Development of a multi-criteria assessment tool to choose between housing systems for the low cost housing market

by

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Thesis presents for fulfilment of the requirements for the degree of Master of Science in Engineering at Stellenbosch

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December 2014

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 authorship owner thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Signature: ………………………………

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December 2014

Abstract

It is well known that South Africa has a major housing backlog and that the population is growing every year. Consequently, more people are left homeless, without the finances to acquire a minimum standard house. The official backlog in 2012 was defined as 2.1 million units, of which 1.1 million households lived in informal settlements in South Africa.

The purpose of this study is to develop a multi-criteria assessment tool that will help a developer to choose between housing systems that can be used in low cost housing developments. Essentially, the tool will aid a developer to allocate funding more appropriately and effectively to develop sustainable communities.

The research followed a procedure of identifying challenges experienced in the low cost housing industry, identifying the important factors to consider when assessing low cost housing systems and finally selecting a multi-criteria decision-making model to select a system. The important factors that need to be considered for this study were gathered from literature and industry experience through using the interviewing technique for data collection. The factors identified will be assessed using the multi-criteria decision-making model, called the Evidential Reasoning Approach.

This study focuses on housing systems as a whole. Specific attention is given to walling systems, but not to other elements such as the foundations and roofs. The primary factors identified are cost, time, quality, environmental performance, density, alteration capability, resource availability and additional features. These factors were then used to develop a user-friendly assessment tool for choosing between housing systems for the low cost housing market.

In conclusion this assessment tool will be available to public and private role players who intend to develop a low cost housing settlement. However, this assessment tool has some imperfections. These are discussed at the end of this study and show how they influence this model.

Key words: Low cost housing, housing, assessment tool, criteria, South Africa

Opsomming

Dit is algemeen bekend dat Suid-Afrika ‘n groot behuisings agterstand het en dat die bevolking jaarlikse groei. Die amptelike behuisings agterstand in 2012 was gedefinieer as 2.1 miljoen eenhede, waarvan meer as 1.1 miljoen van hierdie huishoudings in informele nedersettings in Suid-Afrika geleë is.

Die doel van hierdie studie is dus om ‘n mulit-kriteria assesserings instrument te ontwikkel wat ‘n ontwikkelaar sal help om tussen behuisings sisteme te kies, wat vir lae koste behuising ontwikkelings gebruik kan word. Gevolglik , sal hierdie instrument ‘n ontwikkelaar help om befondsing meer toepaslik toe te ken en om doeltreffende en volhoubare gemeenskappe te ontwikkel.

Die navorsings prosedure het begin deur uidagings in die lae koste behuising bedryf te identifiseer, asook die belangrike faktore wat oorweeg moet word as behuisings stelsels beoordeel moet word. ‘n Multi-kriteria besluitnemings model is gekies wat toepaslik is op hierdie studie. Die belangrike faktore wat in ag geneem moet word, is geïdentifiseer deur literatuur, en industrie ondervinding, deur gebruik te maak van onderhoude om data in te samel. Die kriteria wat geïdentifiseer is sal beoordeel word met behulp van die multi-kriteria besluitnemings model, naamlik *Evidential Reasoning Approach*.

Die kriteria wat gebuik is in hierdie studie het gefokus op die behuisings stelsel as ʼn geheel. Alhoewel spesifieke aandag gegee is aan die mure van die stelsels was ander elemente, soos die dakke en fondamente nie bespreek nie. Die primêre faktore wat geïdentifiseer is, is koste, tyd, kwaliteit, omgewings werkverrigting, digtheid, aanbouings vermoë, beskikbaarheid van hulpbronne en bykomende funksies. Hierdie faktore word gebruik om ‘n keuse te maak tussen behuisings stelsels vir die gebruik vin die lae koste behuising mark. Die faktore word voorgestel as ‘n gebruikers vriendelike assesserings instrument.

Ten slotte behoort hierdie assesserings intrument beskikbaar te wees aan oopenbare en private belangstellendes wat beoog om ‘n lae kost behuising nedersetting te ontwikkel. Hierdie assesserings instrument het wel ‘n paar tekortkomming, wat aan die enide van die studie bespreek word, asook hoe hierdie terkortkomming die model kan beïnvloed.

Acknowledgements

I would like to acknowledge the contributions of the following people and entities that helped me bring this research report into being.

A special thanks to my supervisor, Prof. Jan Wium, who guided me throughout my research and writing this thesis. Thank you for all you motivation and time for proofreading my thesis. I have learned many life lessons during the past two years to incorporate in my future.

Thanks to all of the participants that were willing to give their personal time for interviews and to share their knowledge and ideas they have gathered in their professions.

I want to thank my parents for all their patience, love and understanding throughout my life. Thank you for providing me with the opportunity to complete my studies, all the prayers and support. Thank you so much, Mom and Dad.

Thank you to my sisters, Nicolene and Marlize, for all their love and support during my life and for always being by my side. I also want to thank their love ones, Willem and Hawaiian, for their support.

I would like to thank all my friends that encouraged me during tough times and spending many hours with me behind the books. A special thanks to Philip, Louwrens and Charlie who worked with me almost every day in the past year.

I want to thank a very special person in my life, Marianza. Thank you for all your love, kindness and support. Thank you for all your encouragement and understanding during my studies.

Finally, I want to thank the Almighty God for providing me the opportunity to study, to be healthy and fortunate for having all these special people in my life. Thank you for all my abilities and to be able to have come this far in my life.

Phil 4:13 – “I can do all things through God who strengthens me”

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List of abbreviations

ABT	Alternative Building Technologies
AHP	Analytical Hierarchy Process
CAHF	Centre for Affordable Housing Finance in Africa
CBO	Congressional Budget Office
CO_2	Carbon dioxide
DF	Daylight factor
DI	Daylight illuminance
DoB	Degree of Belief
EPWP	Expanded Public Works Programme
ER	Evidential Reasoning
FFL	Finished Floor Level
FLISP	Financial Linked Individual Subsidy Programme
GBCSA	Green Building Council of South Africa
GHS	General Household Survey
IRDP	Integrated Residential Development Programme
MADA	Multi-attribute decision analysis
MADM	Multi-attribute decision-making
MCDM	Multi-criteria decision-making
MEC	Member of executive council
MODM	Multi-objective decision-making
NGO	Non-governmental organisation
NHBRC	National Home Builders Registration Council
PHP	People’s Housing Process
RDP	Reconstruction and Development Programme
SAHF	South African Housing Foundation
SANS	South African National Standards
SCCPA	Southern Coastal Condensation Problem Area

Symbols for in-text calculations

A	Area
A	Alternative housing systems
β	Degree of belief
C_j	Criteria
C_u	Conductance per unit floor area
D_t	Decision maker
du/ha	Dwelling units per hectare
H	Evaluation grades
I_t	Degree of importance of decision maker
K	Kelvin
m^2	Square meters
Ñ	Fuzzy number
R	Thermal resistance
U	Measure heat loss through a structural element
	Fuzzy membership function
W	Watt
W	Weight vector
	Linguistic weight of criteria
Y	Admittance

Chapter 1

Introduction

South Africa has a major housing backlog and the population is growing every year (Centre for Affordable Housing Finance in Africa, 2012). Consequently, more people are left homeless, without the finances to acquire a minimum standard house. The aim of this study is to develop a multi-criteria assessment tool, which will aid a decision maker with choosing between different housing systems for low cost housing developments.

This chapter provides a general introduction and background information as motivation to the study.

The introduction provides a background on the housing situation of South Africa and discusses the purpose of the study. The problem statement is also discussed, followed by the assumptions and limitations of the study.

The objectives are presented to indicate the issues which are addressed in this study and a possible outcome of this study is discussed. The methodology of this study is also described to explain why certain subjects were researched and how the study was conducted. Finally, a chapter overview is provided at the end of this chapter to show the flow of the study.

1.1 Background

Cornelissen (2001) defined housing as: "a variety of processes through which habitable, stable and sustainable public and private residential environments are created. This recognises that the environment within which a house is situated is as important as the house itself in satisfying the needs and requirements of occupants."

The Centre for Affordable Housing Finance in Africa (Centre for Affordable Housing Finance in Africa, 2012), which is a non-profit organisation and whose focus is to be a primary source of information regarding housing finance in Africa, stated it is well known that South Africa had a housing backlog, in 1994. Many resources estimated this backlog to be more or less three million houses. However, the government did not have the finances to resolve this problem.

The government then initiated an ambitious housing subsidy programme. The programme was and still is called the Reconstruction and Development Programme or RDP subsidy (other programs more recently implemented are discussed in Section 2.4.3). The programme entitles all households who earn less than R3500 a month, along with other criteria, to apply for a fully subsidised house (Centre for Affordable Housing Finance in Africa, 2012).

Under this programme the subsidy beneficiaries were entitled to a freehold title of a 250 m^2 serviced stand with a 40 m^2 top structure, at no cost. This programme has already provided more than 2.2 million households with housing units according to the CAHF and other resources.

However, the official backlog in 2012 was still defined as 2.1 million units, of which 1.1 million households lived in informal settlements in South Africa (Centre for Affordable Housing Finance in Africa, 2012).

The focus of this study is to analyse the provision of housing to house owners, whose monthly household income is less than R3500 per month. In order to provide housing to this financial income group it is important to incorporate effective budgeting and the utilisation of innovative techniques in order to reduce construction costs. This can be done, amongst others, through using materials that are locally available along with improved skills and technology without sacrificing the strength, performance and life of the structure (Centre for Affordable Housing Finance in Africa, 2012).

1.2 Purpose of the study

The housing backlog is an ever-growing headache and fewer houses are being delivered by the government each year. According to statistics from the South African Housing Foundation, the backlog increased from 1.5 million housing units in 1996 to 1.8 million units in 2001 and then to 2.1 million in February 2013. Therefore, it becomes important to encourage innovative ideas and solutions to bridge the backlog and put resources together for the greater good (SAHF, 2013; Steyn, 2014).

However, housing provision is not the only concern. There are many complaints that housing delivery is not according to the required standard and not sustainable for the users (Statistics South Africa, 2012). Osburn (2010) also stated that users spend a fair amount of their finances on electricity to create suitable living conditions, which can be mitigated with the use of adequate housing systems.

This study will provide a tool that will aid a developer to allocate funding more appropriately and effectively. Thus, the purpose of this study is to:

- Encourage innovative alternative housing systems
- Enable developers to compare different housing systems with one another
- Choose the housing system which will be the most suitable for a specific project

This study will further aid developers in establishing what characteristics of a system make it better than another system. This can then be used to state why one system should be used above another.

This is essential as the public often perceives that the housing, which is provided, does not adhere to the minimum standards. The minimum standards are discussed in Section 2.3. The main reason for this is that the public, often, do not have knowledge on the alternative housing systems. The public should be made aware of the various systems available to make good informed decisions (Steyn, 2014; Byron, 2014). For the purpose of this study, the factors for choosing between housing systems will not include the public's perception. However, the result of the assessment tool will be used to inform the community of the advantages and disadvantages of the chosen system. The tool can be used to change the perception of the community of alternative housing systems and motivate why a housing system should be used for a specific project.

1.3 Problem statement

A major challenge experienced by the housing industry of South Africa is that people are migrating to the metropole areas, such as Cape Town and Johannesburg (Tonkin, 2008). This creates a concern for the provinces and municipalities with inadequate land to build acceptable houses. They also have challenges with allocating funds to build the infrastructure that is required to provide services to these housing developments. In order to address the problem, of inadequate land and insufficient funds, it is important to know what solutions there may be to try and mitigate it.

There are many different types of building materials and building systems available around the world today. To address the housing problem that South Africa is facing it is relevant to have appropriate knowledge of the different building materials and the building systems that are currently available and in use. The different types of building materials and building systems are therefore discussed in Section 2.2.2 and Section 2.2.3. This knowledge would consequently enable one to make more effective use of alternative methods and systems to reduce widening of the backlog. Another factor to consider is the availability of local materials and materials that are available internationally.

Finally, the challenges experienced through providing housing and the limitations for the further use of certain housing systems need to be identified.

1.4 Assumptions and limitations

Before commencing the study it is important identify the assumptions and limitations. An informative background is also required to understand what needs to be achieved through the study.

This study was conducted in the Western Cape of South Africa, specifically in the Cape Peninsula and Cape Winelands districts. Therefore, the Western Cape will be used as reference point. Although all of the interviews and most of the information were gathered in this region, the criteria are not limited to this region. This decision-making tool will be applicable to various situations and can be implemented in other parts of South Africa or elsewhere.

This study will focus on housing systems as a whole. Specific attention will be given to walling systems, but not to the other elements such as the foundations and roofs. Foundations are determined by local geotechnical conditions, while the roofs for low cost housing are assumed to be standard and according to specifications, as set out by the National Building Regulations. It is assumed that the infrastructure services are already in place and do not have to be accounted for in the planning of construction.

It is important to also recognise that the subjects raised in this research paper are mostly applicable to denser populated areas and are not necessarily applicable for less populated areas. Another assumption is that the housing systems evaluated with the use of this study adhere to the minimum specifications as set out for housing delivery. These legislations and specifications are further discussed in Section 2.3.

There are a variety of factors influencing housing delivery; these factors include (Ballerino 2002):

- The attitudes of the people who make the decisions and those who benefit from them
- The available technology
- Some external factors, such as globalisation

Referring to the above mentioned factors, from a South African perspective, it is evident that the factors influencing the housing conditions the most are the attitudes of the people and the technologies that are available. Therefore, it should be recognised that these factors may change over time and influence some of the decisions made during this study.

The background, purpose of study, problem statement, assumptions and limitations has now been discussed individually. With this information acquired, the objectives of this study are set out in the following section.

1.5 Objectives

The aim of this study is to develop a decision-making model which could be used to choose between different housing systems for the low cost market. A number of factors are considered and through this study the appropriate factors are used to establish a decision-making model. This will then be made available to different parties involved in the low cost housing industry, including the public and private sector.

The main objectives for this study are to:

- Establish the factors that impact the decision between housing systems for low-income developments
- Research decision-making models and choose the model which would fit best
- Use the identified decision-making model in collaboration with the factors and develop a housing system assessment tool

To reach the main objectives, the following secondary objectives need to be completed:

- Research different building materials and walling systems that are currently available, locally and internationally
- Identify the challenges being faced by the housing industry of South Africa
- Identify the relevant specifications and standards applicable to low cost housing in South Africa
- Identify the various role players in the low cost housing industry
- Identify alternative housing typologies (for example; detached housing, attached housing and apartment blocks.)

These objectives should provide an understanding of the low cost housing problem experienced and identify the various factors to consider before commencing a low cost housing project. Consequently, the study should provide the various role players a tool for choosing an appropriate housing system.

1.6 Methodology

The study aims to identify the various factors to consider when comparing alternative housing systems. To achieve this, the study firstly examines the housing situation of South Africa and defines the factors included in delivering houses. This information is gathered from literature and discussions with various role players in the low cost housing industry.

The study begins with a literature review, which is used to provide a clear understanding on:

- The current low cost housing situation in South Africa
- The types of materials and building systems available, locally and internationally
- Different housing typologies that are available
- The specifications and standards applicable to low cost housing
- The various role players in delivering houses
- Climatic conditions of South Africa

Following the literature review, the relevant factors for the assessment tool are established using the following methods:

- Alternative building systems are researched to indicate the advantages and disadvantages of various systems and to identify the successes of implementing them
- Discussions with various role players, to identify the problems being experienced and factors to consider
- Completed projects have been studied to identify the setbacks and successes

After the factors have been chosen, research is conducted regarding different multi-criteria decision-making models. The most appropriate multi-criteria decision-making model is then chosen. Finally a user friendly assessment tool is developed which could be used by the different role players in the low cost housing industry.

1.7 Chapter overview

The chapter overview provides a brief summary of each chapter. Figure 1.1 shows the chapter layout for the study.

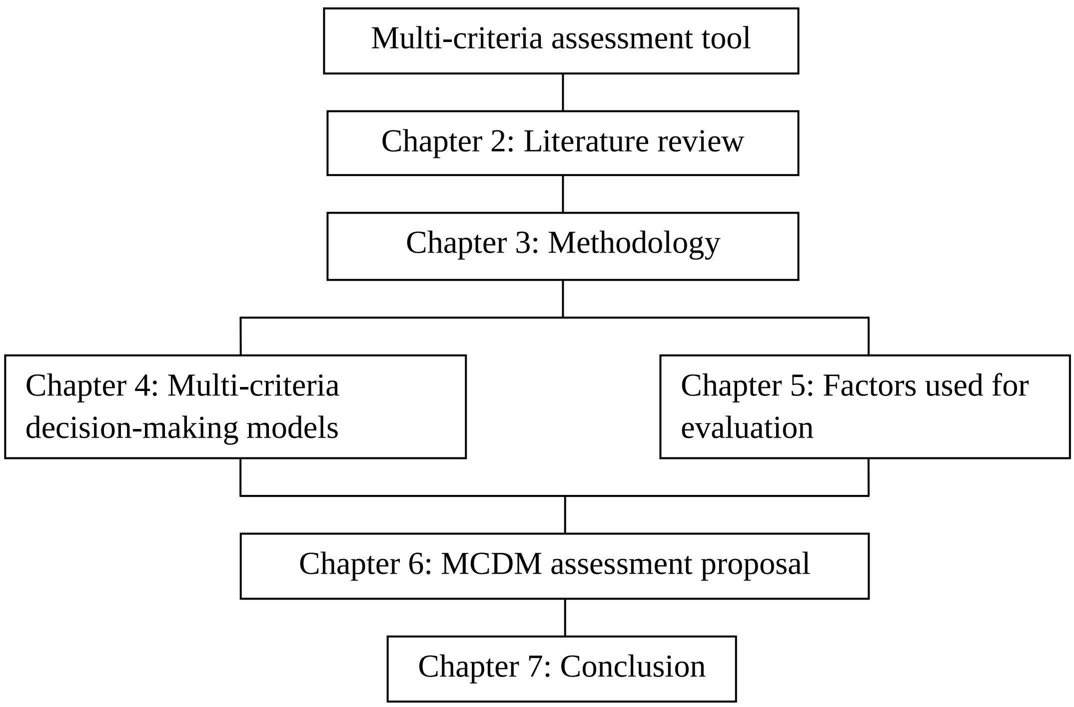


Figure 1.1 Chapter layout

Chapter 1 – Introduction

This chapter provides an introduction to the research study. It discusses the problem statement as well as the assumptions and limitations to the study. The research objectives as well as a brief methodology are defined. A chapter overview is provided with a summary of each chapter.

Chapter 2 - Literature review

Chapter 2 discusses the current housing situation and challenges faced for providing housing, as experienced in South Africa. Walling systems, building materials and housing typologies currently implemented in the low cost housing industry are also discussed. The chapter provides a description of the legislation on low cost housing and the different parties involved in the housing industry. The different climatic regions in South Africa have also been identified.

Chapter 3 – Research design and methodology

Chapter 3 provides the methodology used for obtaining the required information for the study. The objectives of the research, the approach used in the study and the strengths and weaknesses of implementing the approach are discussed. Finally, the ethical considerations of the study were provided and the chapter ends with concluding remarks.

Chapter 4 – Multi-criteria decision-making

Chapter 4 discusses the decision-making process, which starts off with identifying the decision-making team. The process includes the weighting of the identified factors and essentially ranking the alternatives. The decision-making model used to rank the alternatives is discussed and provides an example of the implementation of the identified model.

Chapter 5 – Factors used for evaluation

Chapter 5 discusses the methodology used to identify the factors used in this study. It discusses each factor individually and shows the assessment model of each. From this chapter it should be clear why the factors have been chosen and how it will influence the decision.

Chapter 6 – Multi-criteria assessment tool proposal

Chapter 6 provides the implementation of the factors identified. A proposal is provided for the multi-criteria assessment tool developed. This tool will aid a decision on which housing system would be fit for the purpose of a projected low cost housing development. A user-friendly model has been developed for these purposes. This chapter also discusses the limitations identified for this study.

Chapter 7 – Conclusion and recommendations

Chapter 7 summarises the research study and shows how all the chapters contribute to the initial problem statement. Recommendations are also provided for future studies in the field of low cost housing.

Chapter 2

Literature review

This chapter provides an overview of the literature obtained and the key concepts of the current study.

The current housing situation in South Africa is discussed along with the challenges experienced. An overview of the typical housing systems is discussed, including the housing typologies, building materials and walling systems. The legislation that is applicable to low cost housing is mentioned and the responsibilities of the different role players are discussed. Figure 2.1 provides a chapter outline.

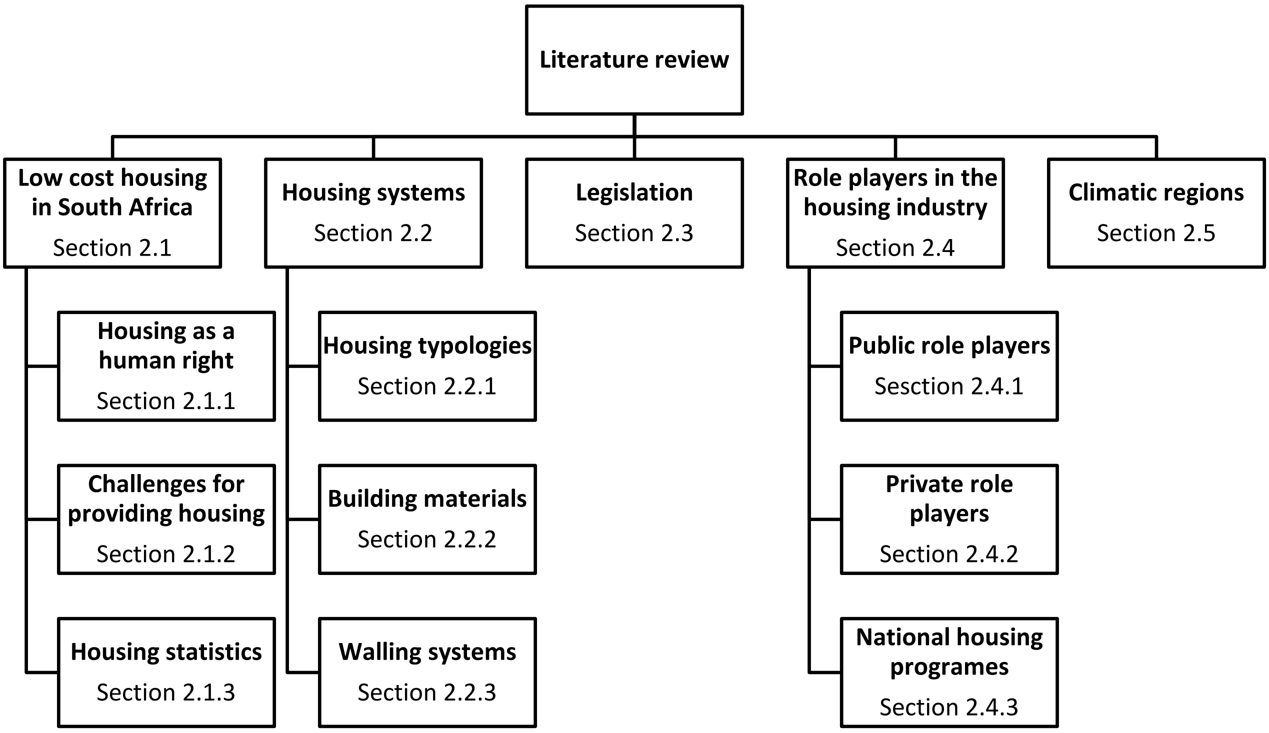


Figure 2.1 Chapter 2 flow diagram

2.1 Low cost housing in South Africa

The housing situation differs from one country to another. The challenges faced by each country may have common characteristics, but each has their own unique cultural challenges. In this section background information and unique challenges faced by the Republic of South Africa are provided. It also provides knowledge on housing as a human right and present statistical information regarding housing delivery in South Africa.

2.1.1 Housing as a human right

One of the basic human rights recognised in many international institutions and agreements is the right to adequate housing. This is seen as one of the most important human rights where shelter, food, sleep, relaxation and the ability to raise a family are some of the basic needs required in order to survive.

Section 26 of the Constitution of South Africa, no. 108 of 1996, states that: "Everyone has the right to have access to adequate housing. The government must take reasonable steps within its available resources to provide people with housing and access to land." With this statement the government wants to explain that steps should be taken to provide housing "within its available resources." Thus, they can only provide housing if it is affordable (Republic of South Africa, 1996:Section 26).

The government of South Africa interpreted the right of access to adequate housing as more than just a brick and mortar top structure. It should provide the necessary available land and the services required, such as the provision of water and sewage removal. This land and services should also receive the funding necessary. Therefore, for an individual to have access to acceptable housing all of these conditions should be met (The right of access to adequate housing, 2002) .

The government also implemented the White Paper on Housing after the 1994 elections. The aim of the White Paper is to construct settlements where households could have access to opportunities, infrastructure and services. The purpose of this paper is to provide these applications explicitly to all the citizens of South Africa. It stated that everyone should have a residential structure to protect them from the elements, have potable water and the necessary sanitary facilities including waste disposal and electricity (Tissington, 2011a).

It has been established that everyone has the right to adequate housing, through the conditions expressed via Section 26 of the Constitution of South Africa. However, numerous challenges arise when housing is provided. These are discussed in the following section.

2.1.2 Challenges of providing housing

There are numerous challenges for delivering affordable housing in South Africa. These challenges do not end at delivering the houses, but also include structural issues being experienced after delivery, as seen by the complaints in Section 2.1.3. Section 2.1.3 provides statistics of house owners, who received subsidised houses and indicated that the strength of the walls and roofs of their houses are not according to standard. These structural issues should be noted as one of the main challenges for delivering houses effectively.

Therefore, it should be important to the government to have mechanisms and policies in place, which could prevent problems such as, structural defects, deliverance and aesthetical flaws of the houses provided.

One of the key challenges the housing sector is facing is the subject of *well situated land*. The problem which the major cities, such as Cape Town and Johannesburg, are facing is that many people are moving to urban areas for work opportunities. Thus, the problem arises of providing suitable land that could be used for residential developments, of all types, and then to further provide the funding needed for the bulk infrastructure of services required for these sites.

Another problem for these major cities is the strain placed on *housing budget provisions*. As the demand for housing increases, the affordability of the houses decreases. This makes it hard for government and for the private sector to provide housing for the income group between R3 500 and R10 000 per month, known as the “gap” market (Khaki, 2009). The following paragraph clarifies the challenge of providing houses to the above mentioned income group.

The housing subsidy scheme is a government initiative where government provides homes for people with a monthly income of less than R3 500. The banks only start giving housing loans to people with a monthly income above R10 000. Therefore, providing houses to the “gap” market group with a monthly income between R3 500 and R10 000 is a difficult task. This income group cannot afford reasonable housing and it is also challenging to provide housing for them.

The Banking Council of South Africa estimates that only 20% of new households can afford to pay for mortgage loans. They also estimate that only 22% of households can afford non-mortgage finance (Loans that are typically less that R10 000). This means that almost 80% of new households do not have the finances to gain access to adequate housing on their own (Tonkin, 2008).

The global recession in 2008 also did not leave South Africa unharmed, as the economy had a large effect on the commercial banks that fund these housing developments. The private sector developers were greatly affected as they rely on financial institutions for development finances and end user funding for purchasers (Khaki, 2009).

The government seeks innovative ideas in order to provide more houses quicker and at a lower cost. However, these new housing systems are not always accepted by the different role players due to the uncertainty of success and the initial production costs.

Although the South African government have given much attention to provide housing to the low income group new challenges regularly occurs. According to Goebel (2007) many problems have become clear with the housing delivery process unfolding. Goebel (2007) identified the following problems with the housing delivery process.

- The low income community are being placed in new houses and townships in “ghettos” on urban peripheries, which is not near jobs and services.
- The new houses and infrastructure (such as sewerage services) constructed are of poor quality, are rapidly deteriorating and require maintenance.
- The free-hold tenure does not adequately deal with the dynamics of poverty.
- The people do not like the model of housing used and would prefer larger houses. This situation was addressed in 1998 when the minimum standard house was increased from a minimum size of 30 m^2 to 40 m^2.
- These mentioned problems often result in people selling or renting their subsidised houses and moving back to informal settlements, which is closer to economic activities.
- There are also environmental concerns regarding the new developments, which include an increase in vehicular traffic caused by urban sprawl and land use changes.

In addition, there are many challenges relating to the delivery of water and electricity at lower costs to the low income community. Some of these issues are being addressed by delivering houses that are more energy efficient and that require less electricity to heat and cool the low cost houses. These are addressed in Chapter 5.

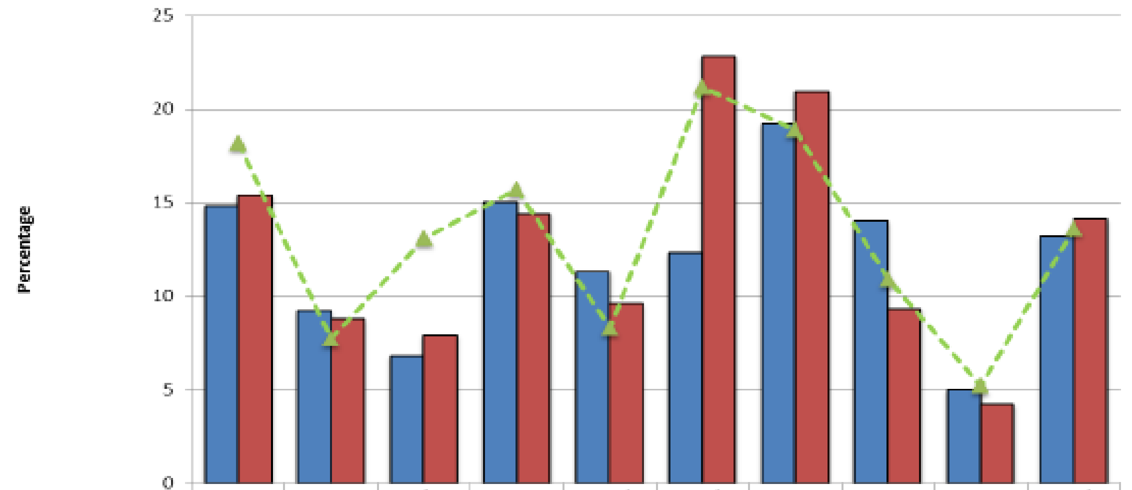
South Africa has made progress in providing housing and basic services to the low income community. However, many challenges still remain in delivering adequate housing of which this study attempts to address only a part of this problem.

2.1.3 Housing statistics

Statistics South Africa conducts an annual General Household Survey (GHS), where they collect information on various aspects of living arrangements from a selection of households. The section of the study relating to housing focuses on the type of dwellings in South Africa and the quality perceived by the home owners. The data used in this study was sourced between 2002 and 2012 (Statistics South Africa, 2012).

The statistics showed an overall *increase* of fully owned houses from 52.9% to 54.5% in the time span, as well as an increase in renting *formal dwellings*. The statistics also showed a slight overall increase of households living in *informal dwellings* of 0.9% between 2002 and 2012. Figure 2.2 shows the percentage of households living in informal dwellings per province over the 10 year span. Figure 2.2 indicates that the North West province had the highest percentage of informal dwellings and Gauteng province had the second highest percentage of informal dwellings (Statistics South Africa, 2012).

Although some of the percentages differ, the survey’s estimates compared fairly well with the statistics derived from the Census 2011. In 2011 a formal census was conducted by Statistics South Africa, which is done every 10 years (Statistics South Africa, 2012).



	Western Cape	Eastern Cape	Northern Cape	Free State	KwaZulu-Natal	North West	Gauteng	Mpuma-langa	Limpopo	South Africa
2002	14,8	9,2	6,8	15,0	11,3	12,3	19,2	14,0	5,0	13,2
2012	15,4	8,8	7,9	14,4	9,6	22,8	20,9	9,3	4,2	14,1
Census 2011	18,2	7,7	13,1	15,7	8,3	21,2	18,9	10,9	5,2	13,6

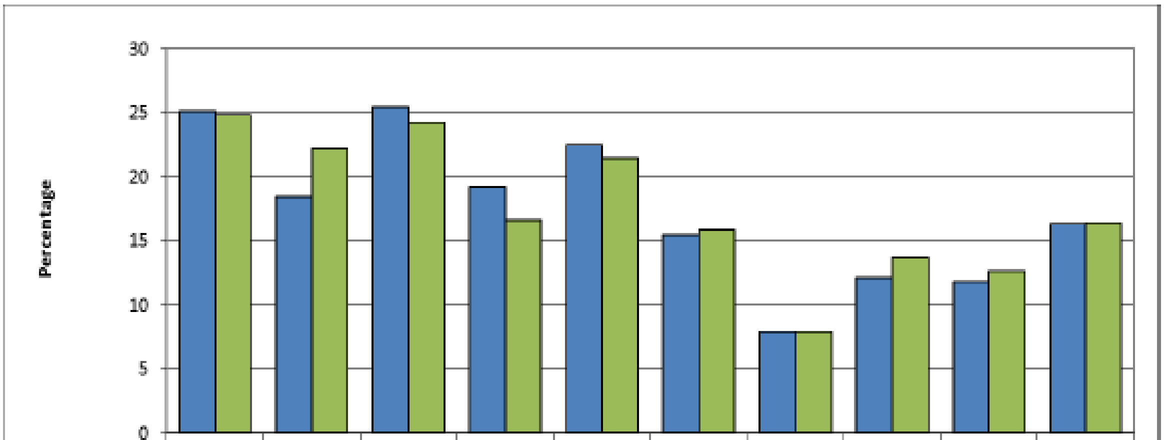
Figure 2.2 Percentage of households living in informal dwellings per province, Census 2011 (Statistics South Africa, 2012)

The study from the GHS 2012 also tried to establish to what extent subsidised housing provided by the state was being used, what the quality of the houses were and how the waiting list was being used.

The housing waiting list is a government initiative, where families who earn less than R3500 per month can apply to receive a house from the government. Theoretically this list should ensure that those who have waited the longest for a house should receive one first.

The survey showed that in 2012 14.2% of South African households consisted of people living in RDP or state subsidised dwellings and a further 13.3% of households had at least one member who was on a waiting list for state subsidised housing (Statistics South Africa, 2012).

Furthermore, the survey wanted to analyse the quality of the houses provided by the subsidised housing program, as a consequence of concerns raised by the community. The survey determined what problems were detected with the construction of these subsidised dwellings and asked the respondents to indicate whether their walls and roofs were: "very good, good, need minor repairs, weak or very weak." The statistics, summarised in Figure 2.3, show the findings of households who indicated the walls or roofs of their RDP or subsidised houses are weak or very weak. It was found that an overall 16.3% of the home owners indicated their walls are weak or very weak and 16.4% of home owners indicated their roofs are not up to standard (Statistics South Africa, 2012).



	Western Cape	Eastern Cape	Northern Cape	Free State	KwaZulu-Natal	North West	Gauteng	Mpuma - langa	Limpopo	South Africa
Walls weak	25,1	18,4	25,4	19,2	22,5	15,4	7,9	12,1	11,8	16,3
Roof weak	24,8	22,2	24,2	16,6	21,4	15,9	7,9	13,7	12,6	16,4

Figure 2.3 Percentage of households who feel their RDP or subsidised houses' walls or roofs are weak or very weak, by province (Statistics South Africa, 2012)

Lastly, the GHS 2012 showed an overall increase from 5.5% in 2002 to 8.2% in 2012 for subsidy houses provided by the government. The most households that received housing are females who are head of their houses. This shows that the government adheres to their policy of providing households to vulnerable groups, including females and people with disabilities (Statistics South Africa, 2012).

2.2 Housing systems

This section provides a brief overview of the different types of housing typologies, building materials and walling systems currently used in South Africa and internationally. References are made to international trends to show where some improvements could be implemented to solve the housing backlog experienced in South Africa.

2.2.1 Housing typologies

The location of a housing project can play an important role in the design of a settlement. Higher density housing may be more applicable to urban areas, where available land is becoming a problem to the municipalities. Therefore, this section will provide information on housing typologies that are relevant to the South African context.

Housing typologies refer to the physical structure of residential buildings, but contribute to the social, psychological and the cultural environment (Tonkin, 2008).

The housing typology determines a variety of factors which have a significant impact on a development. These factors include the design of the building and the site, provision of services, project costs, open space patterns and the residents' perception of satisfaction with their housing environment (Tonkin, 2008).

When designing and planning a development the typology should play an important part of the overall development process, consequently, the following factors should be considered (Austin & Biermann, 2005):

- Territory – The site should be utilised as far as possible. As many houses as possible should have private or semi-private outdoor space. This will require creative design work, considering the visual, auditory and olfactory (relating to smell) factors.
- Orientation – The design should pay attention to insolation (absorption of the sun's thermal energy) and insulation (suppression of the sun's thermal energy.) It should also attempt to optimise the natural light in the house and keep in mind the wind conditions.
- Privacy – In medium density housing, the privacy is created through walls, floors, ceilings and fences. Internal privacy is created through rooms with doors and windows, while external privacy is not as easy to create.
- Identity – An important factor of settlement planning is socio cultural, where home owners want to choose a housing style, therefore a variety of combinations of housing typologies is important.
- Convenience – It is important to consider the users of the house and the ease to which they will be able to carry out tasks in the house.
- Accessibility – The accessibility must be adjusted to the needs of the intended user. Certain areas should be inaccessible to children and others accessible to disabled users.
- Safety – The safety of a house can be determined through the site, size and access to open spaces. Thus, the house must be able to withstand certain natural forces and be reasonably fire-proof.

The main reason for implementing different housing typologies is to create higher density developments, especially in urban areas. In South Africa, low density is generally accepted at less than 40 dwelling units per hectare (du/ha), medium density between 40 and 100 du/ha and high density at 100 du/ha or more (Deckler and Graupner, 2012).

However, residential densities have two interrelated components. The first component is the density of residential dwellings. Here the gross residential density is expressed through dividing the number of dwelling units with the total site area, and the net residential density expressed through dividing the dwelling units with the part of the site taken up by residential use only. The second part is the density of population, expressed as the number of people divided by the site area. In South Africa a gross density of over 50 du/ha is accepted as appropriate in most developing urban areas (Austin & Biermann, 2005; Steyn, 2014).

There are several types of housing typologies. Designers and planners should have appropriate knowledge of each house type to answer the community, environmental, economic and institutional needs and to choose innovative typology combinations (Tonkin, 2008).

There are mainly *four types* of housing typologies used for low income housing, namely:

- Detached housing
- Attached housing
- Apartment blocks
- Mixed houses

Detached housing is typically used in South Africa, especially in low-density areas. It is most commonly used in middle-income suburbs and the most RDP houses are built in this manner. Figure 2.4 shows an example of detached housing.

The Metropolitan Design Centre in Minneapolis also refers to detached housing as the most common housing type, in America, and states that these types of housing have a strong individual identity and personalisation. The disadvantage of such developments, however, includes a low number of public amenities available to the occupants. This is due to the low number of residents, which does not make it feasible to allocate finances for more amenities (Metropolitan Design Centre, 2005).

Figure 2.4 Example of detached housing (State of the Gauteng City-Region, 2009)

Attached housing is normally used in between low-density and medium-density areas. With this typology the houses are typically joined at a side or on top of each other, where each house has its own out-door entrances and a piece of private outdoor space. The use of this typology often gets implemented to reduce cost through using a communal wall between two houses. Figure 2.5 provides an example of attached housing.

The advantages of this type of housing include that it is adaptable to different kinds of sites and although it is attached, each household still has its own privacy and territory. However, the maintenance of this type of typology can sometimes be a problem, due to the low income of the households and the shared costs that may be implemented (Metropolitan Design Centre, 2005).

Figure 2.5 Example of attached housing (Cape Town Community Housing Company, 2013)

Apartment blocks are typically used in *high-density areas*, normally near high populated cities. In apartments several housing units will share the same mutual entrance and also share an enclosed space through a public structural cover. Figure 2.6 provides an example of an apartment block. The structure will usually consist of three- to four storeys. A limitation was established at four stories in the Western Cape through a number of determinants, of which stairs was the most significant (Tonkin, 2008).

An advantage of apartment blocks includes its location, which are usually closer to facilities, such as transportation and work opportunities. However, the design for parking can be complicated and the interior layouts are critical for the liveability of families (Metropolitan Design Centre, 2005).

Figure 2.6 Example of an apartment block (Gauteng Partnership fund, 2014)

Mixed housing projects are not as common in South Africa, as privacy and noise from neighbours are major problems, due to shared walls and communal spaces. This is where two or more types of housing typologies are combined to provide other options to users with different needs and requirements. This type of typology encourages race and class integration, as it usually provides common facilities, such as gardens, play areas, parking, roads, drying yards and laundry (Tonkin, 2008).

In conclusion, when considering different housing typologies it provides opportunity for increasing densities in the form of infill housing in urban areas. Different housing typologies should also be considered to meet the social, economical and environmental needs of as many households as possible.

2.2.2 Building materials

The aim of this study is to make housing developers and home owners aware of *alternative building materials,* which could be used for low-income housing units. Through considering alternative building materials the construction costs of the houses can be reduced and a variety of other advantages can be added to the housing system.

When considering construction with alternative methods it is important to have knowledge of the different types of building materials and walling systems that are available. This section describes the fundamentals of building materials as described by Ballerino who did a study on low cost housing in Port Elizabeth, South Africa. Ballerino's study is applicable to the South African context of this study and therefore it has been decided to make use of her findings (Ballerino, 2002).

Local conditions are an important factor to consider when choosing building materials for a housing system, as the weather can have a significant impact on different materials. Ballerino (2002) divided materials into two groups, namely *raw (natural) building materials* and *processed building materials*.

Raw (natural) building materials have been used for decades and many cultures have created their own building materials from what was available in their surroundings. This also led to different cultures establishing their own construction methods, which are passed on from generation to generation. The traditional techniques that were developed involved local labour and the use of natural raw materials such as earth, soil, natural fibres, natural rubber, stones and timber (Ballerino, 2002).

Some of the traditional construction materials internationally include, mud or mud-brick used in Ghana (Tipple, 2011), wood frame houses used in Canada (Sun Ridge Group, 2002) and clay, whether it is pure or mixed with sand, used in Germany and other European countries.

The benefits of natural materials are based on environmental principles, such as its renewability, energy efficiency and recyclability. It also includes the social involvement that went along with the traditional building methods, which involved self-construction by the family and community working together (Ballerino, 2002).

The weaknesses of natural materials are its reliance on availability, water absorption, resistance to natural hazards, contamination susceptibility (soluble salts, biological agents, etc.) and its social acceptability (Ballerino, 2002).

Processed building materials on the other hand can be materials which are natural or man-made, such as concrete, ferro-cement and other fibre cement mixtures such as, glass, metal, polymers and recycled materials. These building materials are commonly known to be alternatives for raw materials and are considered as more scientifically developed with improved chemical, mechanical or physical properties (Ballerino, 2002).

The benefits of processed materials are their distinct application abilities, improved properties, higher productivity and possible time savings during construction. Their flaws, however, include their failure to meet the realities of local conditions and high base cost for manufacturing and transportation. When processed materials are assessed this is done according to economical, technical and environmental standards (Ballerino, 2002).

It was found by Tam (2011) that alternative building materials, in India, could be more cost-effective through enhanced and innovative building techniques and consequently, can play a great role in providing improved housing methods and protecting the environment.

In conclusion, there are a variety of building materials available, whether they are natural or processed. These materials need to be incorporated with the right walling system to draw all the possible benefits. The following section discusses the typical walling systems used.

2.2.3 Walling systems

As mentioned in Section 2.2.2, construction methods have been developed over centuries and have been passed on over the generations. Many alternative walling systems have been tried and flourished where others did not meet the required needs. The following section provides a background on the types of walling systems available for low-income housing. These walling systems are used for developing the decision-making criteria, discussed in Chapter 5.

Walling systems have developed significantly over the last decade and many alternative systems have been developed. Some of the main reasons for improving the housing systems are to increase the speed of erection, improving energy efficiency and to lower the construction cost. The following section discusses the current popular walling systems.

2.2.3.1 Massive wall system

The conventional construction method is known, according to Ballerino (2002), as a massive wall system. The construction of these walls is based on a single material. This system is typically constructed using hollow or massive bricks, for example clay bricks, and is connected and rounded off with mortar, normally a cement mixture. In some projects the walls will receive plastering for protection and appearance purposes, but this is not a requirement. Figure 2.7 shows an example of a conventionally constructed house.

One of the main physical characteristics of these systems is that the *walls are self-supported*. The equipment and construction techniques will differ according to the types of materials used during construction. Examples of the base materials used for massive wall systems are: adobe bricks, burnt clay bricks, concrete blocks and bricks, timber and reinforced concrete.

Figure 2.7 Conventional constructed home with clay brick (Corobrick, 2011)

Advantages of massive wall system

Some of the advantages of the massive wall system are (Ballerino, 2002; Kosny, Kossecka et al., 2001; Sun Ridge Group, 2002):

- Reduced number of materials and components
- High thermal resistance
- In-situ materials can be used
- High fire and sound ratings
- Above average damping resistance
- Medium construction speed
- Information required for the design, construction and maintenance are easily accessible

Disadvantages of massive wall system

According to Ballerino (2002), the massive wall system also has the following flaws:

- High quantities of the same material are needed
- Wall finishing is required in order to improve the performance
- Additional support is needed during construction to prevent verticality problems and structural failure
- Large openings need additional beam support

The above mentioned advantages and disadvantages apply to the housing system as a whole. The various base materials could provide their own advantages and disadvantages to a system, depending on a variety of factors, such as the local conditions. The following two walling systems are not as common as the massive wall system, but have their own significant characteristics as they are both younger technologies.

2.2.3.2 Frame wall system

A frame wall system, also known as the *skeleton wall system*, is made of vertical, horizontal and angular members, usually made out of timber, steel or reinforced concrete. The members are sequentially joined together to give strength to the structure. The voids between the frames can be filled with different materials such as masonry, to provide it with the characteristics of a solid wall, or with composite boards, to provide it with the characteristics of light weight walls. The filling materials will, along with the roof, provide stability to the whole system and will prevent distortion (Ballerino, 2002).

Figure 2.8 provides an illustration of a frame wall system and its connections built out of light gauge steel.

Figure 2.8 Example of a light gauge steel frame wall system with its connections (Finish housing, 2012)

Materials typically used for the frame wall system are natural fibre frames, aluminium frames, steel frames and timber frames. The advantages and disadvantages of the frame wall system as set out by Ballerino (2002) are now provided.

Advantages of frame wall system

The frame wall system has the following advantages:

- Fast construction speed
- Medium resistance to natural hazards
- Medium level design and construction techniques

Disadvantages of the frame wall system

The frame wall system has the following disadvantages:

- Information about the design, construction and maintenance of this system are not easily accessible
- There are a variety of components, equipment and skills needed for construction
- It is compulsory that the walls receive finishing

As mentioned at the massive wall system, in Section 2.2.3.1, these advantages and disadvantages of the frame wall system apply to the system as a whole. The different building materials could provide their own advantages and disadvantages to the walling system.

2.2.3.3 Core wall system

The core wall system is made from a combination of materials, an *inner material*, *external layer* and an *outer reinforcement*. The inner, or commonly known as the core, materials are usually made out of polymer matrix resin to reach the desired requirements such as thermal performance, chemical and fire resistance etc. The external layer serves as the protection or cladding of the wall and is usually made out of mortar. Finally, the outer reinforcement provides the strength to the wall and is typically manufactured from metal sheets, fibre etc. (Ballerino, 2002). A study by the Sun Ridge Group (2002) on alternative wall systems provides different types of core wall systems used in Canada.

A typical example of a core wall system is a pre-fabricated panel, with a polystyrene core, encapsulated in high-tensile steel and galvanised wire mesh. These panels can be constructed according to certain specifications such as thermal properties, wall functions and cost requirements (Ecobuild, 2014). Figure 2.9 provides a close-up example of a polystyrene core covered wall, with galvanised wire mesh and cladding.

Figure 2.9 Close up view on the core wall system (Structural concrete insulated panels)

The advantages and disadvantages of the core wall system that follows were gathered from various sources from South African and international literature (Ballerino, 2002; Ecobuild, 2014, Sun Ridge Group, 2002).

Advantages of the core wall system

The advantages of the core wall system are:

- Very good thermal insulation
- The system is energy efficient
- Quick and easy to build
- Good damping resistance
- Construction work on site is reduced when pre-fabricated panels are used
- Pre-fabricated walls can be transported easily
- Cost effective

Disadvantages of the core wall system

The core wall system has the following disadvantages:

- High skilled labour is necessary for construction
- Advanced design and connections
- Design, construction and maintenance information is not easily available
- Special equipment is needed during construction
- The materials are usually imported or partially imported
- There is a higher possibility of insects and vermin attacks

As mentioned under the description of the other walling systems, the advantages and disadvantages refer to the system as a whole and different materials may provide their own advantages and disadvantages.

These are the fundamental walling systems, currently used, which could have a variety of techniques and building materials incorporated into each of them. These systems were identified as three principle walling systems, while other walling systems can be classified under these three systems. Other systems may include “tilt-up” walling, sliding shutter and other modular walling systems. Different building materials will provide different characteristics to the housing systems. For example; one housing system may have high energy efficiency, whereas another housing system provides more resistance to the natural elements. The type of construction method that will be chosen could have a significant impact on the delivery of a large housing project.

2.3 Legislation

Since the ANC government came into power in 1994, several laws have been changed and new legislation has been established regarding the housing situation in South Africa. Much secondary legislation has been established involving regulatory, financial, technical, environmental, and development procedures. This section includes some of the more relevant standards that have to be met and names the codes which have to be adhered to, to ensure the delivery of acceptable housing.

The Housing Act of 1997 along with the White Paper on housing attempt to arrange for a sustainable housing development process. It provides general principles for establishing housing developments in all spheres of the government. It states the individual responsibilities of the national, provincial and local governments regarding housing development and acts as basis for financing these housing projects (Tissington, 2011b). The responsibilities of the various levels of governance are discussed in Section 2.4.

The National Department of Housing in South Africa established requirements which should be met when designing and constructing a house. The first requirement is to comply with the requirements of the National Building Regulations and Standards Act 103 of 1977 and the Housing Consumer's Protection Measures Act 95 of 1998 (National Department of Housing, 2003).

Further requirements include compliance with the needs and performance descriptions of the users and the parameters set regarding the following characteristics in Table 2.1 (National Department of Housing, 2003):

Table 2.1 Parameters that need to be adhere to

Condensation	Structural serviceability
Fire safety	Structural durability
Functionality	Thermal performance
Moisture penetration	Sanitation
Structural safety	Storm water disposal

Furthermore, in 1999, the National Norms and Standards for the Construction of Stand Alone Residential Dwellings were introduced by the Minister of Housing. These standards provided *minimum specifications* and included environmental efficient design proposals. These standards are now contained in the 2009 National Housing Code. The minimum standards for any single unit house constructed through the National Housing Programmes must adhere to the following requirements. Each house must at least have (Tissington, 2011b):

- A minimum size of 40 square metres of gross floor area
- Two bedrooms
- A separate bathroom with a toilet, hand basin and a shower or bath
- A combined living area and kitchen with a wash basin
- A ready board electrical installation, if electricity is available in the project area

These standards are minimum standards, and any project may exceed this level of housing. However, if these minimum norms and standards are not met, the project must be rejected according to the National Housing Code.

According to the National Housing Code the Housing Consumers Protections Measures Act, 1998 (Act No. 95 of 1998) also established the National Home Builders Registration Council (NHBRC) in terms of Section 2. The NHBRC is a statuary body that has the primary objective of providing protection to consumers through the regulation of the home building industry. The provision states that all home builders must be registered with the NHBRC and a home builder may not begin with the construction of a house unless the house is registered with the NHBRC. The NHBRC has also published Home Building Manuals. The technical requirements contained in these manuals are consequently enforced by the NHBRC (Department Human Settlements, 2009).

In 2014 the government implemented new enhancements to low cost housing as an effort to improve the quality of low cost houses built by government. According to the head of the Department of Human Settlements, the norms and standards for a minimum size 40 square meter house are adjusted by implementing the following measures. These measures should improve the thermal performance of dwellings (South African government, 2014):

- The installation of a ceiling with the prescribed air gap for the entire dwelling
- The installation of above-ceiling insulation comprising a 30mm mineral fibreglass blanket for the entire house
- Plastering of all internal walls
- Rendering on external walls
- Smaller size windows
- Special low E clear and E opaque safety glass for all window types as prescribed

Newly built houses will also be fitted with a standard basic electrical installation comprising of a pre-paid meter with a distribution board and lights and plugs to all living areas of the house.

The government also stated that the cost of new dwellings should increase from R64 000 to R110 947 and be applied to all new houses built by government from the 1st of April 2014 (South African government, 2014). The Western Cape Government provides a housing subsidy at an amount of R160 573, to include additional provisions, due to the weather conditions in this region. The amount of R160 573 will be used in the remainder of the study.

2.4 Role players in the low cost housing industry

The purpose of this section is to explain the different responsibilities of the respective role players in the low cost housing industry. The low cost housing industry has an effect on many levels of governance and should be delegated from the highest level to help solve the housing backlog of South Africa. In turn there are many role players that have an influence on the low cost housing industry, which include public and private role players, and this section provides a short description of each.

2.4.1 Public role players

The public role players have a variety of levels to ensure everyone has access to houses. According to the Housing Act of 1997, there are different levels of government which have different roles in the housing industry. The housing policy is mainly formulated and financed by the national government and implemented by the provincial and local governments.

2.4.1.1 National government

The role of the national government is primarily to establish the national housing policy, which includes the standards as set out for housing development (Report on the evaluation of the national housing subsidy scheme, 2003):

- Create a National Housing Code with national norms and standards
- Set a multi-year goal for housing delivery, where funds are allocated from the South African Housing Fund
- Monitor the performance of the set out delivery goals and funding allocations
- Help and improve the capacity of provincial and local governments to meet the goals

The main bodies that are responsible at the national level are:

- The Human Settlements Minister, who is responsible for the National Housing Policy
- Department of Human Settlements, who manages the national strategy and programmes and who also assists and monitors the national programmes
- The South African Housing Development Board, who monitors the application of the national housing policy and counsels the minister on matters related to housing development

2.4.1.2 Provincial government

Each province has its own local government whose responsibilities are limited to its area of jurisdiction. The primary housing responsibilities of the provincial government are to (Report on the evaluation of the national housing subsidy scheme, 2003):

- Develop a policy for a province in correlation with the National Housing Policy. The policy must encourage the delivery of housing to the province
- Promote provincial legislation in order to guarantee effective housing provision
- Formulate and uphold, in accordance with the National Housing Policy, a multi-year provincial plan, which indicates the plans for housing programmes

The bodies that are responsible at provincial level include:

- MEC for housing, who is responsible to implement the Provincial Housing Policy
- Provincial housing department, which manages the provincial strategy and monitors the projects that are incorporated
- The provincial housing department, which also subsidises the local authorities for projects

2.4.1.3 Local government

The local government, or commonly known as municipality, is usually responsible for implementing the policies set out by the national and provincial government. The Housing Act of 1997 states that: “Every municipality must, as part of the municipality’s process of integrated development planning, take all reasonable and necessary steps within the national framework of national and provincial housing legislation to ensure that (Report on the evaluation of the national housing subsidy scheme, 2003):

- The population of its area of jurisdiction has access to adequate houses on a progressive basis
- Conditions not conducive to the health and safety of the inhabitants of its area of jurisdiction are removed
- Services in respect of water, sanitation, electricity, roads, storm water drainage and transport are provided in a manner which is economically efficient."

Essentially the roles of the local governments are to:

- Initiate, plan, co-ordinate and facilitate housing developments as best as they can
- Set goals for housing delivery and prepare a local housing strategy
- Prepare land for housing developments
- Facilitate resolution of conflicts
- Enter into joint venture contracts with private sector developers, NGO's and CBO's

2.4.2 Private role players

Private role players include consultants, contractors and private developers. These are the people who usually do the physical work and in some situations work in collaboration with the public role players.

According to Vosloo (2012) there are a variety of private role-players that have an important role in delivering housing projects. He identified the following private role players, each with their primary role within the housing delivery process:

- Financiers: They have the responsibility to provide finance for the execution of housing projects
- Producers: It is their responsibility to carry out the development. This includes the responsibility for constructing the housing units and the infrastructure of the sustainable housing settlement
- Support organizations: They have the responsibility to provide advice as needed
- Consumers: It is their responsibility to provide contributions to the construction, such as user specifications.

From this section it is evident that the delivery of housing to low income communities cannot be distributed to one entity, but it is the responsibility of various institutions. The national and provincial government have the responsibilities of planning and overseeing housing developments, whereas the local government and private role players have the responsibility of delivering adequate housing to the communities. The following section describes national housing programmes who work in collaboration with public and private role players to develop settlements.

2.4.3 National housing programmes

Within the government there are also various housing programmes that have the responsibility to integrate with the community and develop housing settlements in collaboration with them. The national government developed the National Housing Code, 2009. This code sets out policy principles, guidelines and norms and standards that apply to the government's various housing assistance programmes, which were introduced since 1994.

These programmes are described as housing subsidy instruments by the National Housing Code, which is available to assist low income households to access adequate housing. However, each housing programme has its own goals and objectives within the National Housing Code. Some of the housing programmes currently implemented in South Africa are described in this section.

2.4.3.1 Integrated Residential Development Programme (IRDP)

The Integrated Residential Development Programme (IRDP) was developed to facilitate the development of integrated human settlements in well-located areas. The programme provides convenient access to urban facilities, including places of employment. The programme also aims at creating social cohesion.

2.4.3.2 Social Housing Programme

The Social Housing Programme aims to assist areas that are identified by municipalities as areas that have economic opportunity. The programme also focuses on areas where urban restructuring impacts can best be achieved. Where other programmes provide freehold tenure to households, the Social Housing Programme aims to deliver affordable rental units that offer secure tenure to households.

2.4.3.3 Financial Linked Individual Subsidy Programme (FLISP)

The Financial Linked Individual Subsidy Programme (FLISP) was developed by the Department of Human Settlements. The aim of this programme is to enable sustainable and affordable housing to first time homeowners that earn between R3 500 and R15 000 per month, known as the “gap” market. The aim of this programme is to help individuals whose income is regarded as too low for mortgage finance, but too high to qualify for the government “free-basic-house” subsidy scheme.

2.4.3.4 People’s Housing Process (PHP)

The People’s Housing Process (PHP) has the goal to support households that wish to enhance their housing subsidies by building or organising the building of their homes themselves. This programme aims to harness community initiatives, support participation and ownership, promote community empowerment and build community partnership.

2.4.3.5 Individual subsidies

Finally, low income households can also apply for individual subsidies where an applicant wishes to buy a residential property for the first time. The subsidy can be used to buy an existing house, including the property, or to finish an incomplete house.

In conclusion, this section shows various programmes that provide different ways for the community to apply for financing of housing. Each programme has its own aims and objectives and focuses on different groups of people.

2.5 Climatic regions

The climate of a district plays an important role in the design of houses. The climatic conditions influence the design of houses in respect of comfort and energy efficiency. The design of a house should consider the most appropriate material for a climatic region in order to optimise the energy efficiency.

To incorporate the best possible combinations of designs such as insulation, thermal mass and natural ventilation it is essential to have knowledge of the various climatic conditions. This section provides information on the different climatic regions in South Africa and also provides information on the high condensation areas in the country.

In November 2011 a new standard was introduced in the SANS 10400-XA, *Energy usage in buildings*, which made it compulsory for all new buildings to be insulated. This standard is a result of the high energy demand that is experienced in South Africa (Therm guard, 2012). Figure 2.10 provides the different climatic zones in South Africa. With each of the climatic regions having their individual heating and cooling needs, the same principles of energy efficient design apply to each of them, with their applications varying slightly. For example; they may have different levels of insulation, thermal mass or variations in window sizes (TIASA, [no date]).

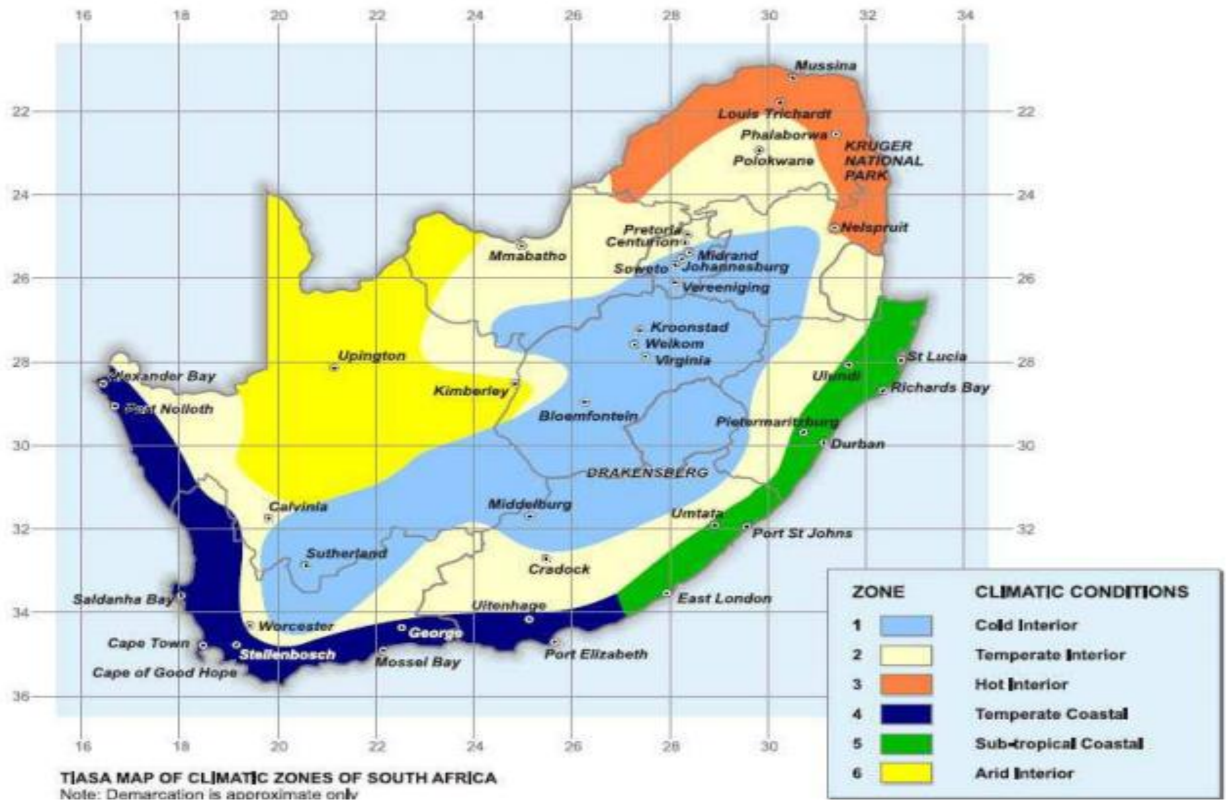


Figure 2.10 Map of climatic regions of South Africa (TIASA, [no date])

Within theses climatic regions South Africa has a sub-region called the *Southern Coastal Condensation Problem area* (SCCPA). This area has a high winter rainfall with low temperatures. This occasionally leads to temperatures inside a dwelling dropping below the temperatures outside of a dwelling. Consequently, situations occur where condensation forms on the internal walls and leaving the walls wet and prone to the growth of bacteria (Sibande, 2013).

Physical on-site investigations in combination with computer simulations were conducted regarding the thermal performance of low cost dwellings. The study found that severe condensation is mainly a problem in the coastal area of the Southern Cape, which is shown in Figure 2.11 (Sibande, 2013).

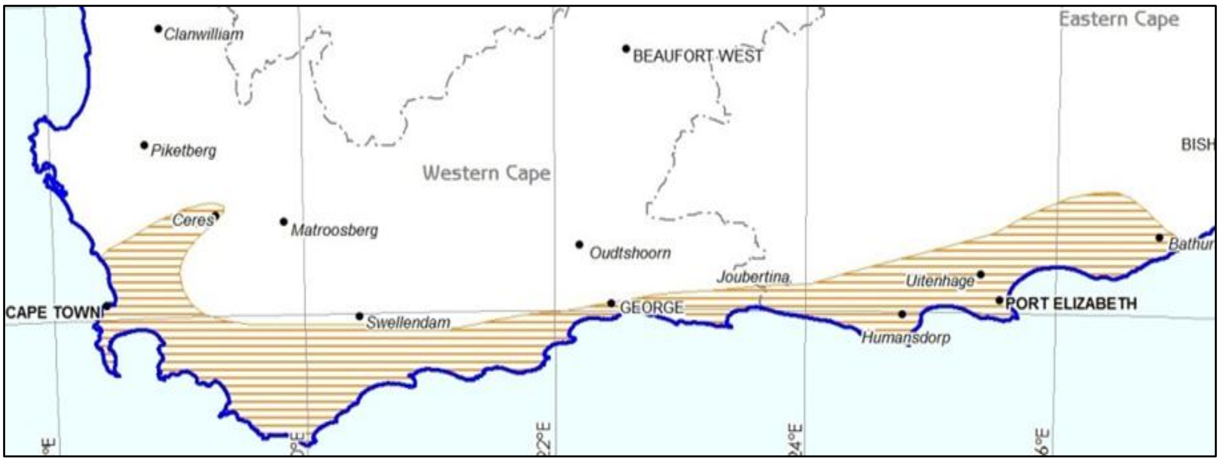


Figure 2.11 Southern Coastal Condensation Problem Area (Sibande, 2013)

This region receives special attention in terms of regulations that need to be adhered to when constructing a house. Additional regulations in terms of thermal insulation are put in place to prevent condensation in these houses. These regulations include factors such as window sizes, orientation of the buildings, compulsory ceilings and wall thicknesses (Agrement South Africa, 2002).

From this section it is clear that the location of the house has an obvious impact on the housing system. Different climatic regions require different specifications to ensure healthy living conditions for the occupants and to reduce the electrical demand from the low income communities. To address the climatic variations of the different regions the SANS 204:2011 can be consulted, which focuses on the energy efficiency of buildings and the respective design requirements (SABS Standards division, 2011).

2.6 Chapter conclusion

From this chapter the reader should have a clear background on the current housing situation experienced in South Africa. One should also be familiar with current housing systems that are available and in use. A brief overview of the current housing legislation is provided and the parties responsible for implementing the various stages of delivering houses are discussed. Finally, the climatic regions of South Africa are discussed.

Section 2.1: Low cost housing in South Africa

Section 2.1 discusses the current low cost housing situation in South Africa. In South Africa it is the responsibility of the government to provide housing to everyone within their available resources, as everyone has a right to housing. However, this is not an easy task as there are a variety of challenges in providing these houses, such as; structural challenges, well-situated land, budget provisions and financing shortages. Finally, some statistics are provided regarding housing delivery and the quality of these houses.

Section 2.2: Housing systems

Section 2.2 discusses the typical housing systems used in South Africa and internationally. The first part of this section discusses the different types of housing typologies being used in South Africa, such as detached housing, attached housing, apartment blocks and mixed housing. It also implies that the housing typology not only refers to the amount of houses delivered, but contributes to the social, psychological and cultural environments of the occupants.

Secondly background of building materials are provided, which is important when considering a housing system. Through considering alternative building materials it could lead to various benefits to the user in different situations. This section divides building materials into two groups, namely; raw (natural) building materials and processed building materials.

Finally, this section discusses the different types of walling systems currently used. By implementing different walling systems with different materials it can offer significant benefits to the user and developer. It is important to apply appropriate time and resources to choose the best walling system and materials to gain the most benefits.

Section 2.3: Legislation

This section discusses the current housing legislation being implemented in South Africa. The relevant norms and standards that should be adhered to are briefly discussed and the relevant codes are named for the delivery of acceptable housing.

Section 2.4: Role players in the low cost housing industry

As previously mentioned, the delivery of housing is not an easy task. There are a variety of participants in this industry and each has their own responsibility. The role players are divided into public participants including; national government, provincial government, local government, and private participants as described in the section. The national housing programmes most commonly implemented in South Africa are also briefly discussed.

Section 2.5: Climatic regions

Section 2.5 shows that South Africa has many climatic regions, with significant temperature differences. It is important to consider the climatic region when constructing a house, as it influences the thermal comfort, thermal mass and ventilation of the housing system. Different climatic regions require different specifications to ensure a healthy living environment for the occupants and to reduce the electrical demand from the low income communities.

Concluding remarks

This chapter shows South Africa has a major housing backlog that needs attention. Statistics showed many houses have been delivered, but not necessarily according to the prescribed standards. With the knowledge obtained from the various housing systems available and the different climatic regions, applicable factors can be identified to do a comparison between housing systems. These factors could aid various role players to allocate funds more appropriately and provide houses more effectively.

It is the responsibility of the various role players to work in collaboration to ensure sustainable houses are delivered to those in need. It is also the responsibility of the various role players to monitor delivered houses to ensure quality dwellings are constructed.

Chapter 3

Research design and methodology

This chapter discusses the methodology used for obtaining the required information for the study. The objectives of the research, the approach used in the study and the strengths and weaknesses of implementing the approach are subsequently discussed. Consequently, the methodology used will aid in developing a multi-criteria assessment tool for choosing between housing systems for the low cost housing market.

3.1 Research aim and objectives

The research found its origins in the major housing backlog that is experienced by South Africa. Alternative housing systems should be considered in order to expedite the housing delivery process, by making optimum use of available finances and resources to ensure sustainable housing developments (Steyn, 2014).

Therefore, the key objectives of this research study are to:

- Research the current housing situation in South Africa
- Establish the current challenges in delivering adequate houses
- Research different possibilities for housing systems, such as building materials, walling systems and alternative typologies
- Determine the primary factors that should be used when comparing different housing systems
- Research multi-criteria decision-making methods and choose one for making a decision between different housing systems
- Propose a user-friendly decision-making assessment tool for choosing between housing systems

If these above mentioned objectives are completed, there should be a clear understanding of what the low cost housing situation in South Africa entails and enough data would have been gathered to develop a user friendly assessment tool for housing systems.

3.2 Research design and approach

Research is a logical and systematic procedure in search of new and useful information on a particular topic (Rajasekar, Philominathan & Chinnathambi, 2006). The purpose of this research is to contribute to a solution for the current housing backlog in South Africa and to develop a tool that can be used to evaluate different housing systems.

The design of such research studies are generally divided between two approaches, namely quantitative research and qualitative research. Quantitative research is normally based on quantitative measurements of some characteristics, where qualitative research is concerned with qualitative experiences, which aims at discovering the underlying motives and desires, using for example in depth interviews. For the purpose of this research a qualitative approach is followed to identify the factors required for the assessment tool.

A qualitative approach is chosen as experience and knowledge from industry role players are used to formulate the decision-making criteria. Most of the factors chosen are not quantifiable and are gathered through interviews. The use of the qualitative approach is discussed in the following section, which shows why the method is applicable to this study.

3.2.1 Qualitative research

Qualitative research is known to be 'subjective' in nature, as it emphasises meanings and experiences. The information gathered from qualitative research is also sub-divided into two separate categories, namely exploratory and attitudinal research. Exploratory research is typically used when limited knowledge is available about a topic. The use of interviews is usually selected as a method of data collection, which will be discussed in Section 3.2.2. The use of exploratory research is also used to diagnose a situation, screen alternatives and to discover new ideas (Naoum, 2012).

Attitudinal research, however, is used to 'subjectively' evaluate the opinion, view or the perception of someone towards a particular variable, factor or question. The researcher would typically ask yes or no questions, or questions which would require a person to state whether they agree or disagree to certain extents (Naoum, 2012). For the purpose of this study the exploratory research method is conducted.

An exploratory research method was chosen to gain knowledge from interviews and to identify challenges and successes experienced in the industry. The housing industry is an evolving process and the use of interviews provides insight into the experiences in the industry. Following are some strengths and weaknesses of using the qualitative research method.

3.2.1.1 Strengths of qualitative research

According to Velez (2013), qualitative methods tend to be rich in narrative and description, and rather than providing an outcome it tends to discuss a process. Thus, qualitative inquiries attempt to understand the context studied. Qualitative research also attempts to make sense of what is being observed, to understand it and to finally discover some meaning through detailed explanations. The following are some strengths of qualitative research as discussed by Johnson and Onwuegbuzie (2004):

- Qualitative research is useful for describing complex phenomena
- Qualitative research provides understanding and description of people's personal experiences
- The researcher can identify contextual and setting factors as they relate to the phenomenon of interest
- Qualitative approaches are responsive to local situations, conditions, and the needs of the stakeholders
- Qualitative researchers are responsive to changes that occur during the conducting of a study and may shift the focus of their studies as a result

However, there are also weaknesses to using a qualitative research approach, which are discussed in the following section.

3.2.1.2 Weaknesses of qualitative research

The use of qualitative research can be described as imprecise. Some of the critics state that samples are small and not necessarily representative of the broader population. Consequently, it is asked how far results can be generalised. It is also said that findings may lack rigour in it not being precise (Patton & Cochran et al, 2002). Another weakness of qualitative research is that, although it has context-rich, value-laden, narrative-filled reports, it does not have enough hard evidence. It is a concern that the researcher may not be objective enough as the researcher is actively involved in the study and is likely to be passionate about the context of the study (Velez, 2013).

From a practical point of view, the more insightful qualitative research is the more time consuming it becomes. The gathering of data is not a simple process and may involve various opportunities for human error, whereas quantitative research methods involve the input of numerical data and getting results from it (Velez, 2013). Johnson and Onwuegbuzie (2004) listed the following weaknesses of qualitative research:

- It is difficult to make quantitative predictions
- Qualitative research may have lower credibility with some administrators and commissioners of programmes
- It generally takes more time to collect the data when compared to quantitative research

From this section it is evident there are various strengths and weaknesses to using a qualitative research approach, however, this can be influenced with the specific techniques used for data collection as described in the following section.

3.2.2 Techniques for data collection

This study makes use of the qualitative research method, described in Section 3.2.1. Within this research an appropriate technique should be chosen for data collection. There are a variety of different data collecting techniques, which includes; surveys, case studies, interviews and questionnaires.

The use of personal interviews was decided upon as the most appropriate manner to collect information and opinions. This was chosen as knowledge from the housing industry was necessary for the study. Personal interviews are conducted in order to obtain answers applicable to the research hypothesis. The interview technique is especially applicable to the following circumstances (Naoum, 2012):

- When the people being interviewed are homogeneous and share the same characteristics
- When interpersonal contact is essential to explain and describe the questions
- When case studies are investigated and detailed questions are necessary
- When explanation is needed why respondents answer as they do, and yes or no answers are not enough

Interviews typically take one of three forms or a combination of these forms, namely unstructured, structured and semi-structured interviews. The individual forms of interviews will now shortly be discussed.

3.2.2.1 Unstructured interview

The unstructured form of interview is based on 'open' questions, which encourage discussions between the researcher and the interviewee. The researcher uses this technique to see in which way the interviewee directs the conversation. Unstructured interviews can be conducted at the beginning of a research, as *exploratory interviews*, when the goal of the researcher is to gain more information on a subject area. However, general knowledge is required to understand the points discussed. It can be seen as a pure exploratory exercise where the same information is not necessarily required from the various interviewed participants, but to see if information has common characteristics and/or new information is obtained (Naoum, 2012).

3.2.2.2 Semi-structured interview

The semi-structured interview is more formal than the unstructured interview in that there are specific topics around which the interview is built. The questions asked are 'open' and 'close-ended' and are not asked in a specific order, but rather to discover as much information as possible regarding specific issues related to a subject area. Semi-structured interviews have four distinguishing characteristics (Naoum, 2012):

1. The respondents are known to have experience in the field of study.
2. It refers to situations that have been analysed prior to the interview.
3. Proceedings are on the basis of an interview guided by specifying topics related to the research hypotheses.
4. It is focused on the experience of the respondent regarding the situation under study.

The method of using a semi-structured interview usually starts with indirect questions to build up a framework with the respondent. It then explores the specific topics that the interviewer has in mind. This type of interview also provides the interviewer the freedom to investigate different areas and to raise queries during the course of the interview (Naoum, 2012).

3.2.2.3 Structured interview

All structured interviews are conducted in the same manner, with the questions presented in the same order and with the same wording to all the interviewees. The researcher has total control over the questionnaire throughout the entire process of the interview. The questions used in this technique will typically start as 'open' questions, but will move towards a 'closed' question format. The main advantages of the structured interview are (Naoum, 2012):

- The answers are more accurate
- The response rate is high, especially if the interviewees are contacted directly
- The answers can be investigated with finding out why the particular answers are given

From this section it is understood that there are several methods for implementing the interview technique for the gathering of data. The two interviewing methods used in this study are the unstructured and semi-structured interviewing methods. These methods were chosen as knowledge from participants in the low cost housing industry was essential in choosing the different factors and assessment criteria, as discussed in the following section.

3.2.3 Data collecting procedure

As mentioned, in the previous sections the data collecting procedure consisted of literature studies and interviews. A broad and insightful background study on low cost housing was conducted before the initial set of interviews was commenced. The literature included factors relating to low cost housing in South Africa and internationally. Current housing systems available were analyzed to determine what makes one system different from another. The analysis focused on the advantages and disadvantages, and also the successes of implementing these systems. The research also identified the current housing conditions of South Africa, the climatic conditions and the housing materials, walling systems and typologies used in South Africa.

The initial set of interviews can be described as *unstructured interviews*, as mentioned in Section 3.2.2.1, which were conducted to obtain more information on the current housing conditions and challenges experienced by the various role players. The interviewees identified challenges for implementing alternative building technologies and factors to consider when choosing between different housing systems. These interviews were conducted with two municipal officials in the Cape Winelands, one official from Western Cape provincial government, who manages housing delivery, and also a contractor in the low cost housing industry.

The individual interviews used in this study are considered as a suitable manner to collect data from people. The main advantage of these interviews is that each person is able to respond to the questions, and ask questions in order to understand the context. Comments get exchanged according to the experiences and opinions of the person being interviewed.

The information gathered from the unstructured interviews was used with further research on low cost housing projects and sustainability factors which should be implemented to develop more sustainable communities. This information was then used to form *semi-structured interviews* with a manager of housing delivery from the City of Cape Town, a national housing programme employee and consulting role players from the NHBRC and Stellenbosch University.

The semi-structured interviews were based on a set of questions, used for gathering information, but provided the interviewee the opportunity to suggest more factors that had not been considered yet. The first part of the questionnaire aimed to highlight the main aspects of factors affecting the choice between housing systems. The second part asked the participant to provide insight into the individual factors and sub-factors and the third part defined the importance of the relevant factors. Here a participant had to rank the factors according to the importance from his/her point of view for illustration purposes, bearing in mind that some factors may have equal importance.

This technique enabled the researcher to define the assessment measures, as the participants could suggest measures to consider. This method for establishing factors is useful as it is easy to understand and explain the context of a situation face-to-face with a participant. The interviews were conducted where and whenever it was suitable for the participant, after he/she agreed to participate in the study.

The data collecting technique used was an iterative process as each interview has its own insights and the new information gathered from interviews was useful to include in future interviews. Figure 3.1 illustrates the data collecting procedure.

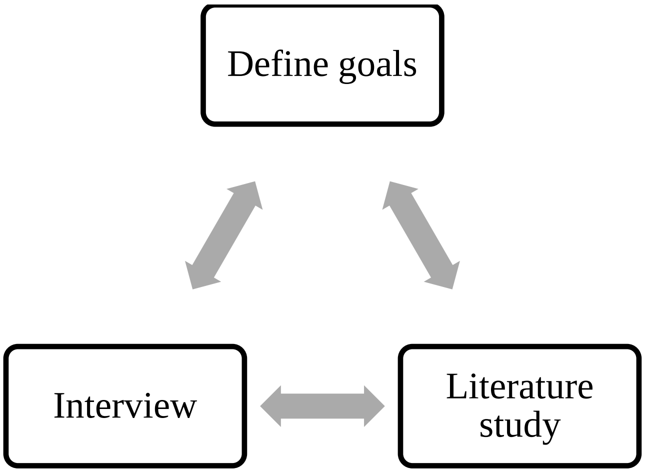


Figure 3.1 Data collecting procedure

3.3 Ethical considerations

The methodology of the research also includes ethical considerations. These considerations were regarded as minor ethical issues, due to the nature of the study. The purpose of the interviews was to gain knowledge from interviewees related to the low cost housing industry. Their knowledge would be used to develop a multi-criteria assessment tool to choose between housing systems.

The possible ethical issues identified for this study included:

- Issues of confidentiality and privacy
- Intrusiveness of participants time
- Informed consent

To address the possible problems mentioned, an ethical procedure is followed to counteract these problems. The process starts by receiving approval from the institution the researcher represents to allow interviews to be conducted. Individuals working in the low cost housing industry or known to have knowledge of the industry are then identified and contacted for a possible interview.

The approach for establishing an interview is with a letter of consent, which includes a brief background of the study, the purpose of the research, purpose of the interview and details of the researcher and the supervisor. The letter also clearly indicates that participants to this study may withdraw their participation at any time during the study without any penalty.

On the consent to participate the interviewees are asked to provide where and when they would want to meet, if they are willing to participate. The interviews were conducted in and around Cape Town and in two towns in the Cape Winelands district.

The institution the researcher represents, Stellenbosch University, and the research ethics committee of the Department of Civil Engineering have approved this procedure. Appendix A provides the proof of the approval.

3.4 Identifying a multi-criteria decision-making model

The multi-criteria assessment tool used in this study was selected through research on multi-criteria decision-making models. The study included decisions that are quantitative and qualitative in nature. Decisions can also consist of information that is uncertain or where no knowledge of the subject is available.

These were some of the factors to consider when choosing a decision-making model for this study. The research included studies on other multi-criteria decisions, such as material and motorcycle selection. These examples proved to make the same type of decisions experienced in this study, which are subjective in nature.

Further research included journals on decision-making, where many multi-criteria decision-making models were identified. It was decided to make use of the Evidential Reasoning Approach. The selection process of this approach is further described in Chapter 4.

In the final part of the study the factors will be proposed as a user-friendly assessment tool. This assessment tool could be used by low cost housing developers or government institutions. The assessment tool could aid these role players in choosing between housing systems to develop new low cost housing settlements.

3.5 Chapter conclusion

This chapter discusses the methodology followed to identify the relevant factors needed to develop an assessment tool for the choice between different housing systems. The chapter provides the aims and objectives of the study followed by the methodology used to complete these aims and objectives.

It was decided that a qualitative research approach would be used to obtain the necessary information, with the use of unstructured and semi-structured interviews as data collecting techniques. The strengths and weaknesses of the qualitative research approach are also subsequently discussed.

The data collecting procedure implemented for gathering the required information is discussed, with Figure 3.1 as a summary of the process. The ethical procedure used for this methodology is also discussed.

A brief methodology used for identifying a multi-criteria decision-making model applicable to this study is described. The identification of the multi-criteria decision-making model used in this study is discussed in detail in Chapter 4. Finally, the factors and decision-making model identified would be combined to develop a user-friendly assessment tool.

Chapter 4

Multi-criteria decision-making

This chapter describes the methodology used to make multi-criteria decisions, which would facilitate the choice between alternative housing systems.

This chapter also reflects on the complexity of multi-criteria decision-making and provides a brief overview of the different types of multi-criteria problems that may be encountered. A step-by-step approach is followed for addressing multi-criteria decision-making, which starts with choosing the decision-making team and weighing the factors. Thereafter, the decision-making models are discussed in detail. Figure 4.1 shows the chapter outline.

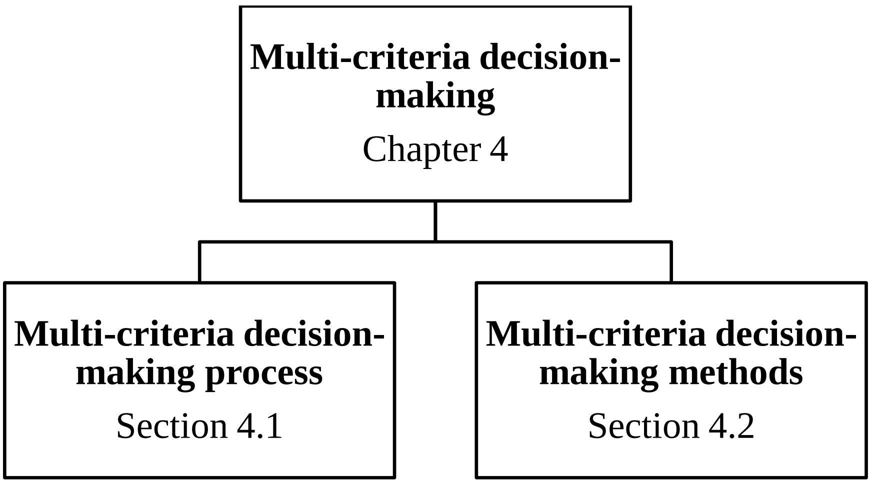


Figure 4.1 Chapter 4 outline

4.1 Multi-criteria decision-making process

Decision-making forms a part of everyday life and the decisions that are made have their own individual consequences. Most decisions require the balancing of multiple factors that have to be considered in correlation with each other to ensure the most suitable outcome. This can lead to very complex decision making. When a housing system is required it also involves a complex decision-making process. Such a decision usually incorporates a large number of factors, which should be measured and evaluated simultaneously.

These factors also have an effect on one another, and in many instances, if one factor improves another may often weaken as an effect. When selecting a housing system there are *qualitative* and *quantitative* terms to consider. Therefore, it is important that the decision maker(s) have the necessary experience to provide professional and subjective judgment where data cannot be analysed in a quantitative manner.

Harrison (1995) stated that it is customary to focus on one or more of three elements: the decision-making process, the decision maker, and the decision itself. For the purposes of this study, the decision which has to be made is known. Therefore, this chapter will discuss the decision-making process and briefly discuss the decision maker.

The objective of this chapter is to research multiple decision-making models and to choose the appropriate model for the selection of the most suitable housing system for a low cost housing project.

4.1.1 Overview of process

Decision-making has become more important with global markets becoming more competitive. Many decisions may affect resources such as labour, materials and non-recoverable capital funds and, therefore, well-informed decisions should be made. Thus, it is essential for decision makers to devote much of their time and effort to solve problems to the best of their abilities (Sönmez, Yang & Holt, 2001).

Decisions made in the construction industry are typically accompanied by conflicting characteristics that need to be considered. Therefore, these situations can be formulated into multi-criteria optimisation problems in order to help with the decision-making process (Mela et al., 2012). This idea is supported by Xu and Yang (2005) who state that multi-criteria decision-making refers to making decisions with multiple and usually conflicting criteria.

These decisions become even harder once there are subjective factors involved. A systematic procedure could act as an aid to such complex decision-making. According to Sönmez et al. (2001), a decision is complex and difficult where the following conditions apply:

- Multiple factors exist, which can be quantitative or qualitative in nature
- Uncertainty and risk is involved
- Multiple decision makers may be involved
- The decision (input) data may be vague, incomplete or imprecise

Hence, *multi-criteria decision-making (MCDM) methods* are introduced, which are used for making decisions in the presence of multiple factors. As mentioned previously, these decisions consist of multiple factors which can be quantifiable or qualitative in nature. The objectives are in many instances contradictory, therefore, the solution may be highly dependent on the preferences of the decision maker. The result can also be dependent on a group of decision makers, where each has their own point of view, which should be resolved in a framework of considerate and mutual compromise (Pohekar & Ramachandran, 2004).

There are typically two types of multi-criteria decision-making problems, due to the various problem settings.

- The first type of MCDM problem has a finite number of alternative solutions, and
- The second has an infinite number of solutions.

Typically, problems that are related to selection and assessment have a limited number of solutions, where problems consisting of design may have any number of solutions (Xu & Yang, 2005). This study will focus on multi-criteria with a finite number of alternatives, due to the alternatives being limited to what is accepted within the existing framework of policy and legislation as discussed in Section 2.3.

Multi-criteria decision-making methods may further be subdivided into *multi-objective decision-making* (MODM) methods and *multi-attribute decision-making* (MADM) methods. These methods may also include priority based, outranking, distance based and mixed methods for various problems. Each method consists of its own characteristics, and can also be described as deterministic, stochastic or fuzzy methods (Pohekar & Ramachandran, 2004).

These methods share the mutual characteristics of conflict among factors, incomparable units and difficulties in selection of alternatives. *Multi-objective decision-making* consists of alternatives which are not predetermined, but instead a set of objective tasks is optimised subject to a set of limitations. The most suitable and efficient solution is then chosen. *Multi-attribute decision-making*, on the other hand, consists of a number of alternatives evaluated against a set of attributes which are often hard to quantify. The most suitable alternative will then be selected by comparing the alternatives with respect to each attribute (Pohekar & Ramachandran, 2004).

For the purposes of this study, the alternatives are known and are then compared against each other with respect to the factors. Therefore, MADM methods will be most suitable to solve the problem in view of the nature of decisions to be taken for choosing an appropriate housing system.

It is clear that the decision-making process for choosing the most suitable housing system is very complex. Therefore, it has been decided to simplify the process with a step by step breakdown. Figure 4.2 provides a simplified illustration of this process, where it is subsequently discussed.

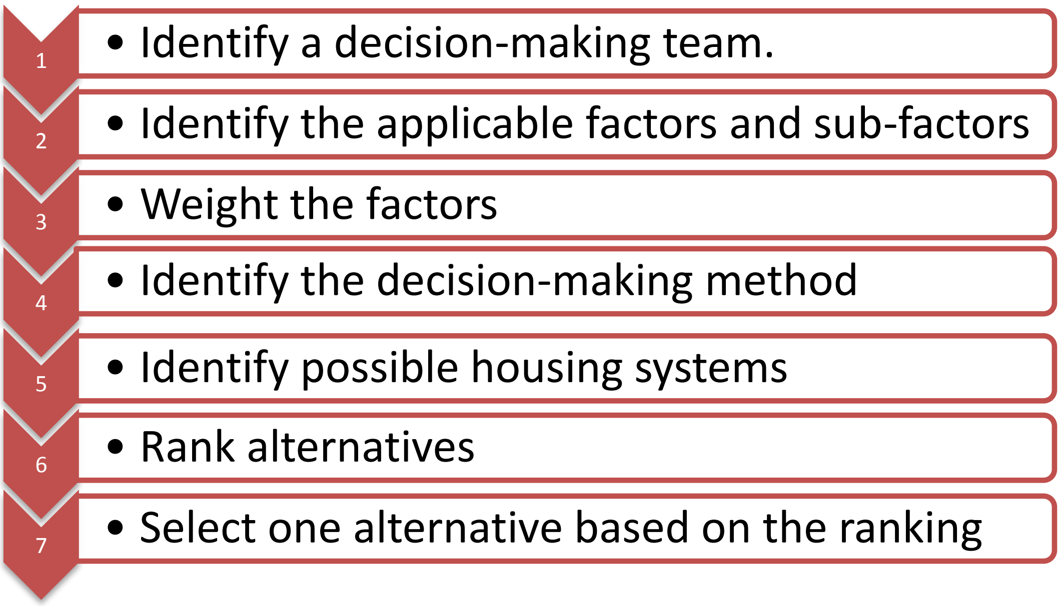


Figure 4.2 Steps in the decision-making process

4.1.2 Identify a decision-making team

The role of the decision-making team is to allow the opportunity for all the role players to provide their input into a decision. In many instances, it may happen that the decision-making committees consist of individuals whose opinion is much more important or reliable than the other members of the group. This may be due to experience or a hierarchical order in the work environment. Such groups are known as heterogeneous groups. However, in other circumstances it may occur that all of the team members have equal importance and their input into the decision should be ranked equally. This type of decision-making group is known as a homogenous group.

When there is more than one decision maker, it can lead to conflict when deciding which factors are more important. Therefore, in this study the fuzzy approach is used to rank the factors. The fuzzy assessment will provide the relative importance of a factor according to the individual decision maker's opinion. The various opinions are then combined and the importance of the factors is calculated with Equation 4.1, as discussed in this section.

Fuzzy assessments are expressed through probabilities that vary. Fuzzy values range between 0 and 1, where 0 represents a value of non-conformance and 1 a value of absolute conformance.

When fuzzy assessments are generated by decision makers, it can be aggregated via several methods. Chou, Chang and Shen (2008), stated that the most popular of these methods include the mean, median, max, min and mixed operators. Nevertheless the mean, or also known as the average, operator is the most commonly used aggregation method. The problem, however, arises when the importance (or reliability) of individual decision makers differs in practice as the levels of expertise vary (Chou et al., 2008).

Therefore, the goal of a heterogeneous group is to ensure that individuals with more experience and expertise in a subject provide a greater contribution to the decision, to essentially reach the main goal of the project. Consequently, Chou et al. (2008) included Equation 4.3 into the weighting process, as described in Section 4.1.4.

The assumption is made that the committee consists of *k* decision makers (D_t, t = 1, 2, .., k), who are responsible for weighting *n* factors (C_j j = 1, 2, ..., n) according to their importance. The degrees of importance, or reliability, of the decision makers is symbolised with I_t, t =1, 2, ..,k, where I_t Є [0, 1] and $\sum_{t=1}^{k} I_t = 1$. Thus, if the degree of importance of the decision maker is included in the fuzzy weights, ϖ_j, then the degree of importance is defined as follows (Chou et al., 2008):

$$I_t = \frac{d(\varpi_t)}{\sum_{t=1}^{k} d(\varpi_t)} \qquad \text{Equation 4.1}$$

Where $d(\varpi_t)$ provides the defuzzified value of the fuzzy weight by making use of the signed distance. However, if $I_1=I_2=I_k=1/k$, then the decision-making group is known to be homogenous. The decision-making team will have the responsibility of choosing the applicable factors and providing each with the necessary weight according to their contribution to the decision. This is discussed in the following sections.

4.1.3 Identify the applicable factors and sub-factors

The factors with their respective sub-factors form an important part of this study. The factors and sub- factors were developed through extensive study, which consisted of past studies, professional opinions, and studies on current housing systems that are available. The following factors and sub- factors are discussed in Chapter 5:

- Cost
- Construction Time
- Quality
- Environmental performance
- Housing density
- Alteration capabilities
- Resource availability
- Additional features

These factors and sub- factors can be used as a basis for specific projects, and can be adapted in order to fit the needs of specific situations. In the following section the method for weight assignment to the factors is described in order to compare the housing systems in this study with each other.

4.1.4 Weighting method

It is necessary to assign weights to the factors according to their contributions towards the overall objective. These weights should be assigned to both the factors and sub-factors to help calculate the most appropriate outcome for the various alternatives.

Several methods for weight assignment have been proposed in literature (Chou, Chang & Shen, 2008; Barron & Barrett, 1996; Wang & Parkan, 2005). The weights are used to spread the sub- factors assessments to their respective upper levels (Sönmez, Yang & Holt, 2001). In many cases it is easier for experts to express their opinions in linguistic terms, rather than real values. This is because a value with a range may be more suitable to qualitatively express the subjectivity of a person's impressions.

For this study, it has been decided to make use of linguistic terms instead of crisp values to express the weighing of the different factors that is used in the decision-making model. Thus, in order to convert the linguistic terms into a value range, fuzzy numbers will be used.

4.1.4.1 Fuzzy additive weighting description

To understand the proposed method it is necessary to understand the following definition. A fuzzy set A= (a, b, c, d) on R, $a < b < c < d$ is called a trapezoidal fuzzy number if its membership function is as in Equation 4.2, in this section. The fuzzy number Ñ is characterised with the membership function $\mu_{\tilde{N}}(x)$ (Chou et al., 2008).

$$\mu_{\tilde{N}}(x) = \begin{cases} \frac{(x-a)}{(b-a)}, & a \leq x \leq b, \\ 1, & b \leq x \leq c, \\ \frac{(x-d)}{(c-d)}, & c \leq x \leq d \\ 0, & otherwise, \end{cases}$$ Equation 4.2

Where *a*, *b*, *c*, *d* are real numbers, Figure 4.3 provides an illustration of the trapezoidal fuzzy number that can be denoted by (*a*, *b*, *c*, *d*). The *x* in interval [*b*, *c*] gives the maximal grade of $\mu_{\tilde{N}}(x)$; this also indicates the most feasible value of the evaluation data. It is clear that the constants *c* and *d* provide the lower and upper bounds of the available area for the evaluation data. Therefore, these constants reflect the fuzziness of the evaluation data (Chou et al, 2008).

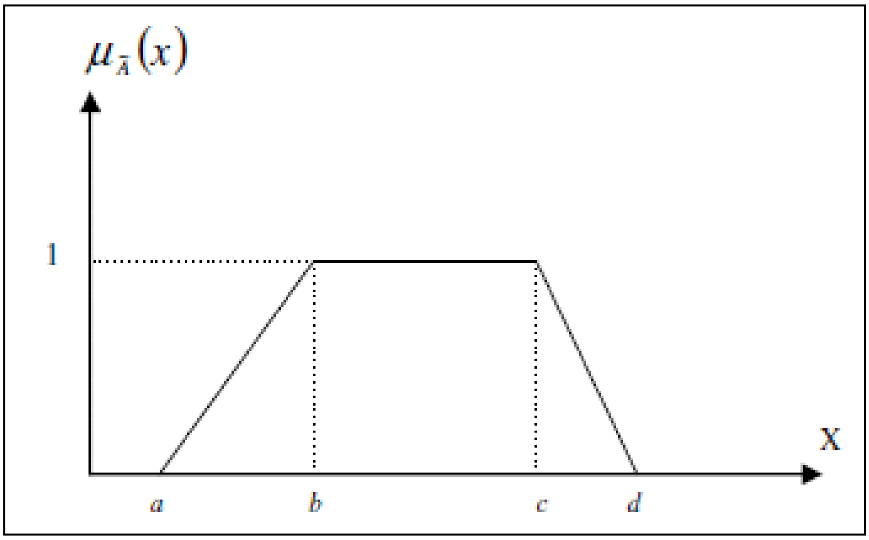


Figure 4.3 A trapezoidal fuzzy number A (Chou et al, 2008).

In this study, fuzzy numbers represent aggregated fuzzy weights and total fuzzy scores. Thus, to weight the different factors against each other, the fuzzy numbers are transformed into crisp true numbers to enable the ranking of the factors. This is done through the use of conversion scales. For the purposes of this study a conversion scale of 1 to 5 is used to indicate the importance weight of the different factors (Chou et al, 2008).

With the problem of choosing housing systems in mind and from the literature examples, it was decided to make use of the linguistic terms and the various values as indicated in Table 4.1. The factors that are identified would have different importance for different decision makers. The variables chosen were decided as a simplistic approach to identify the importance of the factors to the various role players.

Table 4.1 Linguistic variables and fuzzy numbers for the importance weight

Linguistic variables	Fuzzy numbers (a, b, c, d)
Unimportant (UI)	(0, 0, 0, 3)
Low importance (LI)	(0, 3, 3, 5)
Moderately important (MI)	(2, 5, 5, 8)
High importance (HI)	(5, 7, 7, 10)
Very important (VI)	(7, 10, 10, 10)

Following is a four-step method for determining the individual weights of the factors that are used in the decision-making process.

4.1.4.2 Summary of the fuzzy additive weighting system

With the information provided in the previous sections a four step procedure is described in order to obtain the rank of the factors that will be used in the decision-making model (Chou et al, 2008):

1. According to Chou et al. (2008), the first step of ranking the factors is choosing a committee of decision makers. This committee of decision makers will have the responsibility of choosing the most appropriate housing system for a project. The importance for compiling a committee is discussed in Section 4.1.2.

2. After the decision-making team has been established, it will be important to determine the degree of importance (or reliability) of the decision makers. If the degree of importance of the decision makers is equal, then the committee is known to be a homogeneous group. If the degree of importance of the group differs, the group will be known to be heterogeneous. This is also discussed in more detail in Section 4.1.2.

3. In step 3, the linguistic weighting variables, as indicated in Table 4.1, are introduced. These are used to assist the decision makers to assess the importance of the factors and aggregate fuzzy weights to the individual factors. Assume the linguistic weight is expressed by $\varpi_{jt} = (a_{jt}, b_{jt}, c_{jt}, d_{jt})$, where j = 1, 2, ..., n, is the factor weight; and t = 1, 2, ..., k, is the decision maker, for the subjective factor C_1, C_2, ...,C_h, by decision maker D_t. The aggregated fuzzy factor weight, $\varpi_j = (a_j, b_j, c_j, d_j)$, of factor C_j, which is assessed by k decision makers will be expressed by Equation 4.3.

$$\varpi_j = (I_1 \times \varpi_{j1}) + (I_2 \times \varpi_{j2}) + \cdots + (I_k \times \varpi_{jk}),$$ Equation 4.3

Where $a_j = \sum_{t=1}^{k} I_t d_{jt}$, and similar for b_j, c_j and d_j.

4. The final step of this procedure is to convert the fuzzy weights of the factors into a single unit and normalise the weights to construct a final weight vector. In order to convert the fuzzy weights, the signed distance procedure is adopted as described by Chou et al. (2008), this is done by Equation 4.4. The conversion of $\varpi_j$is expressed by $d(\varpi_j)$.

$$d(\varpi_j) = \frac{1}{4}(a_j + b_j + c_j + d_j), \qquad j = 1, 2, \ldots, n.$$ Equation 4.4

Thus, the crisp value of the normalised weight for factor C_j, expressed as W_j, with

$$W_j = \frac{d(\varpi_j)}{\sum_{j=1}^{n} d(\varpi_j)} \qquad j = 1, 2, \ldots, n,$$ Equation 4.5

Where $\sum_{j=1}^{n} W_j = 1$. Finally the weight vector is $W = [W_1, W_2, \ldots, W_n]$.

Once the weights of the factors have been estimated, it can be used in the *Evidential Reasoning Approach* as discussed in Section 4.2. Appendix B provides an example of implementing this weighing method.

4.1.5 Identify the decision-making method

The decision-making process has by now identified the decision-making team and identified the importance of the decision makers. It has identified the factors, which will be used to assess the housing systems. A weighting method has been identified and weighted the applicable factors according to their importance for a housing project.

This part of the process identifies the decision-making model that will be used to choose between alternative housing systems. This section, as further discussed in Section 4.2, identifies decision-making models through literature and chooses the model that will be fit for the purpose of this study. It further describes the implementation procedure for this model and discusses the approach of the model.

4.1.6 Identify possible housing systems

This step of the study requires knowledge of the housing situation that is experienced, housing challenges and the factors which play a role in the low cost housing industry. This was discussed in the literature review, Chapter 2. Different aspects of the housing system were also discussed in Chapter 2. These aspects indicate the factors which are considered in this study.

Government institutions or project developers usually receive tenders when commencing a low cost housing project. It may happen that an overload of tenders is received, and a filtering process needs to be implemented. At this moment one would need a clear indication of the goal of the project and filter the alternatives according to the objectives.

This study will not identify possible housing system that can be assessed. Each project has its own set of goals and objectives and each project will receive different tenders and housing systems that can be used. The purpose of this study is to evaluate the housing systems received in the tenders through the assessment tool proposed in this study. The alternatives for this study will be indicated with the symbol A and a set of alternatives will be denoted as (A_1, A_2, ..., A_k).

4.1.7 Rank and select alternatives based on the ranking

The final two steps of the decision-making process are to:

1. Rank alternatives
2. Select alternative based on ranking

These two steps should be implemented with the use of this study. This study should then identify the most suitable alternative housing system for a specific project.

4.2 Multi-criteria decision-making methods

As part of the decision-making process discussed in the previous section, Section 4.1, it is important to identify a decision-making method that can be used in this process. This section identifies the most common decision-making methods used and discusses the most applicable one for this study. Figure 4.4 provides an outline of this section.

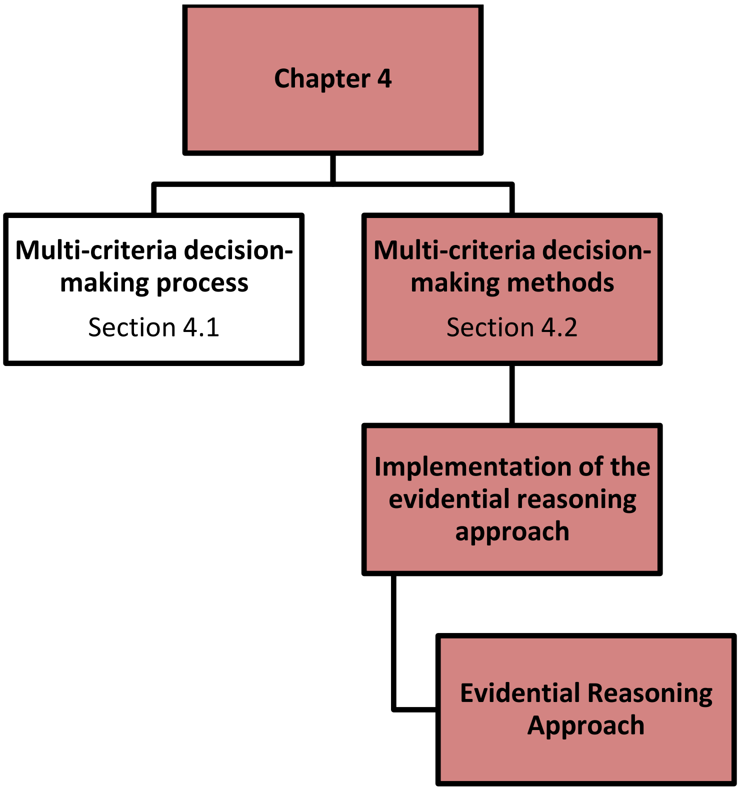


Figure 4.4 Section 4.2 outline

As mentioned, the process of decision-making is caused by numerous conflicting factors. Therefore, multi-criteria decision-making (MCDM) methods will be used to rank the alternative housing systems. Consequently, the highest ranked system would be recommended as the best choice. However, with the variety of decision-making methods available, the decision maker(s) often struggles to choose the most appropriate method (Athawale & Chakraborty, 2012).

Athawale and Chakraborty (2012) found that in at least 40% of the cases the different decision-making methods deliver different results from each other. The reason for this is due to the following factors:

- The methods use factors weights differently in their calculations
- The methods differ in their approach of selecting the best alternative
- The methods have some peculiar features and inherent logic reflecting the specific characteristics of the alternatives compared
- Many methods attempt to scale the objectives, which affects the weights already chosen
- Some methods introduce additional parameters which affect the top ranked solution

Consequently, the different types of MCDM methods require certain types and amounts of data to be used successfully. Much research has been conducted regarding MCDM methods related to different decision-making fields (Athawale & Chakraborty, 2012; Mela, Tiainen & Heinisuo, 2012; Bredell, 2003; Xu & Yang, 2001).

The different methods that were examined in these publications include:

- Simple additive weighting (SAW) method
- Weighted product method (WPM)
- Weighted sum model (WSM)
- Analytical hierarchy process (AHP) in various forms and revisions
- Technique for order preference by similarity to ideal solution (TOPSIS) method
- Multi attribute utility theory (MAUT)
- Simple Multi-Attribute Rating Technique (SMART) method
- Elimination and choice expressing realty (ELECTRE) method
- Evidential Reasoning (ER) approach

Most of the research investigated, supports the use of the AHP approach and stated that it is the most popular technique for MCDM, especially where the implementation of quantitative and qualitative aspects is needed (Bredell, 2003; Pohekar & Ramachandran, 2004; Xu & Yang, 2001; Sönmez, Yang & Holt, 2001; Wang & Elhag, 2008).

The use of the AHP method is well-known, however, Xu and Yang (2001) have considered its weaknesses and developed a decision-making model which improved this method. They called it the ER approach. To better understand the ER approach they did a comparison of these two methods to show where improvements have been implemented.

Research showed that the use of the ER approach is not as well-known as the AHP, but according to XU and Yang (2001) it provides a fair amount of advantages above the AHP (Sönmez, Yang & Holt, 2001). Therefore, it has been decided that for the purpose of this study, of choosing a housing system, the applicable *multi-criteria decision-making* methods may be narrowed down to these two previously named methods.

As both mentioned methods utilise a hierarchical structure to model a *multi-attribute decision analysis* (MADA) problem, they found it useful to compare these two methods. The ER approach differs from the AHP as follows.

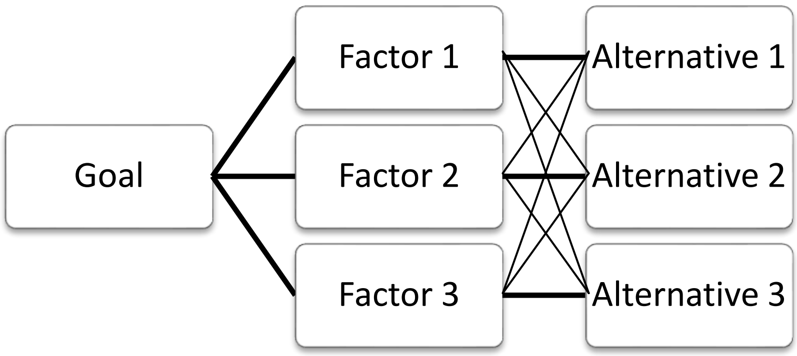
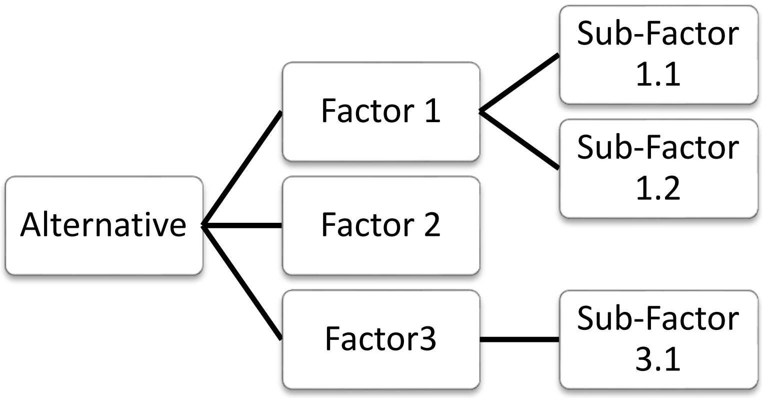
1. The alternatives do not form part of the hierarchical structure in the ER framework, while in the AHP all the alternatives consist of the bottom level of hierarchy. This is according to Xu and Yang (2001) the most criticised principle of the AHP. Table 4.2 provides a simplified example of the difference.

2. The ER approach uses a generalised decision matrix. The elements of the matrix are distributed assessments of the attributes using the degree of belief theory. The ER framework does have a special scenario where a conventional matrix is used, where each element of the matrix is a single number. The AHP, on the other hand, is a decision matrix which is seen as a comparison matrix describing the relative importance of one attribute over another.

3. The ER approach as described in Section 4.2.2 aggregates the distributed assessment (degrees of belief) of the lower level attributes to higher level attributes progressively. AHP generates average scores by using pair-wise comparison matrices.

Furthermore, the ER approach utilises the theory of *Degree of Belief* (DoB) as a preference elicitation tool. The DoB is described by Sönmez et al. (2001), as the degree of expectation that an alternative will provide a certain result according to a particular criterion. The DoB depends on the knowledge and experience of an individual regarding a certain subject. Therefore, it is essential to recognise that the DoB involves the ambiguity, uncertainty and imprecision of human decision-making. In essence, the decision maker expresses his or her knowledge and experience in probabilistic terms, which is used as a tool to overcome the imprecision and ambiguity of human decision-making (Sönmez, Yang & Holt, 2001; Wang, Yang, Xu & Chin, 2006; Wang & Elhag, 2008) .

Table 4.2 Comparison of the AHP approach and the ER approach

Analytical Hierarchy Process	
Evidential Reasoning Approach	

Through the comparison of the AHP and the ER approach it is shown that the ER approach may be described as an improvement of the AHP. Although the ER approach is not as common as the AHP it is decided that it will be fit for the study at hand. It incorporates measures for the imprecision and ambiguity of human decision-making, which will be important when choosing a housing system for a low income community. It also assesses each alternative alone, where the AHP uses pair-wise comparison for decision-making. The following section will discuss the implementation of the evidential reasoning approach.

4.2.1 Implementation of the Evidential Reasoning Approach

When making important decisions, such as choosing a housing system for low cost developments, diverse factors have to be considered. The factors used in this study are described in Chapter 5. It is clear that these factors are hard to quantify and in some instances imprecise.

Sönmez et al. (2001) describes the Evidential Reasoning (ER) Approach as a hierarchical evaluation process, where all the decision factors are aggregated into one, namely the goal of the problem. Table 4.3 provides a stepwise approach of the ER process.

Table 4.3 Summary of the steps to rank the alternatives using the ER approach (Sönmez, Yang & Holt, 2001)

Steps	Description
Step 1	Present a decision-making problem in a hierarchical structure.
Step 2	Assign weights to the individual (main) problem factors and their sub-factors, if it is applicable.
Step 3	Choose an assessment method for a factor, whether it is quantitative or qualitative in nature.
Step 4	Transform the assessments between a main factor and its associated sub-factors if they are assessed using different methods (quantitatively or qualitatively).
Step 5	Evaluate each alternative according to the lowest (bottom) level factors in the hierarchical structure.
Step 6	Quantify the qualitative assessments at the top level if necessary and determine an aggregated value for each alternative.
Step 7	Rank the alternatives based on these aggregated values and (normally) choose the highest rank.

The following section uses the steps in Table 4.3 to describe the Evidential Reasoning Approach in further detail.

4.2.2 Evidential Reasoning Approach

The Evidential Reasoning Approach differs from traditional multi-criteria decision analysis (MCDA) methods as it uses an evidence-based reasoning process to reach a conclusion. The ER approach was designed to especially include MCDA problems, which consist of quantitative and qualitative aspects with uncertain and subjective information (Xu & Yang, 2005).

The ER approach was developed by Yang and Xu (2001), and has been used for several multi-criteria decision-making problems. Such examples include contractor selections (Sönmez, Yang & Holt, 2001) and motorcycle selections (Yang & Xu, 2002). An example of the ER approach is available in Appendix C. This section discusses the ER approach in further detail.

The decision maker is able to choose an alternative a_i from a limited number of alternatives $a_1, a_2, a_3, \ldots, a_n$ (i = 1, 2, 3, …, n). These alternatives should then be evaluated according to p main factors $c_1, c_2, c_3 \ldots, c_p$. Within the main factors there may be any number of sub- factors

k to give $c_{i1}, c_{i2}, c_{i3}, \ldots, c_{ik}$ (i = 1, 2, 3, …, p). Once the factors and sub-factors are chosen, it will be necessary to assign weights to the individual factors $\omega_1, \omega_2, \omega_3, \ldots, \omega_p$ and also to the individual sub-factors $\omega_{i1}, \omega_{i2}, \omega_{i3}, \ldots, \omega_{ik}$ (i = 1, 2, 3, …, p) to show the relative importance of each factor according to the decision that has to be made (Sönmez, Yang & Holt, 2001).

Xu and Yang (2001) implemented the ER approach through a belief structure in order to represent an assessment as a distribution. They explained the ER approach as follow. For example, if a housing system should be chosen, the following five evaluation grades could be chosen:

$$H = \{H_1, H_2, H_3, H_4, H_5\} \quad = \{Poor, Fair, Average, Good, Excellent\}$$

Therefore, if there are n alternatives, A_j (i = 1, 2, ..., n) and p factors, C_i (j = 1, 2, ..., p) to consider, the five evaluation grades can be denoted as follows. If an assessment with factor C_1 and alternative A_1 is considered the belief structure will be denoted as in Equation 4.6.

$$S(C_1(A_1)) = \{(\beta_{1,1}, H_1), (\beta_{2,1}, H_2), (\beta_{3,1}, H_3), (\beta_{4,1}, H_4), \}(\beta_{5,1}, H_5) \qquad \text{Equation 4.6}$$

Where $1 \geq \beta_{n,1} \geq 0$ (n = 1, 2, 3, 4, 5) provides the degree of belief that the factor C_1 is assessed to the evaluation grade H_n. Thus, S (C_1 (A_1)) means that the factor C_1 is assessed to the grade H_n to a degree of $\beta_{n,1}$ x 100% (n =1, ..., 5) for the alternative A_1 (Xu & Yang, 2001).

It is important to recognise that there should not be $\sum_{n-1}^{4} \beta_{n,1} > 1$. However, according to Xu and Yang (2001), the ER approach is able to assess complete and incomplete assessments. S (C_1 (A_1)) can be considered a complete assessment if $\sum_{n-1}^{4} \beta_{n,1} = 1$ and an incomplete assessment if $\sum_{n-1}^{4} \beta_{n,1} < 1$.

In the ER approach, a MCDM problem with the factors (C_i), alternatives (A_j) and evaluation grades (H_n). Each attribute is represented using an extended decision matrix with S ($C_i(A_j)$) as its element at the i-th row and j-th column. S ($C_i(A_j)$) is represented as in Equation 4.7.

$$S\left(C_i(A_j)\right) = \left\{\left(H_n, \beta_{n,i}(A_j)\right), n = 1, \ldots, N\right\} \; i = 1, \ldots, M, \;\; j = 1, \ldots, K \qquad \text{Equation 4.7}$$

It is possible for each factor to have its own individual set of evaluation grades, which may differ from the other factors. For simplification of this study the evaluation grades will be the same for all the factors.

The ER approach makes use of an Evidential Reasoning algorithm, instead of aggregating average scores. These scores are developed on the basis of decision theory and the evidence combination rule, as described by the Dempster-Shafer theory, in order to aggregate belief degrees (Yang & Xu, 2002). It is this algorithm that makes the ER approach different from traditional MCDM approaches, as it is not necessary to aggregate average scores for the different factors.

In order to describe the evidential reasoning approach in more detail, it will be assumed that ω_i is the relative weight of factor C_i and is normalized in order to provide $1 \geq \omega_i \geq 0$ and $\sum_{i-1}^{L} \omega_i$ where L is the total number of factors in the same group sharing the same upper level factor in the factors hierarchy. For the purpose of easy explanation the Evidential Reasoning algorithm will be explained with the use of two factors with complete assessments (Xu & Yang, 2001).

Assume that the first assessment is provided as in Equation 4.6 and the second $S(C_2(A_2))$ as provided by Equation 4.8:

$$S(C_2(A_1)) = \{(\beta_{1,2}, H_1), (\beta_{2,2}, H_2), (\beta_{3,2}, H_3), (\beta_{4,2}, H_4), (\beta_{5,2}, H_5)\} \qquad \text{Equation 4.8}$$

The goal is then to aggregate these two assessments, $S(C_1(A_1))$ and $S(C_2(A_2))$, in order to generate a combined assessment $S(C_1(A_1)) + S(C_2(A_2))$. It is assumed that both $S(C_1(A_1))$ and $S(C_2(A_2))$ are complete. Thus,

$$m_{n,1} = \omega_1 \beta_{n,1} \text{ and } m_{H,1} = 1 - \omega_1 \sum_{n-1}^{5} \beta_{n,1} = 1 - \omega_1$$

$$m_{n,2} = \omega_2 \beta_{n,2} \text{ and } m_{H,2} = 1 - \omega_2 \sum_{n-1}^{5} \beta_{n,2} = 1 - \omega_2 \qquad \text{Equation 4.9}$$

Where each $m_{n,j}$ (j = 1,2) indicates the basic probability mass, which is essentially indicated by the decision maker, and each $m_{H,j}$ (j = 1,2) is the remaining belief for factor j unassigned to any of the H_n (n = 1, 2, 3, 4, 5).

The Evidential Reasoning algorithm then aggregates the basic probability masses to generate combined probability masses, represented by m_n (n =1, 2, 3, 4, 5) and m_H using the following equations:

$$m_n = k(m_{n,1}m_{n,2} + m_{H,1}m_{n,2} + m_{n,1}m_{H,2}), \text{ (n = 1, 2, 3, 4, 5)}$$

$$m_H = k(m_{H,1}m_{H,2}) \qquad \text{Equation 4.10}$$

Where,

$$k = (1 - \sum_{r-1}^{5} \sum_{\substack{n-1 \\ r \neq n}}^{5} m_{r,1}m_{n,2})^{-1} \qquad \text{Equation 4.11}$$

Hence, the combined probability masses can then be aggregated with the third assessment in the same manner. This process will be repeated until all the assessments are aggregated. It does not matter in which order the individual assessments are aggregated, as the final combined probability masses are independent (Xu & Yang, 2001).

Finally, the assessments' combined degree of belief β_n (n = 1, ..., 5) is calculated with:

$$\beta_n = \frac{m_n}{1-m_H} \quad \text{Equation 4.12}$$

Thus, the combined assessment for the alternative A_i can be presented as follows:

$$S(A_1) = \{(\beta_1, H_1), (\beta_2, H_2), (\beta_3, H_3), (\beta_4, H_4), (\beta_5, H_5)\} \quad \text{Equation 4.13}$$

Furthermore, an average score for A_i, represented by $u(A_i)$, is calculated as the weighted average of the scores (utilities) of the evaluation grades with the belief degrees as weights, or

$$u(A_1) = \sum_{i=1}^{5} u(H_i)\beta_i \quad \text{Equation 4.14}$$

Where $u(H_i)$ is the utility of the i-th evaluation grade H_i. Assume that the evaluation grades are distributed equally in the utility space, it will be given as follows:

$$u(H_1) = u\ (Poor) = 0.2$$

$$u(H_2) = u\ (Fair) = 0.4$$

$$u(H_3) = u\ (Average) = 0.6$$

$$u(H_4) = u\ (Good) = 0.8$$

$$u(H_5) = u\ (Excellent) = 1$$

In the case of incomplete assessments, a minimum value and maximum value are calculated for the assessment to provide an average score range for the assessment using the following equations:

$$u_{min}(A_1) = (\beta_1 + \beta_H)u(H_1) + \sum_{n=2}^{5} u(H_n)\beta_n \quad \text{Equation 4.15}$$

$$u_{max}(A_1) = \sum_{n=1}^{4} u(H_n)\beta_n + (\beta_5 + \beta_H)u(H_5) \quad \text{Equation 4.16}$$

An example of the assessment process as discussed in this chapter is available in Appendix C.

4.3 Chapter conclusion

In conclusion, it has been decided that the Evidential Reasoning Approach will be fit for the purposes of selecting an applicable housing system for a low cost housing development. It is important that this process begins with assigning an appropriate decision-making team with the necessary experience and with a clear objective.

Furthermore, it is important to decide which factors and sub-factors should be selected to achieve the set objectives. The relative weights of each factor according to their importance regarding the project goal should be computed. The relevant factors for this study are discussed in Chapter 5.

The Evidential Reasoning decision-making method was discussed and explained in detail in this chapter. This method implements both quantitative and qualitative data, which is both present when selecting a housing system for low cost housing developments. An example of both the weighting method and the Evidential Reasoning Approach from Sections 4.1.4 and 4.2 can be seen in Appendix B and C separately.

Chapter 5

Factors used for evaluation

When a house is constructed there are a variety of factors that need to be considered. Such factors include specifications dependent on user requirements and user needs, and are important to fulfil when commencing construction. Identifying user needs is important to establish functional and performance factors, which are used to provide a framework for providing a satisfying living environment. User requirements, however, differ from one community to another and relate to factors that are not necessarily a need, but a privilege (NHBRC, 2003).

This chapter will discuss the methodology used to identify the factors and will discuss each factor individually. It is important to recognise the distinctive link between certain factors and the impact they may have on each other. Some factors may have a direct impact on each other, where others may only have an indirect impact on each other.

5.1 Methodology

The objective of this chapter is to identify the relevant factors to consider when choosing a housing system for low cost developments in South Africa, which is a developing country. Figure 5.1 shows the methodology used for identifying the applicable factors.

The methodology for identifying factors is divided into three parts. The first part involves *unstructured interviews*, as discussed in Section 3.2.2, with government institutions, at provincial and municipal level in the Cape Winelands district and in Cape Town, and with a contractor in the low cost housing industry in the Cape Peninsula district. The interviewees were chosen due to their involvement and experience in low cost housing developments. The discussions with the participants identified challenges and problems with housing developments and factors they consider when planning a housing development.

The second part of the methodology consists of a literature review of important factors that need to be considered when choosing a housing system. As part of the literature review, completed developments are analysed, the advantages and disadvantages of existing housing systems are investigated, international trends are evaluated and housing norms and standards from South African institutions are used for establishing the factors.

The third part of the methodology consists of *semi-structured interviews* with industry participants, which includes a housing manager of the City of Cape Town, a national housing programme employee and consulting role players from the NHBRC and Stellenbosch University. The choice of interviewees was based on the participants' knowledge on low cost housing and their involvement and experience in low cost housing developments. With these semi-structured interviews more important factors are highlighted for the use of this study. The interviews are also used to evaluate the factors gathered from previous discussions and literature.

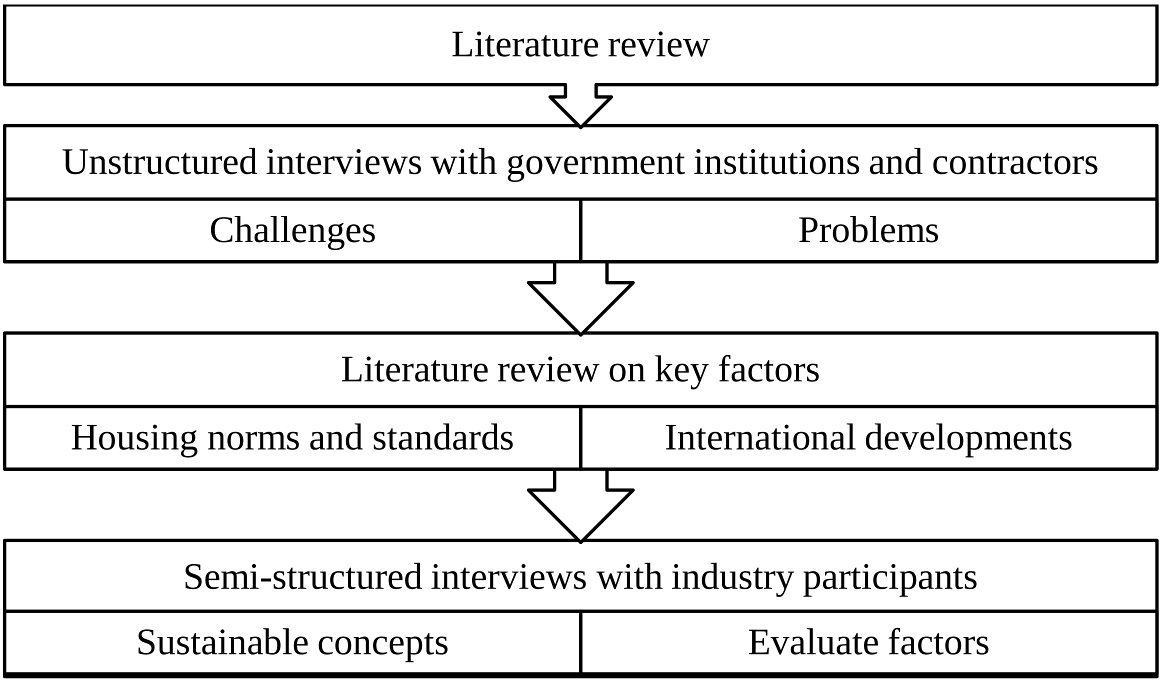


Figure 5.1 Methodology for identifying factors

5.1.1 Interview structure

The study used the methodology and interviewing techniques, as described in Chapter 3. This methodology is described in further detail in this section. The study started with a literature review to understand the housing situation experienced in South Africa and to identify the different challenges in the low cost housing industry. From the literature review a questionnaire was formulated for the use of unstructured interviews.

These interviews were conducted with provincial and local government employees and contractors in the field of low cost housing, as previously discussed. The interviewees were all involved in delivering housing developments and were experienced to make a decision between various housing systems.

These were exploratory interviews used to gain more knowledge of low cost housing and to identify factors and problems experienced in the industry. The aim of these questions was to:

- Identify factors important to these participants
- Identify problems experienced in the low cost housing industry
- Establish how tenders are evaluated
- Establish the norms and standards used for evaluation

The knowledge gained from these interviews lead to further research on the topics discussed and sustainable factors that can be used in the assessment tool. This information was then used to formulate semi-structured interviews, where information was required about the factors identified thus far. These interviews were conducted with consulting role players who research alternative housing systems and employees from the City of Cape Town and the Development Action Group (DAG), who are involved in choosing housing systems for new developments. The aim of the semi-structured interviews was to:

- Validate identified factors
- Gather information on identified factors
- Indentify assessment evaluations for the factors
- Identify the importance of the identified factors
- Ask for any additional comments or suggestions

These interviews, along with the literature, were then used to formulate the assessment tool, discussed in Chapter 6. The identified factors are discussed in the following section. The questionnaires are available in Appendix D.

5.2 Identified factors

The following section will discuss the factors, gathered using the above mentioned methodology. From this section it should be clear how the specific factors were chosen. The factors should also help choose the most suitable housing system for a low cost housing development, in South Africa.

In this section the assessment of each factor is explained. As discussed in Chapter 4, the factors are evaluated using five categories, namely; poor, fair, average, good and excellent. Where;

- Poor is regarded as the worst rating
- Fair is regarded as the second worst rating
- Average is regarded as the middle and most common rating
- Good is regarded as the second best rating
- Excellent is regarded as the best rating

This section shows the assessment for each factor after each discussion.

Figure 5.2 provides the hierarchy of the factors that have been identified and that will be used for choosing a housing system. These are discussed in the subsequent sections.

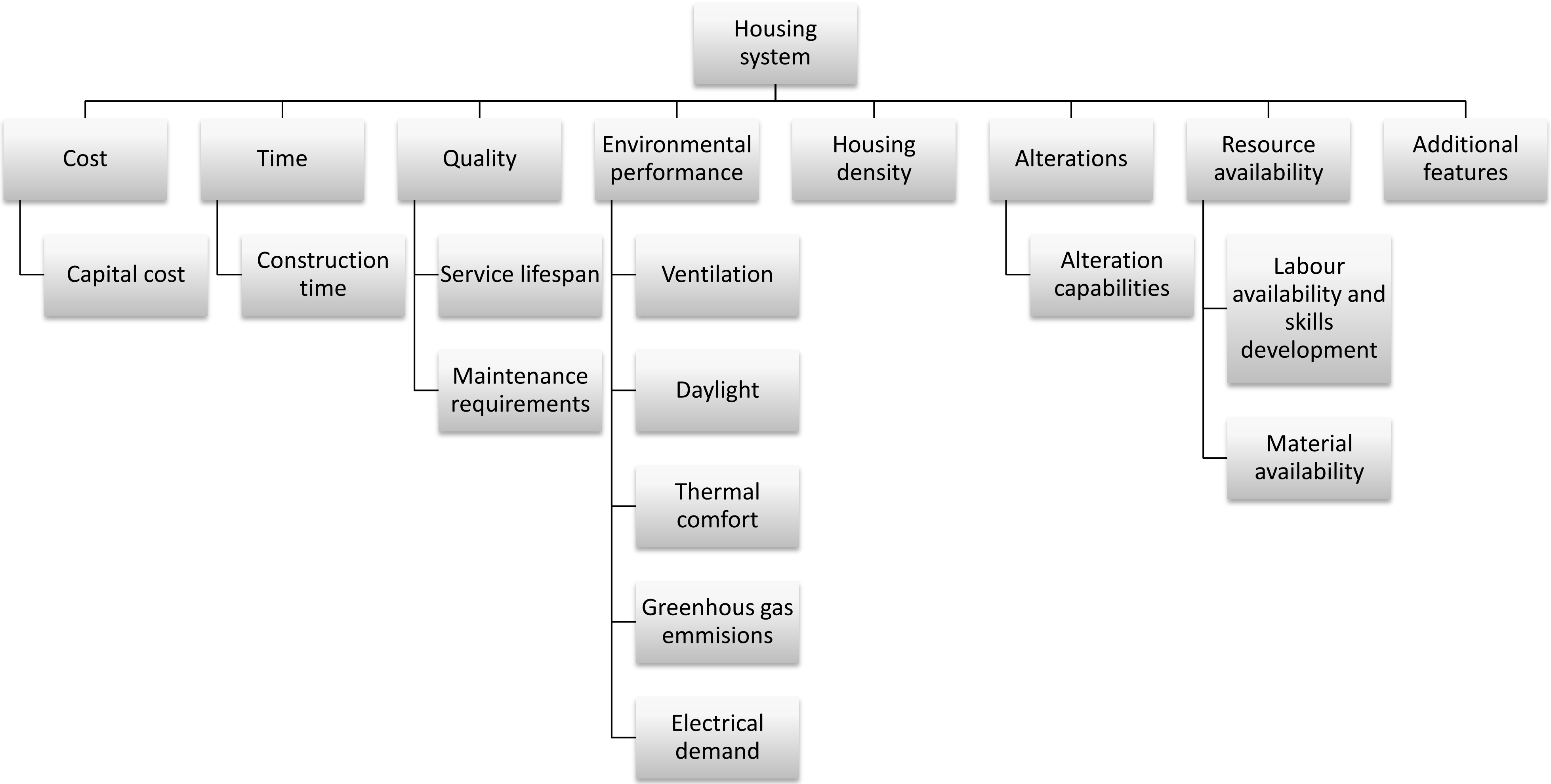


Figure 5.2 Identified factors

5.2.1 Cost

The South African government subsidises an amount of R160 573, as discussed in Section 2.3. This amount includes all the costs associated with the construction of a house including the land cost, civil services infrastructure, electrical infrastructure and the top structure. Therefore, careful planning is necessary when commencing with house construction.

When considering alternative housing systems, resource costs such as materials, labour and equipment costs should be considered before undertaking any construction project. Within alternative building systems different material costs may vary significantly. This may be influenced by the availability of the materials or the costs for producing it.

Labour costs are also hard to quantify, as some housing systems require much more labour than others. The different systems may also require different skills from labourers, which could increase the costs of the labour required. Another issue to consider with labour is the learning curve involved in producing the housing. When a new system is constructed it may take the labourers a longer period to erect, which will mean higher labour costs, but once the labourers get used to the system the erection time may decrease and in effect costs may reduce.

According to Keoleian, Blanchard and Reppe (2000), the direct capital costs are usually associated with the delivery of the house, which include, but not limited to, the design costs, land and development costs, costs of raw material, construction cost, equipment costs and transportation costs. However, the capital costs should also include the labour, management and training costs where necessary. The Western Cape Government provides a housing subsidy for low cost developments, as discussed in the literature review, Chapter 2, at an amount of R160 573 per house (Western Cape government, 2014). From interviews with participants in the housing industry, this amount is used as the norm when housing tenders are evaluated against each other (Rossouw, 2013; Steyn, 2014). Therefore, this will be used as the average cost within the decision-making model.

From interviews it was gathered that the size of the project may have a significant influence on the costs of using alternative building systems. Big projects will involve repetition of the construction of houses, which may in turn decrease the construction costs of alternative building systems. Therefore, it was decided, in order to provide a rational comparison of the various housing systems the houses should be evaluated on the unit cost and not the overall project cost. Table 5.1 will be used as the assessment criteria for different housing systems in terms of cost.

The various assessments indicated in Table 5.1 were gathered from interviews with individuals who are in control of housing tenders or who are aware of the prices of alternative building systems (Steyn, 2014; Galada, 2014; De Villiers G., 2013).

Table 5.1 Assessment criteria for cost

Cost	Capital cost
Excellent	Up to 10% less than R160 573 or less
Good	Up to 5% less than R160 573
Average	R 160 573
Fair	Up to 10% more than R160 573
Poor	Up to 15% more than R160 573 or more

5.2.2 Construction time

The term *construction time* refers to the duration for completing a project. According to Chan and Chan (2004) time plays an important role in the success of a project and therefore, it should form part of the factors when evaluating a housing system.

The construction time of a housing system is highly dependent on external influences such as the weather, suppliers or labour. These factors should, however, be discussed in the contract document. For the purpose of this study the construction time will be evaluated using the time of the construction phase of the project as provided by the supplier in the tender document.

The construction time factor may have a direct impact on many of the other factors, however each factor should be evaluated individually and the effects on the other factors should not be considered when assessing a housing system.

Nonetheless, in order to assess each housing system one could calculate the average construction time of a single unit. This information would be gathered from the bidder or alternatively a *completed project* will be used to divide the total construction time with the number of houses constructed. This is not ideal as each project has its own unique challenges and circumstances.

The construction time will be assessed by estimating the average construction time of a single unit. This can be done by dividing the time of the construction phase of the project with the number of houses proposed to be constructed. Table 5.2 is used in the assessment criteria, where the conventional building system's construction time is used as the *average* construction time.

From an interview with Steyn (2014), it was gathered that the construction time may vary due to the size of the project. Generally, the construction time of a conventional building system may be between 6 to 8 weeks, which includes the casting of the foundations that may take up to 7 days. However, from another interview with Galada (2014) it was gathered that the conventional system can be constructed between 3 to 5 weeks, depending on the weather. The interviews agreed on the average construction time of alternative building technologies (ABT). This was validated through investigating current housing systems available, at between 7 to 10 days, excluding the casting time of the foundations. The shortest construction time of ABT systems may be between 3 to 5 days, excluding the casting of the foundations. The construction time assessment includes the casting time of the foundations.

From the information gathered the *average* construction time evaluation, based on the conventional system, differs from one project to another. However, the construction time of ABT systems is much shorter than the conventional method. The current alternative housing systems available showed a large decrease in construction time (Wallbaum et al., 2012) and this was validated with interviews (Galada, 2014; Steyn, 2014). Therefore, it was decided to give the *average* construction time assessment a bigger interval in the assessment criteria used in Table 5.2. The *good* and *excellent* ratings have very short time intervals, which would favour ABT systems and, as stated in the interviews, the conventional building system's average construction time will exceed three weeks.

Table 5.2 Assessment criteria of construction time

Rating	Construction time
Excellent	Less than 14 days
Good	14 to 21 days
Average	21 to 49 days
Fair	49 to 59 days
Poor	More than 59 days

5.2.3 Quality

Quality is one of the key issues in the construction industry. Quality focuses on avoiding rework which uses unnecessary time, material and financial resources. Zunguzane (2013) summarised issues that contribute to the lack of success and the non-achievement of quality in the low-income housing industry:

- Sufficient financing not available
- Unskilled labour is used
- Emerging/low experienced contractors is used
- The private sector does not contribute sufficiently
- There is a lack of management commitment towards the achievement of quality
- The workmanship has a substandard quality

One of the ways to measure the quality of a house is to evaluate the durability. Agrément describes the durability of a building as the period for which it is able to fulfil its anticipated function acceptably. Here it is assumed that the building is subjected to normal use and it is maintained on a regular basis, as intended, without major repairs or upgrades. In effect the lifespan of the building will depend on the life of its various components, the quality of the materials used and the skill level of labour used during the manufacturing and erection stages of the building (Agrément 2002; Sun Ridge Group, 2002).

Therefore, it was decided that for the purpose of this study, quality will be measured by evaluating the *service lifespan* and the *maintenance requirements* of the housing system. Figure 5.3 shows the hierarchy of the quality factor.

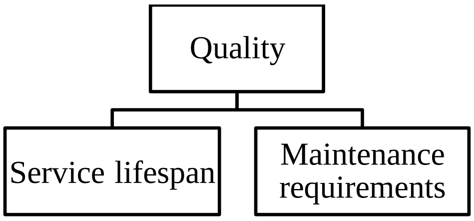


Figure 5.3 Hierarchical structure of quality factor

When assessing the durability of a house, Agrément South Africa assumes that the structure, with its foundations, have been designed in accordance with best practice for the particular location, such as the climatic and soil conditions of the site. Therefore, the durability of a building is assessed by the performance of the structure, through for example; physical damage and weathering due to; corrosion, wetting, drying, heating, freezing, solar radiation and chemical reaction (Agrément, 2002).

The quality of a house is not just affected by weather conditions, but can also be affected by decisions made by the home owners. Thus, Zunguzane (2013) has expressed that the quality of housing should be assessed with the end user in mind, to create a sustainable living environment. Still, there are other factors which lead to poor quality of the houses, such as:

- Too many people living in a house, which it was not designed for
- The houses do not meet the building standards, such as the sound reduction or heat insulation
- The housing settlements do not provide basic facilities and do not supply all the necessary services

Wallbaum, Ostermyer, Salzer and Zea Escamilla (2012) stated that the *service lifespan* of a house should play a major role when considering alternative building technologies. A good building should be durable against insects and natural deterioration, such as high humidity, earthquakes, flooding and wind loads. Consequently, for this study, these factors should all be considered through evaluating the theoretical *service lifespan* of the housing system. Table 5.3 provides the assessment periods as presented by Wallbaum et al. (2012) for the service lifespan of the housing system, which serve as an indication of its durability. They validated these values through assessing housing systems available for low cost housing.

Table 5.3 Assessment criteria for service lifespan

Rating	Service lifespan
Excellent	> 40 years
Good	30 - 40 years
Average	20 - 30 years
Fair	10 - 20 years
Poor	0 - 10 years

The second sub-factor which is important when addressing the quality of the house is the *maintenance requirements*. It should be important to determine to what extent costs and labour requirements are affected to maintain a building. Maintenance intervention requirements are important when taking into consideration the building's life cycle. The costs over the building's life cycle can be reduced if the maintenance intervention requirements are reduced. Table 5.4 provides a guideline for assessing the maintenance requirements of low cost houses. The assessment criteria are based on the maintenance interventions required for repairs and preventive measures discussed by Wallbaum et al. (2012).

The National Department of Housing (2003) states preventative maintenance cycles of buildings, other than the typical low cost house building, shall not be more frequent than five years. Further maintenance requirements for the typical low cost house building are not stated. However, from the interview with Galada (2014) the following information was gathered. For regular maintenance cycles of low cost housing, these guidelines can be used:

- Painting can be required every 5 years
- Plumbing maintenance can be required every 2 years, and
- If timber is used for window frames, painting may be required every 3 years

Day-to-day maintenance, such as broken lights, taps or windows will not from part of the maintenance requirements of the housing system. Any maintenance interventions needed more than prescribed for the regular interventions will be seen as frequent interventions. Each activity has its own level of skill sets. For example, plumbing can be divided into basic plumbing skills and advanced plumbing skills. The decision makers should use their experience and knowledge to indicate whether the skills required for maintaining a house is of low, medium or advanced level.

Table 5.4 Assessment criteria for maintenance requirements

Rating	Maintenance requirements
Excellent	Almost no interventions required
Good	Interventions using low skill and low cost
Average	Regular interventions using medium skills and costs
Fair	Frequent interventions using medium skills and costs
Poor	Interventions using advanced skills and cost

In conclusion, delivering quality houses is important if the South African government wants to improve the lives of the low income population and mitigate the housing backlog. Assuring housing systems with high quality will mitigate a future dilemma of repairing and replacing homes for the low income industry.

5.2.4 Environmental performance

Various researchers and institutions have devoted time and money to determine the environmental impact of low income housing. These studies show that if the energy efficiency of the houses is improved the capital costs of an environmentally friendly house may be more than a conventionally built house. However, the long term benefits may improve the health of the occupants and reduce energy costs (Ampofo-Anti, 2012; Keoleian et al., 2000; Wentzel, 2006).

When homes are constructed it provides social and economic benefits to the society, but it also contributes considerably to environmental degradation. A large focus is being placed on the environmental performance of residential buildings, in South Africa and internationally, in terms of energy efficiency. To address this situation it is required to look at the environmental impact of building materials and how the energy efficiency of houses can be improved (Ampofo-Anti, 2012).

As additional information, although not entirely applicable to South Africa, a study on the energy efficiency of alternative housing systems was conducted in Canada, by the Sun Ridge Group (2002). The study showed that most of the systems can be as energy efficient as Canada's conventional building system, a wood-frame house. While some systems require additional elements and materials to make them perform as energy efficiently as the conventional system, other systems label energy efficiency as a strong characteristic.

For South Africa however, according to a study by Ampofo-Anti (2012) on alternative housing systems in South Africa, taking into account the energy consumption of low cost houses can lead to economic and environmental benefits. This can reduce the energy bill for underprivileged families; improve the air quality and health of humans; and result in an overall decrease in operational energy demand. Ampofo-Anti's (2012) study included a comparison on the energy and thermal performances of two houses, where he improved the performance of one house by implementing the following measures:

- Appropriate north-south orientation
- Appropriate roof overhang combined with north-facing windows
- Cavity walls (modular, hollow concrete blocks)
- Insulated ceilings
- Insulated external walls (thermal plaster)

The alternative building technology showed a clear improvement on energy efficiency and thermal performance. The implementation of such measures could result in a significant decrease of environmental impacts if the large scale production of providing housing is considered (Ampofo-Anti, 2012).

A study in the United Kingdom, by Monahan and Powel (2011), showed that 57% of CO_2 emissions by households were due to space heating, 25% due to water heating and 18% due to cooking, lighting and other appliance usage. From this study, it is clear that the housing system can reduce significant amounts of CO_2 emissions if it is able to improve its thermal comfort in the house. This situation may not have much importance for the South African context, but shows similar results as stated in the following paragraph.

Osburn's (2010) study showed by implementing various roof insulations, ceiling insulations, wall insulations and carpets, can result in up to 45% less energy usage than a conventional house in South Africa. This can then result in potential CO_2 savings (Ampofo-Anti, 2012). Looking at the housing demand, these savings can avoid substantial quantities of CO_2 emissions. Therefore, the inclusion of the *environmental performance* of a housing system into the decision factors is essential. The measurement procedure for the environmental performance criterion is described below.

The *environmental performance* factor, to be used here, will be evaluated with the use of the rating tool from the Green Building Council of South Africa (GBCSA), which is a well-recognized institution. The rating tool is used to evaluate the environmental design and performance of South African buildings, based on a number of criteria (Green Building Council of South Africa, 2011). A score is then provided to a building to present it with a green star rating.

However, the environmental performance factor used in this study will not award a housing system with a green star rating. The criteria indicators relevant to low cost housing systems have been drafted from the rating tool for *Multi Unit Residential v1* buildings of the GBCSA and are adjusted to fit into this study.

The green star rating tool was developed to (Green Building Council of South Africa, 2011):

- Establish a common language and standard of measurement for green buildings
- Promote integrated, whole building design
- Raise awareness of green building benefits
- Recognize and reward environmental leadership
- Reduce the environmental impact of developments.

This above mentioned vision of the GBCSA encouraged the inclusion of the *environmental performance* factor. The rating tool for *Multi Unit Residential v1* buildings was examined and the relevant criteria were drafted to use in this study. Table 5.8 is used to evaluate the environmental impact of a housing system. The housing system will receive a scoring as discussed in the following section.

Each criterion described below, and shown in Table 5.8, has specific conditions that have to be met. If the required conditions are met, the housing system receives the amount of points available per criterion. These points will then be added to provide a housing system with a total *environmental performance* score. This score will then be classified according to Table 5.9 to give it a rating in the final *decision-making model.* The assessment intervals used in Table 5.9 are determined with an equal distribution of the total score for the five ratings. Figure 5.4 shows the evaluation system of the environmental performance factor.

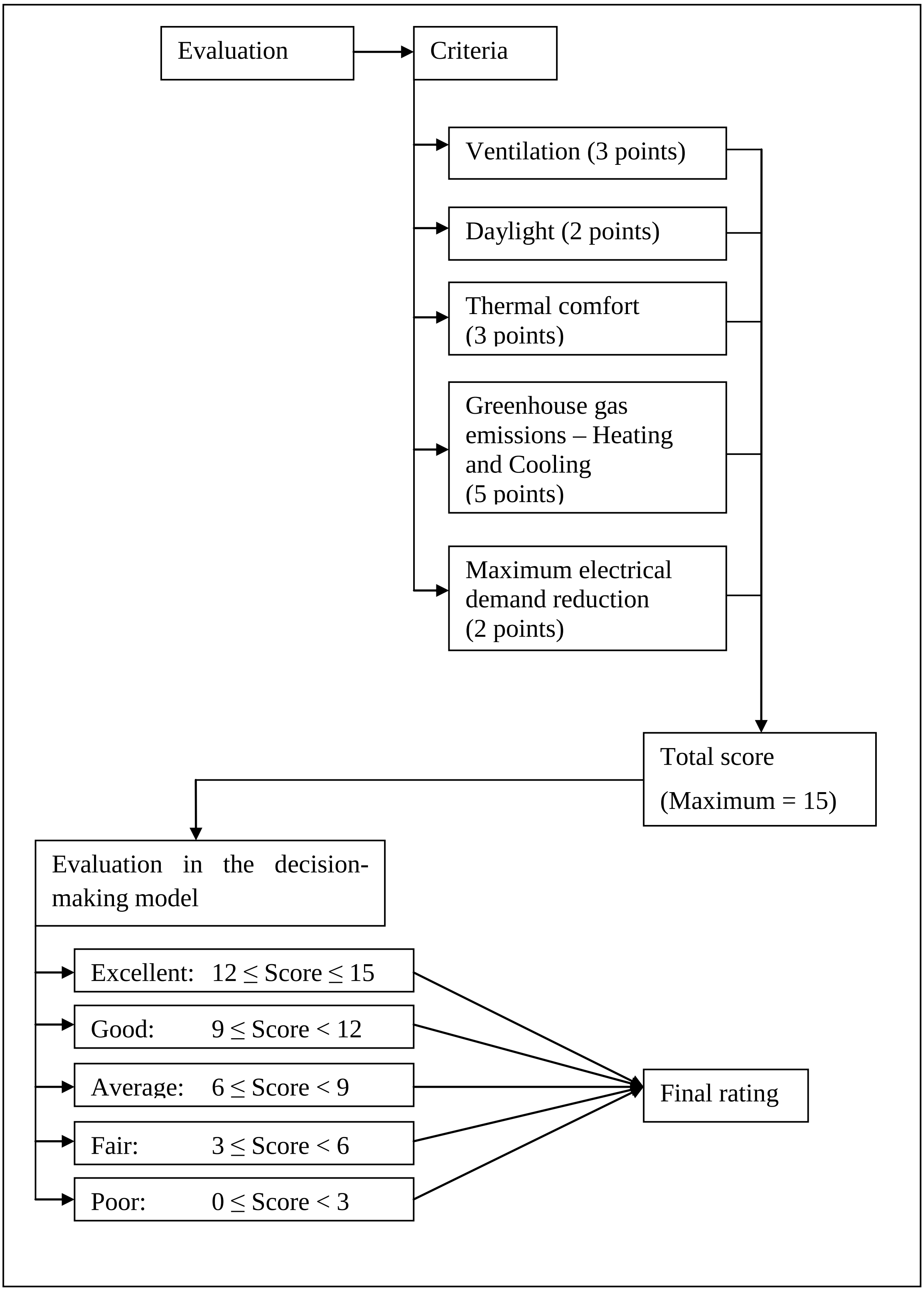


Figure 5.4 Evaluation structure of the environmental performance factor

The following summaries are used to provide a better understanding of the criteria used in Table 5.7 (GBCSA, 2011).

5.2.4.1 A-1: Ventilation

A housing system will receive a higher ranking if it promotes and recognizes designs that provide ample amounts of outside air to counteract build-up of indoor pollutants and moisture (GBCSA, 2011). Up to three points are available under this criterion.

5.2.4.2 A-2: Daylight

This criterion promotes and recognizes designs that provide good levels of daylight within the housing system (GBCSA, 2011). Up to two points are available under this criterion.

5.2.4.3 A-3: Thermal comfort

Thermal comfort is very important to low cost communities, especially for their health. This criterion promotes and recognizes designs that achieve suitable levels of thermal comfort for the occupants (GBSCA, 2011). Up to two points are available under this criterion.

5.2.4.4 A-4: Greenhouse gas emissions – Heating & Cooling

Greenhouse gas emissions are a major concern in South Africa and internationally. This criterion promotes and recognizes housing system designs and building materials that minimize greenhouse gas emissions associated with operational heating and cooling energy consumption. This criterion is further sub-divided into three categories, discussed below. Up to five points are available under this criterion.

The first two points available under this criterion will be awarded if the housing system adheres to the *compulsory initiative* values used in Table 5.5 and Table 5.7. The compulsory initiative values are values set out by the SANS 204:2011 requirements. These are specifications based on tests from masonry construction. Consequently, if the housing system satisfies the compulsory initiative requirements as set by SANS 204:2011, used in this criterion, it will gain 2 points (GBCSA, 2011).

Part A - Wall Thermal Resistance (1 point)

The thermal resistance (R-value, m^2K/W) of a wall refers to the ability of a wall not to conduct heat through the wall. For example, a cavity wall or insulated wall will provide more thermal resistance than a solid un-insulated wall. Walls with higher thermal resistance will reduce heat loss from housing systems during cold periods, which in turn need less energy to heat the dwelling for comfort.

Table 5.5 provides the values for wall thermal resistance required for the *compulsory initiative-1*. These values are based on requirements as set out by SANS 204:2011 for masonry construction. The values for wall thermal resistance required for 1 more point are based on the higher R-value requirements in SANS 204:2011 (GBCSA, 2011).

Table 5.5 Minimum values of Thermal resistance R in m^2K/W (GBCSA, 2011)

Climatic zone	1 (Johannesburg)	2 (Pretoria)	3 (Nelspruit)	4 (Cape Town)	5 (Durban)	6 (Upington)
Compulsory initiative-1	1.2	1.0	1.0	1.2	0.7	1.2
Plus 1 point	2.2	1.9	1.9	1.9	1.9	2.2

Part B - Thermal Mass (1 point)

South Africa's climate has large daily variations in external temperatures. In some seasons it may be cold during the night, but pleasant temperatures during the day time. If the building materials could trap this warmth, the energy needed for heating a house can be reduced. To measure the thermal mass of a housing system, the assessment tool of the GBCSA measures the Admittance (Y) of the dwelling.

This measurement uses the same unit (W/m^2K) as the U-value, which is the inverse value of the thermal resistance of the wall (1/R-value), but differs from it as described here. While the *U-value* measures the ease of the heat transferred from the inside of the house to the outside, the *admittance value* measures the ease of the heat to be absorbed/emitted by the construction. As stated by GBCSA (2011), all surfaces visible to the occupants contribute to thermal mass (inside surfaces of external walls, internal walls, floors and ceilings). Therefore, it is necessary to calculate the average admittance of all interior surfaces of the housing systems.

The admittance of the interior surfaces of a dwelling are calculated using Equation 5.1, which provides the weighted average of the admittance.

$$Average\ admittance = \frac{A_1Y_1+A_2Y_2+A_3Y_3+\cdots}{Total\ internal\ surface\ area} \qquad \text{Equation 5.1}$$

Where A_1 is the surface area in m^2 of surface 1 and Y_1 the admittance in W/m^2K. Table 5.6 shows the average admittance of the different climatic zones as indicated by the GBCSA.

Table 5.6 Values for average admittance provided by the GBCSA (2011)

Climatic zone	1 (Johannesburg)	2 (Pretoria)	3 (Nelspruit)	4 (Cape Town)	5 (Durban)	6 (Upington)
For 1 point	3.5	3.0	3.0	3.0	3.0	3.5

Part C - Window Conductance (1 point)

Windows provide daylight into houses, but also contribute significantly to heat loss in the winter. Optimizing it and its glazing elements are a key feature in designing energy efficient dwellings. The window conductance is calculated in conductance per unit floor area (C_u) with Equation 5.2:

$$C_u = \frac{(A_1U_1 + A_2U_2 + A_3U_3 + \cdots)}{Total\ habitatible\ floor\ area} \qquad \text{Equation 5.2}$$

Where A_1 is the surface area (m^2) of window 1, which has a U-value U_1. The conductance of a window should comply with the requirements as set out by SANS-204:2008 Part 2 to achieve the *compulsory initiative-2* point. The values for 1 more point are based on improving the conductance by 20% as provided by the GBCSA (2011). See Table 5.7 for the average window conductance values.

Table 5.7 Values for average window conductance (GBCSA, 2011)

Climatic zone	1 (Johannesburg)	2 (Pretoria)	3 (Nelspruit)	4 (Cape Town)	5 (Durban)	6 (Upington)
Compulsory initiative-2	1.2	1.4	1.4	1.4	1.4	1.2
For 1 point	1.0	1.2	1.2	1.2	1.2	1.0

5.2.4.5 A-5: Maximum electrical demand reduction

This criterion recognizes and encourages dwelling designs, which enable the occupant to reduce the maximum demand on the electrical supply. Up to two points are available under this criterion.

5.2.4.6 Environmental performance assessment

The *environmental performance* of a housing system will now be evaluated with the use of Table 5.8 (GBCSA, 2011). As previously stated, a score will be provided to a housing system according to the following specifications. This score will then be used in Table 5.8 to provide it with the environmental performance ranking.

Table 5.8 Environmental performance assessment

Name	Description	Score
A-1: Ventilation	**Up to 3 points are available independently as follows:**	**(3)**
	One point is awarded where: • Dwellings are naturally ventilated in accordance with SANS 10400-O.	**1**
	Two points are available where: • A housing system will be rewarded a point for each of the qualifying ventilation initiatives implemented, described below. **Qualifying ventilation initiatives are:**	
	Kitchen extract: The kitchen is provided with a dedicated extraction system.	**1**
	Bathroom ventilation: All rooms within which there exist shower(s) and/or bath(s) are provided with a dedicated mechanical extraction system	**1**
A-2: Daylight	**Two points are available:**	**(2)**
	One point is awarded for dwellings where: • 60% of the habitable area [excluding kitchens] of each dwelling meets the minimum daylight criteria detailed below. OR	**1**
	Two points are awarded for dwellings where; • 90% of the habitable area [excluding kitchens] of each dwelling meets the minimum daylight criteria detailed below. **The minimum daylight criterion for Credit Criteria compliance is;** • A Daylight Factor (DF) of no less than 1.5% (measured at FFL); OR • A Daylight illuminance (DI) of no less than 150 lux (lumens/m^2) (measure at FFL).	**2**

A-3: Thermal comfort	**Two points are available:** **One point is awarded where:** • A housing system is provided with an active heating or cooling system in at least one communal room in the house. **One point is awarded where:** • No active heating systems are provided within the development contract, a dwelling must demonstrate all of the following: – High performance specifications for wall, roof and window insulation, by achieving one point for **A-4 Part A**; – High performance specifications for window insulation, by achieving one point for **A-4 Part C**. **One point is awarded where:** • No active cooling systems are provided within the development contract, a dwelling must demonstrate all of the following: – Effective natural ventilation is achieved via 'cross-ventilated design', by achieving first point in **A-1**; – Effective thermal mass, by achieving one point for **A-4 Part B**; – Effective control of solar heat gains, by achieving one point for **A-4 Part C**.	**(2)** **1** **1** **1**
A-4: Greenhouse gas emissions – Heating & Cooling	A total of 5 points can be awarded under this criterion, where the housing system can be awarded two points if it adheres to the compulsory initiatives as outlined in Table 5.5 and Table 5.7 and a further three points if it satisfies the values as stated. **Part A - Wall Thermal Resistance** One point is awarded where: • The R-value of each wall achieves the minimum required as outlined in Table 5.5. **Part B - Thermal Mass** One point is awarded where: • The admittance of floor, ceiling and wall constructions achieve the minimum required as outlined in Table 5.6. **Part C - Window Conductance** One point is awarded where: • The conductance of the window is improved by 20% of the compulsory initiative as shown in Table 5.7.	**(5)** **2** **1** **1** **1**
A-5: Maximum electrical demand reduction	**Up to two points are awarded where:** • For each dwelling, a minimum number of qualifying maximum electrical demand reduction design initiatives are incorporated, awarded as follows; – Two design initiatives for one point; OR – Three design initiatives for two points.	**(2)** **1** **2**

	The qualifying maximum electrical demand reduction design initiatives are: **Space heating:** Where an active space heating system is installed, it utilises a non-electric primary energy source. **Domestic hot water:** A hot water system with a non-electric primary energy source is installed. **Cooking appliances:** All stoves/hobs and ovens installed are non-electric. **On-site energy generation:** On-site energy generation is installed and can provide 200W per occupant at time of maximum electricity demand in the supply network. **Smart metering** 'Smart Meters' linked to hot water geysers are installed to allow the utility to switch off geysers automatically at time of maximum electricity demand in the supply network.	

Table 5.8 will be used to provide a score for the housing system. This score will then be used in accordance with Table 5.9, which will provide the housing system with a final environmental performance rating. As previously mentioned, the assessments used are determined with an equal distribution of the total score for the five ratings.

Table 5.9 Assessment criteria of environmental performance

Rating	Environmental performance
Excellent	$12 \leq$ points < 15
Good	$9 \leq$ points < 12
Average	$6 \leq$ points < 9
Fair	$3 \leq$ points < 6
Poor	$0 \leq$ Points < 3

5.2.5 Housing density

For a long period in South Africa's history the planning and design of settlements was based on political systems of separate development. With the apartheid era being in the past it is important to start creating a new framework for establishing settlements which will improve life in settlements and help with urban reconstruction and development.

The government has already incorporated this plan into policy. The government's Urban Development Framework calls for "the physical, social and economic integration of our towns and cities." Here the government puts stress on the need for higher density, more compact and more mixed-use settlements (CSIR, 2000).

In the same manner, the Development Facilitation Act, No 67 of 1995 calls for environments which:

- Promote the integration of social, economic, institutional and physical aspects of land development
- Promote integrated land development in rural and urban areas in support of each other
- Promote the availability of residential and employment opportunities in close proximity to or integrated with each other
- Optimise the use of existing resources, including resources relating to agriculture, land, minerals, bulk infrastructure, roads, transportation and social facilities
- Discourage the phenomenon of "urban sprawl" and contribute to the development of more compact towns and cities
- Encourage environmentally sustainable land development practices and processes

From these above mentioned statements it is evident that well located land and housing densities should be considered together. A good location, which is defined by Tonkin (2008) as giving access to employment, industry, commerce, transportation, schools, clinics and public services, is the reason why people who live in medium and high density areas succeed. The main advantage of a good location is that people spend less on transportation costs and in some cases, especially for the low cost community, a well situated location can be more important than having a good quality home (Tonkin, 2008). Therefore, higher density housing is necessary in urban areas.

In some situations, such as urban areas, the reason for incorporating higher density developments is to mitigate urban expansions. However, in other cases, away from urban areas, low-density or medium-density housing will carry more advantages for the residential environment.

The level of densification should consider the housing situation of a community. It should recognise the social, economic and strategic implications that may be experienced by the residential area and home owners themselves. In many developments the implementation of higher density housing has other trade-offs, such as privacy and plot (erf) size (Metroplan town and regional planners, 2000).

It is not easy to quantify the exact number of buildings that constitute low, medium and high density developments, but from South African literature (Tonkin, 2008) and interviews (Galada, 2014; Steyn, 2014) it was decided that *low density* will be understood as roughly 40 or less dwelling units per hectare (du/ha), *medium density* at 40-80 du/ha, and *high density* at 80 or more du/ha (Tonkin, 2008). Austin and Biermann (2005) also stated that a gross density, as described in Section 2.2.1, of over 50 du/ha is accepted as appropriate in most developing urban areas. Therefore, the assessment criteria shown in Table 5.10 will be used to assess the *housing density* factor.

For the purpose of this study, high density housing would be considered as good. The reason for this is urban areas need higher density housing to mitigate urban expansions, which was used as reference point, as stated earlier. The assessment tool also provides the decision maker the opportunity to give the *housing density* factor an *unimportant* weighting if density is not a concern for a specific project.

Table 5.10 Assessment criteria of housing density

Rating	Density (du/ha)
Excellent	>100
Good	80-100
Average	60-80
Fair	40 to 60
Poor	<40

It is possible that the criteria chosen for the housing density classification are too simplified and that housing densities with too many houses may have negative impacts on crime, urban decay and other social issues. In Section 7.2.2 it is suggested that a study should be commenced to determine the optimal number of houses per hectare that satisfies environmental, social and economic needs.

5.2.6 Alteration capability

The alteration capability of a housing system refers to a house that has been constructed to allow for low-cost and low-energy alterations to address the changing needs of the occupants. In the low-cost communities it is almost inevitable that alterations will be added onto the housing system. A house is described as easily adaptable if additions to the house are possible without high costs and energy intensive alterations (Pullen, Arman et al., 2010).

It is important to consider low cost alterations that can keep the quality and durability of a housing system. Alterations to a housing system should be possible without compromising the other characteristics of the system. Pullen, et al. (2010) stated that the adaptability of a house is seen as an obvious characteristic, but it may be to the cost of other characteristics. For example; the adaptability of a house may be cost-effective for future needs, but it involves more additional up-front costs, which is already a major concern in South Africa.

Changes to houses are mostly required for additional family members or additional rooms for rent, to provide an extra income for the home owner. This involves extensions internally and externally, which can involve complicated construction activities, such as breaking down walls, placing doors and finishing external walls.

From interviews it was gathered, to assess the alteration capabilities of a housing system, three factors would need to be considered, namely (De Villiers W., 2014; Steyn, 2014);

- Cost
- Ease of alterations
- Use of combined systems

Alterations should be incorporated at low cost, using materials that are easily available and constructed without needing highly skilled labour. The low-income communities, in many instances, do not have the required financial income to improve their houses using the same technology used to construct the existing structure. The use of traditional brick/block and mortar materials is generally used for adding to their homes. Home owners also want to use the cheapest labour possible, which in many circumstances end up being the home-owners themselves.

Therefore, the housing system that can be altered at the lowest cost, in the easiest manner and being adaptive to other, especially local, materials will receive the highest rank

(De Villiers W., 2014; Steyn, 2014; Rossouw, 2013). Table 5.11 will be used as the assessment criteria for the *alteration capability* of the housing systems. The assessment criteria were changed after comments from the interviewees (Steyn, 2014; Galada, 2014). They suggested that three assessment criteria are applicable for the *alteration capability* factor, or else some of the assessment grades overlap.

Table 5.11 Assessment criteria of alteration capability

Rating	Alteration capability
Excellent	- Lowest cost - Easy to add onto house - Using any material - Using materials within a 400 km radius*
Good	
Average	- Medium cost - Semi-skilled labour needed - Limited materials can be used - Using South African based materials*
Fair	
Poor	- High cost - Skilled labour needed - Only same technology can be used - Using imported materials*

* The radius used for the material's distance from the construction site may be altered by the housing authority

5.2.7 Resource availability

The availability of resources is important to consider before starting any project. The availability of resources can have a great impact on the different phases of projects and the procurement thereof is necessary. Projects often get delayed, due to suppliers not being able to deliver or due to labour not having the skills to finish a task (De Villiers G., 2014). The availability of resources is sub-divided into two sub-factors, namely; *material availability* and *labour availability and skills development opportunities*. The inclusion of these factors is discussed in the following sections. Figure 5.5 provides the section outline.

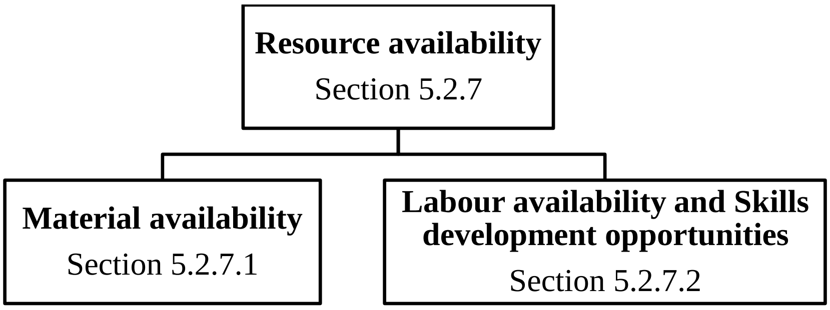


Figure 5.5 Hierarchy of resource availability

5.2.7.1 Material availability

A study by Kadir et al. (2005) showed the most significant factor causing low labour productivity, in Malaysia, was due to material shortages. This problem arises due to inaccessibility of items and the excessive time it takes to get hold of them. The construction activities are related to each other and the lack of critical materials such as *rebars*, *ready-mixed concrete* and *formwork* affect the progress to a great extent. According to Kadir et al. (2005) the lack of materials is also the main cause of construction delay in Indonesia, Iran and Nigeria. In urban areas, where open spaces are usually a problem, it is important for materials to be delivered on time as there may not be space for other materials to be stored.

Another problem that regularly arises is the late supply of certain materials (De Villiers G., 2014). This occurs due to a shortage of local materials, such as steel bars in Malaysia (Kadir et al., 2005), or prefabricating plants not being able to deliver according to the need.

From previous studies it is clear that the availability of construction materials plays an important role when constructing infrastructure, such as houses. The use of local materials adds a significant advantage when the construction phase is underway as it takes a shorter period of time for the materials to arrive on site (Ugwu, Haupt 2007). Through discussions with industry participants (De Villiers G., 2014; Steyn, 2014; Galada, 2014) it was also made clear that the use of South African materials should be favoured, for the purpose of this study, as it develops economic growth.

From the interviews it was gathered that a housing system would receive a better rating if the materials are sourced within a close radius of the construction site. Table 5.12 provides the assessment criteria for the materials used in the construction of a housing system. The assessments used were formulated from the GBCSA (2011) rating tool for *Multi Unit Residential v1* buildings and validated with interviews (De Villiers G., 2014; Galada, 2014).

5.2.7.2 Labour availability and skills development opportunities

Much research has been conducted regarding the implementation of labour during infrastructure developments. The research has shown that the construction industry aids as an important part of employment opportunities and that skills development should be encouraged through this manner (Thwala 2005; Watermeyer, [no date]; Boiser, Wilkinson et al., 2011).

According to Fitchett (2009) the construction industry of South Africa, was responsible for 468 000 jobs by March 2008 and it is suggested, through several studies, that directed labour-intensive methods can substantially increase employment opportunities. By creating work for unskilled labour, problems that address rural employment, income distribution and economic growth are considered (Thwala, 2005).

This situation was addressed by the South African government in 2004, when they launched the Expanded Public Works Program (EPWP). This programme encourages labour intensive construction methods for infrastructure projects and supports skills development through this process. Some success of this program was reported in EPWP's five year report (2004/5-2008/9).

It is important to choose housing systems where work can be generated and skills can be developed (Galada, 2014). By incorporating training programmes, where higher technical skills and managerial skills are developed, will lead to more employment creations and will have various benefits for the labourer. Some of these benefits include (Fitchett, 2009):

- The training programs provide more marketable skills for participants and makes them more employable
- Skilled workers can generate jobs for less skilled workers, for example every skilled worker would need unskilled or semi-skilled workers to work with them in order to be a productive team
- Better skilled labourers can lead to better credibility to the industry and reduce maintenance work, thus improving the life-cycle value of the building
- Greater skill allows the employer to have flexibility in the choice of detailing and requirements and thereby allowing higher labour satisfaction in these areas
- Small contractors or specialised workmanship can be born out of training programmes

The implementation of delivering programmes such as the Reconstruction and Development Programme (RDP) can lead to various advantages. At the one end it promotes an increase in employment opportunities by using labour-based technologies, while on the other side it creates opportunities where entrepreneurs can establish small scale enterprises (Watermeyer, [no date]).

New Zealand provides a suitable example when addressing the problem of labour availability. The problem they experienced was with available skilled labourers for the repair and maintenance of housing. A study by Boiser & Wilkinson (2011) indicated that the participants in the housing industry pointed out that skills development programmes should be implemented for these problems to be solved.

Housing developments should be considered as an aid to generate new jobs, especially for unskilled labour. Housing technologies that require high level of skills face problems in finding labourers with the required skills amongst the low-income communities. For the purpose of this study, it was gathered that houses constructed with the use of local labourers and implementing skills development programmes in a short period should receive a higher ranking (Wallbaum et al., 2012). Table 5.13 provides the assessment criteria for this section.

Skilled labour is defined as employees with high skill levels that create economic value through the work they perform. Skilled labourers are usually associated with high education or expertise levels and high wages. The work done by skilled labour involves complicated tasks that require specific skill sets, education, training and expertise. However, *unskilled labourers* are associated with low skill levels and small wages. Work that requires minimal education or experience is often done by workers that are labelled as unskilled labour (Investopedia, 2014).

Fitchett (2009) stated that the expected duration of a planned training programme providing a worker with applied competence and basis for further learning is between 12 and 18 months. She also stated that programmes focussing on specific skills and linked to specific projects can range between two to six months.

However, the short training programmes are criticised for the reason that they do not provide sustainable employment opportunities. The interview with Galada (2014) validated this literature by stating that training programmes implemented by the Development Action Group ranges between 3 and 18 months.

In conclusion, Table 5.13 indicates that the housing system with the lowest required skills, that can receive minimal training and which can make use of local skills will receive the highest rank. This means in some areas local skills may be available, such as masons, brick layers and other skilled labourers, which can be used during construction. Minimal training will be needed for other non-skilled individuals or skills development opportunities, such as managerial and financial programmes can be conducted to the more skilled labourers.

Table 5.12 Assessment criteria for material availability

Rating	Material
Excellent	- 30% of the project's contract value is represented by materials sourced within 400 km of site. - 20% of the project's contract value is represented by materials sourced within 50 km of site.
Good	- 20% of the project's contract value is represented by materials sourced within 400 km of site. - 10% of the project's contract value is represented by materials sourced within 50 km of site.
Average	- 20% of the project's contract value is represented by materials sourced within 400 km of site
Fair	- Materials are South African based
Poor	- Materials used are internationally imported

Table 5.13 Assessment criteria for labour availability

Rating	Labour
Excellent	- Unskilled labour, minimum training required (Less than 1 month). - Local skills available - Training opportunities (12-18 months) - Provide excessively more opportunities than set out by EPWP requirements
Good	- Unskilled labour, short training required (Less than 2 months) - Local skills available - Training opportunities (6-12 months) - Provide more opportunities than set out by EPWP requirements
Average	- Unskilled labour - Intensive training required (6 months) or skilled workers - Adhere to the EPWP requirements
Fair	- Advanced skills required - Required training (12-18 months) - Do not adhere to requirements from the EPWP
Poor	- Information not available

5.2.8 Additional features

The *additional features* factor provides the decision maker with the opportunity to give preference to a system that provides additional value to the house. These features may differ from one project to another. It sometimes occurs that bidders present other enhancements to the housing system or to the home owner that are not included in the previously discussed factors. Examples of these advantages are listed in Table 5.14.

Table 5.14 Additional features that can be applied to a housing system

Private outdoor space	Energy efficient lighting
External appearance improvements	Rainwater goods (e.g. Gutters)
Rainwater harvesting	Facia boards
Water wise taps and toilets	Increasing m^2 of house
Applying better roof materials (e.g. tiles)	Security features

To the project developer these aspects may have no specific advantage, but to the occupants of the house it could make a significant difference. Through implementing certain additional features into low cost housing it can improve living conditions and offer sustainability to certain individuals.

These guidelines are not limited to the above mentioned advantages, but can vary between tenders, as long as the enhancement provides the occupants the opportunity to improve their lives or create a living environment that the occupants can be proud of. Table 5.15 is provided as a guideline to the decision maker, but can be adjusted to comply with the situation of the decision maker.

Table 5.15 Assessment criteria of additional features

Rating	Additional features
Excellent	Many additional features have been added to the house to improve the living conditions and aesthetics of the house
Good	
Average	Additional features that will improve the living conditions or enhancements that improve the aesthetics of the house have been provided.
Fair	
Poor	No enhancements

5.3 Chapter conclusion

From this chapter it is evident that there are a variety of factors that need to be considered before commencing a housing development. Choosing the most appropriate housing system for a development is not easy and will vary from one project to another.

The factors identified in this chapter only focus on the elements affecting the housing system and do not incorporate technical specifications of individual elements, such as the walls, roof or flooring. The scope of the study also explicitly excludes the public or community's perception as these factors focus on the development of housing systems and their sustainable needs.

The factors identified in this chapter are; cost, time, quality, environmental performance, density, alteration capabilities, resource availability and additional features. Each of these factors is discussed in detail and practical experiences are used to verify their inclusion. The assessment criteria of each factor are also provided at the end of the discussion.

The following chapter will provide a proposal of how the identified factors can be used in the industry. A user friendly decision making model is then developed to choose between different housing systems.

Chapter 6

Multi-criteria assessment tool proposal

This chapter focuses on the implementation of the factors discussed in Chapter 5. This chapter provides the multi-criteria assessment tool developed to aid in the decision on which housing system would be fit for the purpose of a projected low cost housing development.

A user friendly model is developed, from Chapter 4 and 5 combined, in order to simplify and ease a decision to choose between various housing systems. Figure 6.1 shows the part of the study addressed.

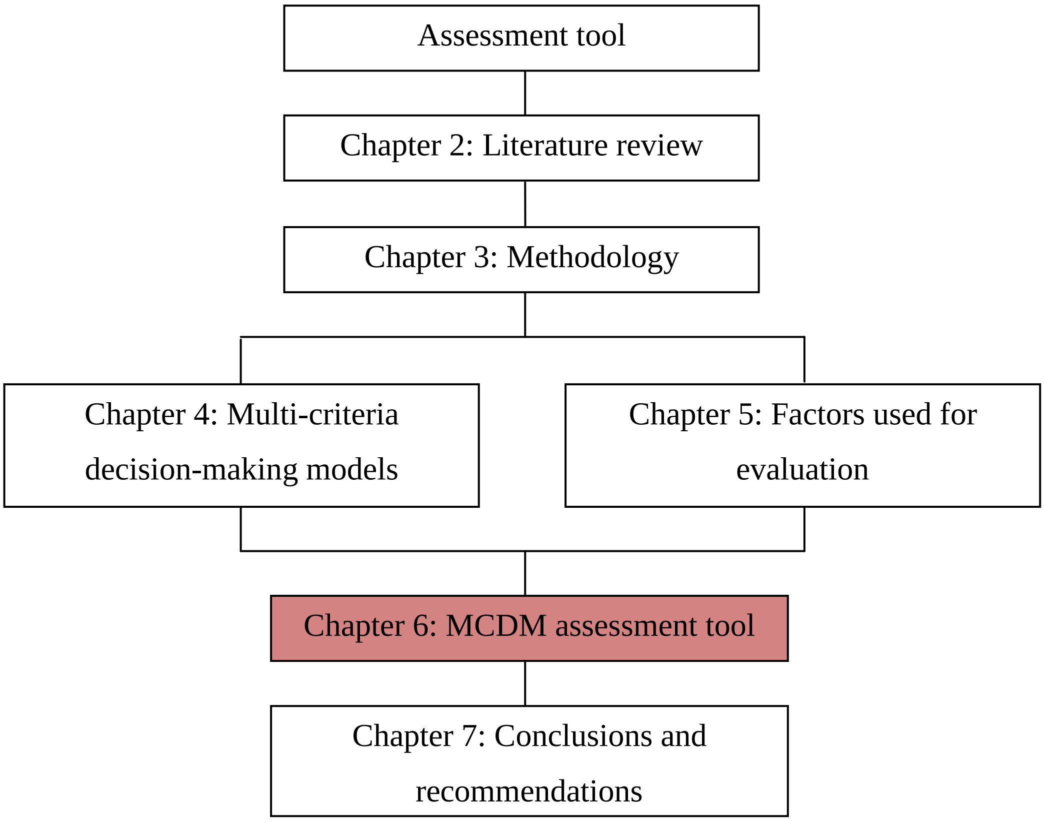


Figure 6.1 Flow diagram illustrating the part of study under discussion

This chapter forms part of the decision-making process, as discussed in Chapter 4. The following section discusses the implementation of the multi-criteria assessment tool.

6.1 Overview of the decision-making process

From the decision-making process discussed in Chapter 4, all the information required to implement the assessment tool is now known and will it be possible to provide an alternative with an assessment score. The following is a brief summary of the information obtained from the previous chapters.

- The first step is to identify a decision-making team. This step will be addressed when a housing system needs to be chosen for a specific project.
- The second step is to identify the applicable factors and sub-factors, which are discussed in Chapter 5.
- The third step is the responsibility of the decision maker to weight the factors and sub-factors according to their importance as described in Section 4.1.4. ω_i is used to assign the different weights.
- The fourth step involves the identification of the decision-making method, which is discussed in Section 4.2. The method chosen is the *Evidential Reasoning Approach*.
- The fifth step is to identify possible housing systems. The alternative housing systems would normally be identified by the tenders received for the construction of the development.
- The sixth and seventh steps are where the alternatives are ranked and one is chosen. This will be discussed in the following section.

6.2 Implementation of the decision-making model

This section provides the implementation procedure for the use of the assessment tool proposed in this study. The decision maker (or makers) would typically receive a variety of housing systems from contractors for the construction of new developments. Table 6.1 and Table 6.2 will be used to assess these housing systems, and are known as the *assessment tool*. The alternative systems would then be provided with scores using the *Evidential Reasoning Approach*, as discussed in Chapter 4. The systems would then be ranked, from the system with the highest score to the system with the lowest score.

Consequently, the highest ranked system would be regarded as the best choice of housing system, according to the weights of importance of the factors and sub-factors, provided by the decision makers.

Table 6.1Summary of assessment criteria

Criterion	Sub-criterion	Poor	Fair	Average	Good	Excellent
Cost	**Capital cost**	Up to 15% more than R160 573 or more	Up to 10% more than R160 573	± R160 573	Up to 5% less than R160 573	Up to 10% less than R160 573 or more
Time	**Construction time**	More than 59 days	49 to 59 days	21 to 49 days	14 to 21 days	Less than 14 days
Quality	**Service lifespan**	0 - 10 years	10 - 20 years	20 - 30 years	30 – 40 years	> 40 years
	Maintenance requirements	Interventions using advanced skills and cost.	Frequent interventions using medium skills and costs.	Regular interventions using medium skills and costs	Interventions using low skill and low cost.	Almost no interventions required.
Environmental performance	**Performance score**	$0 \leq$ score < 3	$3 \leq$ score < 6	$6 \leq$ score < 9	$9 \leq$ score < 12	$12 \leq$ score < 15
Density	**Housing density**	Less than 40 du/ha	40-60 du/ha	60-80 du/ha	80-100 du/ha	More than 100 du/ha
Alterations	**Alteration capability**	- High costs - Skilled labour needed - Limited materials can be used - Materials need to be imported		- Medium costs - Semi-skilled labour needed - Limited materials can be used - Using South African based materials		- Low costs - Easy to add onto house - Using any material - Using materials produced within a 400 km radius
Resource availability	**Material availability**	- Materials used are internationally imported	- Materials are South African based	- 20% of the project's contract value is represented by materials sourced within 400 km of site	- 20% of the project's contract value is represented by materials sourced within 400 km of site	- 30% of the project's contract value is represented by materials sourced within 400 km of site

Table 6.2Summary of assessment criteria - continue

					- 10% of the project's contract value is represented by materials sourced within 50 km of site.	- 20% of the project's contract value is represented by materials sourced within 400 km of site
	Labour availability and skills development opportunities	Information not available	- Advanced skills required - Required training (12-18 months) - Do not adhere to requirements from the EPWP	- Unskilled labour - Intensive training required (6 months) or skilled workers - Adhere to the EPWP requirements	- Unskilled labour, short training required (Less than 2 months) - Local skills available - Training opportunities (6-12 months) - Provide more opportunities than set out by EPWP requirements	- Unskilled labour, minimum training required (Less than 1 month). - Local skills available - Training opportunities (12-18 months) - Provide excessively more opportunities than set out by EPWP requirements
Additional features		No enhancements		- Additional features improving the living conditions/ enhancements that improve the aesthetics of the house have been provided.		- Many additional features added to the house to improve the living conditions and aesthetics of the house

Table 6.3 Evaluation of housing system

Evaluation of housing system:							
Factors		**Sub-factors**	**Degree of belief**				
Overall performance	Cost: $\omega_1 =$ ……		P =	F =	A =	G =	E =
	Time: $\omega_2 =$ ……		P =	F =	A =	G =	E =
	Quality: $\omega_3 =$ ……	Service lifespan: $\omega_{31}=$ ……	P =	F =	A =	G =	E =
		Maintenance requirements: $\omega_{32} =$ _……	P =	F =	A =	G =	E =
	Environmental performance: $\omega_4 =$ ……		P =	F =	A =	G =	E =
	Housing density: $\omega_5 =$ ……		P =	F =	A =	G =	E =
	Alteration capability: $\omega_6 =$ ……		P =	F =	A =	G =	E =
	Resource availability: $\omega_7 =$ ……	Material availability: $\omega_{71} =$ ……	P =	F =	A =	G =	E =
		Labour availability and skills development: $\omega_{72} =$ ……	P =	F =	A =	G =	E =
	Additional features: $\omega_8 =$ ……		P =	F =	A =	G =	E =
Total: $\sum =$							

Table 6.2 represents the weights assigned by the decision maker and the degree of belief the decision maker allocated for the assessment criteria, as described in Chapter 4. The symbols used in the table represent the various DoB; P = Poor, F = Fair, A = Average, G = Good and E = Excellent. The information gathered from Table 6.2 should now be evaluated with the use of the *Evidential Reasoning Approach*, as discussed in Chapter 4. The assessment tool can be used by various housing institutions. Government bodies, housing developers and housing programmes can use this tool to help choose a housing system that would comply with their aims and objectives of a housing development. An example how to use the assessment tool proposal is available in Appendix E.

6.3 Validation of model

The complexity of the low cost housing industry and the lack of available resources make this model difficult to develop and to validate. The methodology used for the development of the model is described in Chapter 3. Unstructured interviews, with participants experienced in the low cost housing industry, were used to identify challenges in the low cost housing industry and to identify the factors to consider when assessing a housing system. These challenges and factors were validated with a literature study, which lead to more factors to consider.

After evaluating the identified factors their assessment criteria were validated. These were validated using semi-structured interviews with role players who manage new housing developments and who have experience with evaluating tenders where different housing systems are assessed. These interviews validated the criteria already identified and provided additional information which should be included in the assessment.

In Section 7.2.2.4 it is suggested that this assessment tool should be used in practice a number of times and should be evaluated by various role players. This should aid in improving the assessment tool developed and aid various role players in choosing between housing systems. However, all assessment tools have limitations and the following section discusses the limitations of this model.

6.4 Limitations of the assessment tool

There is no doubt that assessment tools have imperfections that limit them to certain extents. It is important to recognise these limitations and show were improvements can be implemented to identify whether the assessment tool would be applicable to a situation. This section provides the limitations to the proposed assessment tool, identified by the researcher and by the interviewed participants.

6.4.1 Change

The first limitation identified is change. It is almost certain that changes will occur to the National Housing Norms and Standards in the future, discussed in Section 2.3. These changes could affect the assessment criteria used in the assessment tool and can impact the ranking of the alternative housing systems. The researcher was aware of this problem since the start of this study and has indicated that the assessment criteria have been developed as a guideline to choose housing systems. Improvements can be implemented to the assessment criteria.

However, this does not mean that the assessments should be adjusted to favour a specific housing system.

Another change which was identified is the change of the social perception of the community. The perception of a community changes from one settlement to another and including this perception into the assessment tool could influence the ranking of the housing systems to a great extent. Thus, this model does not consider the public's perception.

However, it was decided to use the results of this assessment tool to inform the community of the advantages and disadvantages of the chosen system. This tool could be used to change the community's perception of alternative housing systems and motivate why a housing system should be used for a specific project.

6.4.2 Identified factors not used

Through the process of identifying the applicable factors to use in this study, there were factors that were rejected due to certain reasons. These factors include:

- Maintenance cost: From the interviews (Galada, 2014; Steyn, 2014) and literature it was gathered that there have not been adequate studies on maintenance cost of low cost housing systems. Therefore, this is an uncertain factor and is not included at this stage.
- Quality assurance: Although this study considers the long term quality factors of a house, the construction phase has a significant influence on the quality of the product delivered. Some interviewees were in favour of considering *quality assurance* as a factor (Steyn, 2014), where other interviewees stated that quality assurance is mostly affected by the monitoring process during the construction, rather than being affected by the difficulty of the construction activities (Galada, 2014). Literature has also shown that quality assurance procedures should be implemented by the developer to ensure quality housing is delivered (Abdul-Rahman, Kwan & Woods, 1999).
- Demolition of the house: From the interviews and literature it was determined that there is not sufficient information available to include this factor. The current housing situation of South Africa does not allow it to implement housing demolition strategies with the huge housing backlog experienced.

The limitations discussed in this section do not influence the assessment tool to a great extent. However, it is important to take note of them for future studies. The assessment tool was developed to accept changes for future needs and through further studies this tool can be improved.

6.4.3 Number of interviews

One of the limitations is the number of interviews that were conducted during the study (Patton & Cochran, 2002). As discussed in Chapter 3, the qualitative research approach may be described as imprecise. There may be critics who state that the data used in this study is a function of the number of people who were interviewed and that it is not the representation of the broader population. It may also be stated that the assessment criteria may lack rigour in it not being precise. However, most of the interviewees provided the same opinions and comments. They also stated that these factors are fit to assess a housing system. In Chapter 7 it is recommended that this assessment tool should be used for a number of projects and then be improved.

The choice of interviewees was based on their individual experiences in the low cost housing industry, their knowledge of the field of low cost housing and their involvement in planning for new low cost housing developments.

6.5 Chapter conclusion

This chapter provides a proposal for the use of the multi-criteria assessment tool developed in this study. The chapter provides an overview of the decision-making model chosen, in Chapter 4, and shows how the factors identified, in Chapter 5, will be used to choose between housing systems for low cost housing developments.

The chapter then describes the implementation procedure of this assessment tool. This is done in two phases. In the first phase the user will evaluate the housing system according to the assessment criteria provided in Table 6.1 and in the second phase the user will fill in Table 6.2. With the information required for further implementation, documented in Table 6.2, the user can determine the rating of the housing system with the use of the Evidential Reasoning Approach. An example how to use the assessment tool is provided in Appendix E.

The chapter also discusses limitations of the assessment tool identified throughout the study. These limitations include changes that may be implemented towards the current national norms and standards of low cost housing and the change of the perception of the public. Other limitations also include factors that have been identified, but were not included in the study, due to various reasons.

Chapter 7

Conclusion and recommendations

This chapter summarises the research study and shows how all the chapters contribute to the initial problem statement. Recommendations are also provided for future studies in the field of low cost housing.

7.1 Conclusion

This study provides a background of the low cost housing industry in South Africa. Housing is considered as a human right over the world and legislation in South Africa requires that government should provide housing to everyone, within their available resources. However, numerous challenges affect the provision of housing and delivering these houses is a difficult process. Statistics relating to housing provision and the quality of these houses are provided.

The study discusses different types of walling systems and building materials that are typically used for the construction of a low cost house. It discusses various housing typologies currently implemented in South Africa and internationally. Combinations of these walling systems and building materials should be implemented with different types of typologies to try and find the optimal solution for a housing development to ensure a sustainable community.

The housing legislation currently implemented for building low cost houses is reviewed, the required standards are briefly discussed and the documentation that needs to be adhered to is mentioned. This legislation should be implemented by various role players in the low cost housing industry. These role players include public and private entities. The national and provincial governments have the responsibility of planning and overseeing developments, whereas the municipalities and private sector role players have the responsibility of delivering adequate housing to the communities. Some of these responsibilities are also delegated to national housing programmes as discussed in the study.

This study also shows the climatic conditions of the South African region, which can have a significant impact on the choice of housing systems. The different climatic regions have different specifications to ensure healthy living conditions for the occupants and to reduce the electrical demand and environmental impact.

The purpose of the background used in this study was to provide insight into identifying the required factors to consider when developing a housing assessment tool. The identification procedure consisted of a qualitative approach through using interviews as a data collecting technique. The interviews were used to obtain information of the current housing conditions and challenges experienced by the role players in the housing industry. The interviews were also used to define assessment measures and identify more factors to consider in the study.

From the literature study and interviews eight primary factors have been identified to consider when choosing between housing systems. This choice had to be made using a multi-criteria decision-making model. The Evidential Reasoning Approach was adopted in the assessment tool as it provides opportunity for qualitative and quantitative factors and has uncertainty measures if the user does not have adequate information about a factor. The ER approach also assesses the factors according to assessments provided, rather than comparing the systems with each other as in the AHP.

The study describes the factors and criteria that were chosen. It provides local and international literature to explain the importance of the various factors and describes why the assessment criteria measures have been chosen as shown in the assessment tool. The factors with their sub-factors are identified in Table 7.1.

Table 7.1 Identified factors and sub-factors

Factors	Sub-factors
Capital cost	
Construction time	
Quality	Service lifespan
	Maintenance requirements
Environmental performance	
Housing density	
Alteration capability	
Resource availability	Material availability
	Labour availability and skills development opportunities
Additional features	

These factors are proposed as a user-friendly assessment tool for assessing housing systems in the low cost housing market. This tool can be used by various role players who need to choose a housing system for a specific housing project. It is suggested that the developer of the settlement should address the procurement guidelines of the CIDB to decide whether information of the evaluation process should be made available to the tenderers of various housing systems.

The government seeks innovative ideas to provide more houses quicker and at a lower cost. However, many challenges arise with the acceptability of new housing systems by the different role players, due to uncertainty of success and initial production costs of these systems. This assessment model, represented by Table 6.1 and Table 6.2, can aid a decision maker to identify the various advantages and disadvantages of a housing system and can aid a developer to allocate funding more appropriately and effectively.

7.2 Recommendations

Through this study areas of research have been identified as relevant for future research. This study was performed over a two year period and only allowed for limited aspects to be investigated. The following areas are recommended for future studies. Recommendations are also made to the industry to improve the housing delivery process.

7.2.1 Recommendations for future research

7.2.1.1 Lifecycle cost savings of environmental low cost housing

It is well known that initial costs increase as the environmental performance of a house increases (Ampofo-Anti, 2012). However, with the number of low cost houses that need to be constructed the energy demand can decrease significantly if the environmental performance of a house is improved. It is suggested that a lifecycle analysis be done on the cost savings of an environmentally responsible low cost house in comparison with the initial cost. The result of this study would show if it is worthwhile to have a higher capital cost and if costs could be saved in the future and improve the living conditions of the low income community.

7.2.1.2 Maintenance cost on low cost housing

One of the limitations to the study was the insufficient information available on the maintenance costs of low cost housing. It is suggested that a study is done on the housing systems to determine what type of maintenance is necessary to low cost housing and how it will affect the lifecycle costs of the houses.

7.2.1.3 Effect of transportation on low cost housing

In this study it was found that the delivery of construction materials can delay projects for long periods of time. The distance from the construction site can affect the project cost and the environmental impact of the materials that need to be delivered. It is suggested that further investigation be done to determine the effect of transportation on the delivery of materials. This effect can be measured in terms of the cost, time and environmental impact the distance has on a project.

7.2.1.4 Distribution of environmental performance assessment

The environmental performance assessments, used in Table 5.9, have been equally distributed for the five assessment criteria from the total score acquired from Table 5.8. It is suggested that the impact of the assessment factors, used in Table 5.8, on the housing system is determined. This could influence the distribution of the assessment criteria used to provide the housing system with an environmental performance rating.

7.2.1.5 Determine the optimal amount of houses per hectare

In Section 5.2.5 the housing density of a new development is assessed. This study assumed that if more houses per hectare can be constructed it would provide a better rating. It may be of opinion that the criteria chosen for the housing density classification are simplified and that housing densities with too many houses may have negative impacts on crime, urban decay and other social issues. It is suggested that a study should be commenced to determine the optimal amount of houses per hectare that satisfies environmental, social and economic needs. The use of a bell curve may be favourable.

7.2.2 Recommendations for the South African industry

7.2.2.1 Involving community in delivering process

One of the major challenges in delivering housing systems is the social acceptance from the community. Galada (2014) suggested that a committee from the community should form part of the delivery of the process, from the planning phase to the construction phase. It is suggested that procedures should be implemented to involve the community in the developing process to create ownership in the community.

7.2.2.2 Availability on information of ABT systems

A major challenge experienced in the low cost housing industry is the lack of available information on ABT systems. Steyn (2014) suggested that procedures should be implemented to make developers and home owners more aware of ABT systems. He also suggested that research should be conducted on ABT systems and that top 5 systems should be suggested for a region. This information could make people more aware of ABT systems to ease the delivery process and hopefully provide better quality housing to the low income community.

7.2.2.3 Develop criteria for the Gap market

The housing income group with a monthly income between R3 500 and R10 000 is known as the “gap housing market.” The government has major challenges to subsidise housing to this income group, as discussed in Section 2.1.2. From interviews it was gathered that the factors to consider for this income group will be different from the factors identified in this study for the low cost income group. It is suggested that attention is given to the “gap” market and to identify the factors to consider when housing needs to be provided to this group of people.

7.2.2.4 Use the proposed model to improve it

The assessment tool proposed in this study is a function of the time that was available to conduct the study. It is suggested that this assessment tool should be used a number of times and should be evaluated by various role players. This should aid in improving this assessment tool and to develop a model that can be used by all the different role players in the future.

Chapter 8

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Appendix A

Department ethics committee questionnaire

Department of Civil Engineering

Stellenbosch University

Departmental Ethics Screening Committee questionnaire.

This questionnaire shall be completed by each researcher (and or student) who wishes to involve persons/animals in their research.

1. General information :
    a. Name and surname: Petrus Johannes Theart
    b. Application date: 14 April 2014
    c. Project title: Develop a multi-criteria assessment tool to choose between housing systems for the low-cost housing markets
    d. If for degree purposes, which degree: M.Eng Civil
    e. Study leader (if applicable) : Prof. J.A. Wium
2. Type of people to be surveyed:

- ☐ Adults
- ☐ Children
- ☐ Stellenbosch university students
- ☐ Professional engineers- √
- ☐ General population
- ☐ Other?

3. Roughly how many involved?

Seven professionals

4. Form of survey:

- ☐ Qualitative interview with individual a) face-to-face - √
  b) Telephone interview
- ☐ Qualitative interview with group (focus group)
- ☐ Quantitative survey tool a) hard copy form
  b) electronic online survey

5. How will you ensure the participants are well informed about the purpose of the research and how the research results will be disseminated?

A letter with the consent to participate will be provided to the participant. This letter will consist of a brief background of the study, purpose of the study, purpose of the interview and information of the researcher and the supervisor. This information will also be discussed with the participant at the start of an interview.

6. How will you record their consent to participate?

Their consent to participate will be recorded through emails.

7. Communication issues

- Are there likely to be any communication issues due to language or education? No
- If YES, how will you ensure that the person is fully informed of their rights?

____

8. Nature of information requested:

- Any personal information recorded (name, address, id number)? Yes
- If Yes what information? Each participants name and position at institution
- Any information of a personal nature (personal experiences?) No
- If Yes what information?
- Any information of a particularly sensitive nature (relating to traumatic experiences, potentially triggering memories of traumatic events; relating to unsafe or illegal activities?) No
- If Yes what information?________________________________
- Any information relating to other identifiable people? No
- If Yes what information and from what people?

9. How will you ensure rights to privacy and confidentiality?

Data will be kept in a controlled environment, only accessible to the researcher and supervisor

10. How will you keep data safe and available for future auditing?

Not applicable

11. Will the respondents benefit in any way – directly – from participating? ie do they stand to gain financially/ are you providing an incentive etc?

No

12. How will you ensure fair selection of research participants?

Identifying experienced participants in the low cost housing industry

13. Provide details of a risk benefit analysis.

Not applicable

14. How will research in a community be coordinated in order not to place unwarranted burden upon such community?

Not applicable

DEPARTEMENT SIVIELE INGENIEURSWESE

DEPARTMENT OF CIVIL ENGINEERING

Department Ethics Screening Committee – Status Determination Form

Date of Meeting: 17/04/2014

The DESC hereby confirms that the project entitled: Development of a multi-criteria assessment tool to choose between housing systems for the low cost housing market

Undertaken by Researcher: Petrus Johannes Theart

Who is Student within the Department of Civil Engineering
[If for degree purposes, which degree? Master of Science in Engineering (Civil)
Study leader (if applicable) Professor J.A. Wium]

Has been assessed and determined to be:

- ☑ Low risk – research can proceed without need to submit to Stellenbosch University's Research Ethics Committee (REC)
- ☐ Medium to High risk – Ethics Approval should be sought from REC; OR
- ☐ Low risk but needs to be submitted to REC for the following reasons:

____

Signed:

Prof Jan Wium
DESC Chairman, Department of Civil Engineering

Appendix B

Example of weight assignment

A municipality received funds to develop a new low cost housing development for a township in their district. The municipality received three housing systems as alternatives A_1, A_2 and $A3$. A committee of four decision makers, D_1, D_2, D_3 and D_4 is formed to choose the most suitable alternative. They decided to evaluate the housing systems using four attributes namely 1) Availability of skilled workers; 2) Climatic conditions; 3) Added value creation and 4) Investment costs.

Step 1 and 2: The decision-making team have been chosen as stated in Step 1. The second step is to determine the importance, or reliability, of the decision makers. For the purpose of this example the decision makers have been awarded equivalent importance (I_1=I_2=I_3=I_4=$\frac{1}{4}$) and are therefore known as a homogeneous group.

Step 3: The linguistic weights and their respective fuzzy numbers will be used as given in Table B.1 Table B.2. Table B.1 gives the linguistic variables as described by the decision makers for the attributes and Table B.2 provides the fuzzy numbers with the aggregated fuzzy weights (AFW), with the use of Equation 4.3.

Table B.1 Importance of attributes as indicated by decision makers

Factors	**Decision makers**			
	D_1	D_2	D_3	D_4
C_1	Moderately important	Very important	Moderately important	High importance
C_2	High importance	Very important	Very important	Moderately important
C_3	Very important	High importance	High importance	Very important
C_4	Very important	High importance	Very important	Very important

Table B.2 Fuzzy weights of the attributes with the AFW

Factors	Decision makers				
	D_1	D_2	D_3	D_4	*AFW*
C_1	(2, 5, 5, 8)	(7, 10, 10, 10)	(2, 5, 5, 8)	(5, 7, 7, 10)	(4, 6.75, 6.75, 9)
C_2	(5, 7, 7, 10)	(7, 10, 10, 10)	(7, 10, 10, 10)	(2, 5, 5, 8)	(5.25, 8, 8, 9.5)
C_3	(7, 10, 10, 10)	(5, 7, 7, 10)	(5, 7, 7, 10)	(7, 10, 10, 10)	(6, 8.5, 8.5, 10)
C_4	(7, 10, 10, 10)	(5, 7, 7, 10)	(7, 10, 10, 10)	(7, 10, 10, 10)	(6.5, 9.25, 9.25, 10)

Step 4: The final step of this procedure converts the fuzzy numbers into a single unit with the use of Equation 4.4 and then calculate a normalised weight of the attributes with Equation 4.5. This information is available in Table B.3 to give the weight vector of W = [0.2116, 0.2455, 0.2635, 0.2794].

Table B.3 Simplified values of the aggregated fuzzy weight and normalized values

Method	Attribute			
	C_1	C_2	C_3	C_4
Simplified values	6.625	7.6875	8.25	8.75
Normalized weights	0.2116	0.2455	0.2653	0.2794
Weights as percentage (*W* x 100)	21.16%	24.55%	26.53%	27.94%

Appendix C

Example of the Evidential Reasoning Approach

This example, as explained by Xu and Yang (2002), is adjusted for the purpose of this study. The example will analyse the performance of a housing system according to three factors. The step-wise approach as described in Section 4.2.1 will now be used. For the purpose of the example, qualitative factors are used, although quantitative factors may also be used.

The three factors that are used in this example are; *quality*, *resource availability* and *alteration capability*. Using the grades as defined in Section 4.2.2, the previously mentioned factors can be represented using the following distributions;

$S(quality) = \{(average, 0.3), (good, 0.6)\}$

$S(resource\ availability) = \{(good, 1.0)\}$

$S(alteration\ capability) = \{(good, 0.5), (excellent, 0.5)\}$ Equation A.1

Note that only grades with non-zero *degrees of belief* are listed. To generate a precise assessment, relative weights need to be assigned. As previously mentioned, there are several methods for weight assignment. For the purpose of this example it has been decided that equal weights should be implemented. Thus, the Evidential Reasoning Approach can be applied.

The three factors will be denoted as e_1, e_2, and e_3 respectively, with the weights being $\omega_1 = \omega_2 = \omega_3 = 1/3$. Thus, the degrees of belief are denoted as:

$\beta_{1,1} = 0$; $\beta_{2,1} = 0$; $\beta_{3,1} = 0.3$; $\beta_{4,1} = 0.6$; $\beta_{5,1} = 0$

$\beta_{1,2} = 0$; $\beta_{2,2} = 0$; $\beta_{3,2} = 0$; $\beta_{4,2} = 1.0$; $\beta_{5,2} = 0$

$\beta_{1,3} = 0$; $\beta_{2,3} = 0$; $\beta_{3,3} = 0$; $\beta_{4,3} = 0.5$; $\beta_{5,3} = 0.5$

From these one can calculate the basic probability masses.

$m_{1,1} = 0$; $m_{2,1} = 0$; $m_{3,1} = \frac{0.3}{3}$; $m_{4,1} = \frac{0.6}{3}$; $m_{5,1} = 0$; $m_{H,1} = \frac{2}{3}$; $M_{H,1} = \frac{0.1}{3}$

$m_{1,2} = 0$; $m_{2,2} = 0$; $m_{3,2} = 0$; $m_{4,2} = \frac{1}{3}$; $m_{5,2} = 0$; $m_{H,2} = \frac{2}{3}$; $M_{H,1} = 0$

$m_{1,3} = 0$; $m_{2,3} = 0$; $m_{3,3} = 0$; $m_{4,3} = \frac{0.5}{3}$; $m_{5,3} = \frac{0.5}{3}$; $m_{H,3} = \frac{2}{3}$; $M_{H,3} = 0$

From these it is necessary to calculate the combined probability masses as follow. In the first part the *quality* and *resource availability* are aggregated.

$$K_{1(2)} = \left(1 - \sum_{r-1}^{5} \sum_{\substack{n-1 \\ r \neq n}}^{5} m_{r,1} m_{n,2}\right)^{-1}$$

$$= [1 - (0 + \cdots + m_{3,1} \times m_{4,2} + 0 + \cdots +)]^{-1}$$

$= [1 - 0.1 \times 0.333]^{-1} = 1.0345$

And $m_{H,i} = m_{H,i} + M_{H,i} (i = 1, 2, 3)$, one then have

$m_{1,1(2)} = K_{1(2)}(m_{1,1}m_{1,2} + m_{1,1}m_{H,2} + m_{H,1}m_{1,2}) = 0$

$m_{2,1(2)} = K_{1(2)}(m_{2,1}m_{2,2} + m_{2,1}m_{H,2} + m_{H,1}m_{2,2}) = 0$

$m_{3,1(2)} = K_{1(2)}(m_{3,1}m_{3,2} + m_{3,1}m_{H,2} + m_{H,1}m_{3,2})$

$= 1.0345\left(0 + 0.1 \times \frac{2}{3} + 0\right) = 0.069$

$m_{4,1(2)} = K_{1(2)}(m_{4,1}m_{4,2} + m_{4,1}m_{H,2} + m_{H,1}m_{4,2})$

$= 1.0345(0.2 \times 1/3 + 0.2 \times 1/3 + 2.1/3 \times 1/2 = 0.4483$

$m_{5,1(2)} = K_{1(2)}(m_{5,1}m_{5,2} + m_{5,1}m_{H,2} + m_{H,1}m_{5,2}) = 0$

$M_{H,1(2)} = K_{1(2)}(M_{H,1}M_{H,2} + m_{H,1}M_{H,2} + M_{H,1}m_{H,2}) = 0.023$

$m_{H,1(2)} = K_{1(2)}m_{H,1}m_{H,2} = 1.0345 \times \frac{2}{3} \times \frac{2}{3} = 0.4598$

Now the combined result of *quality* and *resource availability* will be combined with *alteration capability*. Since

$k = \left(1 - \sum_{r-1}^{5} \sum_{\substack{n-1 \\ r \neq n}}^{5} m_{r,1(2)}m_{n,3}\right)^{-1}$

$= [1 - (0 + \cdots + m_{3,1(2)} \times m_{4,3} + m_{3,1(2)} \times m_{5,3} + m_{4,1(2)} \times m_{5,3} + \cdots + 0)]^{-1}$

$= [1 - (0.69 \times \frac{0.5}{3} + 0.069 \times \frac{0.5}{3} + 0.4483 \times \frac{0.5}{3})]^{-1} = 1.1083$

And $m_{H,1(2)} = m_{H,1(2)} + M_{H,1(2)} = 0.4598 + 0.023 = 0.4828$, one then has

$m_{1,1(3)} = K_{1(3)}(m_{1,1(2)}m_{1,3} + m_{1,1(2)}m_{H,3} + m_{H,1(2)}m_{1,3}) = 0$

$m_{2,1(3)} = K_{1(3)}(m_{2,1(2)}m_{2,3} + m_{2,1(2)}m_{H,3} + m_{H,1(2)}m_{2,3}) = 0$

$m_{3,1(3)} = K_{1(3)}(m_{3,1(2)}m_{3,3} + m_{3,1(2)}m_{H,3} + m_{H,1(2)}m_{3,3}) = 0.051$

$m_{4,1(3)} = K_{1(3)}(m_{4,1(2)}m_{4,3} + m_{4,1(2)}m_{H,3} + m_{H,1(2)}m_{4,3}) = 0.5032$

$m_{5,1(3)} = K_{1(3)}(m_{5,1(2)}m_{5,3} + m_{5,1(2)}m_{H,3} + m_{H,1(2)}m_{5,3}) = 0.0892$

$M_{H,1(3)} = K_{1(3)}(M_{H,1(2)}M_{H,3} + m_{H,1(2)}M_{H,3} + M_{H,1(2)}m_{H,3}) = 0.017$

$m_{H,1(3)} = K_{1(3)}m_{H,1(2)}m_{H,3} = 1.1083 \times 0.4598 \times \frac{2}{3} = 0.3397$

Thereafter, the combined degrees of belief are calculated by

$$\beta_n = \frac{M_{n,1(3)}}{1 - m_{H,1(3)}} = 0, n = 1,2$$

$$\beta_3 = \frac{M_{3,1(3)}}{1 - m_{H,1(3)}} = \frac{0.051}{1 - 0.3397} = 0.0772$$

$$\beta_4 = \frac{M_{4,1(3)}}{1 - m_{H,1(3)}} = \frac{0.5032}{1 - 0.3397} = 0.7621$$

$$\beta_5 = \frac{M_{5,1(3)}}{1 - m_{H,1(3)}} = \frac{0.0892}{1 - 0.3397} = 0.1350$$

$$\beta_H = \frac{M_{H,1(3)}}{1 - m_{H,1(3)}} = \frac{0.017}{1 - 0.3397} = 0.0257$$

The assessment of the housing system by aggregating *quality*, *resource availability* and *alteration capability* is therefore given by the following distribution

$$S(housing\ system) = S(quality + resource\ availability + alteration\ capability)$$
$$= \{(avarge, 0.0772), (good, 0.7621), (excellent, 0.0257)\}$$

It is important to note that changing the order when combining the three factors does not change the final result at all. From this distribution it is also noticed that the degree of incompleteness of the housing system is 0.135 (or 13.5%), due to an incomplete assessment in the quality factor.

Using the utility values as provided in Section 4.2.2, the exact score of the housing system can be evaluated and the housing systems can be ranked against each other. The following equation is used to determine the final score of the housing system.

$$u(housing\ system) = \sum_{i=1}^{5} u(H_i)\beta_i$$
$$= 0.0772 \times 0.6 + 0.7621 \times 0.8 + 0.0257 \times 1 = 0.6817$$

However, since the assessment is not complete ($\beta_H$is not equal to zero), a utility interval needs to be determined, using the following.

$$u_{min}(housing\ system) = (\beta_1 + \beta_H)u(H_1) + \sum_{n=2}^{5} u(H_n)\beta_n$$
$$= (0 + 0.135)(0.2) + 0.6817 = 0.7087$$

$$u_{max}(housing\ system) = \sum_{n=1}^{4} u(H_n)\beta_n + (\beta_5 + \beta_H)u(H_5)$$
$$= (0.6 \times 0.0772 + 0.8 \times 0.7621) + (0.0257 + 0.135) \times 1$$
$$= 0.8167$$

Appendix D

Summary of interviews

Interview 1

Name:	**Brian Rossouw**
Location and date:	**Paarl, 10 December 2013**
Institution:	**Drakenstein Municipality, Department of Human Settlements**
Job title:	**Head of Housing Department**

The interview was conducted in person after a background of the study was provided.

1. **What are your main criteria?**
   - The main criterion is cost, as they get a budget from the government and have to build a designated amount of houses with it.
2. **What is the adaptability of the houses? Will the user be able to add onto his house and does this impact your decision?**
   - Precast houses are not feasible in this aspect, as one cannot build onto them at a later stage. The problem also arises, with these alternative building systems, that the materials and elements are imported and is not easily accessible to the home owners.
3. **Do you consider different housing typologies or do you ask for a specific typology, when receiving a tender?**
   - In the Drakenstein municipality, especially Paarl, they try to construct double story or attached houses, as there is not as much available open land.
4. **How important is the cost to you? (Do you get the task to build an amount of houses or do you get a budget?)**
   - As previously mentioned cost is the biggest concern and they are responsible to build a certain amount of houses with the budget they receive. In the Western Province the housing subsidy is more than other parts due to the Southern Cape Coastal Condensation Area. The rain season and cold weather causes precipitation on the zinc roofs. Therefore, ceilings are necessary under the roofs to prevent this.
5. **To what extent does the location impact the decision?**
   - It does not impact their decision. They get a location for a development and they construct the settlement.
6. **How important is the speed of erection of the house against the cost or for example job creation?**
   - It is not a big concern
7. **What challenges do you experience?**
   - They have various problems with using alternatives. The community perception is usually one concern. There are also various concerns with using alternatives in terms of safety, for example the fire risks of straw houses.

Interview 2

Name: **Greg de Villiers**
Location and date: **Cape Town, 20 February 2014**
Institution: **Provincial Government, Department of Human Settlements**
Job title: **Chief Engineer, Directorate: Professional and Project Management services**

Mr De Villiers was provided with questions before the interview, as with the other interviews, for preparation reasons. He answered the following questions in his own words and in terms of a current project, at the time of the study. The project's details are not known. This allowed the interviewee to prepare additional information. A personal interview then followed.

1. **What are your main criteria?**
   - The original intention of the project was to procure Alternate Building Technologies (or non-standardised construction) – not to procure conventional construction.
   - It had to be awarded within a set budget and the project had to deliver a certain number of units within 12 months as set in the Annual Performance Targets of the Western Cape Government Department of Human Settlements.
   - The Project had to make use of local labour, provide training opportunities and create jobs through the Expanded Public Works Programme.
   - Green technologies would be given preference in that they would score higher points in the evaluation.
   - Quality, durability health and safety had to meet Western Cape Government minimum standards and also be Agrément Certified – see attached Agrément Certificate.
2. **What is the adaptability of the houses? Will the user be able to add onto his house and does this impact your decision?**
   - The house can be modified using the same technology, or added to it using brick/block and mortar. This was built into the evaluation criteria whereby ease of alterations and whether it was South African based, attracted more points.
3. **Do you consider different housing typologies or do you ask for a specific typology, when receiving a tender?**
   - The project is funded from the standard National Subsidy which pays for a 40m^2 unit with standard specifications throughout the country. The typology would have had to meet this standard spec – but the internal layout could be different as well as the external appearance. The proposed typologies would also have had to yield the required number of units on the project.
   - The Department did however specify and provide the Town Planning Layout of the units, as well as the approved SG (Surveyor-General) plans.
4. **How important is the cost to the province? (Do you get the task to build an amount of houses or do you get a budget?)**
   - The Department provided a set budget and a set amount of houses was required – as the rate per house is set by the National Dept of Human Settlements, the tender costs should be within what subsidy makes available. However the Western Cape Government is paying a premium for this technology at present.

5. To what extent does the location impact the decision?

- It does not impact the decision at all. The housing product must be fit-for-purpose with the elements. Perhaps we can discuss this question some more for me to understand it better?

6. How important is the speed of erection of the house against the cost or for example job creation?

- The Alternative building Technology currently used is claimed to be 40% quicker to erect – however the contractor is experiencing delays due to supplier problems.
- It was part of the evaluation criteria and was one of the reasons why the system was chosen for the project.

7. How did you evaluate the different housing tenders for the project?

Once the product was confirmed as being on-standard, the offers were evaluated and points scored for the following functionality requirements:

- Experience of company and staff
- Experience with non-standardised construction previously
- Enhancements offered
- Thermal performance in summer temperatures similar to standard brick house and better than standard brick house in winter as indicated in Agrément certificate
- Energy usage to heat dwelling will be much less than required for standard brick house as indicated in Agrément certificate
- Acoustic performance better than satisfactory as indicated in Agrément certificate
- Condensation superior than standard brick house and suitable for Southern Coastal Condensation Problem Areas (SCCP Area) as indicated in Agrément certificate
- Alteration and Additions, system is South African based
- Alternate green technologies offered – solar water heating, Solar photovoltaic panels, rainwater harvesting, water wise taps and toilets
- Time for completion

Thereafter those that scored above a certain threshold would progress to the 90/10 evaluation where 90 points are available for price and 10 for B-BBEE status.

8. What challenges do you experience?

- Very simplistically the evaluation had to determine whether the bid under consideration was standard or not. If standard, then the bid was deemed non-responsive and there was no need to consider any Agrément Certificates or a Rational design which the product might have had (tests of the products fit-for-purposes as a house).
- If, however, it was not standard, then that meant the Department didn't have a clue what it was and needed surety of its fit-for-purpose as a house. This comfort would then be provided from an Agrément Certificate or Rational Design.
- How does one determine whether a bid was standard or not? If the product offered was covered in SANS10400 building standards, was contained in the NHBRC

Manuals or was covered in the deemed to satisfy rules of the National Building regulations, then it was considered standard.

- First the bidders must prove it is non-standard, and then rely on any Rational Design or Agrément certificate to endorse the product as fit for housing purpose. Only then would it be evaluated in terms of Functionality and Price.
- The challenge we experienced was finding non-standard housing products meeting the above technical criteria, but also meeting the strict Supply Chain requirements of tender submission requirements, etc.
- Challenges after award have been from unsuccessful bidders claiming their products were non-standard and should have been evaluated.
- And currently the key construction challenges experienced on site relate to poor product quality, supplier problems of the product, teething problems with assembly, poor construction management, etc – so much so that the project is experiencing almost 12 months of delay.

9. Is the conventional brick and mortar house a "set standard" by which you measure?

- Agrément uses the conventional brick and mortar house as standard by which they measure alternatives.

10. How did they score the houses?

- They gave a scoring to what the houses had to offer and then the houses with a reasonable score went to the next round.

11. Is this a feasible study?

- He thought that it would be better if the study focuses on Gap housing (R3500 – R15000 per month). As he thinks low cost housing is too simple.

Interview 3

Name: **Myra Francis**
Location and date: **Stellenbosch, 9 April 2014**
Company: **Stellenbosch Municipality, Housing Department**
Job title: **Project manager**

The interview was conducted in person after a background of the study was provided.

1. **What are the criteria you consider when choosing a housing system?**
   - They get a set budget from the government and need to construct a certain amount of houses with this budget.
2. **Do you consider the adaptability of the house?**
   - They do not consider this when choosing houses.
3. **Do you consider different housing typologies or do you ask for a specific typology, when receiving a tender?**
   - They ask for a specific typology in the tender. It may happen when the tender is awarded that the contractor provides an alternative.
4. **How important is the cost to you? (Do you get the task to build an amount of houses or do you get a budget?)**
   - Cost is the most important criterion. There are fixed costs which need to be adhered to.
5. **To what extent does the location impact the decision?**
   - It does not impact their decision. They get a location for a development and they construct the settlement.
6. **How important is the speed of erection of the house against the cost or for example job creation?**
   - It does not affect their decision. They only consider the budget. There are however requirements from the Expanded Public Works Programme (EPWP) to ensure job creation and skills development.
7. **What challenges do you experience?**
   - Involving the community may sometimes be a challenge. The budget constraints also usually prevent them from considering alternative building technologies as they are normally more expensive and do not fit into the budget.

Interview 4
Name: **Herman Steyn**
Location and date: **Cape Town, 18 June 2014**
Company: **City of Cape Town, New Housing: Housing Department**
Job title: **Manager: Human Settlements Implementation & Facilitation**

A thorough background of housing was presented by Mr Steyn. It discussed much of the information provided in the literature review. Some information provided by him also encouraged some more additions to the literature review, such as providing a short description of the National Housing Programs. This interview was conducted in person.

1. **What is the current low cost housing subsidy for income groups less than R3500 per month? How does the average cost of alternative building technologies (ABT) compare with the conventional house?**
   - The provision of housing is based on a fixed financing amount, which is more or less R122 000.
   - The average ABT is 10% – 15% more expensive than the conventional system, but this depends on the size of the house in m^2.
2. **Do you consider maintenance cost and how much is it?**
   - This is not considered when choosing a housing system as there have not been adequate studies on the maintenance cost of the housing systems. Thus, this is an uncertain criterion and is not as important at this stage.
3. **What is the typical construction time of a brick and mortar house? What is the average time for an ABT system?**
   - This is very dependent on the size of project and how many houses are constructed. However, for big projects the average construction time for the conventional system can be between 6-8 weeks per house, which will include the settling of the foundation that is more or less 7 days.
   - The average construction time for an ABT system is significantly shorter than the conventional method. On average it can take between 7-10 days for the construction of an ABT system, which will exclude the settling of the foundation. However, some systems may take between 3-5 days to construct, excluding the foundation.
   - Contractors of ABT systems normally insist that the foundations of the houses need to be ready before they construct the system.
4. **Commentary or suggestions for the quality criterion.**
   - One of the challenges experienced by the city of Cape Town is the quality control of the production.
   - It is suggested that the quality control of the construction should be evaluated by estimating the level of risk involved in using a housing system. The quality control can also receive a better ranking if the construction procedures are standard and do not vary from the usual procedures.
5. **What are the average houses per hectare for low, medium and high density houses?**
   - There is not a right answer to this. It depends on the type of typology being used and the community. For single residential developments low, medium and high density

can be described as 25-35 units/ha, 35-55 units/ha and 55 and more units/ha respectively. In general high density is sometimes described between 100-120 units/ha.

6. Commentary or suggestions for the alteration capability criterion.

- The availability of the materials is important when considering the alteration capabilities of the houses. Create a distinction between materials that are available locally, nationally and internationally.
- *Mr Steyn gave some guidance on the evaluation table of the alteration capability criterion. He suggested that the evaluation should only have three rankings.*

7. Commentary or suggestions for the resource availability criterion (only labour).

- He confirmed the training programmes time frame of more or less 2-6 weeks.
- Suggested that some research should be done on the EPWP standards.
- He also suggested that the *poor* and *fair* evaluations should be combined.

8. Other criterion suggestions.

- More suggestions were provided to include as examples: Roof materials, such as the use of clay tiles, should score better. If fascia boards are provided, rain water goods and bigger windows should also aid in a higher score.

9. What are the biggest challenges currently facing existing alternative building technologies?

- One of the challenges that is being experienced is the lack of information on the available ABT systems. *He suggested the NHBRC do research on ABT systems and suggest top 5 systems for an area*.
- The community perception of alternative building technologies is that a bigger house is a better house.
- Municipalities are in favour of implementing new prefabricated alternative technologies, as it reduces the construction time within the settlements, where there are usually many incidents of theft of the construction material.
- ABT systems should be implemented in non-residential buildings to show the improvements.

The final remarks from Mr Steyn were that the criteria chosen are relevant and could aid as an assessment tool for a decision-making body. He was asked to rank the importance of the criteria, keeping in mind that some criteria may have equal importance. 1 is important and 5 is unimportant. This is additional information that was not used in the study.

- Cost: 1
- Time: 2
- Quality: 2
- Environmental performance: 3
- Housing density: 3
- Alteration capability: 4
- Resource availability: 3
- Other: 4

<u>Interview 5</u>
Name: **Xolisani Galada**
Location and date: **Khayelitsha, 31 July 2014**
Company: **Development Action Group, Khayelitsha housing**
Job title: **Project officer**

The interview was conducted in person after a background of the study was provided. He described the process being implemented for new housing developments namely that suppliers, or contractors, provide alternative designs and these are presented to a decision making committee, which includes the community.

1. **What is the current low cost housing subsidy for income groups earning less than R3500 per month? How does the average cost of alternative building technologies (ABT) compare with the conventional house?**
   - The average cost of a conventional house is between R75 000 and R80 000, which includes material and labour costs.
   - The average cost of an ABT can be between R100 000 and R105 000.
   - *These figures were from the top of his head and are not precise*. A margin of 15-20% would be a good estimation.
2. **Do you consider maintenance cost and how much is it?**
   - This is not considered when choosing a housing system as there have not been adequate studies on the maintenance cost of the housing systems. Thus, this is an uncertain criterion and is not as important at this stage.
3. **What is the typical construction time of a brick and mortar house? What is the average time for an ABT system?**
   - The average construction time for a conventional home is between 3-4.5 weeks, which is from the foundation to the roof.
   - *The example used is stone houses for alternative materials*; the believe is the construction time should be longer, because the stones had to be formed to be the right size.
4. **Commentary or suggestions for the quality criterion.**
   - The interviewee agreed to the service lifespan measures as chosen, as was stated that housing bonds at banks are between 25 and 30 years, therefore it was stated that this is a good average estimation.
   - The interviewee gave a couple of maintenance guideline measures, which include;
     - Painting required every 5 years
     - Plumbing every 2 years, can also include cleaning every 6 months if food with much fat is used in for example kitchen basins.
     - Windows with timber frames would need maintenance such as paint every 3 years
     - Roofs should have a service lifespan of between 15 and 20 years.
5. **What are the average houses per hectare for low, medium and high density houses?**
   - It was estimated that low density at 30-40 houses/ha and medium at 60 to 80 houses/ha. This was based on the knowledge gained from doing site work.

6. **Commentary or suggestions for the alteration capability criterion.**
   - The measurements selected were confirmed as adequate for the study.
7. **Commentary or suggestions for the resource availability criterion (only labour).**
   - Suggestions were made that the values used for material availability, such as the percentage of materials available close by, should be changed as the values the researcher suggested are more or less the requirements and to score a better ranking the values should be increased.
   - Suggestions were made that short training programmes, which include physical labour training, can take up to 2 weeks. Whereas, more knowledge orientated training, for example managerial positions can be between 3 and 18 months.
8. **Other criterion suggestions.**
   - Re-named previously called *other* criterion to *additional features*.
9. **What are the biggest challenges currently facing existing alternative building technologies?**
   - A big problem being experienced by DAG is that houses are not being finished and tenders have to be made available again to finish the work.
10. **Additional commentary**
    - The community should be included in all phases of the project, from the design to the construction phase. This would create ownership amongst the community.
    - Ensuring a quality structure is not as easy, as the people involved have the biggest influence on the quality provided. He stated that capable individuals should be appointed to do the work and to monitor the work being done. Therefore, including a sub-criterion of quality assurance would not fit into this study as the housing system may not have an influence on this, but the people involved in construction.

The final remarks from Mr Galata were that the criteria chosen cover all the important aspects that need to be considered for choosing a housing system. He was asked to rank the importance of the criteria, keeping in mind that some criteria may have equal importance. 1 is important and 5 is unimportant. This is additional information that was not used in the study.

- Cost: 1
- Time: 2
- Quality: 1
- Environmental performance: 3
- Housing density: 2
- Alteration capability: 2
- Resource availability: 1
- Other: 3

<u>Interview 6</u>

Name: **Byron Paaiman**
Location and date: **No location, 25 July 2014**
Company: **National Home Builders Registration Council**
Job title: **Structural engineer**

This interview was conducted via phone calls and emails. A thorough background was provided to Mr. Byron through sending him a detailed questionnaire, whereupon he replied the following information.

1. **What is the current low cost housing subsidy for income groups less than R3500 per month? How does the average cost of alternative building technologies (ABT) compare with the conventional house?**
   - I stand for correction but I think it is approximately at R 110 000. The amount excludes the infrastructure budget. The township infrastructure is funded from a different fund.
   - I don't have the figures. It depends to the ABT.
2. **What is the typical construction time of a brick and mortar house? What is the average time for an ABT system?**
   - I don't have the data. The best would be to call a few contractors and get an estimate. From my I would not want to impose my personal opinion on the research.
   - Same as previous answer.
3. **Commentary or suggestions for the quality criterion.**
   I would propose to break the quality in the sub categories (as you have identified). In the model the user should be able to score the following individually:

   - Maintenance frequency
   - Level of skill required for maintenance
   - Availability of the material (i.e. EPS (Expanded Polystyrene Styrofoam) panels which are generally imported material might not be available in rural Eastern Cape.)
   - Durability i.e. in my opinion earth bricks might not be suitable for highly humid and rainy areas.
4. **Are the values assumed for low, medium and high density units per hectare correct?**
   - Not sure as I do not deal with housing densities. I would suggest that reference should be made to the Human Settlements Red Book. You may download an electronic copy of the Red Book from the CSIR website. It was available at no cost last I checked.
5. **Do you have any commentary on the alteration capability assessment criteria?**
   - Noted. It is a good start.
6. **Do you have any commentary on the resource availability assessment criteria (just labour)?**
   - Definition of skilled labour is not well defined. What constitutes skilled labour? In other words what level of training should a person receive to become a skilled labour? I feel the thesis should define the terminology in reference to the current industry norms. May be look at CiDB contractor ranking system (even though it is not so

relevant) or alternatively we may propose a grading system and mention in your thesis that further research is required. I suggest you discuss this with your supervisor first.

- The training lengths are also too short. To make a person skilled the industry norm is training for approximately two years or more. i.e. through FET colleges.

7. Do you know of any additional features that can be added, not yet mentioned?

I propose giving thought on the softer issues:

- Job creation
- Also I am not sure how we link the grading system to treasury regulations with regards to procurement rules. Maybe have a look to the CiDB guidelines for the bidding and tenders. In other words, treasury generally recommends the appointment of the lowest bidder. What happens in a case where the price might be higher but the durability of the system is superior to the cheaper product? How would the model address this?
- Ultimately the model needs to be aligned to treasury rules or maybe we can recognise a misalignment and recommend further research. Or maybe recommend engagement with treasury on the issue of the quality in construction and procurement challenges in construction industry within the South African context.
- Social acceptance of the system needs to be noted in model.

8. Can you rank the importance of the criteria, keeping in mind that some criteria may have equal importance? (Your own opinion)

- I think all the criteria are all equally important, but we know that the finances are the primary constraint. Therefore, cost should be awarded 30% of the importance.

9. What are the biggest challenges currently facing existing alternative building technologies?

- I am not sure if government, stakeholders and the broader construction industry have come to the terms with the objectives of the IBT implementation in mass housing. i.e. are we aiming to save cost? Speed the construction? Save the environment? And is IBT / ABT living up to these expectations?
- To answer the above we also need to understand the reasons behind the backlog in subsidy housing sector.
- Social acceptance remains a constant challenge. Also consumer education in form of booklets and guidelines, etc is required.

Interview 7

Name: **Wibke de Villiers**
Location and date: **Stellenbosch, Various meetings**
Company: **Stellenbosch University**
Job title: **Lecturer**

Wibke de Villiers was consulted throughout this study for insight into the topic. The discussions were not based on questionnaires, but were exploratory interviews to gain knowledge and new ideas on the topic. Various suggestions were made by Mrs. de Villiers that were included into the study and used for other interviews. All of the discussions with Mrs De Villiers were conducted in person.

Interview 8

Name: **William de Villiers**
Location and date: **Stikland, Cape Town, December 2013**
Company: **Lawula projects**
Job title: **Director**

Greg de Villiers was consulted at the start of this study to gain knowledge on the housing situation experienced in the industry and to identify the various role players in the industry. The major concerns, from a contractor's perspective, for developing new low cost housing settlements with alternative building systems were the costs before construction and the public's perception of the housing system.

If contractors want to propose alternative housing systems for low cost housing developments there are many costs that have to be considered. The use alternative prefabricated systems would require new facilities for the fabrication of the elements and this would not guarantee the contractor of any future projects, which does not make it feasible from a business perspective.

The interview identified the various housing regulations for different climatic regions and the increased housing subsidy for the SCCPA. Various additions that can be implemented by the contractor were also identified in this interview.

Appendix E

Example of proposed model

The model proposed in Chapter 6, enables the decision maker to weight the factors for choosing a housing system and providing each housing system with a degree of belief for adhering to the requirements. The following example will indicate how to use the proposed model.

Assume that a decision maker has to choose between two housing systems. The decision maker would follow the steps as described in Chapter 4 to rank a housing system. Assume that the housing systems evaluated in this example is the conventional building system and an environmentally friendly housing system. The factor weights are provided as followed:

- Cost: Very important
- Time: High importance
- Quality: High importance
- Environmental performance: Moderately important
- Housing density: Moderately important
- Alteration capability: Low importance
- Resource availability: Moderately important
- Other: Low importance

With the use of the weighting method, discussed in Section 4.1.4, the decision maker can fill in the various weights in Table E.1 and Table E.2. The weights provided in both tables are expressed as the percentage of the factor's importance (ω_i*100). The weights of the sub-factors are considered equal for this example.

After the weights have been assigned to the various factors the decision maker should provide a degree of belief, as discussed in Chapter 4, on how the housing system adheres to the requirements as summarised in Table 6.1. The values provided in Table E.1 and Table E.2 are only for illustration purposes. The fields with no values indicate that insufficient information was available of the specific factor or sub-factor.

Table E.1 Example of evaluating the conventional building system

Evaluation of housing system: Conventional building system							
Factors		**Sub-factors**	**Degree of belief**				
Overall performance	Cost: $\omega_1 = 20.9$		P =	F =	A = 1.0	G =	E =
	Time: $\omega_2 = 16.38$		P =	F =	A = 1.0	G =	E =
	Quality: $\omega_3 = 16.38$	Service lifespan: $\omega_{31} = 50$	P =	F =	A =	G =	E = 1.0
		Maintenance requirements: $\omega_{32} = 50$	P =	F =	A =	G =	E =
	Environmental performance: $\omega_4 = 11.3$		P =	F = 1.0	A =	G =	E =
	Housing density: $\omega_5 = 11.3$		P = 1.0	F =	A =	G =	E =
	Alteration capability: $\omega_6 = 6.21$		P =	F =	A = 0.2	G =	E = 0.8
	Resource availability: $\omega_7 = 11.3$	Material availability: $\omega_{71} = 50$	P =	F =	A =	G = 1.0	E =
		Labour availability and skills development: $\omega_{72} = 50$	P =	F =	A = 0.3	G = 0.7	E =
	Additional features: $\omega_8 = 6.21$		P = 1.0	F =	A =	G =	E =
Total: $\sum = 46.43$							

With the information provided in Table E.1 the decision maker can determine the overall score of the housing system with the use of the *Evidential Reasoning Approach*, as discussed in Chapter 4. This score can then be used to rank the housing system against other alternative housing systems. Consequently, the highest ranked system would be regarded as the best choice of housing system, according to the weights of importance of the factors and sub-factors, provided by the decision maker. Table E.2 shows the evaluation of the environmentally friendly housing system. From these two evaluations it is suggested that the environmentally friendly housing system would be the best system for this specific project depending on the decision maker's weights of importance and degree of belief.

Table E.2 Example of evaluating the environmentally friendly housing system

Evaluation of housing system: Environmentally friendly housing system							
Factors		**Sub-factors**	**Degree of belief**				
Overall performance	Cost: ω_1 = 20.9		P =	F = 1.0	A =	G =	E =
	Time: ω_2 = 16.38		P =	F =	A =	G = 1.0	E =
	Quality: ω_3 = 16.38	Service lifespan: ω_{31}= 50	P =	F =	A =	G =	E = 1.0
		Maintenance requirements: ω_{32} = 50	P =	F =	A =	G = 1.0	E =
	Environmental performance: ω_4 = 11.3		P =	F =	A =	G =	E = 1.0
	Housing density: ω_5 = 11.3		P =	F = 1.0	A =	G =	E =
	Alteration capability: ω_6 = 6.21		P = 1.0	F =	A =	G =	E =
	Resource availability: ω_7 = 11.3	Material availability: ω_{71} = 50	P =	F =	A = 1.0	G =	E =
		Labour availability and skills development: ω_{72} = 50	P =	F =	A = 0.4	G = 0.6	E =
	Additional features: ω_8 = 6.21		P =	F =	A =	G =	E = 1.0
Total: $\sum$ = 58.66							