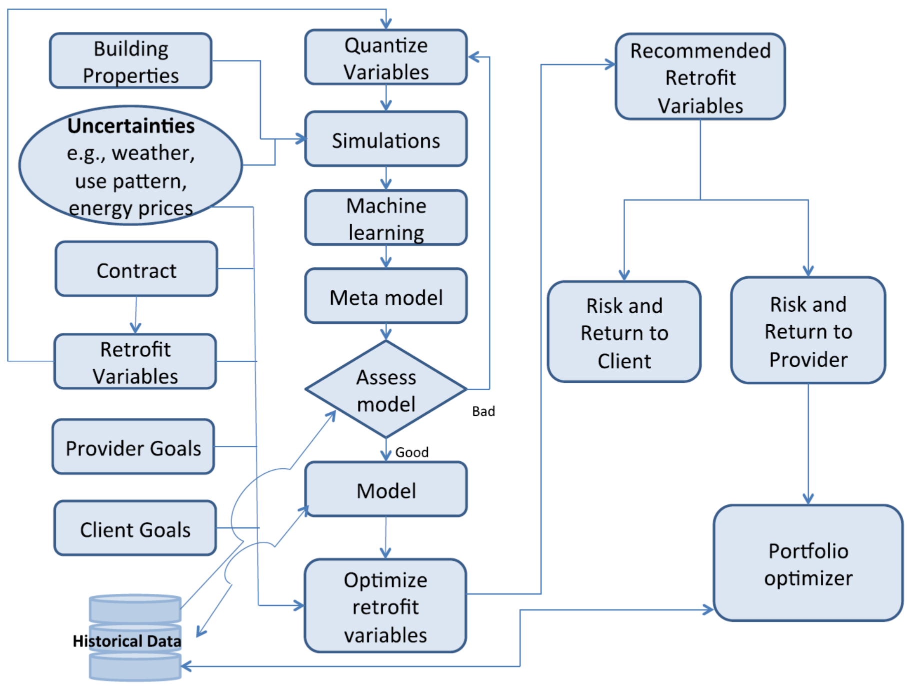


Figure 2.10: Overall design of risk management system. (Wei *et al.*, 2014).

In the second column the inputs are mapped to the outputs. The variables of the retrofit are identified and an appropriate quantization level is determined. A simulation is then carried out and the system continues to the machine learning block where values are obtained of the performance metrics. A model mapping, referred to as the meta model, is constructed to map the retrofit variables to building performance under different scenarios of uncertainty. The meta model is then assessed by comparing it with historical data and user specifications. If the model is inadequate the model is re-built after adjusting the quantization level. After an acceptable model has been determined it is refined using the database information and similar models if they are available. The final model is then stored in the database for future reference. Optimization is then performed on the retrofit profiles with regard to the client/provider goals. After optimization a few retrofit profile packages are recommended that each have risk and return estimations linked to them. The client/provider can make a selection from these recommended packages according to his/her preference of the risk versus reward trade-off, or suggest selection criterion for optimization. Finally the recommendations are narrowed to one retrofit profile (Wei *et al.*, 2014).

Chapman (2001) and Leopoulos *et al.* (2006) provided guidance on project risk management approaches that can be applied in the construction industry. Being aware of the potential risks of the project beforehand brings benefits in the sense that the project team can anticipate and mitigate risky events to minimise the impact. A general project risk identification, analysis and mitigation planning are recommended for any retrofit project. Wei *et al.* (2014) provided a sample risk management system for energy retrofits developed for a medium office building in Chicago in the USA under weather, energy pricing and occupancy uncertainties. The analysis was conducted on five different building categories, namely offices, factories, schools, hospitals and warehouses. In this system the amount and quality of data has an influence on the quality of the risk analysis. The results of the study indicated that the recommended package resulted in less expected cost and more robustness against future uncertainties than the current system did.

2.12 Cost

Whatever the goal behind a specific retrofit project, there is a need to determine whether the investment is worth while (Witt *et al.*, 2015).

The aim of the study by Tsai *et al.* (2014) was to create an integrated decision model that can be used by construction companies for the selection of green building projects without sacrificing profit margins. The life cycle of construction activities and resources is incorporated into the analysis of CO_2 emission cost and low-carbon construction methods. This is done by means of mathematical programming. Equation 2.12.1 is an objective function used to maximise the profit of the construction project. The profit is obtained by subtracting the project costs from the revenue. Constraint equations are also defined to inflict limitations such as discount functions (Tsai *et al.*, 2014).

$$\begin{aligned} Max\ \pi \quad = \quad & Total\ Revenue \\ & -Total\ green\ building\ material\ cost \\ & -Total\ direct\ labour\ cost \\ & -Total\ machine\ cost \\ & -Land\ acquisition\ cost \\ & -Total\ life\ cycle,\ green\ building\ activity\ costs \\ & (Unit-,\ Batch-,\ Environmental-,\ Project-Level) \\ & -Total\ life\ cycle\ CO^2\ emission\ costs \end{aligned} \tag{2.12.1}$$

Mathematical programming decision models can be a valuable tool to aid the decision making process regarding the cost of a green retrofit projects and the entire life cycle of the building. The ABC decision model is intended for construction managers and is developed for the context of countries where carbon taxing applies (Tsai *et al.*, 2014). This profit maximisation approach is simple and by changing the objective function can be adapted for retrofit projects in South Africa.

According to Witt *et al.* (2015) the following cost factors apply to a retrofit project:

- pre-construction and non-construction costs,
- construction costs,
- management costs,
- ancillary costs,
- annual maintenance costs,
- direct building damage costs,
- occupants displacement costs,
- loss of rent,
- loss of business,
- debris removal,
- life disruption costs, and
- costs of lost services for institutional facilities (schools, hospitals, etc.).

The cost factors suggested by Witt *et al.* (2015) can be used to adapt the objective function of Tsai *et al.* (2014).

2.13 Pre-project planning

Abbas *et al.* (2016) did research on the project success and profitability of pre-project planning in the Pakistani construction industry by means of a questionnaire. Eleven key respondents were selected based on their involvement during the pre-project planning stage of eleven projects of the residential, transportation, commercial and power plant types and who had a minimum of five years' professional work experience. From the questionnaire results Abbas *et al.* (2016) observed that project performance could significantly improve if pre-project planning is implemented consistently and decorously. Hwang and Ho (2012) did research on the status, importance and impact of pre-project planning in Singapore. During a survey of 27 companies Hwang and Ho (2012) found that some of the companies are aware of the potential benefits of pre-project planning but do not implement it due to three main barriers: lack of resources, small project size and added costs. Generally it was found that project size and budget have the most influence on the decision whether to implement pre-project planning or not. Twelve of the 27 companies surveyed practised pre-project planning, from which it was determined by the analysis that pre-project planning could reduce the schedule and budget by 15 per cent, improve quality by 10 per cent and reduce project risk by 5 per cent. Abbas *et al.* (2016) listed the advantages of implementing pre-project planning in a project as:

- There is an improved understanding of project complexity and risk as a result of the early stage of integration of the contractor and designer in the project.
- Projects are more likely to succeed.
- Construction performance is likely to improve.
- Business goals are more likely to be accomplished.
- An improved understanding of risks can be expected.
- The initial scope and design changes less.

Gibson Jr *et al.* (1995) developed a functional model for pre-project planning. Professional representatives of sixteen companies, four graduate students and two faculty members helped to develop the model. The technique is based on the IDEF0 approach which was created to model the actions, information and activity flow in a system or organisation. It is appropriate for construction projects due to its structured and hierarchical properties. The model was developed with a generic and flexible design in mind, which is applicable to various companies and project types. During the model validation on three different case studies, the pre-project planning process proved to be of a good generic representation.

As the developed model is flexible and has been shown to represent the pre-project planning process well, and Abbas *et al.* (2016) and Hwang and Ho (2012) perceive pre-project planning to be important, this model is recommended for the retrofitting of existing buildings.

2.14 Conclusion

In the literature review six success factors and five key project phases were identified for a sustainable building retrofit. The management of stakeholder objectives and the scheduling of a retrofit project were also addressed. Thereafter a framework for selecting the optimum retrofit technologies was discussed as well as energy and water frameworks and benchmarking. Information and the management of operations, maintenance, risk and uncertainty, cost and pre-project planning were addressed.

Overall, the frameworks in the literature review cover various aspects but the majority have a strong focus on energy. The frameworks mostly focus on one or two aspects of retrofitting each and there is a scarcity of frameworks that provide a holistic approach to green retrofitting. Therefore a need exists to develop an all-encompassing framework for green retrofitting. An attempt to do this is described in the next chapter.

Chapter 3

Framework Design and Methodology

3.1 Introduction

In this chapter the design of the green-retrofit framework for existing buildings in South Africa is presented. A short description of the principle that determined a large part of the framework structure, namely adequate and early planning follows. Thereafter the framework is explained step-by-step.

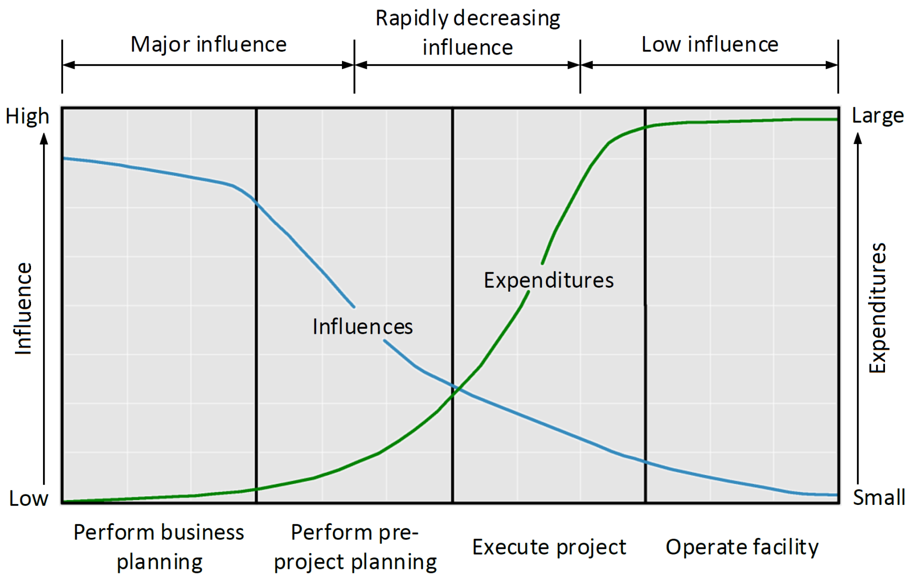


Figure 3.1: Influence and expenditure curves of the life cycle of a project. Amended from Gibson Jr *et al.* (1995).

3.2 The importance of planning

According to Gibson Jr *et al.* (1995) it is common knowledge among industry construction experts that planning efforts in the early stages of a project have the most influence on a project's success than attempts in the later stages. Abbas *et al.* (2016) and Hwang and Ho (2012) support this statement through observations in their studies.

In Figure 3.1, Gibson Jr *et al.* (1995) depict the remaining influences and associated expenditure of a project's life cycle graphically as two curves. The influence and expenditure curves change as a project progresses, demonstrating the principle that high influence in the early stage of a project can come at little or no expenditure, but in later stages of a project little influence can come at a high expenditure. Gibson Jr *et al.* (1995) identified four stages of a project life cycle: (see Figure 3.1) business planning, pre-project planning, project execution and facility operation, grouping the first two stages as project planning.

In order to obtain a financially viable and environmentally conscious project, the simple but important concept of project planning, illustrated in Figure 3.1, should be grasped before attempting a retrofit project.

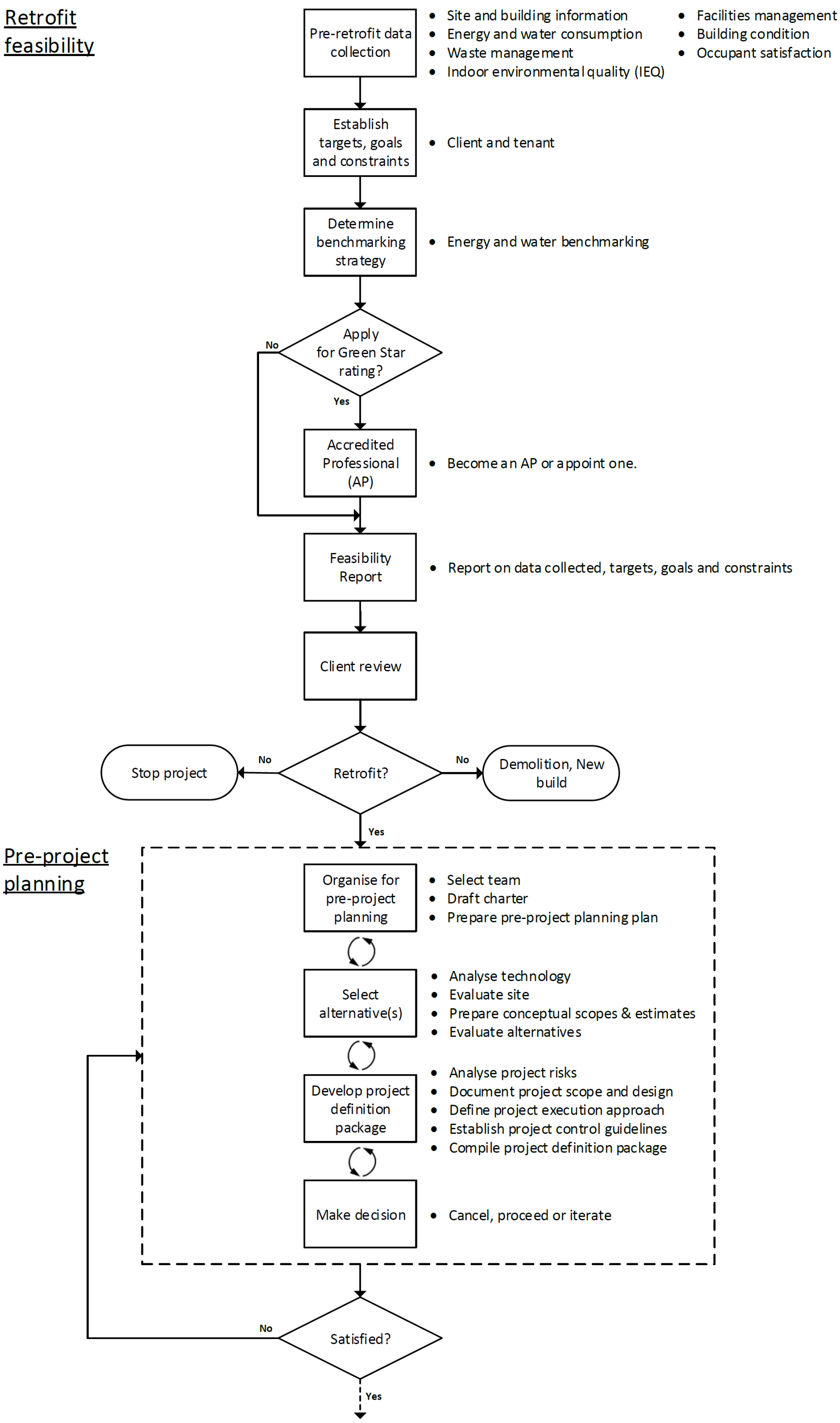
3.3 Framework

Figures 3.2a and 3.2b present the framework developed for green-retrofitting existing buildings in South Africa. The framework consists of five phases, namely a retrofit feasibility investigation, pre-project planning, implementation and commissioning of a retrofit project, post-retrofit activities and finally operation and maintenance. Some of the steps resemble those in the framework by Ma *et al.* (2012) discussed in Section 2.7. A discussion follows on the detail concerning each step of the framework.

3.3.1 Retrofit feasibility investigation

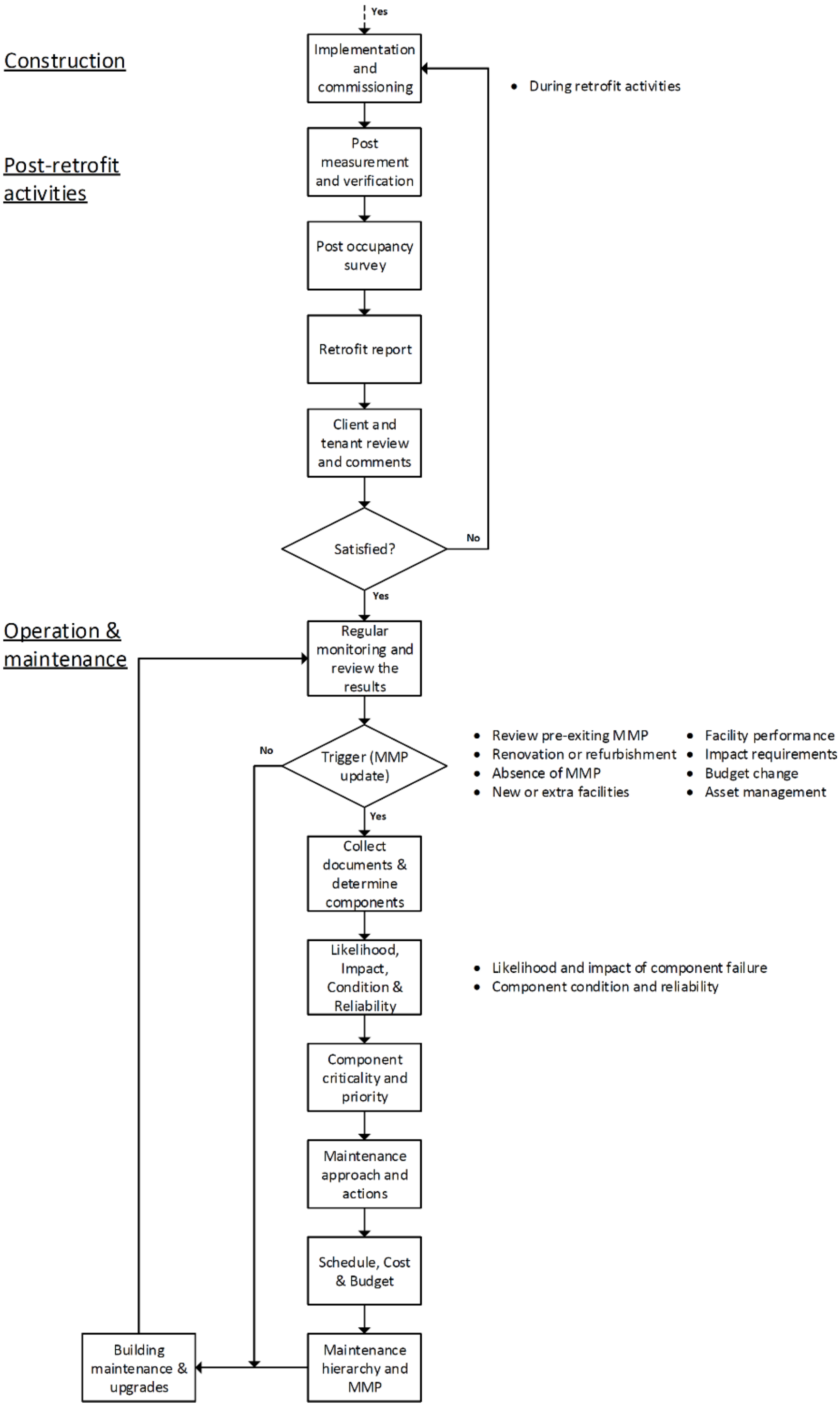
The framework's first step is to **collect pre-retrofit data**. Ma *et al.* (2012) also included data collection in their energy-retrofit framework. The aim of the pre-retrofit data collection step is to acquire site and building-specific information including existing technologies, shortcomings, building inefficiencies and the functional purpose of the building spaces. The following aspects are included in the investigation:

- site and building-specific information,
- energy and water consumption,
- waste management,



(a)

Figure 3.2: Framework for green-retrofitting existing buildings.



(b)

Figure 3.2: Framework for green-retrofitting existing buildings.

- facilities management (FM),
- building condition,
- indoor environmental quality (IEQ), and
- occupant satisfaction.

Building-specific information can include the following: materials, energy resources, occupancy schedule, location, size, type and age of building (Ma *et al.*, 2012). Reviewing the energy and water bills could help to identify abnormal consumption (Building and Construction Authority, 2010). Benchmarking can be used to compare a building's recent data to similar building data and gain a perspective on its performance.

Existing building energy and water benchmarking tools by the GBCSA are customised for the South African context and therefore the recommended choice for benchmarking energy and water performance. Four compliance paths for benchmarking are listed in Figure 2.5. It should be noted that only path 3, historical data, requires that a project have a representative baseline year, within the last 10 years before commencing the retrofit for each separate use of the building. This data set, containing a minimum of 12 months of data, is then used for benchmarking after the retrofit. Paths 1, 2 and 4 of the GBCSA tools only require 12 months of data after the last day of the retrofit to be able to benchmark the building's performance against normalised data. However, benchmarking 12 months of data before commencing the retrofit will make it possible to review its current performance and help to identify areas of the building that require attention. This benchmark is only for the purpose of the project and for the client to review, unless the project will make use of compliance path 3 for benchmarking after the retrofit has been completed. In a multi-use case it may be that there are multiple individual entities sharing a single water and energy source without proper sub-metering to determine separate usages. Therefore such a case would not be benchmarked unless a sub-metering system is installed. If the decision is to do pre-retrofit benchmarking, the project would be delayed by at least 12 months before the retrofit can start. Another option is that only post-retrofit benchmarking is done and the meters are installed during the retrofit project. In the case of a project with only a post-retrofit benchmarking another way to inform the client on the energy and water performance status would be to identify the building's existing technologies and compare them with current available technologies and innovative ideas. This could provide a perspective on the possibilities and improvements available with regard to the building's energy and water performance.

A waste assessment is used to determine the portions of building-generated waste that are recycled or sent to incineration or landfill. The knowledge obtained might help to identify recycling opportunities and reduce waste (Adams, 2008; Building and Construction Authority, 2010).

The FM investigation identifies the current property management process, maintenance schedules, manuals for operation and maintenance (O&M) and finally whether the current building management system is calibrated and used correctly. Poor facilities management (FM) can lead to the early failure of building systems and occupant dissatisfaction (Adams, 2008; Building and Construction Authority, 2010).

The current condition of the building should be investigated and a specialist might be required to evaluate areas of concern. Such an investigation can include aspects such as the building structure; external roof and walls; mechanical, IT and electrical systems; security and safety issues and hazardous materials such as lead and asbestos (Building and Construction Authority, 2010).

Indoor environmental quality (IEQ) can encompass lighting levels, thermal comfort, air quality and noise levels. The performance regarding these aspects and the potential for improvements should be reviewed (Adams, 2008; Building and Construction Authority, 2010; GBCSA, 2014*a*).

Occupant satisfaction surveys can help officials to understand IEQ, operational and transport issues from the occupants' view (Adams, 2008; Building and Construction Authority, 2010). Depending on the size of a project, informal discussion and interactions with occupants may be sufficient for smaller projects, but in the case of larger projects a structured survey should be considered. Observation can be a more accurate and efficient method compared to questionnaires for reporting overt aspects. Combining observation with other methods can be beneficial where there is a need to probe for further information or context (Bryman *et al.*, 2014). Methods for the collection of pre-retrofit data may include, but are not limited to observation, informal discussions or interaction with occupants, making notes on a site/building plan, measurements and photographs. Additional information may be required where difficulties arise in understanding the project context or where strange behaviour is observed. A survey or questionnaire may help with the understanding of these cases. A thorough survey or partial survey, focusing only on specific aspects or areas of the building, may be conducted depending on the need remaining after the primary means of data collection. Surveys can improve accuracy, but can also consume additional time and cost.

The extent to which the pre-retrofit data collection and other pre-project planning steps are applied will vary depending on project-specific details. Hwang and Ho (2012) identified three main barriers to pre-project planning: small project size, insufficient resources and additional costs incurred.

Establishing the target, goals and constraints of the project is part of the second step of the framework and determines the direction of the retrofit project. This step determines the project expectations from both a client and tenant perspective. Factors to consider include, but are not limited to (GBCSA, 2014*a*):

- Improving marketability by raising brand value and enhancing image and reputation.
- Improving property and lease value.
- Increasing productivity and business profitability.
- Reducing operating costs.
- Creating an attractive and desirable environment for potential employees or customers.
- Increasing overall sustainability.
- Legislative compliance.
- Minimising churn.
- Applying for a GBCSA rating.

An understanding of the client's available budget and the willingness of tenants to pay for the improved environment must also be determined during the second step.

Next the **energy and water benchmarking strategy** needs to be determined. For projects that can be benchmarked without any adjustments being made to use compliance path 1, 2 or 4, (Figure 2.5) it is recommended to do pre- and post-retrofit benchmarking. For buildings requiring adjustments in order to benchmark it is recommended to either make these adjustments during the retrofit for post-retrofit benchmarking, or to apply the adjustments and collect 12 months of data before the retrofit project commences for both pre- and post-retrofit benchmarking to be possible. Projects that need to be benchmarked using compliance path 3 will not be able to benchmark at all if they do not have appropriate historical data for comparison purposes. In the case of insufficient historical data, it would be necessary to apply the required adjustments and postpone 12 months for data collection in order to benchmark.

Thereafter it is decided whether the project should apply for a GBCSA Green Star **rating**. It is possible for an existing building to obtain a rating without an energy and water benchmark, but the calculated score of a project's Green Star SA rating suffers.

A short building status **report** should be prepared, containing information gathered from the previous steps. After the client reviews the report it should be decided whether the project should be terminated, the existing building should be demolished to be rebuilt as a new building, or to continue with the retrofit project.

3.3.2 Pre-project planning

In Figure 3.2a four major steps for pre-project planning are listed. This is a model developed by Gibson Jr *et al.* (1995) and introduced in Section 2.13. The model rests on the structured and stratified properties of the IDEF0 approach (Gibson Jr *et al.*, 1995). The four major functions are to organise for pre-project planning, select alternative(s), develop a project definition package and make a decision. These functions are developed for construction and are flexible enough to be applied to many companies and projects (Gibson Jr *et al.*, 1995). The model was tested during three construction case studies and found to be a good generic representation (Gibson Jr *et al.*, 1995).

In Figure 3.3 how the structure of the model by Gibson Jr *et al.* (1995) can be interpreted is illustrated. Functions and processes are represented by boxes. The arrows are representative of things that initiate action. Arrows that enter a box from the left are inputs to be transformed by the process. An arrow that leaves from the right is a process output. Arrows that enter at the top are constraints and controls of the process. The mechanisms that are required for the process, such as people, resources or tools, are indicated by arrows entering from below. The hierarchical design of the model allows processes to be expanded to levels of further detail. The processes are not linear and could run simultaneously. The model also provides for interaction and iteration.

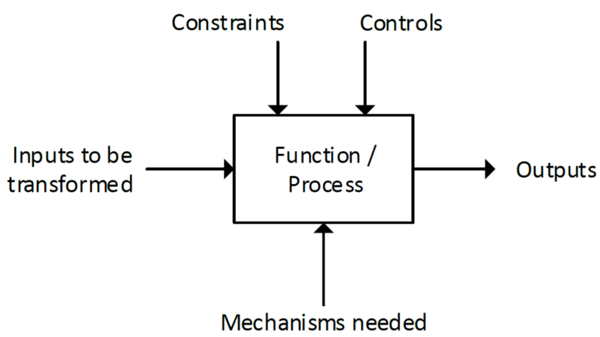


Figure 3.3: Components of the pre-project planning model. (Gibson Jr *et al.*, 1995).

In Figure 3.4 a contextual perspective of the whole Pre-Project Planning model is provided. The main input to the whole process is the *Validated Project Concept* which is the initial reason that motivated the client to investigate the option of a retrofit, before any formal objectives were discussed. This might for instance be to improve on poor productivity, inefficiency and/or unpleasant indoor environment. The input (validated project concept), constraints and controls (the retrofit objectives) would have been uncovered throughout the previous phase and are now incorporated throughout the pre-project planning phase. The *Constraints* are related to the available budget and resources,

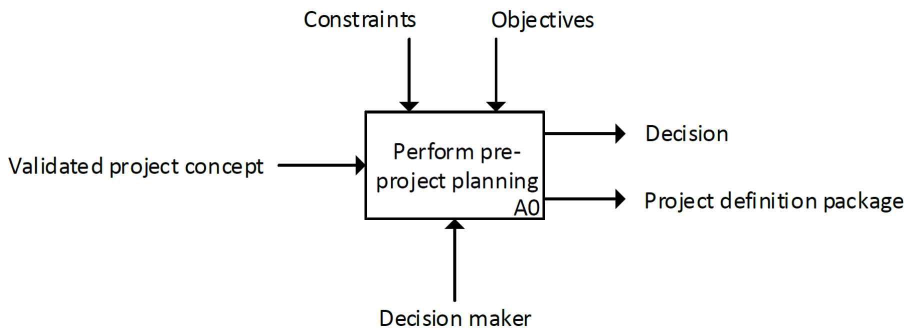


Figure 3.4: Context diagram for the pre-project planning phase (Gibson Jr *et al.*, 1995).

property and tenant market conditions and so forth. *Objectives* refer to the targets and goals of the project set out by the client and can also include site usage criteria. The first output is the *Decision*, made by the *Decision Maker*, whether to continue with the retrofit project or not. The second output is the *Project Definition Package* consisting of the information required for the execution of the retrofit project.

In Figure 3.5 the first level of detail within the Pre-Project Planning model in Figure 3.4 is provided.

1. The first main process is to *Organise for Pre-Project Planning* and can be further expanded to a second level of detail (see Figure 3.6) containing three sub-processes:

    a) *Select Team*: A team is compiled by selecting individuals that will take on the responsibilities for pre-project planning. These members may have diverse expertise in for example the fields of business, project management, safety, environment and sustainability. It is important that the project team maintains uninterrupted representation from business, project management, technical and operations expertise. It is recommended that these individuals have the experience and skills to effectively manage the objectives of the retrofit project.

    b) *Draft Charter*: The initial project concept is developed into a workable project concept. Responsibilities and levels of authority of each team member are documented. The charter must also incorporate guidance from the owner and include a mission statement and quality of deliverables.

    c) *Prepare Pre-Project Planning Plan*: A plan is documented consisting of the methods, budget, contracting strategy, priorities and schedule for the completion of pre-project planning.

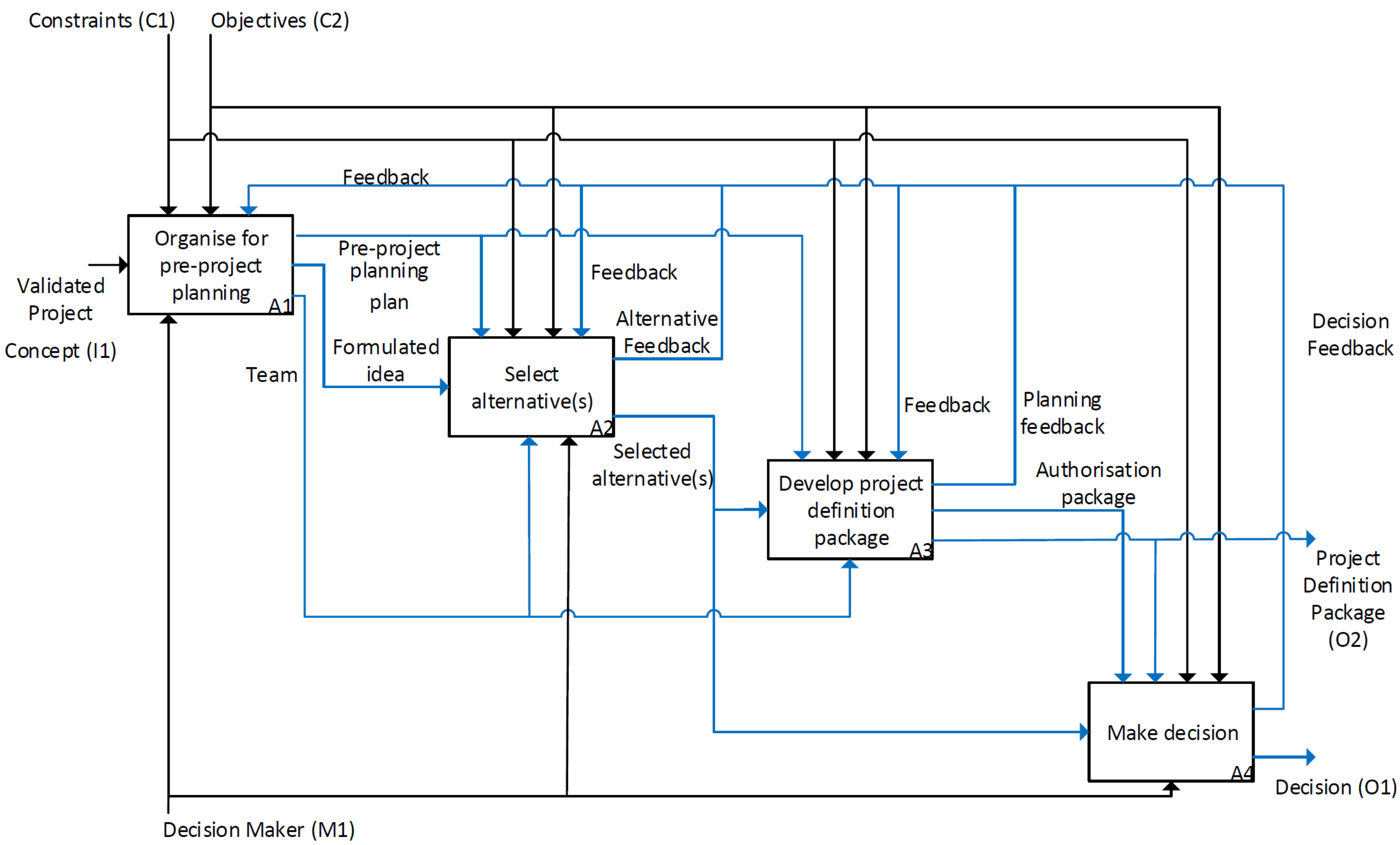


Figure 3.5: Diagram of pre-project planning stages, level 1 IDEF0. (Gibson Jr *et al.*, 1995).

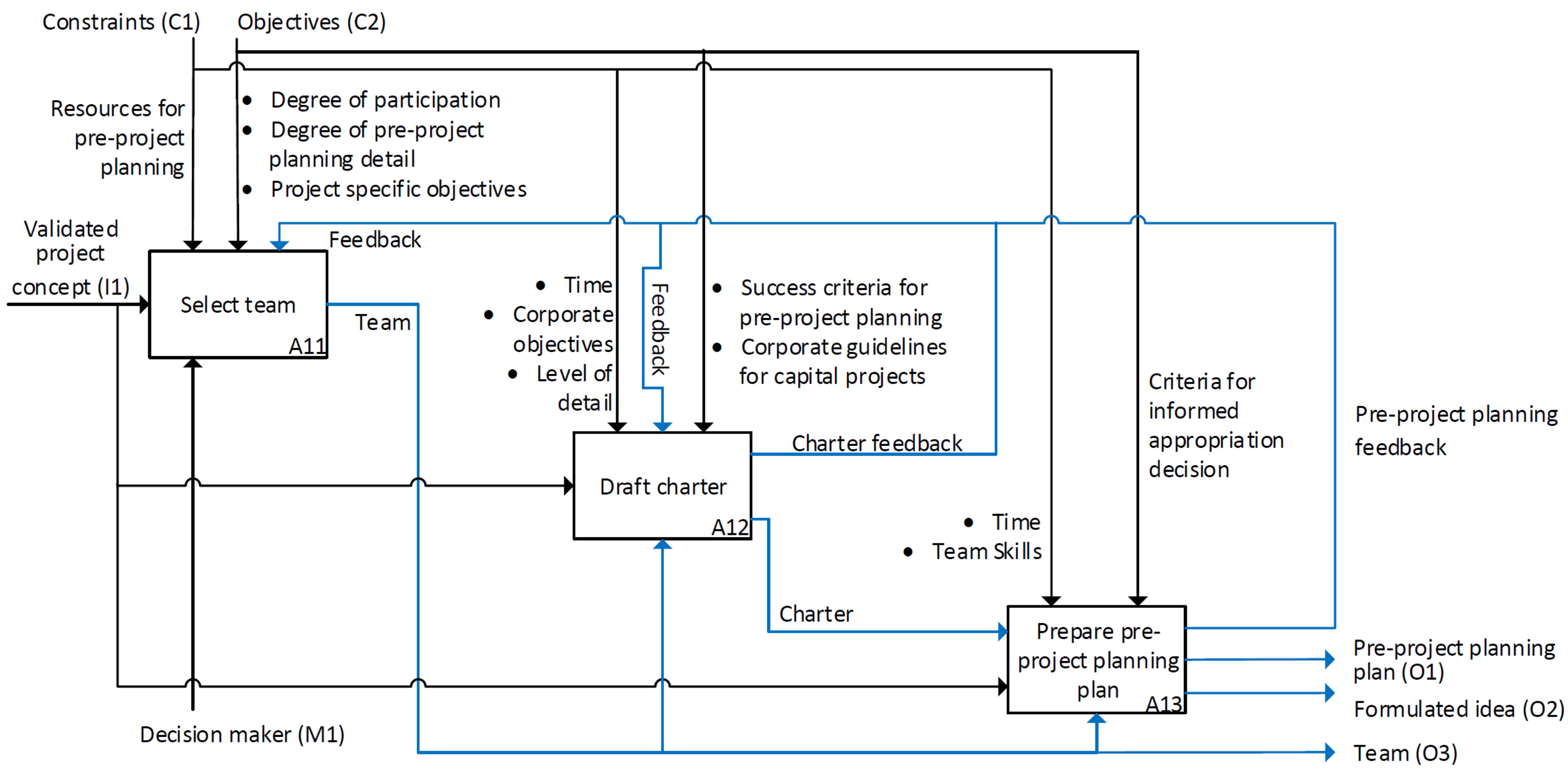


Figure 3.6: Diagram for organisation of pre-project planning, level 2 IDEF0. (Gibson Jr *et al.*, 1995).

2. The *Select Alternatives* process in Figure 3.5 is presented in more detail in Figure 3.7. Its four sub-processes are listed below. The technology selection strategy by Yudelson (2009) and Si *et al.* (2016) in Section 2.6 can be applied in this process.

    a) *Analyse Technology*: Evaluate and compare the existing technologies of the building with current and emerging technologies available. Feasibility and compatibility with business and objectives of the operations should be considered.

    b) *Evaluate Site*: The physical and functional characteristics and dynamics of the building and site are captured and documented to identify inefficiencies and shortcomings.

    c) *Prepare Conceptual Scopes and Estimates*: Various possible combinations of alternatives are assembled in such a way that they can be evaluated according to the targets, goals and constraints of the project.

    d) *Evaluate Alternatives*: The pre-project planning team and decision maker evaluate the alternatives and select the option(s) which is most suited to the business and retrofit project.

3. Thirdly, the *Develop Project Definition Package* process is expanded into five sub-processes (see Figure 3.8):

    a) *Analyse Project Risks*: The risks related to the selected project alternatives are identified by the team. These risks are then analysed according to business, social, project and operational risk categories in order to minimise their impacts on the project. The risk management approaches provided by Chapman (2001) and Leopoulos *et al.* (2006), in Section 2.11.2, are examples of suitable risk management. The project team may select, adapt and implement a risk management approach that suits the specific project needs, or use an approach that the team is already familiar with or skilled at.

    b) *Document Project Scope and Design*: The scope entails the approximate cost of the project, project description, procurement plan, flow diagrams, operation and maintenance considerations. The design stage is finalised to such an extent as to minimise the risk associated with project execution.

    c) *Define Project-Execution Approach*: The methods needed to design, procure, implement and hand over the retrofit are documented.

    d) *Establish Project-Control Guidelines*: Mechanisms and guidelines to control and manage project execution are developed. These could include milestones, critical path schedules, safety procedures, change management and information management.

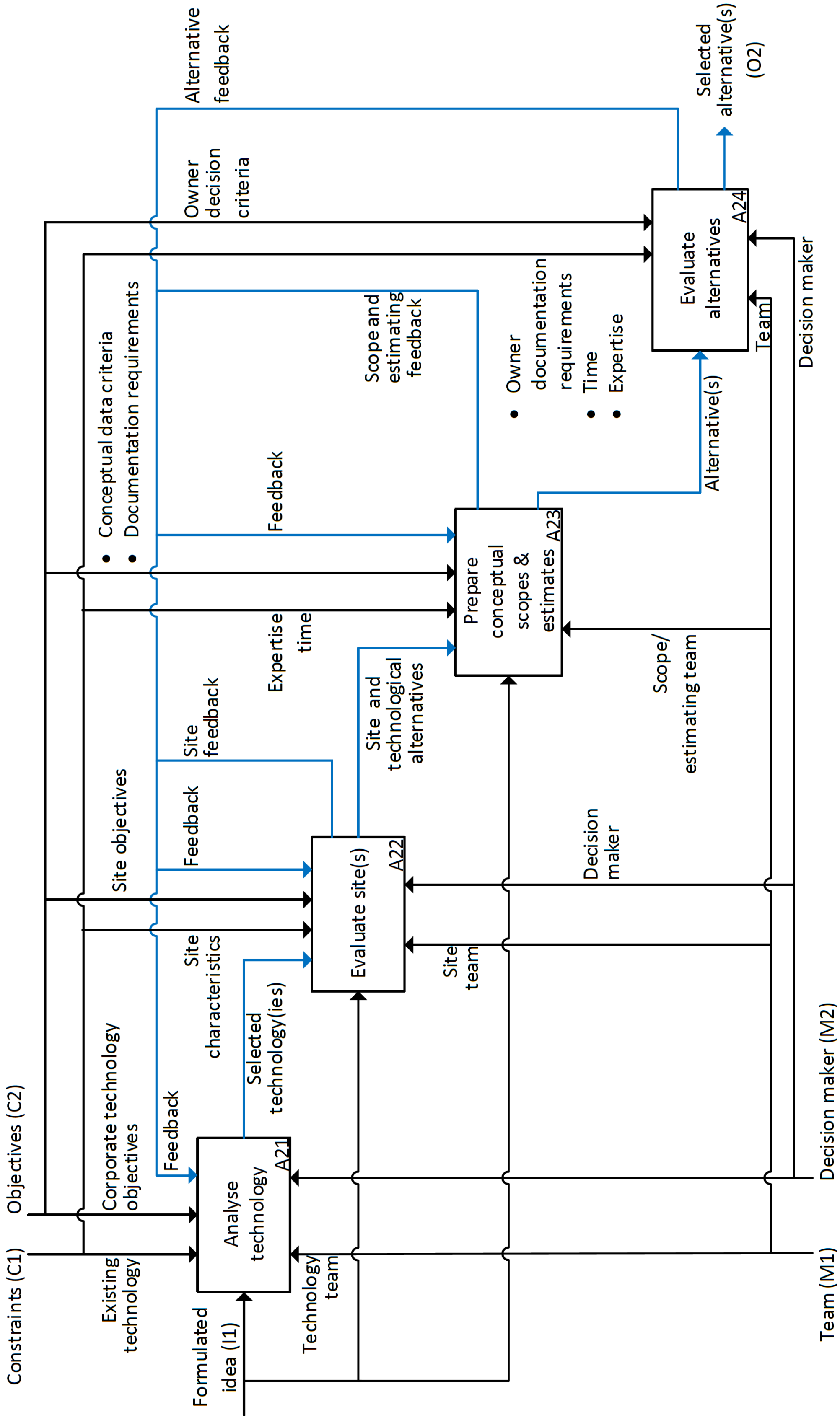


Figure 3.7: Diagram for the selection of alternatives, level 2 IDEF0. (Gibson Jr *et al.*, 1995).

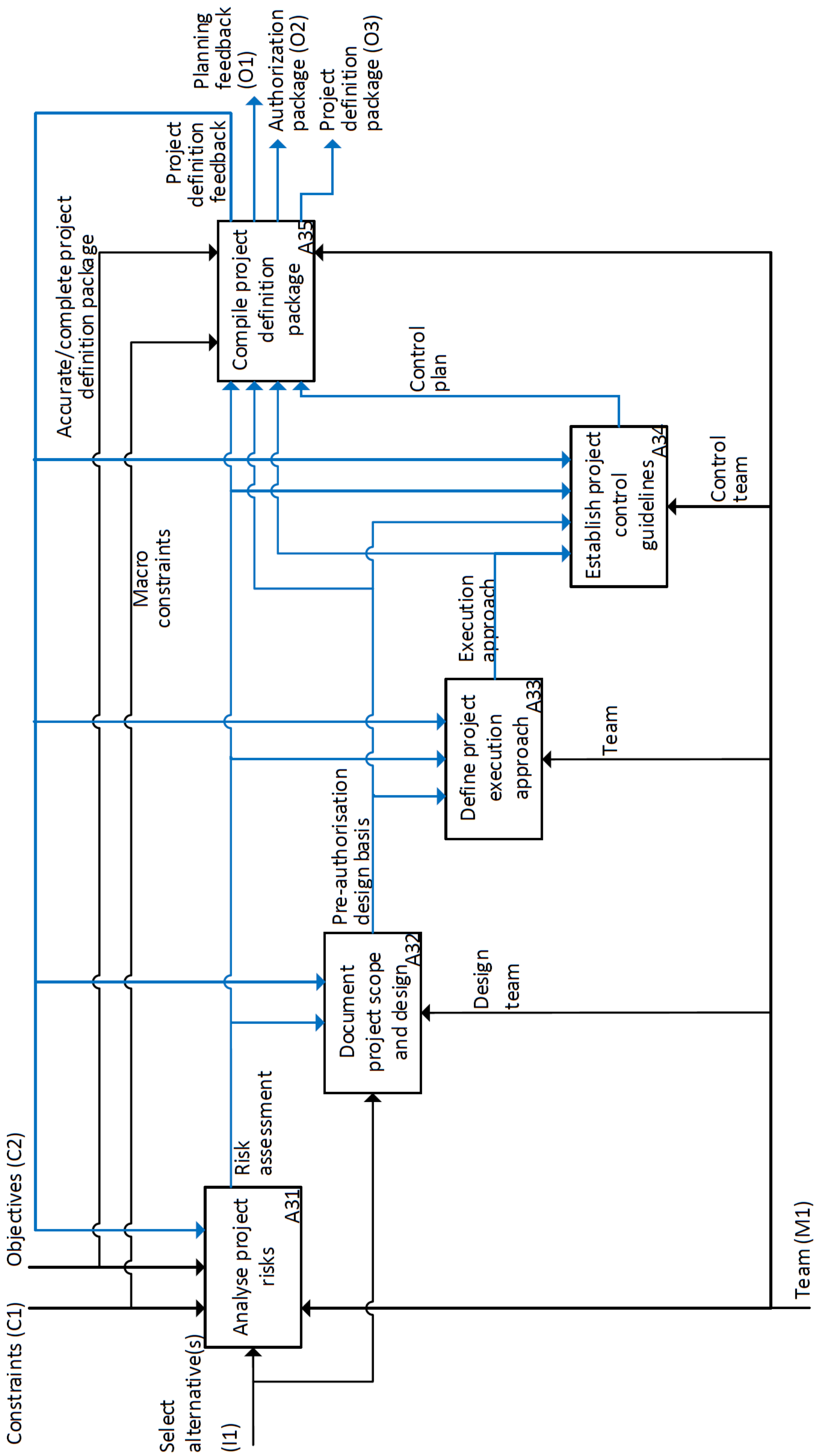


Figure 3.8: Diagram for the development of the project-definition package, level 2. (Gibson Jr *et al.*, 1995).

e) *Compile Project-Definition Package*: An *authorisation package* is compiled by summarising the information from the previous four steps. The authorisation package aids the decision maker in determining the project's feasibility. A *project-definition package* containing more detail is also compiled for project execution .

4. The last major process is the *Make Decision* block and does not feature a specific sub-process breakdown. During this process the decision-maker evaluates the authorisation package to make a decision regarding whether the retrofit project is a feasible pursuit by considering the project objectives and risks involved. Intangible aspects like intuition and business dynamics should be considered in cases where there is uncertainty about whether it will be possible to meet the objectives. The decision-maker can decide to cancel the project, proceed or send the plan back for further evaluation and development.

This model may be customised or adapted to the specific needs of the client or business, as each project has its individual requirements. The composition and level of participation within the pre-project planning team is very dependent on the size and complexity of the project, and the expertise within the company. It is essential that the team be strongly defined from the beginning of the planning stage. It is important to document the progress of the pre-project planning process so that the project can be resumed easily and with minimal disruption if an interruption or halt occurs due to outside influences (Gibson Jr *et al.*, 1995).

3.3.3 Construction

The **implementation and commissioning** step refers to the retrofit construction period (Ma *et al.*, 2012). Project success is highly dependent on the construction contractor (Puri and Tiwari, 2014). Salama *et al.* (2006) sent out 100 questionnaires to project managers in Egypt and had a 72 per cent response rate. Almost half of the respondents (47 per cent) use the bid price as the only criterion when selecting a suitable contractor. Although cost influences a project greatly, it should not be the only criterion. In Table 3.1, Hatush and Skitmore (1997) identified five primary criteria with four sub-criteria each for contractor pre-qualification and bid evaluation. The criteria identified by Hatush and Skitmore (1997) should also be considered when selecting a construction contractor. These primary criteria are financial soundness, technical ability, management capability, health, safety and reputation. During the commissioning process of a building, all building components should be verified and tested prior to completion (CIDB, 2015*b*).

Table 3.1: Primary criteria for contractor pre-qualification and bid evaluation. (Hatush and Skitmore, 1997).

Main criterias	Sub criterias	
Financial soundness	1	Financial stability
	2	Credit rating
	3	Banking arrangements and bonding
	4	Financial status
Technical ability	1	Experience
	2	Plant and equipment
	3	Personnel
	4	Ability
Management capability	1	Past performance and quality
	2	Project management organization
	3	Experience of technical personnel
	4	Management knowledge
Health and safety	1	Safety
	2	Experience modification rating (EMR)
	3	Occupational Safety and Housing Administration (OSHA) Incidence rate
	4	Management safety accountability
Reputation	1	Past failures
	2	Length of time in business
	3	Past owner/contractor relationship
	4	Other relationships

3.3.4 Post-retrofit activities

The post-retrofit activities were adopted from Ma *et al.* (2012) who suggested post measurement and verification (M&V), a post occupant survey, retrofit report and finally client/tenant review and comments. Ma *et al.* (2012) also suggested regular monitoring and review of the results, but for this framework that is included in the operation and maintenance phase.

$$E_{savings} = E_{pre-retrofit} - E_{post-retrofit} \pm E_{adjust} \tag{3.3.1}$$

$$W_{savings} = W_{pre-retrofit} - W_{post-retrofit} \pm W_{adjust} \tag{3.3.2}$$

Post-retrofit measurement and verification would determine the actual energy and water savings due to the retrofit. Equation 3.3.1 by Ma *et al.* (2012) calculates energy savings ($E_{savings}$) as the post-retrofit measured or estimated energy usage subtracted from the pre-retrofit measured or estimated energy usage ($E_{pre-retrofit}$) and finally adjusted by a factor ($E_{adjusted}$). The adjustment factor accounts for variations due to non-retrofit factors such as occupancy schedules and weather conditions that differ during the pre-retrofit period from the conditions during the post-retrofit period. Equation 3.3.2 for water is based on Equation 3.3.1 and should be calculated in a similar manner.

The International Performance Measurement and Verification Protocol provides four methods, including their applications, that can be used to determine energy savings and can be found in EVO (2007).

Another way to verify energy and water performance could also be to benchmark energy and water performance using the GBCSA benchmarking tools for existing buildings. This could help to provide a perspective on how the building performs alongside similar South African buildings.

A **post occupancy survey** will determine the level of satisfaction of the occupants and the building owner with the completed retrofit (Ma *et al.*, 2012). A **retrofit report** on the water and energy savings/performance, occupant satisfaction and the success of the project is to be compiled. The **client and tenants review** the results of the project presented in the report to decide if they are satisfied, else the stakeholders will revert to the implementation and commissioning step to address and resolve the identified discrepancies.

3.3.5 Operation and maintenance

Regular monitoring and reviews of the results entail building system operation monitoring and reviewing operational data to ensure that the system operates in an efficient manner, as predicted (Ma *et al.*, 2012).

Projects that want to obtain an existing building Green Star SA rating will have to start collecting energy and water usage data for a minimum of 12 months after the retrofit project has been completed. An existing building Green Star SA rating is only valid for three years and a project will have to reapply after this time frame (GBCSA, 2014*a*). Obtaining an existing building Green Star rating could help to drive the regular monitoring and review of the building data, as well as force the implementation of sustainable maintenance so that the building can keep its Green Star status.

It is important to continually maintain a building and its sub-systems after a retrofit-intervention for sustainability. Neglect of maintenance can be seen as unsustainable as the failure of one component or system can have a far-reaching effect on the system as a whole, leading to poor building performance and inefficiency. The maintenance process offers continual opportunities to update old technology with new sustainable options, therefore preventing a state where the whole building has faded into overall unsustainability.

Neglecting building maintenance can be the easiest way to reduce maintenance cost in the short-term, but this is usually very costly in the long-term (Horner *et al.*, 1997). It is strongly advised that a building has a Maintenance Management Plan (MMP) and the development or review of such a plan can be initiated by any of the following **triggers** (CIDB, 2015*b*):

- If there exists no Maintenance Management Plan (MMP) for the existing building.
- After the completion of new or extra facilities.
- After the renovation or refurbishment of the existing facility.
- An existing MMP is reviewed against life-cycle and portfolio requirements.
- Change in the facility performance requirements.
- If the impact of a component failure has changed.
- Change in the maintenance budget.

When the development or review of a MMP is triggered, the first step is to collect all facility **documents** and to determine the facility **components**. Facility documentation should include (CIDB, 2015*b*):

- Operation and maintenance guides.
- Building construction signed Certificates of Compliance (CoC).
- Relevant authorities' inspection certificates and professional service providers' design certificates.
- Equipment systems' commissioning certificates and commission test reports.
- Outstanding contractual conditions and warranty agreements.
- Building acceptance report and certificate.

When determining the **components** of a facility it is important to have an undeviating approach towards the numbering system. The CIDB (2015*b*) suggests a numbering system developed by South African Association of Quantity Surveyors (2013) that can be found in "Guide to Elemental Cost Estimating". It is suggested that each component have the following information available (CIDB, 2015*b*):

- a maintenance planning function number,
- component catalogue name and serial number (if available),

- manufacturer contact details,
- component warranty and guarantee information,
- possible cause of failure,
- cost (material and labour),
- repair time (average),
- failure likelihood,
- condition status,
- reliability rating (currently),
- criticality rating (impact and likelihood),
- maintenance intervention priority (currently),
- procedure to shut down,
- responsibilities and maintenance actions, and
- status after maintenance.

The analysis to determine the criticality and priority of components, needed to select appropriate maintenance approaches and actions for the MMP is best illustrated in Figure 3.9 and also forms part of the framework in Figure 3.2b. Component criticality is a function of the likelihood and the impact of failure. Component priority is a function of the impact of failure and the condition and reliability of the component (CIDB, 2015*b*).

The potential **impact of failure** is generally determined during the handover or design phase of a building. In many cases such information might be lost and should then be re-engineered using gathered facility data or product descriptions. Financial impact is rated in indirect (compensation for serious

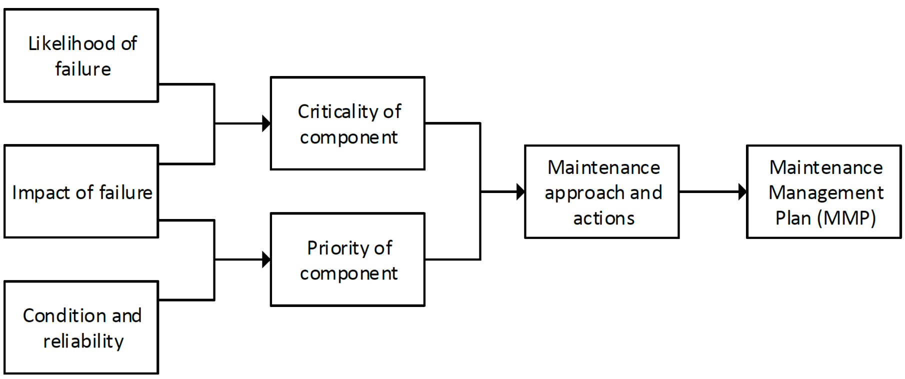


Figure 3.9: Determining component criticality and priority (CIDB, 2015*b*).

injury or death) and direct cost (repair cost) of a particular event of failure. Failure impact should be rated on a scale from I1 to I5, where I1 represents insignificant impact and I5 catastrophic impact (CIDB, 2015*b*).

Likelihood of failure is the final step required for component analysis. Component characteristics form the function that defines the likelihood of component failure. CIDB (2015*b*) suggests that the maintenance planning function should determine the likelihood of component failure as the most severe outcome of the following approaches:

- prediction using the remaining life of the component;
- using the service interval specified by the manufacturer;
- analysis of maintenance records for a component outside of its warranty period or without a specified design life.

The likelihood of failure can be rated on a scale from L1 to L5, where L1 represents a long design life or low failure rate and L5 a short design life or high failure rate.

A component's **condition and reliability** informs the priority for its maintenance. To determine the condition rating of a component the amount of usage wear and tear and the physical condition of its sub-components should be investigated. The reliability is the component's ability to perform the functions it is designed for and is rated based on the frequency of breakdowns. Both ratings use a scale from C1, representing no defects, to C5, where a component is unfit for use and poses an immediate, significant risk (CIDB, 2015*b*).

To determine the **criticality** and **priority** of a component, a criticality and priority matrix has to be set up. The criticality matrix has likelihood versus impact variables, and the priority matrix has condition and reliability versus impact variables (CIDB, 2015*b*). Examples of both these matrices can be found in Appendix A, Section A.1 in Figure A.1 and A.2 respectively.

The **maintenance approach and action** is determined by the criticality and priority of a component. Table 3.2 provides an example of how the maintenance approach is determined.

The **schedule for maintenance actions** should be determined by the frequency in the maintenance approach. It is advised that for high risk and critical items at least 80 per cent of the maintenance is planned and scheduled within the MMP. Scheduling can be defined as the process by which jobs are aligned with resources and sequenced to be performed at a specific point in time. Planning aspect that should be covered in the MMP should include: long-term, medium-term, in-year and short-term planning (CIDB, 2015*b*).

Maintenance cost can include human resources, contractor, material, plant and equipment costs. This should be determined for each maintenance action. Elemental estimates prescribed by the South African Association of

Table 3.2: Maintenance approach. (CIDB, 2015*b*).

	Maintenance approach		
Criticality and priority of component	**Interval-based** Priority Rating 1 (low)	**Condition-based** Priority Rating 2 (medium)	**Corrective** Priority Rating 3 (high)
Reliability Centred Method Extreme Criticality	As scheduled. All critical components should be serviced at specified intervals.	Short term actions. The condition of components should continuously be monitored. Testing should be conducted on an ongoing basis. Any indicators of failure should immediately be acted upon. Preventative action should immediately be taken.	Immediate action required. Spares for this component should be kept in reserve. Replace component immediately with reserve. Spare component should be replaced immediately.
Essential Maintenance Moderate Criticality	As scheduled. All moderately critical components should be serviced at specified intervals.	Increase number of inspections. Components should be monitored through regular inspection as per the component maintenance manual. Testing should be conducted when deterioration occurs. Preventative action should be taken on identifying the deterioration.	Scheduled for short term action. Spare parts do not have to be kept in reserve, and may be obtained from the vendor on demand. Components should be replaced or repaired as soon as deterioration is significant and component is approaching end of life.
Non-essential Maintenance Low Criticality		Address according to schedule or when necessary. Condition is only determined through inspection at a 5-year interval.	Medium term action. Components are allowed to deteriorate and are only replaced when end of life or failure has occurred. Components are repaired or renovated and hardly ever replaced.

Quantity Surveyors (2013) or average costs of similar historic maintenance actions can be used to determine the maintenance cost (CIDB, 2015*b*).

A **maintenance budget** comprises of all maintenance costs and is organised according to the maintenance schedule. This budget should be provided as a formal request to apply for funding.

Figure 3.10 provides a **hierarchy** for the maintenance types, approaches and actions that **determine the MMP**. Two maintenance types were identified in Figure 3.10, preventative and corrective maintenance (CIDB, 2015*b*). Corrective maintenance, also referred to as unplanned or failure-based maintenance, is the simplest form of maintenance and is performed when an element of the building breaks down or does not perform its required task (Horner *et al.*, 1997), and consists of both emergency and planned maintenance approaches (CIDB, 2015*b*). Emergency corrective maintenance responds to breakdown or failures, interrupting the preventative maintenance schedule and is scheduled or planned as they occur. Planned corrective maintenance is meant to prevent breakdowns or failures by eliminating the repeated cause

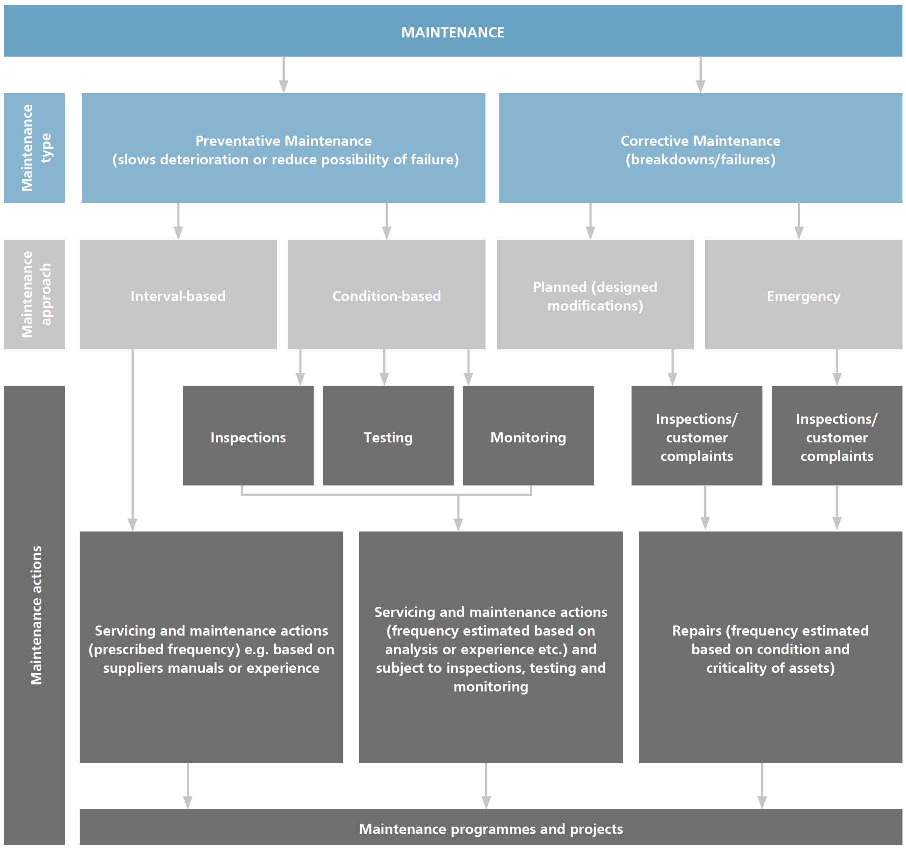


Figure 3.10: Maintenance hierarchy. (CIDB, 2015*a*).

and typically includes design modifications (CIDB, 2015*b*).

Preventative maintenance, also known as time-based, planned or cyclic maintenance, overcomes the disadvantages of corrective maintenance by reducing the probability of failure or sudden failure (Horner *et al.*, 1997). It consists of interval-based and condition-based maintenance approaches (CIDB, 2015*b*). Interval-based maintenance approaches are periodic in nature, planned and scheduled, and can be time-based preventative maintenance or based on machine hours or the number of machine outages. The frequency of interval-based maintenance can also be dependent on variables such as knowledge and operator skills. The condition-based maintenance approach relates to inspection, testing and monitoring, and is based on experience and analysis, and comprises of maintenance and servicing actions (CIDB, 2015*b*).

Building maintenance and upgrades are the last step and indicate the implementation of the MMP. This step continuously loops back to the **regular monitoring and review** step. The maintenance actions and review of building loop is part of a sustainable loop where the building can operate at optimum performance and improve on its sustainability, by continuously upgrading and replacing overdue or failed components with improved sustainable options.

3.4 Conclusion

In this chapter the design of a green-retrofitting framework for existing buildings in South Africa is presented. The framework consists of five phases: retrofit feasibility investigation, pre-project planning, implementation and commissioning of the retrofit project, post-retrofit activities and lastly operation and maintenance. The scope of and extent to which this framework is applied depends on the size, complexity and specific needs of an individual project. This framework was developed to facilitate early project planning. Decent and early planning will minimise project risks and increase the probability of project success.

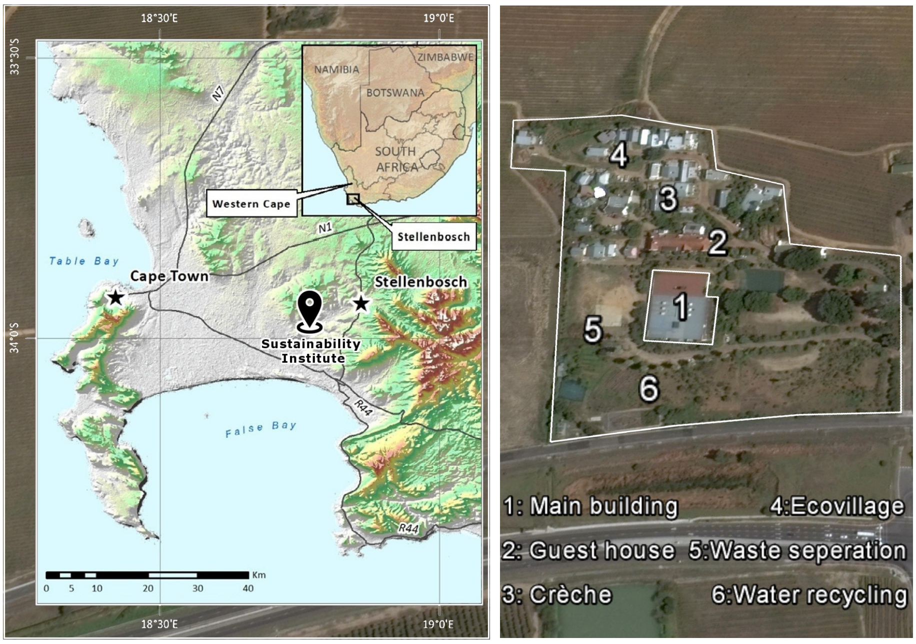
Chapter 4

Implementation and Verification

4.1 Introduction

In Chapter 3 there is a description of the developed framework for the green retrofitting of existing buildings. The framework is depicted in Figure 3.2a and 3.2b. In this chapter there is an attempt to validate this framework by means of a case study.

The building used for the case study is owned by the Sustainability Institute (SI), situated near Stellenbosch in the Western Cape of South Africa, as indicated in Figure 4.1a. In Figure 4.1b an aerial view of the Lynedoch plot



(a) SI location, adapted from Musakwa and Van Niekerk (2013).

(b) Aerial view of SI (Google Earth Pro., 2016).

Figure 4.1: Sustainability Institute

on which the case study building is located is presented. The Lynedoch plot is indicated by the large outlined area. The smaller outlined area, labelled with the number one, indicates the case study building which is known as the main building. Other features on the plot are the guest house, crèche, ecovillage, waste separation plant and a water recycling plant.

4.2 Basic problem identification

The SI is a non-profit trust that originated based on the idea of providing a space that enables people to explore approaches towards a more equitable and sustainable society. Their scope encompasses the education of young children as well as a Masters and PhD degree in Sustainable Development in partnership with Stellenbosch University. They believe in doing relevant research, teaching about it and practising that which they teach (Sustainability Institute, 2016*a*,*b*).

A few problems like extreme temperatures, noise, poor airflow and inadequate lightning are experienced in the main building. The SI intends to improve the sustainability of the main building and seeks advice. They want to improve the building so that it becomes a comfortable space that inspires and promotes innovation in sustainability.

4.3 Framework implementation

The retrofit feasibility and pre-project planning phases of this framework was evaluated as part of this research. This study was conducted over a limited time frame and the time required for the organisation involved to obtain the necessary funding and implement the retrofit exceeded the time available for this study. Therefore the application of the final three phases of the developed framework was not feasible. These three phases are the construction, post-retrofit activities, and operation and maintenance. After the completion of the first phase, retrofit feasibility, a first iteration of the pre-project planning phase was conducted.

4.4 Retrofit feasibility phase

This phase consisted of six steps that were performed for the case study. Pre-retrofit data collection was the first and the largest step of this phase. The focus was on data collection and no revealing conclusions were drawn. Establishing the client and tenant targets, goals and constraints, determining the energy and water benchmarking strategy and deciding whether to include an accredited Green Star SA professional on the project team were the second, third and fourth steps. Finally the fifth and sixth steps were to summarise the information gathered during the retrofit feasibility phase in a short report to the client and let the client decide on the project's future. By the end of the retrofit feasibility phase the client had to decide whether the retrofit project should be continued or if the building should be demolished for a new build or if the retrofit project should be permanently terminated.

4.4.1 Pre-retrofit data collection

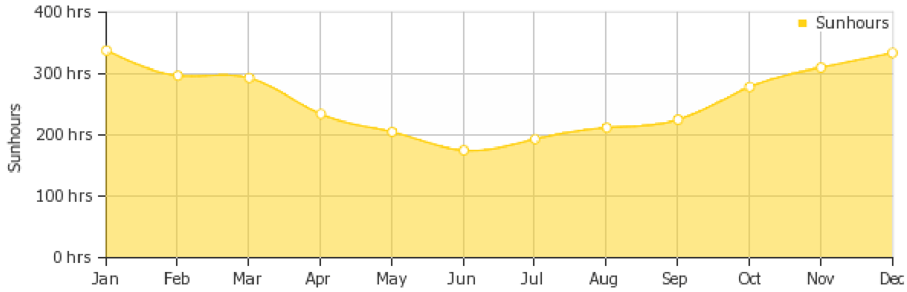
Pre-retrofit data collection includes collecting seven different types of data for the retrofit project. These data types are site- and building information, energy- and water consumption, waste management, indoor environmental quality (IEQ), occupant satisfaction, building condition and facilities management.

4.4.1.1 Site information

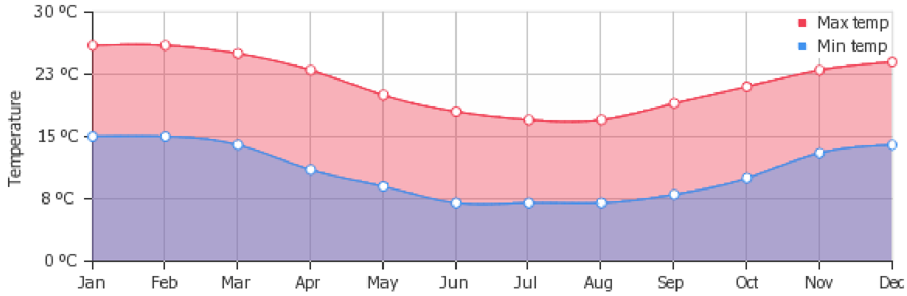
Site information can reveal if the site is located within short travel distance of the closest town or areas of interest and if there are bike paths, buses or trains nearby.

The Lynedoch plot is situated eleven kilometres' drive from Stellenbosch central. The Lynedoch train station is 430 metres and a nearby bus stop 600 metres walking distance from the main building. This train station is connected to 47 other train stations such as: Cape Town, Ysterplaat, Goodwood, Parrow, Kuils River, Somerset West, Strand, Stellenbosch, Paarl and Wellington (Cape Town Trains, 2016). Presently there is no provision for bicycle lanes in this area despite the attractive surrounding scenery. Finally the closest shops are a farm stall and a café that are within 400 metres, i.e. walking distance.

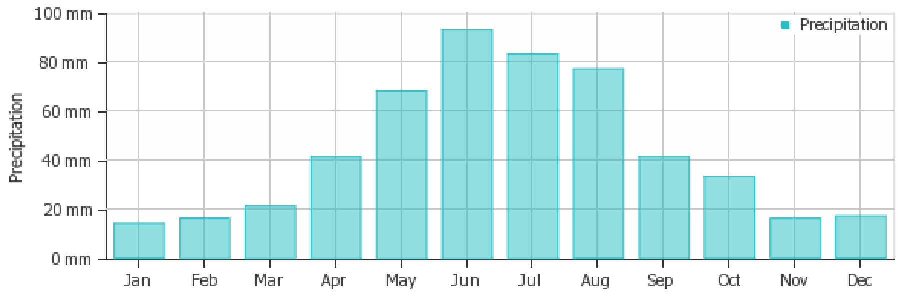
Climate information can be valuable for the understanding of building energy- and water use, occupant behaviour, revealing possible passive design options and understanding the nature of the renewable resources available. In South Africa, spring and summer occur from October to March and fall and winter from April to September (Clark, 2008). Stellenbosch is subject to a Mediterranean type climate characterised by cool, wet winters and hot, dry summers (Barredo *et al.*, 2016; Ntwana, 2007). Climate characteristics of Stellenbosch are presented in Figure 4.2 where monthly averages are provided. The hours of sunshine in Figure 4.2a show that in the past Stellenbosch received most of its sun hours during the months of November to March. Likewise in Figure 4.2b it is shown that Stellenbosch can be at its hottest from November to April, peaking in January and February, and coolest from June to August. According to Figure 4.2c, Stellenbosch receives most of its rain during the months of May to August, expecting peak precipitation during June. Finally, the average wind speeds in Figure 4.2d illustrate that Stellenbosch is subject



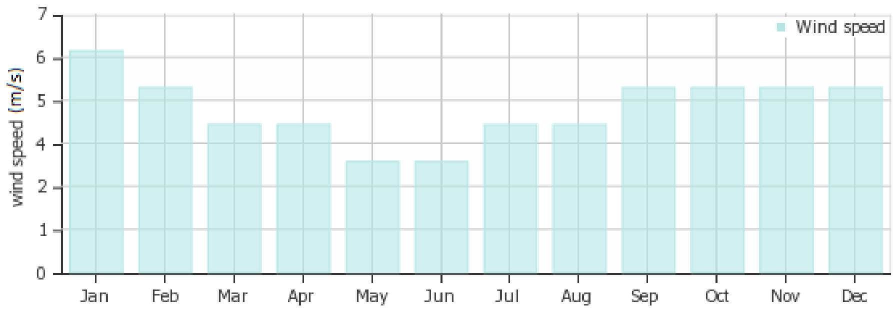
(a) Sunshine hours



(b) Temperatures



(c) Precipitation



(d) Wind

Figure 4.2: Average monthly values for climate conditions in the Stellenbosch region. (World weather and climate information, 2016).

to wind with a minimum speed of 2m/s for the whole year. In Figure 4.2d it is also shown that declined wind speeds can be expected during the months of May to June and increased wind speeds during the months of September to February, with an average peak in January.

4.4.1.2 Building information

The **history** of the building is as follows. Before the existence of the SI, eco-village and other entities, the only property that existed on the Lynedoch plot was a dance hall and hotel. Upon conversion in 2001 the original properties were not entirely demolished, but adapted and extended. As such the hotel building was kept in a similar state, but is currently being operated as a guest house. The dance hall was adapted to accommodate office and school facilities and currently serves as a shared hall in the middle of the main building property. In Figure 4.3 the four **building elevations** of the main building are shown. Further development took place on the site throughout the years such as adding a crèche and extending the eco-village.

Figure 4.3: Main building elevations.

Architectural drawings are the visual road maps of a building and are essential when making building alterations. Drawings of the lower and upper level of the main building were obtained for the adaptations made in 2001. Changes made thereafter to the internal walls were not recorded on them. These drawings were only available as hard copy scans with no scale or dimensions provided. Both the lower and upper level drawing scales were determined by calibrating them with measured data. Updated copies of the drawings, including up to date internal wall changes, were produced with the necessary accuracy by the author and were included in Appendix B.1. Figures B.1 and B.2 show the updated lower and upper level drawings and also numerically identify each space of the building. In Tables B.1 and B.2 the numerical identifiers were associated with the use, tenant and surface area of each space for the lower and upper levels respectively.

Building use is important for retrofit recommendations: it is required in design decisions and building codes, aids in the understanding of occupant needs and behaviour, and is a GBCSA requirement for a rating application.

The main building is owned by the SI and managed by the SI trustees. Its building use includes a primary school, research-, educational-, administrative- and business offices. To better understand the state and dynamics of the building, Figure 4.4 and 4.5 were prepared. Figures 4.4a and 4.4b show the lower and upper level respectively where portions of the main building allocated to rented offices, school and a shared hall are coded with colour. In Figures 4.5a and 4.5b educational and office building use for the lower and upper level respectively have been identified. This technique was chosen to enable an easy and effective visualisation of the current building circumstances regarding its tenants and use. A summary of the building surface areas were calculated and included in Table 4.1. From this table is can be seen that the building is predominantly used for educational purposes as the total surface areas allocated to education and office use are 1531 m^2 and 745 m^2 respectively.

The school is operated from 7:30 to 16:00, Monday to Friday, and the SI from 8:00 to 17:00, Monday to Friday. Both the school and SI can have after-hour activities and the SI is also operated roughly every second Saturday. Other offices in the building are mainly subject to a usual 8:00 to 17:00, Monday to Friday workday occupancy schedule.

4.4.1.3 Energy and water

Energy and water are primary resources on which the operation of many buildings depend. By efficiently managing these resources and applying sustainable techniques, a significant reduction in operating cost and the mitigation of negative environmental impacts can be achieved.

By collecting energy- and water data, inefficiencies and opportunities can be identified. Sub-metering is an effective strategy to monitor zone-specific usage (Styles *et al.*, 2015). In the case of the SI, the municipal energy- and water consumption data available covers all the properties on the Lynedoch plot as one entity. The ecovillage, guest house, crèche, school, SI and rented offices are all served by a single energy and single water bill. Included are the outdoor garden irrigation, pumps and lights. Determining separate monthly

(a) Lower level

(b) Upper level

Figure 4.4: Building plan indicating types and distribution of tenants as at October 2016.

(a) Lower level

(b) Upper level

Figure 4.5: Building plan indicating educational and office use portions as at October 2016.

Table 4.1: Summary of building floor area and use.

Total floor area			3273	m^2
Lower level				1670
	Rented offices			**266**
	School			**753**
		Classrooms		272.0
		Hallways		202.3
		Offices		32.4
		Kitchens or coffee/tuck shops		0.0
		0.5 *Shared hall*[1]		*208.0*
		Toilets		38.2
	SI			**651**
		Classrooms		0.0
		Hallways		200.5
		Offices		120.5
		Kitchens or coffee/tuck shops		68.6
		0.5 *Shared hall*[1]		*208.0*
		Stairs (bottom half, indoors)		13.5
		Toilets		39.4
Upper level				1603
	Rented offices			**37**
	School			**940**
		Classrooms		447.1
		Offices		172.6
		Kitchens or coffee/tuck shops		5.8
		Toilets		72.8
		Hallways		241.7
		0.5 *Shared hallway*[1]		*9.0*
		Other		232.7
	SI			**627**
		Classrooms		395.6
		Offices		116.4
		Kitchens or coffee/tuck shops		4.8
		Stairs (top half, indoors)		8.0
		Toilets		25.4
		Hallways		76.2
		0.5 *Shared hallway*[1]		*9.0*
		Other		67.2
Total educational room area				1531
Total office room area				745

[1] *It was assumed that the school and SI have equal shares in the shared areas.*

usage for the main building from the existing data is highly cumbersome. Although the SI sells water and electricity to the guest house, crèche and ecovillage, the records of the quantities sold is only available in currency and is also subjected to variable rates. The water and electricity are not sold on a monthly basis to these entities, but only on request by the client. The ecovillage consists of thirty small and large residential properties and is of a diverse community, as portrayed in Figure 4.6, that has evolved and expanded randomly throughout the years. For the ecovillage alone it is already burdensome to attempt to calculate a theoretical average of energy and water usage. It was also further revealed during the research that for unknown reasons the water line serving the guest house has also been serving the SI lavatories in the main building.

(a) Small residential (b) Large residential (c) Diversity

Figure 4.6: Lynedoch ecovillage

Figure 4.7 and 4.8 show twelve months of municipal water and electricity data for the entire Lynedoch plot from March 2015 to March 2016. In Figure 4.7 the data presented is actual measured water consumption data. The highest monthly consumption was 1201 kL and 1108 kL during the months of May and June respectively and the lowest was 415 kL during July. Uncertainty regarding the peak water consumption during the winter months exists. Probable causes could include leaks, inaccurate measurements and an unusually dry winter in the Cape area during 2016. A proper sub-metering system is crucial when identifying the cause of unusual consumptions. A small water recycling plant is present on the Lynedoch plot, but only supplies recycled water to lavatories in the ecovillage and some of the gardens and does not have a connection to the main building. Figure 4.8 presents a combination of actual measured and estimated energy data. From the data it is difficult to identify with certainty the actual maximum and minimum monthly energy usages. For example, from November to January the municipality did not take actual readings, and it can be deduced from the data that under-estimations were made, resulting in a high corrective bill in February. It can therefore not necessarily be declared that November, December or January are representative of a monthly minimum usage. Similarly February can not necessarily be declared a maximum usage month. Taking into account that the utility bills in Figures 4.7 and 4.8 serve the main building of 3273 m^2 floor

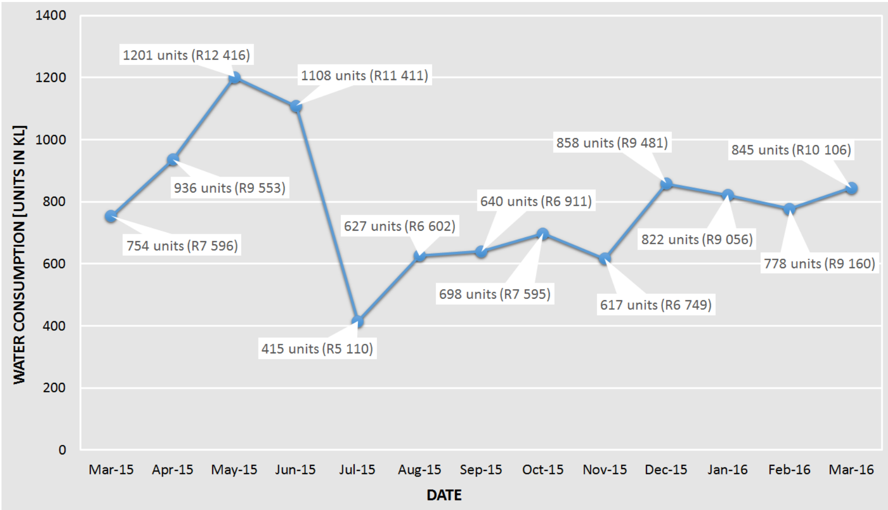


Figure 4.7: Twelve-month municipal bills for water consumption.

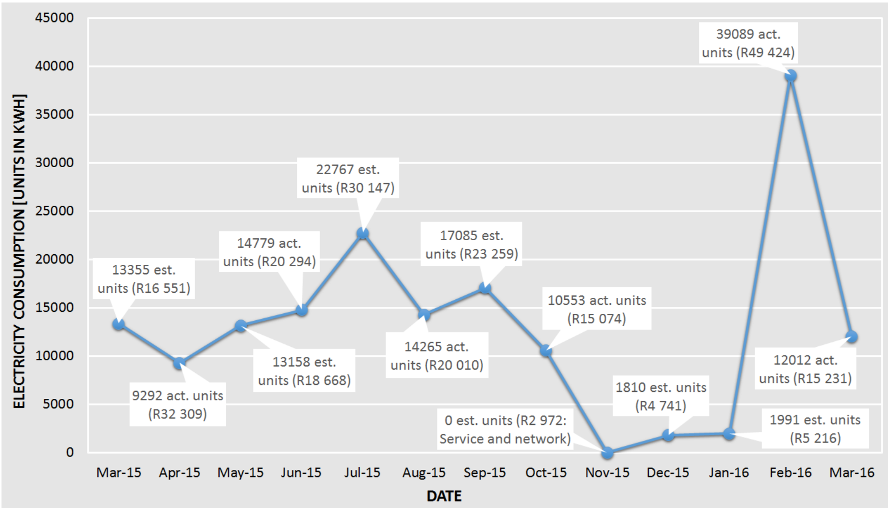


Figure 4.8: Twelve-month municipal bills for energy consumption.

area, thirty houses in the ecovillage, a guest house and a crèche, these bills do not seem very high.

In Appendix B.2, Figures B.3 and B.4 provide two-week representative samples of high and low energy consumption data for the Lynedoch plot. Figures 4.9 and 4.10 are the condensed versions thereof. A third party company, investigating the possibilities for solar technology installation on the Lynedoch plot, collected the data during the past year. The two weeks of highest energy consumption that are shown in Figure 4.9 were during the month of February 2016 and provide more precise and detailed information than that of the municipal records in Figure 4.8. It can hereby be confirmed that a maximum peak energy demand of approximately 20 - 25 kW can be expected during the month of February. In Figure 4.9 it can also be seen

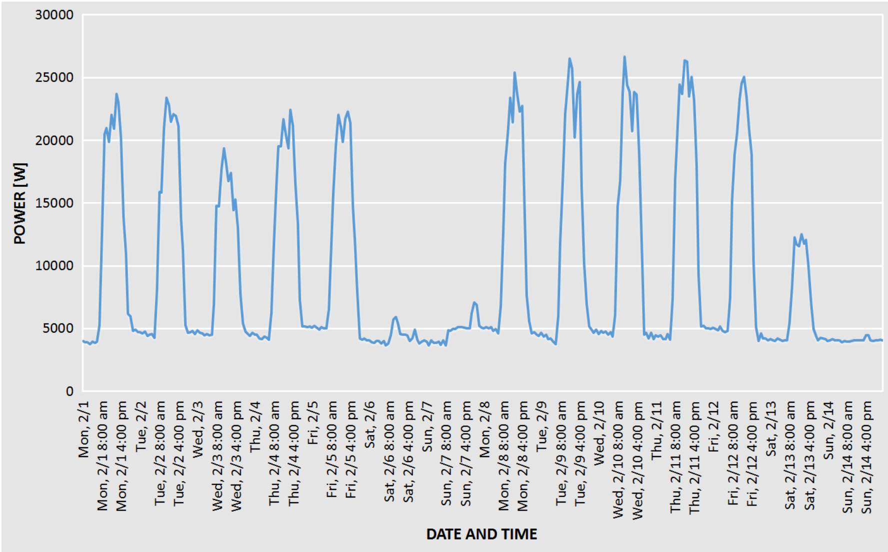


Figure 4.9: Two-week high energy consumption

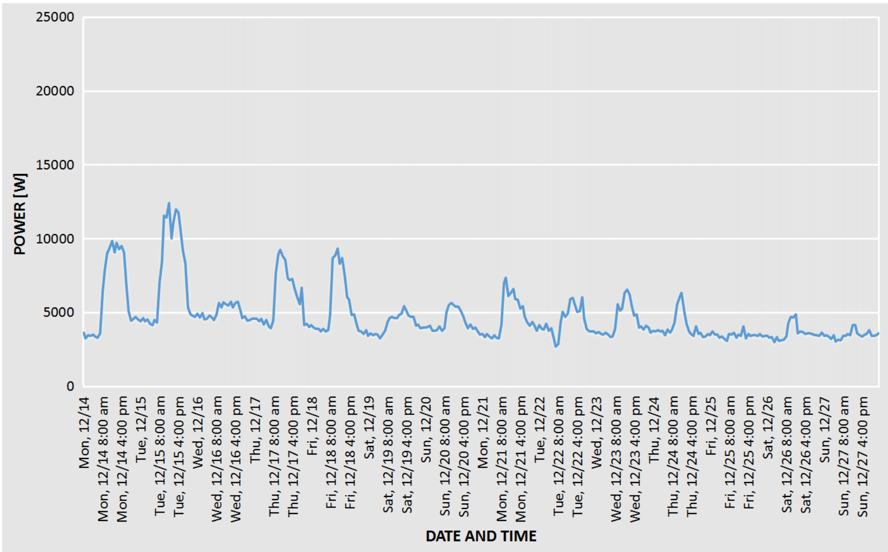


Figure 4.10: Two-week low energy consumption

that the main building was open on the second Saturday, as mentioned earlier with regard to the occupancy schedule, by the small peak in consumption on 13 February. Figure 4.10 shows that the lowest energy consumption was during 14 - 27 December 2015, providing a sure minima that supports the trend in the municipal estimations. Figure 4.10 also shows that during the weeks of lowest energy consumption the peak demand was between 10 - 15 kW and on average could be expected near 5 kW.

From temperatures provided in Figure 4.2b, the measured energy consumption and the recent installations of air-conditioning units in the main building, it can be thought that during the hottest month of February, after all the students and staff have returned from vacation, the air-conditioning could make a significant contribution to the peak energy consumption in February, (Figures 4.8 and 4.9).

4.4.1.4 Waste separation and recycling

Environmental preservation, cost and resources conservation, financial reward and creating financial awareness are some of the benefits of practising waste separation and recycling (Abd'Razack *et al.*, 2017). Waste separation and recycling activities are present on the Lynedoch plot. Photos of the separation bins and the source separation plant are shown in Figure 4.11a and 4.11b respectively. Actual data on the quantities of waste recycled was not available and the facilities manager could only provide estimates. It was estimated that two years ago before recycling was done, the plot produced from 2 and up to 3 tons of waste per month. According to the facilities manager, with the current recycling system in place, this number has been reduced to 1 and up to 1.2 tons of waste per month that is sent to landfill. The facilities manager believes that there is still potential for improvement and plans to send their waste sorting personnel on a short course to improve their recycling ability and efficiency.

(a) Recycling bins (b) Source separation plant

Figure 4.11: Recycling

4.4.1.5 Facilities management

Operation and maintenance (O&M) activities are the longest part of a building life cycle (Róka-Madarász and Mályusz, 2016). Effectively carrying out maintenance can help to slow the deterioration of building components and further improve on its remaining useful life (De Jonge *et al.*, 2017). A holistic O&M approach and a knowledgeable facilities management plan can also help to reduce existing building performance gaps (Min *et al.*, 2016).

There is currently no facilities management or maintenance management plan (MMP) available for the main building. A corrective maintenance approach of essential and mostly non-essential maintenance is followed. An essential corrective maintenance approach is one where components are replaced or repaired when signs of deterioration are significant and when the end of life is approaching. Non-essential corrective maintenance is when components are replaced or repaired only when failure has occurred or the end of life is reached (CIDB, 2015*b*).

Priorities and maintenance objectives originate at an organisation's asset portfolio strategy and plan (CIDB, 2015*b*). Building maintenance serves an important function from the early stages of a building to reduce the overall maintenance cost and to avoid the risks of expensive building failures due to negligence through time (Mohd-Noor *et al.*, 2011). After the main building has been retrofitted it is highly recommended that a facilities management or maintenance management plan be obtained.

4.4.1.6 Building condition

It is assumed that the building complies to national building standards. For a green retrofit the current building condition is not the foremost concern as it is only included to provide additional information that could justify green retrofit possibilities. In the past year the main building was repainted, internally and externally, and this provided the opportunity for the facilities manager to observe and investigate the building condition more thoroughly. Two areas of concern were identified: large wall cracks in the outside corners near the stairs of both rooms 13 and 25 (Figure 4.4a); and the tin roof of the shared hall, room 34 in Figure 4.4a, leaks water during the winter. It is argued that the roof is not steep enough, causing water to collect between the overlapped sheets. Rust typically forms between zinc sheets when exposed to condensation or where rain water causes moisture conditions that evaporate slowly (Nordic Galvanizers, 2016). Many repair attempts have been made by the facilities manager to seal and stop the roof from leaking, but these have unfortunately not been successful. Generally speaking, the wall cracks identified earlier might only require repair, but the roof of the shared hall might require replacement.

4.4.1.7 Occupant satisfaction and IEQ

According to Liang *et al.* (2014) preserving a building's indoor environmental quality (IEQ) is key to the productivity and well-being of the occupants. The occupant satisfaction and IEQ have been determined for the main building using informal discussions with the SI and tenants, records of building complaints and observations. Room numbers referred to in the following discussions will refer to the numbering in Figures 4.4a and 4.4b and similar building plans.

The hallway (room 12) suffers from excessive noise and extreme temperatures during summer and winter. Excessive noise is caused by the doors of the shared hall (room 34) constantly being left open causing the noise of the school children to echo through the hallways. Also, to help cool down the hallway (room 12) during the summer the exit doors near room 11 and 26 are left open, causing additional noise accumulation from the school during school breaks. The noise not only echoes into the hallway (room 12), but up the stairs into the hallway of room 35 and affects the noise level in many of the offices in the upper and lower level. Significant improvement in noise level is obtained once the doors between the shared hall (room 34) and the hallway (room 12) and the doors near room 26 are closed. A glass roof is installed at the stairs (room 19) which provides a good source of natural light but is not sufficient enough to stop heat from penetrating into the building during the summer and out of the building during the winter.

Observation has also led us to believe that room temperatures can be problematic as in many rooms there were heaters present, and in some air-conditioners have been installed.

The main building was built on the footprint of the existing dance hall and therefore unfortunately does not face North, although, the corner inclusive to the front of the school and the main patio next to rooms 1 to 3 and 6 to 13 is North facing. The patio in front of these rooms has an arbour filled with vines, a clever design since a grape vine is deciduous, shedding its leaves annually and therefore providing summer shade and winter sun (Green, 2016). Interestingly through the years tenants have complained that rooms 8-11 can be very hot in the summer and very cold during the winter. This could be because the rooms were once converted from a garage and the installed insulation is not sufficient. The school does not seem to have any problems, but room temperatures may become somewhat extreme during summers. Finally insufficient lighting and ventilation in some of the internal rooms with no windows were also mentioned.

4.4.2 Targets, goals and constraints

The targets, goals and constraints of the tenant and client help in guiding a retrofit project. Representatives for the SI and school, including the director of the SI were involved in this step. The inhabitants of other rented offices were not directly involved since they are not permanent long term tenants and only represent nine per cent of the total building floor area.

A representative of the SI stated that the two most important objectives the SI has for the main building are to make the building more comfortable without using more power from the national electricity grid and to create an attractive and desirable environment for potential employees and customers. Another important objective mentioned by the representative was to improve marketability by raising brand value and enhancing image and reputation, by letting the main building represent the SI values. Finally, the third objective would be to eventually apply for a Green Star SA rating a few years from now. Challenges identified by the representative were to avoid unnecessary additional remunerations by rather using existing employees to take part in simple sustainable tasks, such as opening and closing air vents at the right times. Moreover the representative suggested considering short introductory videos educating the existing staff and new students on how the building should be operated effectively and efficiently. This is related to another challenge namely that the SI does not have control over the actions of the people who come through the building. It was also stated that the SI might favour an investment that can show a return.

The director of the SI also gave valuable feedback. Core values of the SI are education, inspiration and application of the transformation towards a sustainable future. Practising sustainability theory is an important part of the SI and by doing so can add credibility to their work. It is hoped that a sustainable retrofit of the main building could demonstrate that sustainability improvements have multiple benefits apart from just cost saving, like improving the quality of the building and user experience, also a number of environmental benefits. According to the director, the SI is prepared for sustainability investments with no financial return, but there should be improvement in the quality of the environment and a reduction in negative environmental impacts. Another constraint is that at the moment the SI is not able to make large investments if they can not expect a financial return but might be able to do so in five years' time. They are willing to advertise brands in exchange for financial sponsorship, but only if this does not compromise the SI and what they do. Finally the director feels that educating the people who use the building could be beneficial, but rather want the building to be more user friendly.

The school supports sustainability investments and approaches that improve the quality of the environment for the children and help to reduce the operating costs. The willingness of the school to contribute financially to the benefits they receive, varies on a case by case basis. In the past they have made direct investments for sustainability and are receptive to any new improvements. Sustainability is also one of the core values of the school. A retrofit project will have to be planned to avoid interruption of teaching times.

4.4.3 Benchmarking strategy for energy and water

In the long term the SI hopes to apply for a Green Star SA rating for the main building. A large portion of the Green Star rating score, 31 and 39 per cent for new and existing buildings respectively, is allocated to energy and water benchmarking performance. The benchmarking tools supplied by the GBCSA distinguish the building types by the use of the building area. The current building use is approximately 67 per cent educational and this is expected to increase with the coming years. It is recommended that the main building be sub-metered for both water and electricity to make use of the GBCSA tools. Alternative energy- and water resources not supplied by the municipality, for example solar or recycled water, should be measured as well. This data could also be valuable for monitoring and fault identification. Lastly, only three of the twelve months of measured data may be interpolated or estimated data (GBCSA, 2014*a*,*b*).

The current municipal energy- and water data available is that for the whole Lynedoch plot and is not suitable for the main building to do a pre-retrofit energy- and water benchmark with. Also, it should be noted that of the energy data available for the Lynedoch plot, seven out of the twelve months were estimations, exceeding the maximum limit of three months of estimated data specified by the GBCSA (GBCSA, 2014*a*,*b*).

4.4.4 Green Star rating and an Accredited Professional

Applying for a Green Star SA rating forms part of the future plan of the SI for the main building, but first they are going to focus on other goals such as changing the main building into a more sustainable building and improving the building occupant experience. To better make recommendation for the project the author has completed the courses, workshops and written the exam to become a Green Star SA accredited professional (AP).

In order to apply for an existing building Green Star SA rating, it is a GBCSA prerequisite that a Green Star SA AP is present throughout the project to provide the required guidance (GBCSA, 2014*a*). The author has provided this guidance during the retrofit feasibility phase and the first iteration of the pre-project planning phase. It is advised that the organisation maintains AP involvement throughout the additional iterations of the pre-project planning phase and other phases, for instance by having an employee certified as an AP.

4.4.5 Report, client review and decision

An example report of two pages was prepared and included in Appendix B as part of this research for the client. From the data and information collected it can be seen that there is definitely a need for a retrofit of the building. It is feasible to further pursue the retrofit planning.

4.5 Pre-project planning

The pre-project planning phase is structured to aid decision making on whether to pursue the retrofit project or not, and also to provide a project definition package. There are four main processes that need to be completed before a project can obtain such outputs and they are to organise for pre-project planning, to select alternatives, develop a project definition package and finally make a decision. Figure 3.5 is a graphical representation of the interactions of these processes and they will now be discussed.

4.5.1 Organise for pre-project planning

Organising for pre-project planning is the first main process of pre-project planning and includes selecting a team, preparing a draft charter and a pre-project planning plan. This process requires a validated project concept, objectives and the constraints for inputs.

A *validated project concept* is the initial idea that inspires the start of a retrofit project. The main indicators that initiated the project are poor indoor environmental quality (IEQ), specifically extreme temperatures, noise, poor airflow and inadequate lightning, as well as the building not demonstrating sustainability which is the core principle upon which the Sustainability Institute (SI) is based.

Objectives were identified in the second step of the retrofit feasibility phase and can be summarised as:

- To demonstrate that the sustainability adaptations bring multiple other benefits apart from cost saving.
- To create an attractive and inspiring environment for employees and visitors.
- To create a comfortable building without relying on the national electricity grid.
- To serve as a visual example of practising sustainability and the identity of SI and thereby adding sustenance to what they teach.
- To perform the retrofit in such a way bearing in mind a Green Star SA rating in the long term.

There are a number of *constraints and challenges* facing the project and the research study. For the immediate future the SI prefer investments with a financial return. Considering the current financial situation of the SI, they prefer investments that show returns in the immediate or short term. However no-return investments might be considered if there are other associated benefits, such as environmental or social benefits. Large investments that bring no or only show return in the long term will only be considered in a few years' time. The school prefers a retrofit project planned in such a way as to avoid interrupting the teaching times.

Another constraint is that the data available for the project was incomplete, scattered and difficult to obtain. The utilization of the building has mixed dynamics that are constantly changing and are challenging to anticipate, because they are still in the process of deciding what the eventual use of the building will be. There is limited expertise, time and funds available for this project.

Select Team: An individual, the author, rather than a team will be conducting the pre-project planning on a full time basis. This individual will be further referred to as the pre-project planner. The SI has limited funds and sourcing external expertise can be expensive. The selected pre-project planner has expertise regarding the areas of sustainability and the environment as he has done extensive reading on the subject during his research. The knowledge and skills the author holds in project management, business and technical aspects is sufficient for a project such as the SI retrofit. The pre-project planner, maintained close communication with the SI stakeholders, the facilities manager, projects and programme coordinator, spaces manager and the institute director.

Draft charter: As the pre-project planning team only comprises a single individual, there is not a specific breakdown structure or levels of responsibility. Most of the responsibility, involvement and authority therefore rests on the pre-project planner. The pre-project planner is responsible for planning the overall project, and may request members and stakeholders of the organisation and retrofit project to acquire specific information or deliverables, perform specialised tasks or provide feedback.

Collins and Porras (1996) state that the glue that holds an organisation together through time or drives a project is provided through the core ideology. A mission statement can provide a direction, describe project aims and also the manner in which these aims are pursued. In the case of the main building case study, the mission statement can possibly inform the SI of the project's importance to them as a sustainability institute and possibly inspire them to continue pursuing it. As per illustration the following mission statement was prepared: Sustainable thinking is inspired within a sustainable building. The statement hopes to communicate that a retrofit towards such a building can inspire sustainable thinking within employees, visitors and a young generation of school learners.

The quality requirements of the deliverables refer to the 'fit for purpose' aspects such as how well a deliverable must meet the user requirements, and the total ownership cost. Deliverable quality differs from project quality which includes project management aspects such as the correct application of time, cost, resources, communication and project change management. In theory deliverables quality and project quality are in a trade-off with each other, meaning high quality projects could lead to having low quality deliverables and vice versa, but in practice it is much more likely that high quality projects will produce high quality deliverables (Higher National Computing, 2016).

This project is expected to produce a high quality deliverable which satisfies many objectives under tough resource constraints such as limited time, budget and expertise. The quality of the deliverable is dependent on the available resources. It can be very challenging to satisfy so many objectives under the current constraints. It is hoped that this project can deliver a high quality solution without significantly compromising the budget constraint. A compromise on budget might have to be considered as a means to obtain a reasonable quality end product, which has a role to play in portraying the organisation's image and values: teaching, applying and promoting sustainability.

Prepare Pre-Project Planning Plan: A pre-project planning plan can consist of a budget, a schedule, the physical location of the work, pre-project planning priorities and a contracting strategy (Gibson Jr *et al.*, 1995). Pre-project planning is an iterative process and the first iteration for this case study is performed by the author: A budget is not allocated for this iteration; the schedule for this iteration allows a two- to three week time frame; site and building information was collected on the Lynedoch plot, processed and planned at the post graduate office in the the general engineering building of Stellenbosch University and no contracting strategies were required. The highest priority of the first iteration is to stay within the time constraint of the study and to develop the best possible recommendations for the project.

Further iterations will be performed by SI. The budget and schedule have not been specified as they decide on a case by case basis. The SI prioritise a return on investment, as well as investments that have a positive impact on occupants and the environment. All details regarding the physical location for the pre-project planning are not available yet, but all construction will take place on the Lynedoch plot. It is recommended that the SI negotiate a reasonably priced lump sum (fixed price) contract for the construction. If a contractor is willing to agree on a fixed price, it is presumed that either the contractor or others have specified a satisfactory level of the construction works before the tender stage, and that the contractor has investigated all relevant risk factors that need to be included in his pricing (Godwin, 2013). A lump sum contract is recommended for the SI as is has the benefits of a sure end product that mitigates financial risk of unforeseen costs for the SI and also forces the contractor to apply better supervision and diligence.

4.5.2 Select alternatives

Selecting alternatives is the second process of the pre-project planning phase shown in Figure 3.5, and comprises the analysis of technology, evaluation of the site, preparation of conceptual scopes and estimates, and the evaluation of the alternatives. Interactions that are associated with these components are presented in Figure 3.7.

Evaluate site: In the case of an existing building project it seems more appropriate to evaluate the site before comparing possible technology options and making suggestions. Site evaluation is typically performed in conjunction with technology analysis since for a retrofit project there may be existing technologies on site and these should be taken into consideration.

Site evaluation correlates with the pre-retrofit data collection step in the retrofit feasibility phase, Section 4.4.1. In this section, the data collected included site, climate and building information, building use, energy- and water data, waste separation and recycling, facilities management, building condition, occupant satisfaction and IEQ.

In summary: The main building is walking distance from a farm stall, café and bus- and train stations and situated in a Mediterranean type climate. More accurate regional data is available in Figure 4.2. Old architectural drawings of the main building were found and updated in Figures B.1 and B.2 in Appendix B.1. The building is owned by the SI and managed by its trustees, and is primary used for educational purposes, but a significant portion is used for office purposes as indicated in Figure 4.5 and summarised in Table 4.1. Water and energy data are available and provided in Figures 4.7, 4.8, 4.9 and 4.10, but all the property on the Lynedoch plot is treated as an one entity and separate usages for the main building cannot be determined. After studying the peak temperatures in Figure 4.2b and the peak energy consumption during the month of February shown in Figure 4.9, and noticing the recent installation of air-conditioning and the fact that students and staff return from vacation in February, it is fair to conclude that the air-conditioning could be a significant contributor to the peak energy consumption during February. Waste separation and recycling take place on the plot and estimated data show a significant reduction in the waste sent to landfill after the recycling system was implemented. A corrective maintenance approach of essential and mostly non-essential maintenance (Table 3.2) is followed and no facilities or maintenance management plan were available. Building inspection showed cracks at windows on the front corners of the building that should be repaired and the roof of the shared hall might require replacement. Finally the IEQ and occupant satisfaction are low because of excessive noise, extreme temperatures, and rooms with little natural light and fresh air.

Analyse technology: Existing technology in the building and available technology options for the retrofit will be discussed. The SWOT (strength, weaknesses, opportunities and threats) analysis recommended by Yudelson (2009) will be used for analysing existing and new building technologies. Objectives and constraints were already taken into consideration when selecting the possible technologies which have to show compatibility with the project. SWOT analysis is a suitable method for use in this project, but in instances where it is complex and hard to comprehend, the approach of Si *et al.* (2016) can be used.

Existing technologies that are part of the main building include a thermal rock store, locally produced clay bricks, a waste recycling plant, an organic garden that is present on the Lynedoch plot, skylights and air-conditioning. An analysis of these existing technologies follows:

The rock store was a prototype project that was designed for storing thermal energy, so that cold and hot air can be exchanged during the day and night. It was built in 2001 during the retrofit of the main building and is situated under the school. This thermal store was only put to use twelve years after it was constructed, mainly due to difficulties in understanding how it should be operated. It was also revealed that a temperature difference is not noticed during its operation. *Strengths*: No advantages could be identified for this feature of the building since it does not fulfil its purpose and there is not yet a known way to fix it. *Weaknesses*: The feature does not work. *Opportunities*: Since the rock store is hidden under the school there is not really a need to remove it from the building. In the future there might be technology that could be combined with the rock store in some way to gain further thermal efficiency. *Threats*: Spending money on fixing the feature might not deliver the desired solution. Therefore it is a risk to invest in this technology and waiting until more research is done on this case is recommended.

Clay bricks were locally produced from material available on the Lynedoch plot and were used for building some of the internal walls in the main building. *Strengths*: Locally producing the bricks is environmentally conscious and provides jobs for local people. *Weaknesses*: The process of producing the bricks is slow and a lot of time will be required to produce sufficient bricks before the construction project can commence. *Opportunities*: The bricks can help to create a sense of accomplishment and ownership. *Threats*: Care should be taken that the produced bricks have the required moisture content and strength so that they will not fail under load and cause serious injuries. Lastly, producing the bricks might delay the inception of the construction project.

A water recycling plant is available on site and currently serves lavatories in the ecovillage but does not supply recycled water to the main building. *Strengths*: A lot of water can be saved through recycling. The recycled water also has good fertilising properties for plants. *Weaknesses*: The water is substandard and if left unused for a while in lavatories an odour could develop. *Opportunities*: There seems to be spare capacity on the plant and it should be possible to connect the lavatories in the main building to the recycled water. Gardens near the main building that are not yet served by the plant can also be connected. *Threats*: In the SI part, first level, of the main building the existing lavatories have a problem that when the door is left open an unpleasant odour spreads into the entrance hall. This is mainly due to a draft. If the lavatories are connected to recycled water it could worsen this problem.

There is an organic garden near the SI that produces healthy and good standard fresh produce. *Strengths*: The garden produces food without synthetic fertilizers and pesticides. Also it is a form of job creation. *Weaknesses*: The small scale at which the garden is operated is not profitable.

Opportunities: It provides learning opportunities and if well-positioned can help to reduce noise pollution. *Threats*: This feature can come at additional costs to the SI.

Skylights are installed in the main building. *Strengths*: A skylight provides natural light without using electricity and they are environmentally friendly. *Weaknesses*: When not properly installed they have a tenancy to leak. To clean a skylight you need to use a ladder to get on the roof. Thermal losses through a skylight can be significant, depending on the model installed, which can in turn require additional energy to improve thermal comfort. It is a vulnerable aspect of the building compromising security. Installing too many skylights or not positioning them strategically can cause glare. *Opportunities*: A property with skylights might be more attractive and consequently the skylights can raise the value of the property. *Threats*: There have been instances reported where manufactures have over specified the lighting capabilities of their skylights and this can result in insufficient light.

Air-conditioners are present in parts of the main building. Today, air-conditioning has widely been applied to improve the standard of living. *Strengths*: An air-conditioning system provides thermal comfort and improves the indoor air quality, and as a result, cause better work efficiency and health (Yu *et al.*, 2009). *Weaknesses*: Research has shown that sick building syndrome occurs more often in buildings that have air-conditioning compared to naturally ventilated buildings. Recent air-conditioning systems are designed to conserve energy and consequently reduce the fresh air intake to minimise energy losses (Yu *et al.*, 2009). Air-conditioning is not the most environmentally friendly technology and contributes to urban heat island effect. *Opportunities*: Air-conditioning systems that are more environmentally friendly are available on the market today. Combining air-conditioning systems with passive thermal technologies could help to reduce the energy required for controlling the temperature. *Threats*: Some water-cooled air-conditioning systems can when neglected cause outbreaks of Legionnaires' disease (Yu *et al.*, 2009).

Available technology options for the retrofit that will be discussed and analysed are a green roof, thermal mass activation through hollow core slabs, additional insulation, electronic swing door operator, passive hydraulic door-closer, water fountains, energy efficient lighting, motion sensor lighting, solar energy generation, solar charging poles, electric car charge port, bicycle rack, water and electricity sub-metering and recycled water for lavatories in the main building.

The shared hall is a two-storey high hall in the middle of the main building. Many of the main building's inside rooms that are built around the second level of the shared hall suffer poor air quality and insufficient natural light. The current roof on the shared hall has been used for 15 years and is approaching the end of its service life. Many attempts have been made to repair the leaking roof, but these failed and there is a high probability that the the roof will have to be replaced soon. It is therefore suggested that instead of replacing the old roof with a conventional roof, a green roof should be fitted. The green roof can be designed as a concrete slab structure placed on top of the shared hall and supported by installing columns and beams. In figure 4.12 a possible placement of the structure's columns so that it will be less obvious, more practical and does not significantly affect the total usable floor area of the room is depicted. There are six hollow ventilation shafts in the shared hall as depicted at the top and bottom of Figure 4.12. These were intended to be used with the rock store for temperature regulation. They have become obsolete as the rock store did not function as intended. These hollow shafts can be used to house six of the columns indicated in Figure 4.12. The last four columns of the structure are indicated on the left and right sides of Figure 4.12.

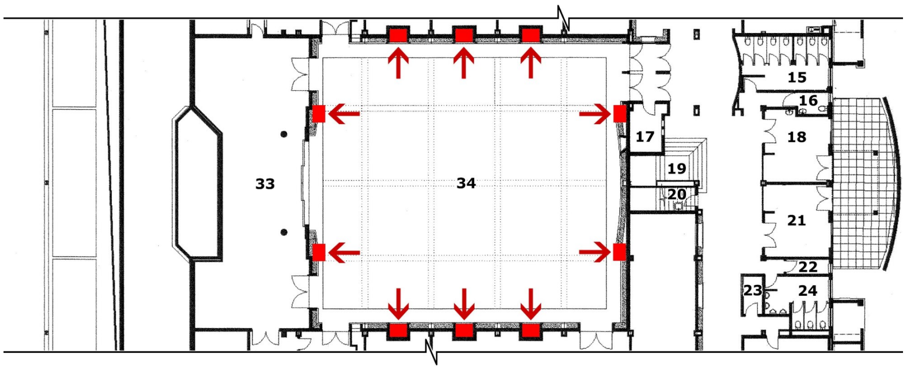


Figure 4.12: Column placement on lower level section of main building.

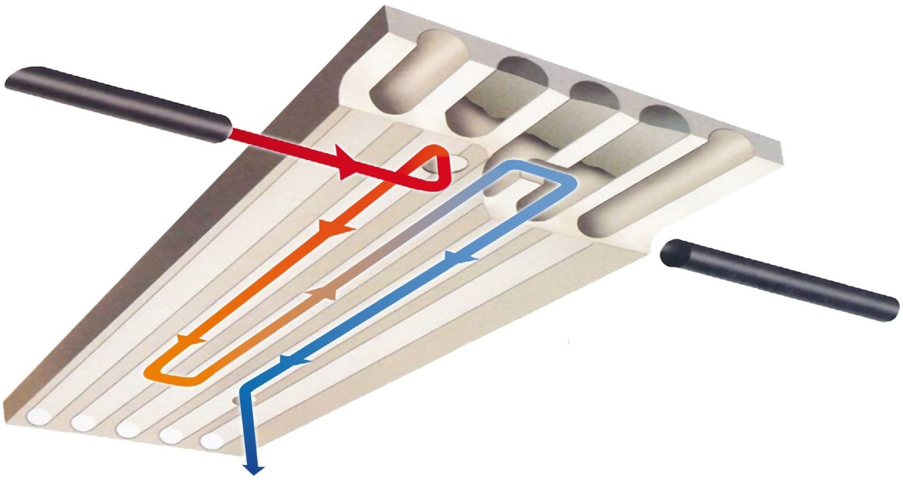
Lowering the roof on the shared hall to approximately three-quarters of a meter above the lower level ceiling height creates an opportunity for the SI to install windows for rooms surrounding the hall on the second floor. By installing a green roof and windows for the surrounding rooms, all of the project objectives are addressed at the same time. The investment cost of the green roof would also be less steep if combined with the maintenance or replacement of the existing roof. *Strengths*: Achieving the project objectives and having a decreased investment cost due to maintenance actions required are prime reasons for considering this technology. Other benefits resulting from green roofs are listed in a South African study by Niekerk *et al.* (2010):

- They create a habitat for biodiversity.
- A green roof attenuates stormwater run-off by reducing the peak flow rate. This helps to prevent soil erosion and smaller stormwater pipes are required.
- Green roofs can reduce building cooling and heating costs as they are effective insulators.

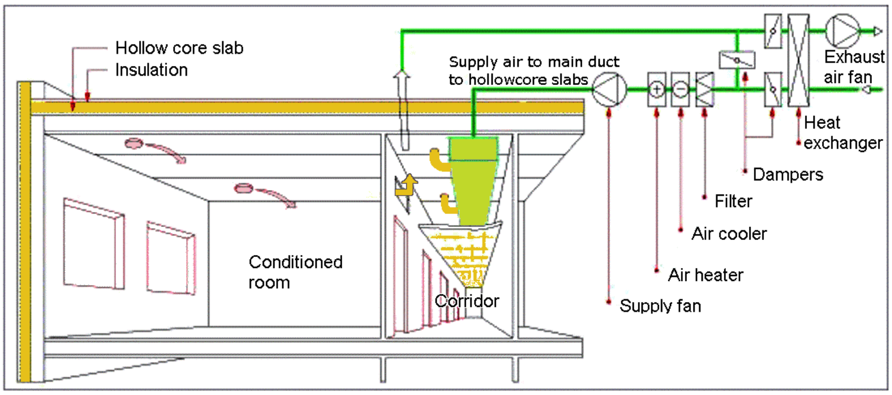
- Conventional roofs generally require replacement every 20 years and because green roof surfaces are less exposed to the natural and climatic elements, more than double the lifespan can be expected.
- A green roof can improve the air quality of surrounding windowed rooms.
- Plants act as a noise buffer. A 5 dB reduction in noise can be expected as a result of dense vegetation and a 10 dB reduction for every 30m of vegetation.
- A green roof improves the living and working environment and this can reduce anxiety, stress and depression.
- A green roof can increase worker productivity.
- A green roof provides food security as basic foods can be produced.

Weaknesses: The initial cost of a green roof is higher than that of a conventional roof. According to Niekerk *et al.* (2010) the construction cost of a conventional roof is from $R320/m^2$ up to $R400/m^2$, where a green roof typically costs $R680/m^2$. Calculations in Niekerk *et al.* (2010) show that the life cycle cost for a green roof is less than that of a conventional roof. Finally, gymnastic activities can require a high roof, but it is currently understood that the shared hall is not used for gymnastic activities. *Opportunities*: A green roof can be combined with the maintenance effort of replacing an aged roof. The investment cost for the green roof is therefore only the additional amount apart from the conventional roof replacement. Lastly, the facilities manager is a key role player in garden- and building upkeep. It might be of interest to the SI that by converting one of the corners on the green roof into a small comfortable office space that overlooks the garden for the facilities manager, can help to instil pride, enthusiasm and creativity. When a building is well maintained and provides an attractive, neat and comfortable environment, building occupants might be inspired to have more pride in their work. *Threats*: The current roof on the main building urgently needs attention and it could be that the SI will not have the necessary funds available to make the additional investment in a green roof. This would mean that it might not be feasible for the next 20 years. A last remark, converting the roof of the shared hall into a green roof will sacrifice roof area that could possibly be used for solar installations. Fortunately the roof over the shared hall represents approximately 26 per cent of the total roof area so this is not very important.

Thermal mass activation through hollow core pre-cast slabs makes use of the thermal energy storage capacity of concrete in ceiling and floor slabs. Concrete slab temperature is relatively cooler during summers and relatively warmer during winter compared to room air temperature. By ventilating air through hollow cores in the concrete slabs, as illustrated in Figure 4.13a, thermal energy stored in the concrete can help to adjust the room temperature



(a) Hollow core slab (TermoDeck, 2016*b*).



(b) Basic system setup (TermoDeck, 2016*a*).

Figure 4.13: Thermal mass activation and hollow core slabs.

by three to four degrees (Rinaldi, 2009). This technology addresses the retrofit objectives by improving thermal comfort without directly using electricity and can earn GBCSA credits. Figure 4.13b shows a typical setup of hollow core slabs for thermal mass activation. A heat exchanger, dampers, filter, air cooler, air heater and supply fan are connected to the main duct that feeds into smaller branch ducts connected to the floor slabs. The air runs through the slab to the diffusers that are usually located near external walls. Exhaust air is then removed from the room and returned to the air-conditioning unit (TermoDeck, 2016*a*). *Strengths*: Precast concrete slabs are manufactured off site, are not influenced by weather conditions, can be ordered to arrive on a specific date, are ready for use immediately and reduce the time a project would have required for the concrete to cure. Less labour is required to manufacture and install the slabs and they have higher sound resistance. The quality of the slab can also be better controlled and project risk factors such as schedule and quality are improved. Hollow core precast slabs have a reduced weight and require smaller columns and beams. Using less concrete to cast hollow core slabs is a more environmentally friendly design. *Weaknesses*: Ordering irregular shaped precast hollow core slabs is costly. Their segments are made according to the possible sizes that can be transported. Transportation over long distances can be expensive. Finally the slabs cannot be cut on site and should be carefully designed. *Opportunities*: Installing these slabs can save on structural costs and can halve the energy required for heating and cooling of the room (TermoDeck, 2016*b*). Also, installing hollow core slabs for thermal mass activation as part of a green roof installation increase the insulation and thermal efficiency. *Threats*: Using hollow core slabs for thermal mass activation would likely work best if connected to an air-conditioning unit and might be expensive.

Building thermal insulation help to reduce the gain and loss of heat in a building and leads to better indoor thermal comfort. *Strengths*: Thermal insulation is an effective and passive technology to reduce the energy required for the heating and cooling of a building. The technology is easy to install. *Weaknesses*: None identified. *Opportunities*: Depending on the type of installation and material used, thermal insulation can also help to reduce noise. *Threats*: Poor quality of installation can compromise the ability of the material to resist the transfer of heat. Also, if the material gets wet it can cause the paint to peal, therefore it is advisable to use a vapour barrier.

Installing electronic swing door operators at the main entrance of the school and the SI part of the main building can help to reduce noise pollution and better insulate the building for improved indoor environmental quality. Swing door operators are recommended above automatic sliding doors since the swing door operators can be easily installed using the existing doors in the main building, making them more affordable. The prices of these operators vary depending on the sensor type chosen, but are still fairly priced. *Strengths*: The advantages of automatic swing doors can be listed as:

- Much more convenient and welcoming than passive hydraulic door closers.
- Provide easy access for disabled individuals.
- Control of noise pollution.
- Isolate odour.
- Reduce air-drafts through the building and improve insulation.
- There is no slamming of doors.
- An easy technology to own, use and maintain.
- Low-energy door operators are also available.

Weaknesses: Electronic swing door operators consume additional building electricity and the installation and upkeep is more expensive compared to that of a conventional door. *Opportunities*: Can improve the noise and thermal comfort of the building. *Threats*: It would be smart to install an operator that allows the door to be used during an electricity outage.

Passive hydraulic door closers for all secondary exits and bathrooms, except wheel chair lavatories, are recommended for the main building. These door closers are inexpensive and a price of around R700 per closer per door is estimated. *Strengths* are:

- Lessen noise pollution from outside.
- Isolate noise and odour.
- There are no slamming of doors.
- It is a simple technology to own, use and maintain.
- Inexpensive.
- Does not require electricity.

Weaknesses can be identified as:

- Wheelchair users can find it challenging to use.
- The upkeep is higher than that of a conventional door.

Opportunities: It can improve thermal comfort, reduce noise and isolate lavatory odour. *Threats*: None identified.

Water fountains: Exposure to noise can cause annoyance, modifify social behaviour and interfere with focus and performance (Stansfeld and Matheson, 2003). Reducing noise pollution is best done using a multi-faceted approach instead of a single tool. Methods for reducing noise can include but are not limited to planting vegetation, building walls and installing water fountains (Sustainable Community Forestry Program, 2008). For the main building a combined solution of installing a green roof, passive and active door closers and water fountains at building exits as well as a smaller fountain in each of the reception halls can be considered. *Strengths*: Fountains reduce noise pollution. *Weaknesses*: Evaporation of water and use of electricity. *Opportunities*: Can provide an attractive environment for building occupants and visitors. Fountains are also a water source for birds and can help to provide a calm and natural atmosphere. Solar pumps are available that can eliminate the additional cost of electricity to operate outside fountains. *Threats*: Care should be taken that the water used in the water fountain is of a good quality so that if consumed by accident, it does not cause any health problems. The fountain must also have shallow water levels to minimise the drowning hazard.

These concerns have to be taken into consideration since there are young school learners on the premises. Finally, the feature should be well built to ensure that the fountain does not leak water.

Energy efficient lighting: It is recommended that the existing lights in the main building be replaced with LED lights. *Strengths*: The advantages of using LED lights are listed:

- They consume significantly less electricity compared to conventional lighting.
- They are environmentally friendly and contain no mercury.
- They have longer lifespans than incandescent and fluorescent lights.
- They do not have low frequency flickering as do fluorescent lights.
- Frequently switching a LED light on-off does not affect its life span as with fluorescent lights.
- LEDs are made of non-fragile solid materials making them immune to breakage and damage.
- They are compact in size.
- They generate less heat than conventional lights.

Weaknesses: LED lights are more expensive than conventional lights. Temperature and age could cause the LED light to change colour. *Opportunities*: The SI can reduce their power consumption by installing LED lighting. Also, an immediate reduction in electricity cost can be observed after the installation is made. *Threats*: Buying a low quality and poorly engineered product could possibly lead to substandard performance and a shorter lifespan.

Motion sensors for lights can be installed in the main building where building occupants pass frequently and only require light when passing. A lumen sensor is also part of the module so that it will only turn on in low light conditions. These sensors are not very expensive as they are priced at approximately R200 per sensor. *Strengths*: Environmentally friendly since less energy is consumed and the useful life of a light is stretched over a longer period. *Weaknesses*: None identified. *Opportunities*: Energy savings due to less energy being consumed. *Threats*: Even though a single sensor isn't expensive, they have to be placed strategically, as they can become an expensive retrofit if all lights are installed with them.

For solar energy generation, the SI have negotiated a deal with a solar company that is currently investigating the solar potential of the main building. *Strengths*: There are no installation costs involved in the contract. The unit cost of the solar electricity is lower than what Eskom charges and the rate of tariff increase is less steep than what is anticipated from Eskom, the national energy supplier. *Weaknesses*: Energy can only be generated during sunshine hours. PV panels are very sensitive to shading, and care should be taken to keep the area shade free. *Opportunities*: A large retail store in a mall in Somerset-West, a neighbouring town, found that after photovoltaic (PV) panels were installed on their roof, they experienced a significant reduction in air-conditioning load during the summer. The installation of the PV panels could help to reduce the extreme indoor temperatures in the summer, especially during the month of February. *Threats*: The solar company might plan to install the panels on the shared hall roof and if the SI does not inform them of their retrofit plans in time this could limit their options. The roof of the shared hall shows signs of deterioration and it might be that other parts of the buildings roof may start showing signs of deterioration soon. This could possibly delay the solar project.

A solar charging pole is a free public charging station for mobile and tablet devices and may also provide free Wi-Fi. Multiple devices can be charged simultaneously at 2.5 ampere per device. The technology was chosen as it fits the SI brand and image. Figure 4.14 is an example of such a pole. Unfortunately the technology is still very expensive and an item with similar charging and Wi-Fi functionality as described above was recently priced at $7500, roughly R105 000 at R14/$ and this does not include the

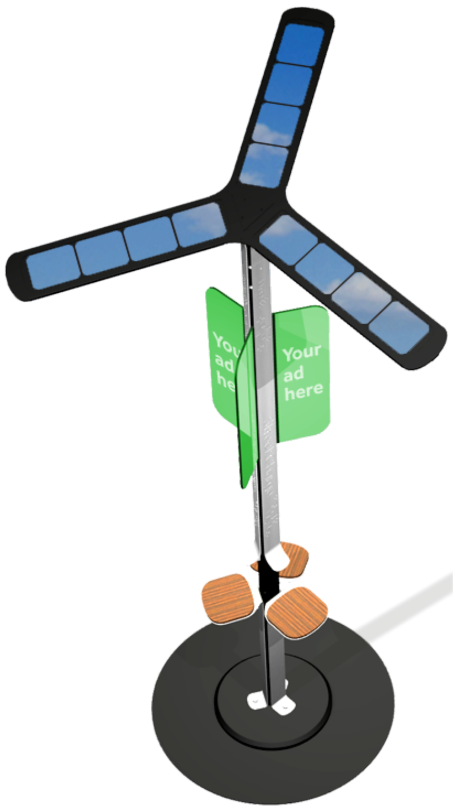


Figure 4.14: Solar charging pole (NRG, 2016).

shipping amount or duty taxes. *Strengths*: The technology makes use of renewable energy when providing a free service. *Weaknesses*: The technology is very expensive and requires a high initial cost investment. *Opportunities*: It provides a free service to the public that is environmentally friendly and sustainable which in turn might raise the SI brand value. Advertising possibilities exist that can generate additional income for the SI. *Threats*: Since the item will be located on the Lynedoch plot there might not be many potential customers for a business to see the necessity to invest in such advertising.

Electric vehicle charging stations (Figure 4.15) can be installed at the SI to help create awareness of lowering emissions through the transition to electric vehicles and renewable sources. *Strengths*: The SI can show their support towards the transition to electrical cars. Charging stations can generate an income if the charging space is rented out. *Weakness*: Ninety-three per cent of the total electricity generated in South Africa is from coal (Eberhard, 2011). If the charging station cannot be connected to a renewable energy source, connecting it to the current national electricity grid will be contrary to the sustainability motive. *Opportunities*: These charge stations attract potential employees who also share a passion for sustainability, thus addressing the second objective of the retrofit. By renting out the charging space or having an active screen for advertising, an income can be generated. This feature can also contribute towards the credits for a Green Star SA rating, the fifth objective of the retrofit. *Threats*: Electric cars are still rare in South Africa and the possibility exists that for the first few years the charging station might only be used on rare occasions. Charging stations that rely on renewable energy sources presents the risk of unavailability and intermittency of power supply.

Bicycle racks and locker rooms can be supplied at the main building. *Strengths*: Cycling is a healthy and environmentally friendly way of transport. *Weakness*: Few of the building occupants cycle to work as the building

Figure 4.15: Electric vehicle charging station.

is not easily accessible by bicycle. *Opportunities*: This is an affordable transport option that can improve the health and well-being of building occupants and demonstrate other sustainability benefits such as reducing carbon emissions. Bicycle racks and locker rooms are some of the affordable and easier investments to make that can earn Green Star SA rating credits. *Threats*: There are no bicycle lanes to the SI and nearby roads are very busy making it dangerous for cyclists and especially for the young school learners.

Sub-metering of water and electricity usage of the main building is recommended. By installing the meters the SI will be able to view their monthly water and electricity usages specific to the main building, as well as the portions of other sources such as renewable energy and recycled water the main building uses. This feature is important to help achieve many of the credits in the water and energy categories of the Green Star SA rating system. *Strengths*: Accurate data of the exact usages and the sources of usage is made available for the main building. *Weakness*: None identified. *Opportunities*: Data measurement with sub-metering can be used to optimise the usage of the main building and help to locate sources of wastage. *Threats*: None identified.

Connecting the main building lavatories to recycled water. *Strengths*: If no additional processes are required to remove odours from the water then this connection can be done at a reasonably inexpensive price. *Weaknesses*: The recycled water might have an odour. Removing odour from the water might not be financially viable. *Opportunities*: Connecting the main building lavatories to recycled water is environmentally friendly and the SI can also benefit financially from it. *Threats*: Lavatories in the SI already have a problem with odour that escapes into their entrance hall and the recycled water can worsen the problem.

4.5.2.1 Prepare conceptual scopes and estimates

During this process combinations of technology alternatives are presented for comparison. There are three interlinked priorities according to which the alternatives are assembled into combinations. These priorities are combining retrofit and maintenance activities, achieving project objectives and environmental performance.

Maintenance is an essential part of managing a building in a sustainable manner. It is financially beneficial to combine a green retrofit with maintenance tasks e.g. the investment cost for the green technology feature is partially or wholly included in the maintenance budget. The environment also benefits from combined retrofit and maintenance actions that do not interrupt the service life of a feature early on, but replaces it at its end-of-life stage. In cases where the immediate environmental benefit from the retrofit far exceeds the long term damage caused by an existing feature, it is recommended that the item be replaced.

Achieving the project objectives and incorporating environmental friendly alternatives is also prioritised. In order to achieve the objectives set out by the SI to an acceptable extent, it is likely that the budget that the SI have in mind will be exceeded. As a NGO there are opportunities to obtain support, collaboration and funding. With the necessary effort the SI should be able to obtain the funds required.

Before the combinations of technology alternatives are discussed, clay bricks, bicycle racks and solar charging poles were eliminated. The idea of electric vehicle charging stations was also adapted.

Clay bricks can delay the project as they take excessive time to produce and present the risk of not being able to carry the required load if the moisture content is wrong. Bicycle racks are eliminated for safety reasons. It is advised to rather reward employees for carpooling. This can help to earn Green Star SA credits. Solar charging poles are eliminated as they are too expensive and do not have the potential to generate return within this context. Electric vehicle charging stations can be expensive and also require high current for rapid charging. Although there is currently no presence of electric vehicles at the SI, it would be good to encourage and attract sustainability conscious people who drive an electric vehicle. Since the employees in the main building generally work full business hours and have their cars parked for most of the day on the same spot, the SI does not require the fast charging units. It is therefore recommended rather to install slow charging wall sockets which are much more affordable. It can be configured in such a way that the car chargers benefit from the additional capacity of the solar panels. The system can be optimised so as to provide each connection with a minimum charge duration from the grid when no surplus solar energy is available. Thereafter charging is only done when surplus solar energy becomes available from the solar panels installed on the main building.

After some of the retrofit technologies suggested were adapted and eliminated, combinations of remaining retrofit technologies were presented. Three combinations were made, with the first a best fit for achieving objectives but which compromises the budget with good reason. The second option is more of a balance between the objectives and the budget. Thirdly, this option is based on doing a retrofit on a very limited budget and achieving minimum objectives.

1. The best technologies for achieving objectives are presented as the first retrofit option:

    - Install water and electricity sub-metering on the main building.
    - Install a green roof on the shared hall and windows on the surrounding second floor rooms.
    - Install skylights in the green roof.

- Use hollow core slabs in the green roof for thermal mass activation.
- Connect an air-conditioning unit to the hollow core slabs.
- Install additional insulation in the roof and walls of the main building where applicable.
- Install electric swing door operators for both the main entrances of the main building.
- Install passive hydraulic door-closers for at all secondary exits, the shared hall and all bathroom doors except for bathrooms for disabled persons.
- Install large fountains near all exits of the main building as well as a decent-size fountain inside the entrance hall in room 12 of the main building. The fountains should make loud burbling and splashing sounds to mask other noises.
- Replace all lighting with LED energy efficient lighting.
- Install motion sensors in all hallways and lavatories for lighting.
- Proceed with the solar energy project.
- Install five electric car slow-charging sockets.
- Connect the lavatories of the building to recycled water and if required, treat water to remove odour.

Note: If only a single light motion sensor is installed in the larger bathrooms, the switch timer will have to be set on a longer delay since occupants in lavatories might not always be in the visible range of the sensor.

2. The second option is to find a balance between achieving the objectives and the budget:

    - Install water and electricity sub-metering on the main building.
    - Install a green roof on the shared hall and windows on the surrounding second floor rooms.
    - Install skylights in the green roof.
    - Use hollow core slabs in the green roof for thermal mass activation.
    - Connect a heat exchanger and exhaust fan to the hollow core slabs. An air-conditioning unit easily be added later.
    - Install additional insulation in the roof and walls of the main building where applicable.
    - Install electric swing door operators for both the main entrances of the main building.

- Install passive hydraulic door-closers for at all secondary exits, the shared hall and all bathroom doors except for bathrooms for disabled persons.
- Install two large fountains, one between the main building entrance of the school and SI offices, the second near the secondary exit of the SI and rooms 25 to 28. Another decent-sized fountain should be placed on the inside of the main building entrance (room 12) and near the shared hall (room 34). The fountains should make loud burbling and splashing sounds to mask other noises.
- Replace all frequently-used lighting with LED energy efficient lighting.
- Install motion sensors in the hallways.
- Proceed with the solar energy project.
- Install two electric car slow-charging sockets.
- Connect the lavatories of the building to recycled water and if required, treat water to remove odour.

3. The last option is to evaluate the alternative of a reduced budget and consequently achieve only some of the objectives of the project:

    - Install water and electricity sub-metering on the main building.
    - Repair the existing roof and add sufficient thermal insulation, choosing insulation with noise damping properties.
    - Install skylights in the roof.
    - Install additional insulation in the roof and walls of the main building where applicable.
    - Install electric swing door operators for both the main entrances of the main building.
    - Install passive hydraulic door-closers for at all secondary exits, the shared hall and all bathroom doors except for bathrooms for disabled persons.
    - Add a decent-sized fountain on the inside of the main building entrance (room 12) that is positioned near the shared hall (room 34). The fountain should make loud burbling and splashing sounds to mask other noises.
    - Replace the current lighting that requires replacement with LED energy efficient lighting.
    - Proceed with the solar energy project.
    - Install an electric car slow-charging socket.

Evaluate alternatives: Installing a green roof and fountains can help to create an attractive environment and improve the experience of building occupants and visitors. Green roofs can demonstrate that sustainability can save cost on the heating and cooling of the shared hall, as well produce food and create a high quality space for an improved living and working environment. Electric car charging sockets and solar panels can motivate potential sustainable enthusiasts to want to work at the SI. The installation of water and electricity sub-metering will aid the SI to better manage their resources and help to build up historical usage data beneficial when wanting to benchmark or apply for an existing building Green Star SA rating. Electronic door operators and passive hydraulic door-closers with additional insulation and hollow core slabs can help to improve the experience and comfort of building occupants. Noise reduction can be expected as a combined result of vegetation, closed doors, fountains and better isolation. Improved air quality and light conditions are also introduced with additional windows on the second floor overlooking the green roof.

All the technologies presented in the three retrofit combinations have been carefully selected. The first combination of retrofit technologies is ideal if the SI wants to achieve all of their objectives without overspending too much. The second option is a balance between achieving as many objectives as possible but is less expensive than the first option. The last option is a minimalistic installation of retrofit technologies that may still achieve most of its objectives in some way.

After comparing the options the second combination was identified as the most suitable for this project, given the current objectives and constraints. It provides a good balance between achieving objectives and keeping within the project budget. These results will become more accurate as the SI repeats these steps in a second iteration after they obtain more certainty regarding the future use of the main building.

The green roof would address all the project objectives by providing windows, natural light and a view to many second floor offices, provide insulation to the shared hall and contributes to an attractive, calming and inspiring working environment that portrays a sustainable image. The current roof of the shared hall is showing signs of needing to be rebuilt and the investment in a green roof can be seen as the additional amount above the roof maintenance cost.

4.5.3 Develop project-definition package

Analyse project risks: The risks related to the project are listed and a mitigation approach is provided for each. It is very important to identify risks so that measures can be put in place during project planning to minimise these risks that threaten the success of the project. These risks are as folllows:

- *Risk*: Predicted use of the building, of specific rooms or as a whole, turns out differently, thus threatening the appropriateness of the design solution. *Mitigation*: This risk is avoided by designing the solution with all possible uses in mind.

- *Risk*: Problems can be experienced in getting the various technologies to function together to achieve the objectives. *Mitigation*: The technologies were selected in such a manner that even in the event of a malfunction or breakdown these technologies do not interfere or counter each other.

- *Risk*: Lack of the necessary experience or knowledge needed for the installation of a specific technology in the construction or installation team. *Mitigation*: Investigate the reliability and experience of the contractor being considered, especially with regard to similar projects. In Section 3.3.3, Hatush and Skitmore (1997) provide primary criteria for contractor selection (Table 3.1). If possible, discuss or go through the design and implementation plan thoroughly before negotiating and signing the contract.

- *Risk*: Installation or construction personnel make mistakes or take shortcuts. *Mitigation*: Have supervision on site that monitors the execution of the plan. Inspect and test the feature as soon as it is completed before the technicians leave the site. Having a fixed cost contract will also protect the SI from paying for unforeseen problems and damages on site. It is also important to be aware of the warrantee/guarantee information and conditions and properly keep proof thereof.

- *Risk*: Chaos or loss of data and documentation. *Mitigation*: Establish a thorough and effective filing system and back-up strategy. Administration and filing should be kept updated and complete on a daily or weekly basis.

- *Risk*: The project exceeds the planned budget. *Mitigation*: Have a mitigation fund or buffer in the budget, the project budget easily increases with twenty per cent. There are many instances where during the project, another alternative, extension or extra becomes an option to consider in order to increase the success of the retrofit, which could not have been foreseen during planning.

Project scope and design, execution approach and control guidelines: These are the middle three sub-processes of the project-definition package development process. They all contribute to developing a suitable project definition package, the main deliverable of the pre-project planning process.

A project execution diagram for the retrofit technologies chosen for the main building were prepared, (Figure 4.16) and is customised for the SI setup. For each retrofit technology it had to be determined whether it can be managed and implemented by the available internal expertise of the SI and facilities management team; or will require external expertise by the appointment of a contractor to completely install the technology; or by letting the SI manage the project but access external sources of expertise for successful implementation. Most of the retrofit technologies selected can be easily implemented by the internal expertise available within the SI. The technologies are then further grouped into sub-projects according to the type of expertise or skill that is required for the installation.

For instance the SI will manage the installation of the additional insulation, but will have to hire an external skilled labourer to successfully execute the

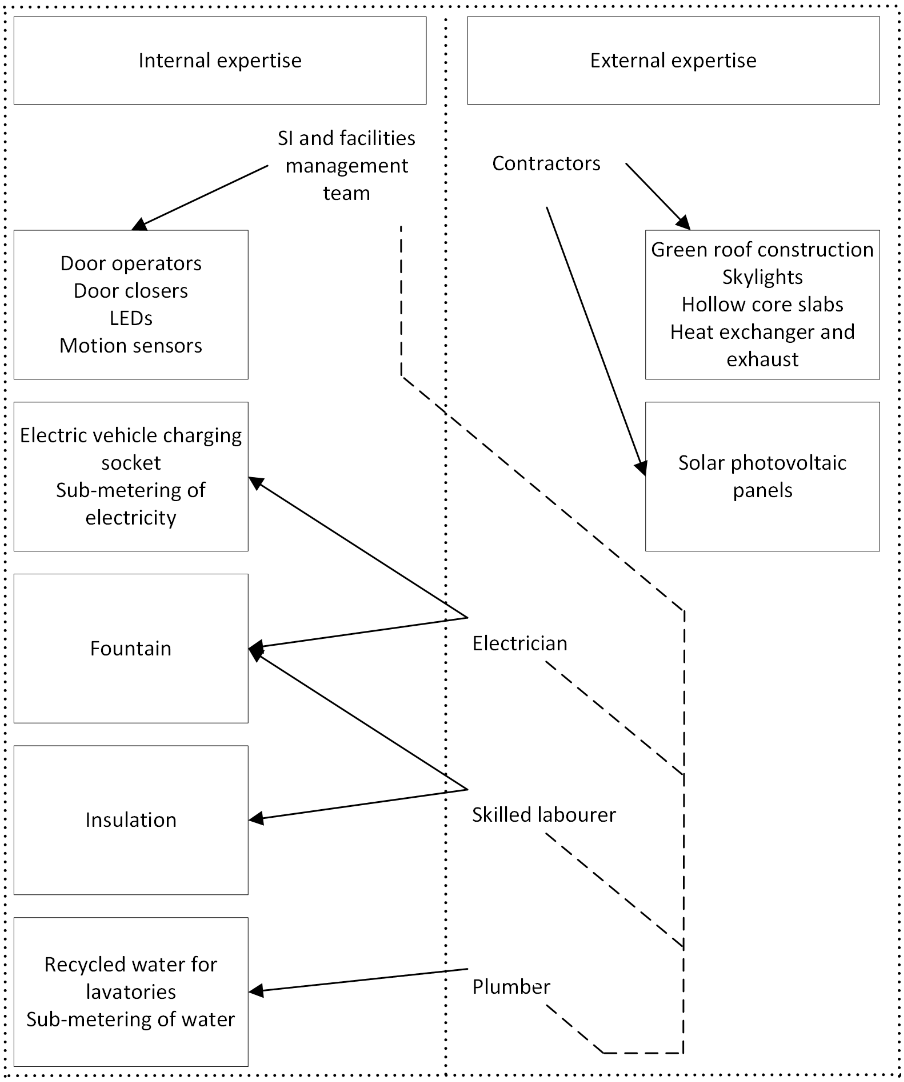


Figure 4.16: Diagram of the SI retrofit project execution.

technical aspects of the installation. By doing so they can reduce installation costs by doing it themselves and where external expertise is required they can optimally apply external resources and skills by clustering related tasks that require similar expertise. Another example is the installation of the solar photovoltaic panels. The SI has a contractor which sells solar electricity to them, but the SI does not have to assist in installation of the PV plant. In such a case the contractor would be managing the solar project.

The sub-projects are independent of each other, are not bounded to a specific order of completion and can have their own attributes such as budget, schedule and the criticality thereof. When it comes to the schedule for the green roof construction, activities will have to be performed during school holidays to avoid disruption of classes. The longest school holidays are the July and December holidays. During December the construction companies are closed for a while over Christmas and New Year. The June holiday offers uninterrupted project execution but is the peak rainfall month, see Figure 4.2c, which is not ideal for construction projects. Because the hollow core slabs are pre-cast this reduces the risks of project delays in June. Other retrofit actions suggested do not need to be completed during the holidays since they do not compromise the ability of the school to function as usual. The sub-projects that are controlled by the SI itself are typically projects that are also low risk. Projects such as installing a green roof is not part of the expertise of the SI facilities management team and can be high risk. For sub-projects that are high risk it is typically recommended to hire a contractor. It is recommended that the SI try to negotiate a fixed cost contract with the contractor for the specific green roof construction sub-project.

This method is developed so that the SI can execute many of the suggested retrofits themselves. By doing so they can reduce installation costs and where external expertise is required they can optimally apply hired resources and skills by clusterings related tasks that require similar expertise into the same sub-project. This execution model provides flexibility as many internal sub-projects are not fixed to a predefined schedule. The SI can then evaluate and select a retrofit sub-project that suits their specific financial situation at a specific time that suits them. Retrofit sub-project activities can be combined with maintenance within the organisation by forming part of the personnel duties and might be spread out over time, thus taking longer, but providing the benefit of reduced project costs.

Compile Project-definition package: The pre-project planning model features non-linear iterative planning processes that can run simultaneously. The planning has now reached the end of the first pre-project planning iteration. The planning still has to be refined through further iterations by the SI.

4.5.4 Make decision

This step depends on what the SI decides and what their needs are after obtaining the required funds before the commissioning of the retrofit.

4.5.5 Further observations and comments

Considering that the roof over the shared hall requires a replacement, it can also be expected that the rest of the main building's roof will require replacement within a few years. It is recommended that when the rest is replaced, the roof overhang be extended to block the summer sun but allow winter sun in at the the second floor North-facing windows. The first floor already has an arbour and deciduous vines to control shading on the first floor rooms and patio.

4.5.6 Summary

In this chapter the green retrofit framework developed in Chapter 3 for existing buildings in South Africa was implemented by applying it to a case study. The case study building belongs to the Sustainability Institute and is situated outside Stellenbosch in South Africa.

The retrofit feasibility phase and a first iteration of the pre-project planning phase were performed. The construction, post-retrofit activities and operations and maintenance phases were not implemented as the organisation requires time to obtain the required funds before the retrofit project can commence, and this study has a limited time frame.

Firstly, the retrofit feasibility was determined by conducting a thorough data and information collection, determining the project objectives and constraints and summarising the findings for the client. From the information gathered it was clear that the SI main building would benefit from a sustainable retrofit.

During pre-project planning, four sub-processes were visited in order to effectively organise for the pre-project planning, select retrofit technology alternatives, and develop a project definition package. The retrofit technologies that were selected for this project manage to address every building objective in some way while hoping that it does not compromise the budget which the organisation has in mind.

A project execution approach was developed around the selected technologies that provides flexibility regarding time and cost-saving opportunities. The pre-project planning phase is an iterative process and the organisation can refine the pre-project plan by performing additional iterations thereof and adding more detail.

A single alteration is suggested for the framework in the *select alternatives* process of the pre-project planning phase: The sub-process *evaluate site* has to be performed before *analyse technology*, as retrofit technologies are selected based on the existing building's properties and not the other way around as might be the case in a new build.

Chapter 5

Discussion and Conclusion

5.1 Introduction

In this research existing building retrofit frameworks were investigated. Literature shows that the available frameworks associable with existing building retrofits have specific focuses and can be categorised. These frameworks were discussed and categorised in Chapter 2 as retrofit success factors, project phases, stakeholders, scheduling, technology selection, energy, water, information and operations management, maintenance, risk, cost and pre-project planning. The majority of the frameworks available were focused on energy retrofits.

To the knowledge of the author there is currently no holistic framework available for the green retrofitting of an existing building in South Africa. Therefore the research involved developing such a framework and focused on the South African context. Many of the different frameworks and methods discussed in Chapter 2 were adapted and integrated as part of the development of this holistic green building retrofit framework in Chapter 3, depicted in Figures 3.2a and 3.2b. This framework consists of five retrofit phases: feasibility, pre-project planning, construction, post-retrofit activities, and operation and maintenance.

The aim with the retrofit feasibility phase is to determine whether performing a retrofit is a feasible action to pursue, and encompasses the site and building data collection; determining the targets, goals and constraints of the client and tenants; a benchmarking strategy for energy and water; if the project should include a Green Star SA accredited professional (AP) and finally reporting preliminary findings to the client and determining if the project is feasible or not.

The pre-project planning phase is based on the work done by Gibson Jr *et al.* (1995) and deals with organising for pre-project planning; selecting the alternative solutions; developing the project definition package and making the decision. The interaction of these processes is illustrated in Figure 3.5. In

Figures 3.6, 3.7 and 3.8 a breakdown of each of these respective processes into sub-processes is provided.

5.1.0.1 Research objectives

All five of the objectives set for this research project were achieved. The first objective was achieved in Chapter 2 when literature related to the green retrofitting of existing buildings was gathered and evaluated according to the contexts the frameworks were applied to. Green retrofitting of existing buildings within the South African context was investigated and understood, fulfilling the second objective set. South African contexts such as the expected growth of urbanisation by 2050, water and energy security, solar potential, green building adoption and life-cycle cost perceptions among South Africa citizens were addressed. In fulfilling the third objective, the research had to determine what the South African context required of the framework. Green building investment cost was identified as a primary barrier for the adoption of green buildings in South Africa. Opportunities to reduce the retrofit cost were incorporated into the framework. The framework is a holistic, but simplified guide for attempting a retrofit and combining maintenance with a retrofit attempt is suggested since the retrofit investment costs are then partially or wholly included in the maintenance budget. Moreover, methods are suggested to incorporate internal resources, skills and expertise to minimise the retrofit cost during the case study. A holistic green-retrofit framework for the South African context was developed, and depicted in Figure 3.2a and 3.2b (Chapter 3) in order to achieve the fourth objective set for this research. Finally, the last objective was to improve the framework applicability by applying it to a case study. During the course of the research the spokesperson of the Sustainability Institute of Stellenbosch asked if the main building could serve as the case study.

5.2 Case study

The main building is owned by the SI, used for both educational and office purposes and located eleven kilometres outside Stellenbosch. Due to many aspects of the main building not functioning sustainably and poor indoor environmental quality, a retrofit project was initiated.

Constraints for the case study are the limited time frame over which the study is conducted. The organisation will require more time than available for this study to obtain the required funding before construction can commence. Therefore during the study only the first two phases could be tested: retrofit feasibility, and pre-project planing. The project is challenged by mixed and constantly changing building dynamics, incomplete data, constrained time, funds and expertise.

The SI wants the retrofit to demonstrate that sustainable adaptions bring other benefits aside from cost savings, and hopes to create an inspiring and attractive environment for visitors and employees. They want a comfortable building without using the national electricity grid, to create a building that can be a visual demonstration of their values as a sustainability institute and to add substance to what they teach. Also, it should be borne in mind that the SI will want to consider a GBCSA Green Star SA rating in the long term.

In the current solution fourteen adaptations to the main building, that will help the SI to address all of the set objectives and to do so in the best affordable way, are suggested. When considering the challenges faced during the implementation of the retrofit feasibility phase, it is clear that the sub-metering of water and electricity usage for the main building and the Lynedoch plot is important. The water line serving the guest house has for unknown reasons been serving SI lavatories and earlier detection would have been possible if a proper sub-metering system was in place. It is assumed that the SI will reiterate the pre-project planning phase for the main building until they have refined the solution to their satisfaction at that future point in time. Lastly, it also assumed that the SI will complete the last three phases of the framework and also devote special attention to developing and committing to a Maintenance Management Plan (MMP).

5.3 Framework validation and adaptations

Applying the framework developed in Figures 3.2a and 3.2b to the SI case study shows that the framework is a good representation and can be used during future projects. During the application of the pre-project planning phase, the 'Select alternatives' process illustrated in Figure 3.7, was adapted. To evaluate the site and building before evaluating possible technology options seems more logical for an existing building retrofit. The technology selection strategies described by Yudelson (2009) and Si *et al.* (2016) in Section 2.6 is still valid and can be applied in this process. The adapted process and corresponding sub-processes are depicted in Figure 5.1, and are discussed below:

1. *Evaluate Site*: The physical and functional characteristics and dynamics of the existing building and site are captured and documented to identify inefficiencies, shortcomings and opportunities.

2. *Analyse Technology*: Evaluate and do a comparison of the existing technologies of the building, current and emerging technologies available. Feasibility and compatibility with business and operations objectives should be considered.

3. *Prepare Conceptual Scopes and Estimates*: Various possible combinations of alternatives are assembled in such a way that

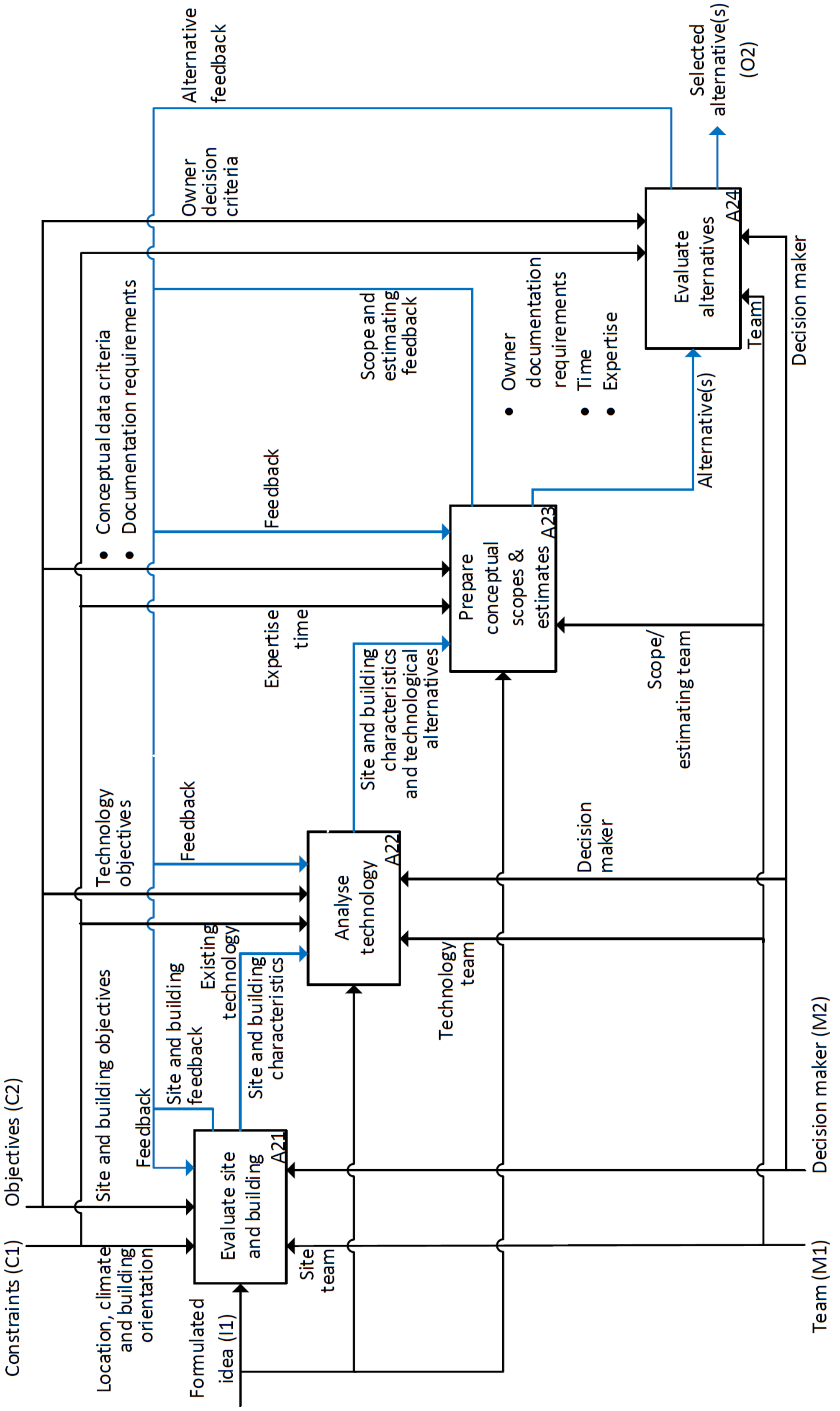


Figure 5.1: Adapted select alternative(s) process. Adapted from Gibson Jr *et al.* (1995).

they can be evaluated according to the project targets, goals and constraints.

4. *Evaluate Alternatives*: The pre-project planning team and decision maker evaluate the alternatives and select the option(s) which is most suited to the business and retrofit project.

5.4 Suggestions for future research

A further study can be conducted on the SI main building to improve the thermal storage performance of the underground rock store to an acceptable level within a limited budget and in an environmentally friendly manner. The idea is that after the rock cave is modified, it should be connected along with an air-conditioning unit to the hollow core slab ventilation system to further improve the thermal comfort, energy efficiency and cost.

5.5 Conclusion

There is an absence of literature addressing green retrofit implementation frameworks for the South African context. There is also a scarcity of literature about frameworks for green retrofitting in a holistic sense, for example not focussing on only one aspect such as project scheduling or one environmental aspect such as energy. A framework was developed and implemented on a case study by applying the retrofit feasibility and pre-project planning phases which validated a good generic representation for green retrofit projects on existing South African buildings. Construction, post-retrofit activities and the operation and maintenance phases could not yet be validated as the case study organisation has not obtained the funds and time for the construction of the retrofit. From a holistic view it is believed that this model does cover all aspects needed in a retrofit project and is suitable for use.

Appendices

Appendix A

Method theory

A.1 Criticality and priority matrix

A.1.1 Criticality matrix

The approach to a component's maintenance is influenced by its criticality. The criticality of a component only changes when certain component parts or characteristics change. The influence of component failure on the functioning of the facility should be determined by (CIDB, 2015*b*):

- Firstly, determining the most severe impact of component failure.
- Secondly, determining the highest likelihood of component failure.
- Thirdly, the component's impact of failure should be rated against the likelihood of component failure (Figure A.1, the criticality matrix).

	Impact of failure				
Likelihood of failure	I5 (Catastrophic)	I4 (Major)	I3 (Moderate)	I2 (Minor)	I1 (Insignificant)
L5	E	E	E	M	L
L4	E	E	M	M	L
L3	E	M	M	L	L
L2	M	M	M	L	L
L1	M	M	L	L	L

Rating	Description
Extremely critical (E)	Life threatening or serious injury/ disease. Service delivery failed completely. Not only would the direct cost of failure be high, but the consequential damage will also impact on the entity's cash flow.
Moderately critical (M)	May cause minor injury or manageable disease. Service delivery objectives are compromised. Direct cost is high with minor consequential costs.
Low critical (L)	No threat to human life. Service delivery rarely interrupted. Direct cost negligible, no consequential cost.

Figure A.1: Criticality matrix. (CIDB, 2015*b*).

A.1.2 Priority matrix

The approach to the maintenance of a component is further influenced by the priority of the component. Component priority differs from component criticality as a component's maintenance priority can change depending on the its condition and reliability, which ultimately changes the maintenance management plan (MMP) priorities. Component maintenance priority should be determined by (CIDB, 2015*b*):

- Firstly, determining the most severe impact of component failure.
- Secondly, determining the highest condition or reliability status of a component.
- Thirdly, the impact of component failure should be rated against the condition or reliability status of the component (Figure A.2, the priority matrix).

	Impact of failure				
Condition and Reliability rating	I5 (Catastrophic)	I4 (Major)	I3 (Moderate)	I2 (Minor)	I1 (Insignificant)
C5 (Very poor)	3	3	3	3	2
C4 (Poor)	3	3	3	2	2
C3 (Fair)	3	2	2	1	1
C2 (Good)	2	2	1	1	1
C1 (Excellent)	1	1	1	1	1

Rating	Description
High priority (3)	Condition: The component is unfit for use. There is immediate high risk to health and safety or property. Reliability: The component is unavailable.
Medium priority (2)	Condition: The component has deteriorated and requires attention. Frequent inconvenience to operations. Some risk to health and safety or property. Reliability: The component's availability is limited. Unavailability is impeding service delivery and performance of other components.
Low priority (1)	Condition: The component has minor defects. Intermittent, minor inconvenience to operations. Probability of risk to health and safety or property is slight. Reliability: The component is mostly available. Unavailability is not influencing service levels.

Figure A.2: Priority matrix. (CIDB, 2015*b*).

Appendix B

Case Study

B.1 Building Plans

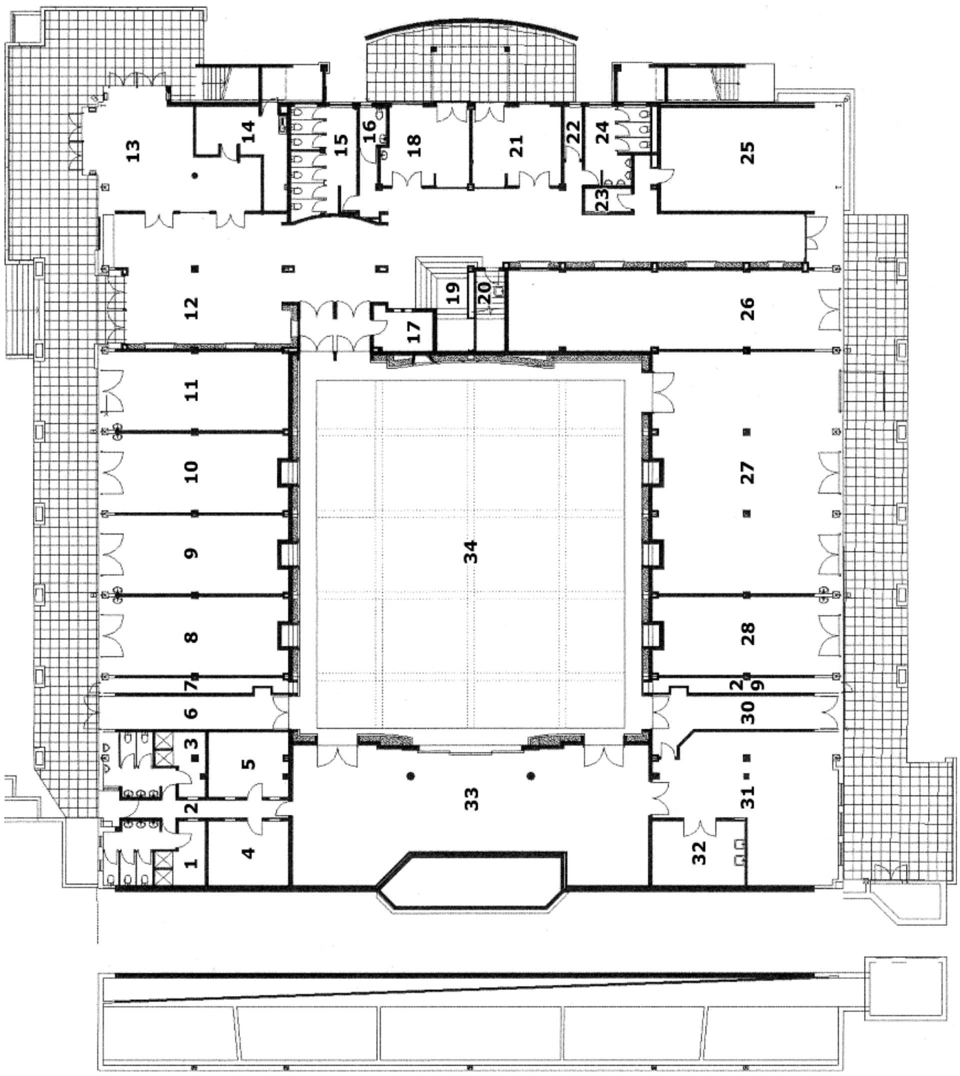


Figure B.1: Updated lower level building plan.

Table B.1: Area identification of the lower level building plan (Figure B.1).

Room ID	Use	Tenant	m^2
1	Toilets	School	19.1
2	Hallway	School	9.6
3	Toilets	School	19.1
4	Room	School	16.2
5	Room	School	16.2
6	Hallway	School	20.2
7	Hallway	School	8.0
8	Classroom	School	45.4
9	Office	Rented offices	45.5
10	Office	Rented offices	45.8
11	Office	Rented offices	46.6
12	Hallway	SI	200.5
13	Coffee shop	SI	51.9
14	Coffee shop kitchen	SI	16.8
15	Toilets	SI	22.2
16	Toilets	SI	3.2
17	Store room	SI	7.3
18	Office	SI	21.6
19	Stairs (bottom half)	SI	13.5
20	Store room	SI	4.1
21	Office	SI	22.7
22	Store room	SI	2.9
23	Store room	SI	3.3
24	Toilets	SI	14.0
25	Office	SI	58.6
26	Office	Rented offices	83.0
27	Classroom	School	141.5
28	Office	Rented offices	45.4
29	Hallway	School	8.1
30	Hallway	School	20.8
31	Classroom	School	66.3
32	Classroom	School	18.9
33	Hallway	School	135.6
34	Hall	School & SI	416.0

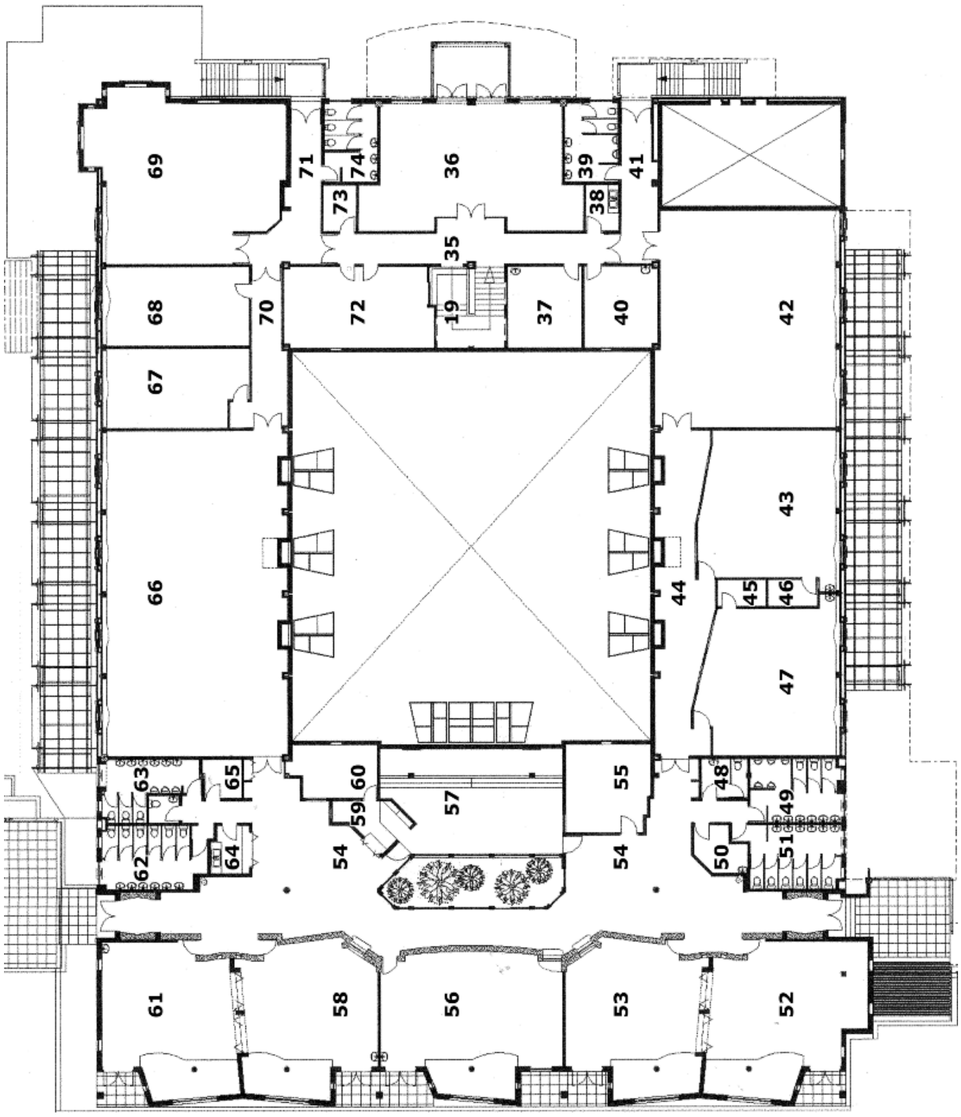


Figure B.2: Updated upper level building plan.

Table B.2: Area identification of the upper level building plan (Figure B.2).

Room ID	Use	Tenant	m^2
19	Stairs (top half)	SI	8.0
35	Hallway	SI	29.3
36	Office	SI	74.5
37	Office	SI	18.7
38	Office kitchen	SI	4.8
39	Toilets	SI	13.0
40	Office	SI	18.4
41	Hallway	SI	16.7
42	Classroom	SI	121.7
43	Classroom	School	63.2
44	Hallway	School	45.9
45	Class store room	School	4.0
46	Class store room	School	4.1
47	Classroom	School	61.9
48	Toilets	School	5.5
49	Toilets	School	17.3
50	Toilets	School	6.3
51	Toilets	School	18.6
52	Classroom	School	66.1
53	Classroom	School	59.0
54	Hallway	School	186.8
55	Office	School	22.5
56	Classroom	School	71.3
57	Office	School	54.6
58	Classroom	School	58.6
59	Office	School	8.1
60	Office	School	13.4
61	Classroom	School	58.8
62	Toilets	School	18.9
63	Toilets	School	6.1
64	Tuck Shop	School	5.8
65	Office	School	4.5
66	Classroom	SI	182.9
67	Office	School	34.0
68	Office	School	35.6
69	Classroom	SI	91.0
70	Hallway	SI & School	18.0
71	Hallway	SI	21.2
72	Office	Rented offices	36.8
73	Office	SI	4.8
74	Toilets	SI	12.4

B.2 High and low energy consumption data

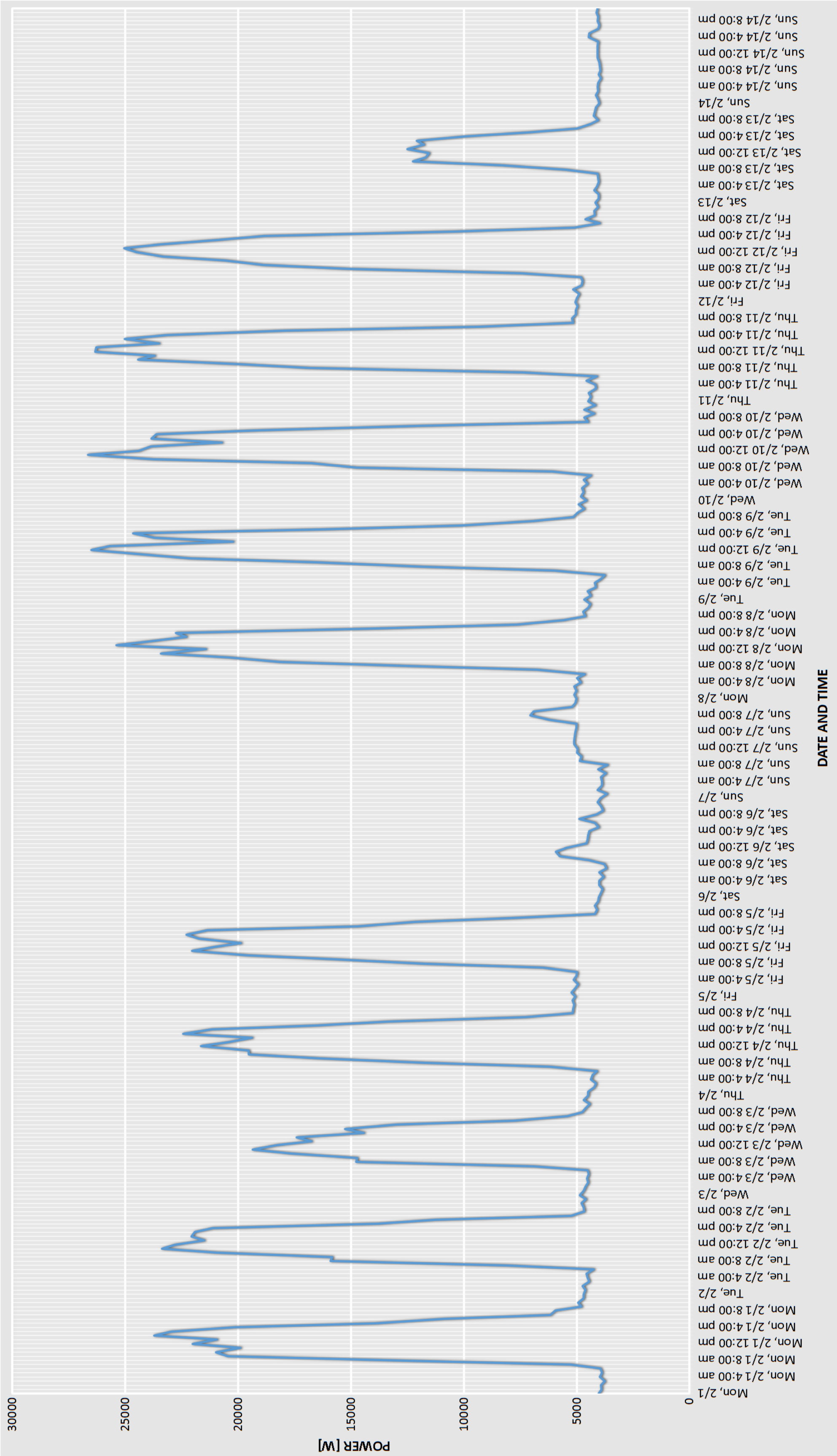


Figure B.3: Two-week high energy consumption data.

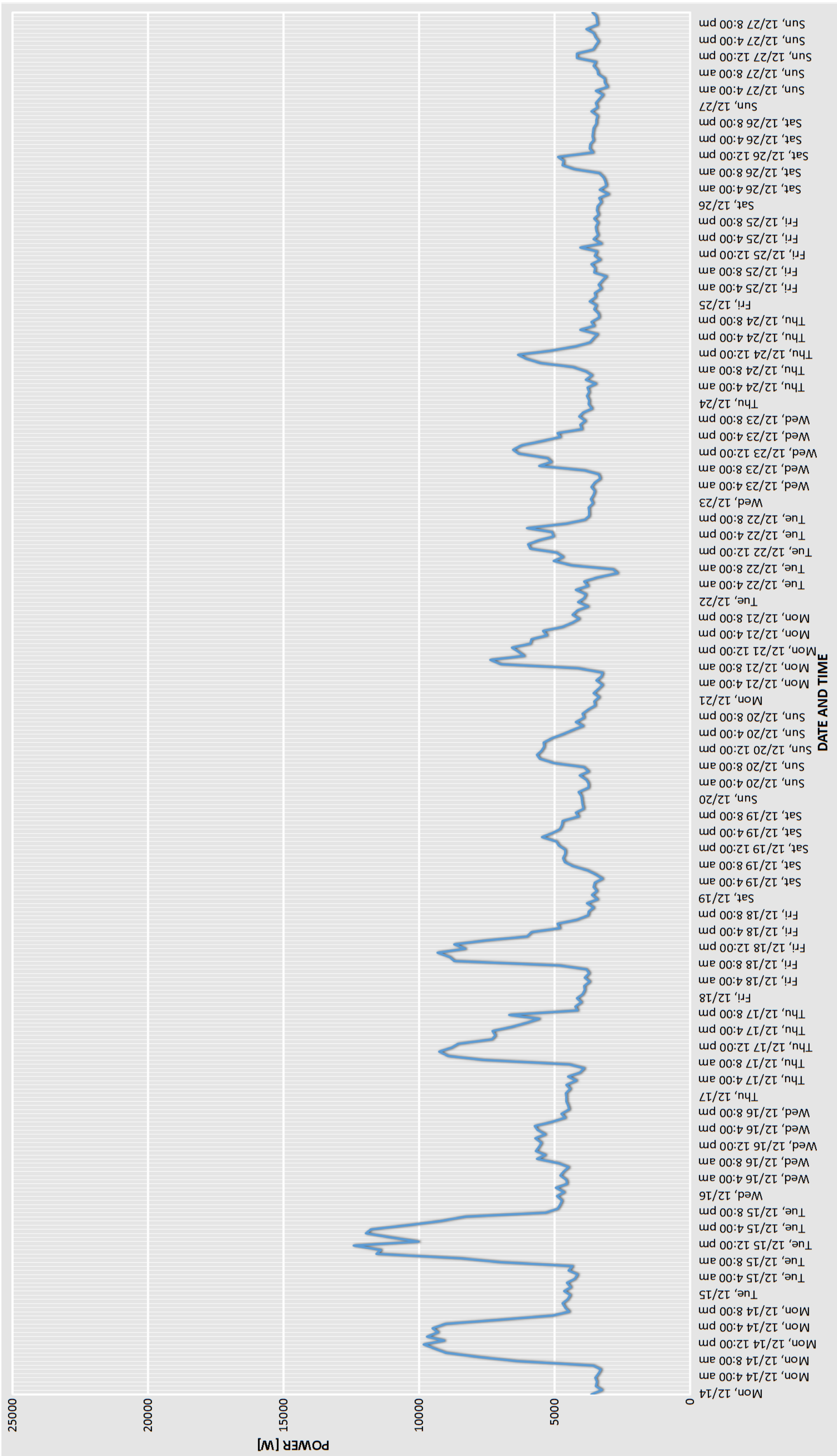


Figure B.4: Two-week low energy consumption data.

B.3 Content of the retrofit feasibility report

The main indicators that initiated the project are poor indoor environmental quality (IEQ), specifically extreme temperatures, noise, poor airflow and inadequate lightning, as well as the building not demonstrating sustainability, which is the core principal.

Project objectives:

- To demonstrate that the sustainability adaptations made have multiple other benefits apart from cost savings.
- To create an attractive and inspiring environment for employees and visitors.
- To create a comfortable building without relying on the national electricity grid.
- To serve as visual example of practicing sustainability and the identity of SI and thereby adding substance to what they teach.
- Perform the retrofit while bearing in mind a Green Star SA rating in the long term.

Constraints: For the immediate future the SI prefers investments with a financial return. Considering the current financial situation of the SI, investments that show a return in the immediate or short term are preferred. No return investments might be considered if there are other associated benefits, such as environmental or social benefits. Large investments that show no or only show return in the long term can only be considered in a few years' time. The school prefers that a retrofit project should be planned so as to avoid interrupting the teaching times. Another constraint is that the data available for the project was incomplete, scattered and difficult to obtain. The utilization of the building has mixed dynamics that are constantly changing and difficult to anticipate, because the eventual use of the building is still being decided on. There are limited expertise, time and funds available for this project.

Building information and use: The main building is owned by the SI and managed by the trustees, and mostly used for educational purposes. Architectural drawings were obtained and updated by the researcher.

Location: Measured from the main building, the site is within walking distance of a farms stall, café, bus and train station.

Climate: Stellenbosch has a Mediterranean type climate.The hottest months are during November to April, with the most sunshine and least precipitation during November to March, has a minimum yearly average wind speed of 2m/s and receives most wind during September to February. Stellenbosch is coolest from November to April, receiving less sunshine during May to July, high precipitation during May to August and lowest wind speeds during May and June.

Energy and water:

- There is only a single municipal energy and water meter for the entire Lynedoch plot and i.e. for all the entities on the property. Separate usage of the main building cannot be determined from this data.
- A peak energy demand of 20 - 25 kW can be expected for the plot in February and a minimum during December, about 5 kW. There is a correlation between the peak temperatures and peak energy consumption both occurring in February, the month when students and staff return from vacation. The air-conditioning could make the main contribution to the peak energy consumption during February.
- A peak water consumption of 1201 kL and 1108 kL can be expected during the months of May and June respectively and a lowest consumption of 415 kL during July.

Waste separation and recycling: Waste separation and recycling activities are present and estimated data show a significant reduction in the waste sent to landfill after the recycling system was implemented.

Facilities management: There are no facilities management plan or maintenance management plans available and a dominantly non-essential and somewhat essential corrective maintenance approach is applied.

Building condition:

- There are wall cracks at the windows on the front corners of the building and these should be repaired.
- There is a good chance that the shared hall needs a roof replacement as it has a leaking problem.

Indoor Environmental Quality (IEQ) and occupant satisfaction: Problems identified by building occupants are excessive noise, extreme temperatures, bad ventilation and the many internal rooms with no natural light.

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