An investigation into the time and cost factors for a decision between in-situ and hybrid concrete construction

by

Philippus Jacobus Piek

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

Supervisor: Professor J.A. Wium

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 sole author thereof (save to the extent explicitly otherwise stated), that reproduction and publication thereof by Stellenbosch University will not infringe any third party rights and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Signature: ……………………………………..

Philippus Jacobus Piek

Date: ……………………………………..

December 2014

Synopsis

The construction industry is a competitive market and contractors need to keep up-to-date with new construction methods and technologies. Project teams in South Africa are required to make decisions during the early stages of construction projects. These decisions often need to be made in a short time period, and include the decision between various construction methods, such as the decision between in-situ concrete construction and hybrid concrete construction.

Hybrid concrete construction is a combination of pre-fabricated concrete and cast in-situ concrete to obtain the supreme benefits of their different construction qualities. This method of construction is ultimately used to achieve faster, and occasionally, more cost effective construction. Hybrid concrete construction, today, is a well-known term in the construction industry and is widely used in the UK and other developed countries. However, the use thereof is limited in South Africa, and in-situ concrete construction remains the conventional method of construction. Possible reasons for the limited use of hybrid concrete construction are investigated in this study. With the intent of improving the construction industry of South Africa, guidelines are provided to assist project teams in a decision between in-situ concrete construction and hybrid concrete construction.

The decision between construction methods is based on many factors, such as project time, cost, quality, safety, environmental performance, socio-economic aspects (labour) and client satisfaction. Project time and cost are, however, the most important of these factors. It is stated that the structure of a building represents typically only 10 % of the construction cost, however, the choice of construction method and material can have significant effects on the cost of other elements throughout the life cycle of construction projects. It is therefore important to measure the whole life cycle cost when deciding between construction methods, such as in-situ concrete construction and hybrid concrete construction.

The aim of this study is to identify and investigate the factors that influence project time and cost, throughout the life cycle of construction projects, and to provide a framework that can assist project teams in their decision between in-situ concrete construction and hybrid concrete construction in South Africa. The decision between these two construction methods is influenced by a vast number of variables that may be difficult to quantify. The framework therefore consists of qualitative information that can assist project teams in their decision.

The framework provided in this study includes the factors that have an influence on the time and cost for a decision between in-situ concrete construction and hybrid concrete construction. These factors are identified for the three primary phases in the life cycle of construction projects. These phases are the design phase, the construction phase and the maintenance phase.

Opsomming

Die konstruksiebedryf is 'n kompiterende mark en kontrakteurs moet op datum bly met nuwe konstruksie metodes en tegnologieë. In Suid-Afrika word daar van projek spanne vereis om vinnige besluite gedurende vroeë stadiums van 'n projek te neem. Hierdie besluite moet dikwels in 'n kort tydperk geneem word, en sluit die besluit tussen verskillende konstruksie metodes in, byvoorbeeld die besluit tussen in-situ en hibriede beton konstruksie.

Hibriede beton konstruksie (HBK) is 'n kombinasie van in-situ en voorafvervaardigde beton elemente. HBK word in die algemeen gebruik om te baat uit 'n vinniger konstruksie tydperk, en kan soms ook ‘n meer koste-effektiewe metode van konstruksie wees. HBK word gesien as 'n bekende term in die konstruksiebedryf en word veral toegepas in ontwikkelde lande soos die VSA, Japan en Engeland. Die toepassing daarvan in Suid-Afrika is egter beperk. In Suid-Afrika word in-situ beton konstruksie nog steeds die meeste gebruik en staan dus bekend as die mees algemene metode van konstruksie. Hierdie studie ondersoek moontlike redes vir die beperkte gebruik van HBK in Suid-Afrika. Met die oog op 'n verbeterde konstruksiebedryf in Suid-Afrika, word rigylyne voorsien, wat projek spanne kan gebruik vir 'n besluit tussen in-situ en hibriede beton konstruksie.

Daar is verskeie faktore wat 'n rol speel in die besluit tussen twee konstruksie metodes. Hierdie faktore sluit in, die tyd, koste, kwaliteit, veiligheid, omgewings impak, sosio-ekonomiese aspekte (soos arbeid) en kliënt tevredenheid, van 'n projek. Tyd en koste is egter die belangrikste van hierdie faktore. Die metode waarvolgens 'n struktuur gebou word kan 'n beduidende uitwerking op die koste van ander elemente in die lewensiklus van 'n konstruksie projek hê. Dit is gevolglik belangrik om die hele lewensiklus koste in ag te neem wanneer daar besluit moet word tussen verskeie konstruksie metodes, soos in-situ en hibriede beton konstruksie.

Die doel van hierdie studie is gevolglik om die faktore wat 'n invloed het op die tyd en lewensiklus koste van konstruksie projekte te identifiesieer. Hierdie faktore word dan gebruik om 'n raamwerk voor te stel. Projek spanne kan hierdie raamwerk gebruik as 'n riglyn om te besluit tussen in-situ en hibriede beton konstruksie. Die besluit tussen hierdie twee konstruksie metodes is afhanklik van 'n groot aantal veranderlikes, wat moeilik is om te kwantifiseer. Die raamwerk bestaan dus uit kwalitatiewe inligting wat projek spanne kan gebruik om 'n ingeligte besluit te neem oor in-situ en hibriede beton konstruksie.

Die raamwerk wat in hierdie studie voorgestel word sluit dus die faktore in wat 'n invloed het op die tyd en koste vir 'n besluit tussen in-situ en hibriede beton konstruksie. Hierdie faktore is geïdentifiseer vir die drie primêre fases in die lewensiklus van 'n konstruksie projek. Hierdie fases is die ontwerp fase, die konstruksie fase en die onderhoud fase.

Acknowledgements

I would like to start by thanking my study leader, Professor J.A Wium, for your guidance, patience and support during this study. Your assistance was greatly appreciated.

I would also like to thank Francois Vermeulen, Grant Bergh and Gerald Le Roux for their input and time during this study.

Thank you, Mr. Johan Volsteedt for your assistance and support during this study. Your input and wisdom throughout my life has encouraged me to always live up to my potential.

Thank you, to each person who offered their time to share knowledge and ideas through personal interviews. Your assistance was greatly appreciated.

I would like to show my gratitude to my family who believed and supported me throughout my life.

- Thank you dad, for your support and encouragement throughout my life. Thank you for teaching me that hard work pays off and thank you for the example you live by. You are truly my role model.
- Thank you mom, for your prayers, love, encouragement and kindness throughout my life and thank you for your spiritual input in my life. You are an inspiration to me and I appreciate the example you live by.
- Thank you Liefa and Nikki, my brother and sister, for your love, support and kindness throughout my life; you are truly a blessing to me.
- Thank you Antoinette and Anton, for your love, kindness and support throughout my life. And thank you Antoinette for your always friendly hospitality, it is appreciated.

I would also like to thank my housemates, Ashleig, Lee-Ann, Nick, Paula and Tammy, for your love and support during the last year.

I would like to thank the guys in the main office, Petrus, Charli and Mossie for the encouragement and working environment you provided.

I would like to thank the structural students, Bakkies, Wessel and Rudi for their support and prayers throughout my thesis.

Thank you, Joan for your support, love and kindness the last year. You are truly a blessing to me.

Lastly I would like to show my gratitude to my Lord and savior. Thank you, God for the strength, knowledge and health you provided. All my success I owe to you.

Table of Contents

List of Figures

List of Tables

Glossary

Falsework

Falsework means a temporary structure of combined support work and formwork, which is installed to support a permanent structure and its associated service loads until such time as the permanent structure is self supporting (Burgess, 2013).

Formwork

Formwork is a temporary or permanent mould of sufficient design strength used to form and maintain the shape of the wet concrete until the concrete is set (Burgess, 2013).

Gantry crane

Gantry cranes lift loads vertically, using a hoist and trolley, but move loads horizontally on beams or rails.

Hybrid concrete construction

Hybrid concrete construction is a combination of precast concrete elements and cast in-situ concrete.

In-situ concrete construction

The application of in-situ concrete in construction is a construction method where the concrete is cast on site. This construction method is where fresh concrete is poured into formwork where it is required to be hardened as part of the final structure.

Precast concrete construction

The application of precast concrete in construction is where the concrete has been prepared for casting, cast and cured in a controlled environment at a location which is not its final destination (Elliott, 2002).

Scaffolding

Scaffolding means a temporary structure, erected to provide access to and from elevated working platforms, for use by site personnel and also used to support materials (Burgess, 2013).

Superstructures

Superstructures are the construction above the basement or foundation, supported by an infrastructure which in turn is supported by the substructure.

Temporary works

Temporary works mean any formwork, scaffold, falsework, support work, shoring or other temporary structure designed to provide support or means of access during construction (Burgess, 2013).

List of Abbreviations

CIBD	Construction Industry Development Board
CIP	Cast-in-place
CPCI	Canadian Precast Concrete Institute
ECSA	Engineering Council of South Africa
HCC	Hybrid Concrete Construction
HBK	Hibriede Beton Konstruksie
LCM	Life Cycle Management
LCC	Life Cycle Cost
MCBS	Modern Concrete Building Systems
MMC	Modern Methods of Construction
PPP	Public Private Partnership
PCI	Precast Concrete Institute
VWSA	Volkswagen of South Africa

Chapter 1

Introduction

1.1 Subject

The subject of this thesis is an investigation into the time and cost factors for a decision between in-situ and hybrid concrete construction.

1.2 Background

Several construction methods have been developed to improve performance in construction projects. One of these methods is known as hybrid concrete construction (HCC). HCC is a combination of pre-fabricated concrete and cast in-situ concrete to obtain the supreme benefits of their different construction qualities (The Concrete Centre, 2005). This method of construction is ultimately used to achieve faster and occasionally, more cost effective, construction (Goodchild & Glass, 2004).

HCC today is a well-known term in the construction industry and is widely used in the UK and other developed countries. Jurgens (2008) and Lombard (2011), however, mentioned that the use of precast concrete is limited and that in-situ concrete construction remains the conventional method in the construction industry in South Africa. The main reasons for this could be the lack of experience on precast design and the shortage of sufficient precast information and guidelines (Gibb & Isack, 2001), (Glass, Federation & British Cement Association, 2000).

In addition to limited precast information and guidelines, project teams are usually required to make decisions during the early stages of construction projects. These decisions often need to be made in a short time period, and include the decision between various construction methods, such as the decision between in-situ concrete construction and HCC. Due to limited precast information and guidelines, Lombard (2011) proposed a framework that can assist project teams in their decision between in-situ concrete construction and HCC.

Lombard (2011) mentioned that the decision between construction methods is usually based on project time, cost, quality, safety, environmental performance, socio-economic aspects (labour) and client satisfaction. Project time and cost are, however, the most important of these factors (Lombard, 2011), (Chan, 2013), (Chow, Heaver & Henriksson, 1994), (Khosravi & Afshari, 2011) . Although it is stated that the structure of a building represents typically only 10 % of the construction cost, the choice of construction method and material can have significant effects on the cost of other elements during the life cycle of construction projects (Goodchild & Glass, 2004). It is therefore important to measure the whole life cycle cost when deciding between construction methods, such as in-situ concrete construction and HCC.

This thesis therefore aims to provide a framework of the factors that might influence the time and cost through the life cycle of construction projects. This framework should assist project teams in their decision between in-situ concrete construction and HCC.

This thesis forms part of a series of investigations on precast modular construction in South Africa, performed by Stellenbosch University. The aim of these investigations is to identify and discuss the obstacles that prevent the application of HCC in the construction industry in South Africa, and to identify the motivations for in-situ concrete remaining the conventional method of construction.

1.3 Aim

Project teams are often required to make quick decisions during the early stages of a project with little information available on the use of HCC. The purpose of this thesis is therefore to investigate HCC in South Africa and to provide sufficient information on the use of HCC, specifically in terms of the impact that HCC has on project time and cost.

Furthermore, the aim of this study is to identify and investigate the factors that influence project time and cost, and to provide a framework that can assist project teams in their decision between in-situ concrete construction and HCC in South Africa. The decision between these two construction methods is influenced by a vast number of variables that may be difficult to quantify. The framework therefore consists of qualitative information that can assist project teams in their decision.

1.4 Objectives

Goodchild & Glass (2004) mentioned that HCC has the ability to reduce the time and cost of construction projects. Therefore, the objectives of this thesis are to:

- Investigate the influence that construction time has on project cost and to investigate the importance of life cycle cost.
- Identify and discuss the design factors that may influence the time and cost for HCC and in-situ concrete construction.
- Identify and discuss the construction factors that may influence the time and cost for HCC and in-situ concrete construction.
- Identify and discuss the maintenance factors that may influence the time and cost for HCC and in-situ concrete construction.
- Identify the cost and time related risks associated with HCC and in-situ concrete construction.

These objectives are used to define a framework that can assist project teams to choose the appropriate construction method in terms of time and life cycle cost during the early stages of a project.

1.5 Scope & Limitations

The topic of HCC vs. in-situ concrete construction is a broad term and the scope & limitations are therefore introduced to set out the boundaries of the study. A project is usually measured by certain critical indicators, such as time, cost, quality, safety, socio-economic aspects (labour), environmental performance and client satisfaction. Although some of these terms may be mentioned, this thesis primarily focuses on the time and cost of construction projects.

This thesis does not focus on specific precast elements, such as beams, columns or walls, however, it investigates the implementation of HCC and in-situ concrete construction in projects as a whole.

The case studies that are investigated in the thesis are limited to South African projects. These case studies are limited to coal bunkers, reservoirs, parking structures and storage facilities. However, the information from these case studies should assist decision makers for any type of concrete application. The identified framework factors that have an influence on the time and cost of construction projects are often difficult to quantify. The framework is therefore not based on mathematical outputs and decision making models, but consists of qualitative information that can assist project teams in their decision between HCC and in-situ concrete construction.

Interviews with professionals, as described in the thesis, are limited to representatives of the South African construction industry and do not include interviews with professionals across borders. This thesis does not focus on technical design aspects, such as precast connections and other detailed design specifications.

The scope of this study is therefore to identify factors that have an influence on the time and cost of in-situ concrete construction and HCC in South Africa. These identified factors are then used to provide a framework that can assist project teams in their decision between in-situ concrete construction and HCC.

1.6 Methodology

The methodology of this project is broken down into three applications. These applications include the investigation of current literature sources on the topic, personal interviews and e-mail correspondence with professional role players in the industry, and case studies performed on several construction projects in South Africa. This was done to identify, investigate and discuss the factors that might have an influence on the time and cost for a decision between in-situ concrete construction and HCC.

These applications are discussed below:

1. In order to gain knowledge and a clear understanding of HCC and in-situ concrete construction, sources have been investigated and information is reflected in a literature review. The literature review provides an investigation on previous precast modular construction research topics at the University of Stellenbosch and includes a discussion of the relevance that this study has to previous and current investigations at the University. The literature review includes the investigation of local and international sources, such as published journal articles, engineering articles, reports and websites that are relevant to this topic. The literature review assisted the author to identify the primary phases in the life cycle of construction projects and to identify and discuss potential benefits, barriers and applications of in-situ concrete construction and HCC.
2. Personal structured interviews and e-mail correspondence have been conducted with professional consultants in the industry. These discussions assisted the author to identify the various factors that might have an influence on the time and cost for a decision between in-situ concrete construction and HCC during the design phase of a project’s life cycle. The discussions and identified factors were then investigated and were validated by the literature review and other related literature sources.
3. Several case studies were done on projects that took place in South Africa where structures have been constructed with HCC methods. These case studies assisted the author to identify and investigate the factors that have an influence on the time and cost for a decision between in-situ concrete construction and HCC during the construction phase of a project’s life cycle. The information of the projects was obtained through site visits, and discussions with representatives (contractors) from the various project teams.

The following case studies have been investigated:

- The Grootegeluk Medupi and Shondoni coal bunkers
- The Cape Town dispatch plant for Value Logistics
- The Bloemfontein Longridge reservoir
- Volkswagen South Africa paint shop

These steps assisted the author to formulate a framework that can assist project teams to make informed decisions when HCC or in-situ concrete construction is considered as alternatives for a project, in terms of project time and life cycle cost. Table 1.1 shows the methodology applications that have been implemented during the respective chapters to reach the various outcomes. Figure 1.1 graphically presents the methodology of this thesis.

Table 1.1: Chapter methodology applications

Chapter	Methodology
2	**Literature review:** The information that is provided in this chapter has been obtained from literature sources, such as published journal articles, engineering articles, reports and websites that are relevant to the research topic. The Literature review includes the following subjects: 1. Investigations at Stellenbosch University 2. Project success and the importance of time, cost and quality 3. Background on in-situ concrete construction and HCC
3	**Construction life cycle:** The information in this chapter has been obtained from literature sources, as described above. The Literature review includes the following subjects: 1. Life cycle management 2. Life cycle phases 3. Life cycle cost 4. Life cycle cost comparison
4	**Design phase:** The information that is provided in this chapter has been obtained from personal interviews and e-mail correspondence conducted with professional consultants in the industry. The information is validated by literature sources throughout the chapter. The interviews can be found in Appendix B. This chapter includes the identification and investigation of the factors that have an influence on the time and cost for a decision between in-situ concrete construction and HCC during the design phase of a project’s life cycle.
5	**Construction phase – Identification:** The information that is provided in this chapter has been obtained from site visits to various construction projects and discussions with representatives from the respective project teams. The information is formulated in case studies in this chapter and the discussions with the respective project teams can be found in Appendix C. These case studies assisted the author to identify the various factors that have an influence on the time and cost for a decision between in-situ concrete construction and HCC during the construction phase of a project’s life cycle.
6	**Construction phase – Discussion:** The information that is provided in this chapter has been obtained from the case studies that are presented in Chapter 5. The information is validated by literature sources and interviews conducted with professionals throughout the chapter. This section investigated the various factors that have an influence on the time and cost for a decision between in-situ concrete construction and HCC during the construction phase of the life cycle.
7	**Maintenance phase:** Most of the information provided in this chapter was obtained from literature sources. One e-mail correspondence was conducted with a professional in the industry. The Maintenance phase includes the following subjects: 1. Service life of concrete structures 2. Maintenance budget 3. Durability considerations
8 & 9	**Conclusions & Recommendations:** Based on the findings of the various chapters in this investigation, the framework with the identified influential time and cost factors is drawn up. Conclusions are drawn and recommendations are made for a decision between in-situ concrete construction and HCC.

1.7 Chapter summary

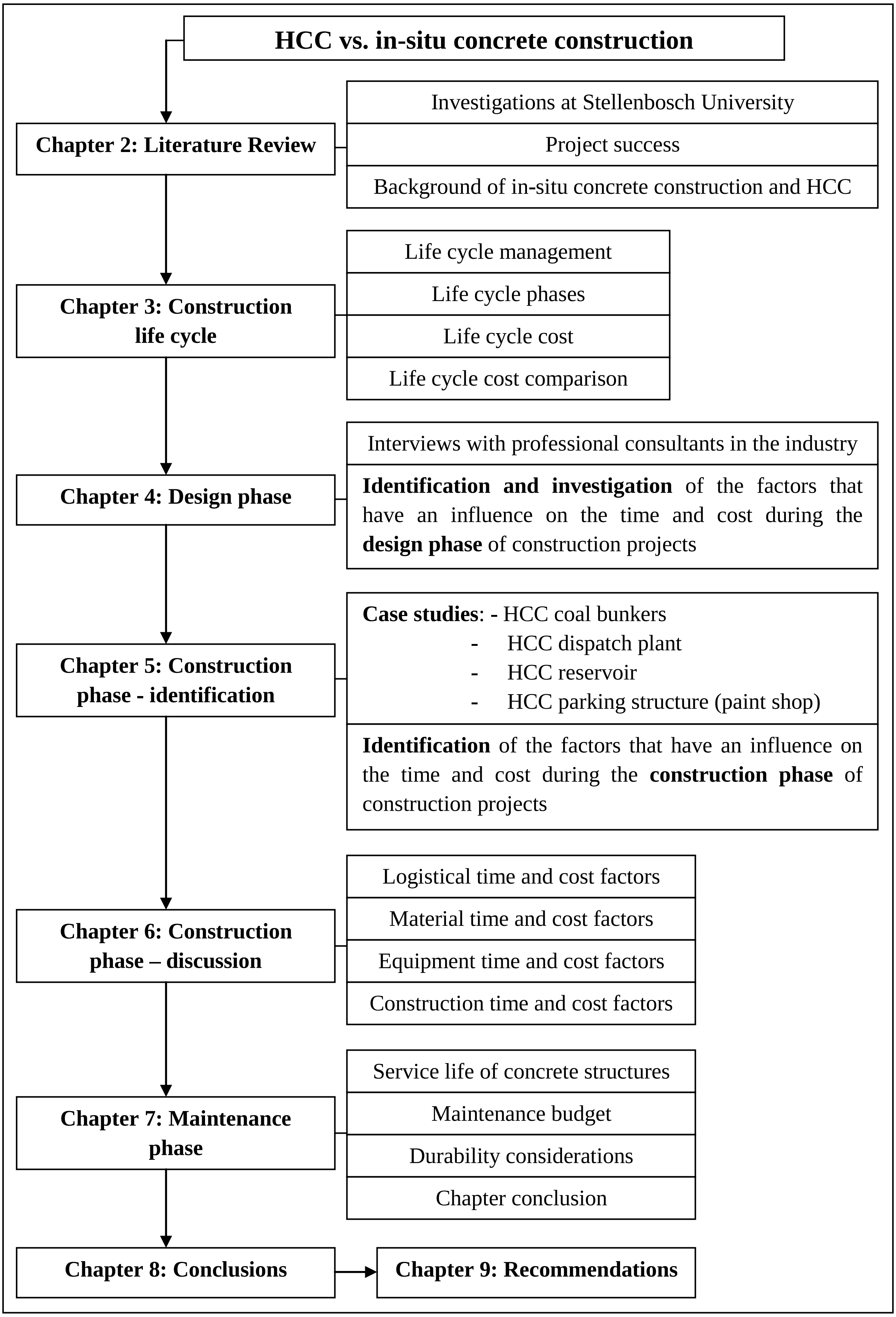

Figure 1.1: Graphic breakdown of the research study

The study is divided into the chapters, as shown in Figure 1.1, which are described in the following sections.

Chapter 2: Literature Review

The literature review provides an overview of literature on the implementation of in-situ concrete construction and HCC. This overview includes the historical background of each construction method and the reported benefits, barriers and applications of each method. It also discusses the various project success indicators with special reference to the importance of project time, cost and quality (iron-triangle).

This chapter also provides a background on previous and current investigations of precast modular construction at the University of Stellenbosch in order to justify the validity of this study.

Chapter 3: Construction life cycle

In order to identify and investigate the various factors that have an influence on the time and cost of construction projects, it is important to consider all phases throughout the life cycle of construction projects. This chapter therefore performs an investigation on the literature of the construction life cycle. This investigation provides a background on life cycle management and how it can be used to decide between various construction methods, such as in-situ concrete construction and HCC.

This chapter also performs an investigation on life cycle cost and the importance thereof in the decision between various construction methods.

This chapter furthermore performs a life cycle cost comparison between a theoretical in-situ concrete construction and HCC project. This comparison investigates the effect of reduced construction time on life cycle cost for construction projects, varying construction costs and also investigates the affect of an increase in maintenance cost.

Chapter 4: Design phase

This chapter investigates the various factors that may have an impact on the time and cost for a decision between in-situ concrete construction and HCC during the design phase of a project. Personal interviews with professional consultants in the industry were conducted to identify these factors. These factors are further discussed and investigated in this chapter.

Chapter 5: Construction phase – identification

Chapter 5 includes a variety of projects in South Africa, which were constructed over the last decade with the implementation of HCC. These projects were investigated and are introduced in this chapter with the use of case studies. The information on these case studies was obtained through site visits to the various projects and through discussions with a representative from the respective project teams. These case studies were used to identify the factors that have an influence on the time and cost for a decision between in-situ concrete construction and HCC during the construction phase of a project.

Chapter 6: Construction phase- discussion

In Chapter 5, the various time and cost factors that play a role in the decision for HCC were identified. This chapter provides a discussion to assist project teams in better understanding these time and cost factors. The identified factors have been categorized into four categories, namely, logistics, material, equipment and construction. The objective of this chapter is to gain knowledge of the time and cost factors that play a role in the construction phase for a decision between in-situ concrete construction and HCC.

Chapter 7: Maintenance phase

This chapter identify the factors that may have an influence on the project time and cost for a decision between in-situ concrete construction and HCC during the maintenance phase of a project. The factors are identified from available literature on concrete maintenance.

Chapter 8 & 9: Conclusions and Recommendations

Chapter 8 and Chapter 9 present a summary of the conclusions and recommendations made based on the main findings of the study.

Chapter 2

Literature review

The literature review includes available information of in-situ and hybrid concrete construction. This chapter is structured around the following objectives:

1. To provide a background on previous and current investigations of precast modular construction at Stellenbosch University and to justify the validity of this thesis.
2. To investigate project success and the importance of:
   - time
   - cost, and
   - quality
3. To provide a background on available information of in-situ concrete construction and HCC by:
   - providing the historical background of each construction method
   - identifying the reported benefits and barriers of each construction method, and
   - providing applications of each method

Figure 2.1 presents the chapter outline of the Literature review.

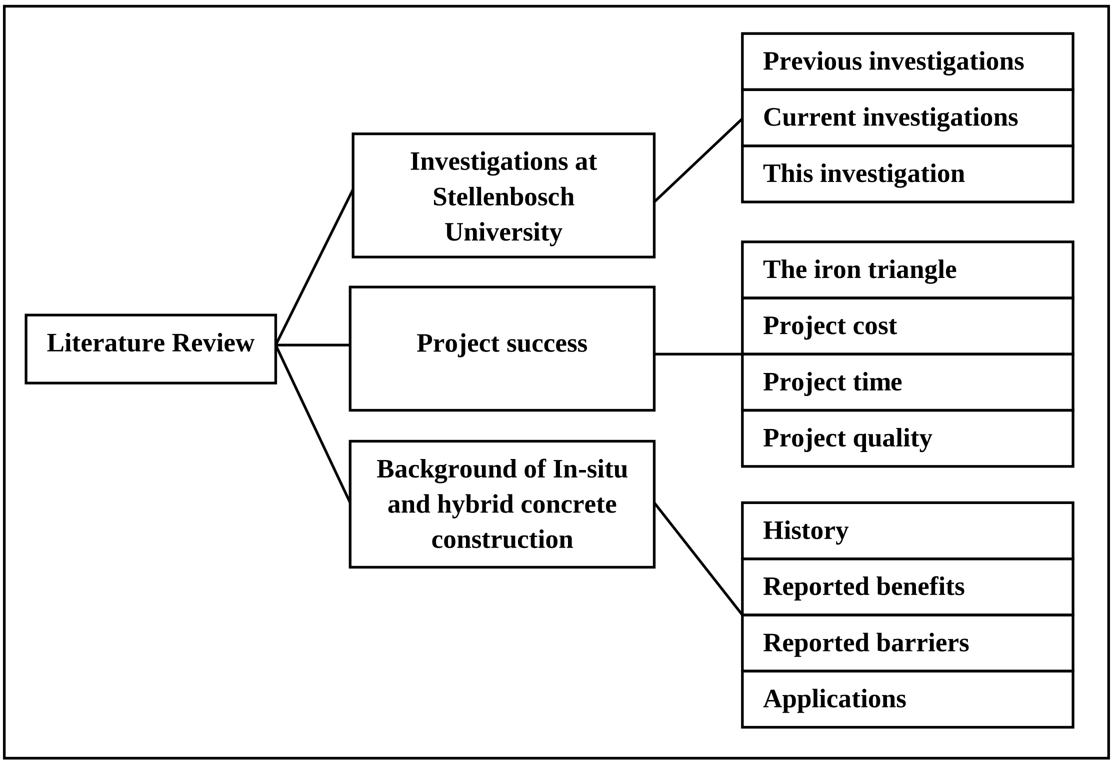

Figure 2.1: Literature review outline

2.1 Investigations at Stellenbosch University

During the last decade, engineering students at Stellenbosch University have been investigating the field of modular construction. One of the techniques of modular construction is that of pre-fabrication. Pre-fabrication in the construction industry has the potential to reduce the construction time of projects, improve the construction quality, improve safety on construction sites and potentially reduce life cycle costs (Gibb & Isack, 2001), (Goodchild & Glass, 2004). Although pre-fabrication of reinforced concrete, also referred to as precast concrete, is well developed in Europe, the United States, China and other developed countries, the utilization thereof is limited in South Africa (Lombard, 2011), (Jurgens, 2008).

Previous investigations have mentioned that although several projects in South Africa have been successfully implemented in using HCC techniques, several others have been less successful (De Klerk, 2013), (Hanekom, 2011). This identified relevant research topics on methods to improve the utilization of precast concrete techniques in South Africa, and why the conventional method of in-situ concrete is still the preferred method of construction in the industry of South Africa.

This section therefore provides the previous and current investigations on precast modular construction at Stellenbosch University, and how these investigations are related to this topic.

2.1.1 Previous investigations

2.1.1.1 An investigation into the feasibility of hybrid concrete construction in South Africa (Jurgens, 2008)

This was the first research topic in the field of modular precast concrete techniques. Jurgens (2008) mentioned that the primary objective of HCC is to produce construction quality, reduce the life cycle project cost and to achieve faster delivery of construction projects. The primary objective of the investigation was therefore to identify the obstacles that prevent the utilization of HCC in the construction industry in South Africa.

Personal interviews were conducted with professional consultants and contractors in the industry to identify the obstacles and to discuss possible solutions. After the interviews, Jurgens (2008) visited a project that was constructed with HCC techniques, where a personal interview has been conducted with the project team. The objective of the site visit was to verify the identified obstacles during the personal interviews, and to identify and investigate the problems that were faced and how they were overcome.

Jurgens (2008) investigated and discussed management aspects, technical aspects and contractual aspects. Although the investigation covered a broad spectrum, recommendations were formed to extend the study through future research into the use of HCC in South Africa.

2.1.1.2 Decision making between hybrid and in-situ concrete construction in South Africa (Lombard, 2011)

Lombard (2011) mentioned that construction methods that prove to be the best today might not be the preferred method for construction in the future. Lombard (2011) also mentioned that precast concrete might be beneficial for some projects, whereas in-situ concrete might be the preferred method of construction for other projects. Project teams are therefore required to make decisions between construction methods during early stages of construction projects.

The primary objective of this investigation was to propose guidelines that can assist project teams in their decision between precast and in-situ concrete for building construction projects in South Africa. The decision making scheme provided by Lombard (2001) was not based on decision making models as it is often difficult to quantify some of the vast number of variables. Therefore, the investigation provided relevant information that project teams can use in the decision making process. The investigation identified the relevant factors of cost, time, quality, social and environmental parameters. These parameters were then used to draw up a framework that can assist project teams in their decision.

2.1.1.3 Increasing the utilisation of hybrid concrete construction in South Africa (Hanekom, 2011)

Hannekom (2011) followed on the investigation of Jurgens (2008). Hannekom (2011) mentioned that HCC is well recognised in developed countries and that the feasibility study performed by Jurgens (2008) has illustrated that it is possible to successfully be implemented in South Africa. The utilization of HCC, however, remains limited in the country. The aim of this investigation was therefore to increase the utilization of HCC in South Africa.

The implementation of HCC encourages early involvement from the respective project participants in order to provide the best value project for the client. The primary objective of this investigation was to identify the potential barriers that prevent the utilization of HCC in South Africa and to provide possible solutions to overcome these barriers. The investigation identified and discussed the necessary drivers of change that need to be implemented in the industry to promote the application of HCC. The investigation also discussed the importance of collaborative contract procurement strategies, such as the design-build, to enhance the application of HCC in South Africa (Hanekom, 2011).

2.1.1.4 Precast modular construction of schools in South Africa (De Klerk, 2013)

De Klerk (2013) performed an investigation on the use of precast concrete techniques as an alternative building method for the construction of schools in South Africa. This investigation made use of the identified barriers by Hannekom (2011) and the proposed framework suggested by Lombard (2011).

De Klerk (2013) applied these identified criteria to the construction of schools in South Africa. The factors that were discussed for modular precast school construction in South Africa included the following:

- time
- cost
- quality
- socio-economic (labour)
- logistics
- health & safety, and
- procurement strategies

De Klerk (2013) therefore performed a feasibility study on precast concrete techniques for school construction in South Africa. This was done by addressing the above factors with the implementation of precast concrete techniques. He concluded that when precast concrete techniques are implemented for multiple schools, numerous benefits in terms of time and cost are possible. He identified and described the importance of repetition and standardization in the implementation of precast concrete construction.

2.1.2 Current and future investigations

Previous investigations made many recommendations for future studies in the field of precast modular construction. Numerous topics have been identified for the research of precast concrete construction in South Africa, and include the following:

- The consideration of labour issues between in-situ and precast/hybrid concrete construction
- The investigation of on site safety with the use of precast modular construction
- The investigation of quality in construction and the comparison thereof between in-situ and precast/hybrid concrete construction.
- The identification and feasibility study of possible areas where precast concrete can be implemented successfully, such as offices, bridges, walls, clinics, houses and reservoirs.
- The investigation on the connections between various precast elements

2.1.3 This investigation

This thesis is based on the previous investigations as discussed in section 2.1.1. Lombard (2011) identified and proposed a framework that can assist project teams in their decision between in-situ concrete construction and HCC. The framework that was proposed included the aspects of cost, time, quality, social aspects (labour) and environmental parameters. The investigation of Lombard (2011) briefly discussed these aspects and their role in the decision between in-situ and hybrid concrete construction.

This thesis goes further to identify the factors that may influence the time and cost parameters in the decision between in-situ and hybrid concrete construction. These time and cost factors are used to propose a framework, which can assist project teams in their decision between in-situ concrete construction and HCC.

The focus of this thesis is presented in Figure 2.2. The figure presents the necessary criteria that need to be considered for a decision between various construction methods, as identified by Lombard (2011), Hannekom (2011) and De Klerk (2013). This investigation, however, focuses on the factors that have an influence on the time and cost, that need to be considered for a decision between in-situ concrete construction and HCC.

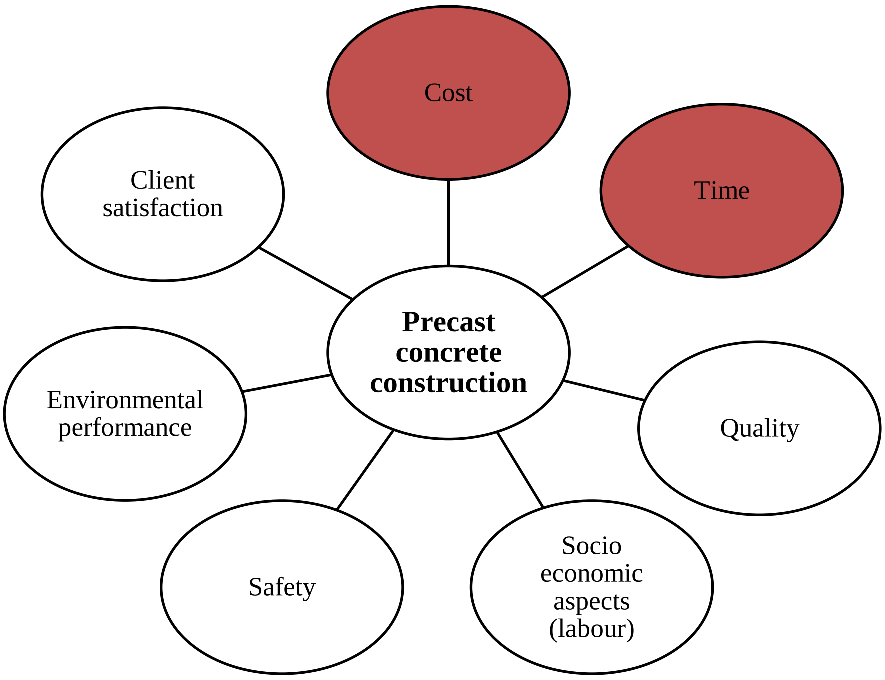

Figure 2.2: Criteria for a decision between construction methods (Chan, 2013), (Lombard, 2011)

2.2 Project success and the importance of time, cost and quality

Project success is the ultimate goal for every construction project (Chan & Chan, 2004). The concept of measuring project success, however, differs for different participants and projects. It is difficult to define a successful project as there is a lack of agreement as to how this term should be defined (Chan, Scott & Lam, 2002).

Success can be defined as a favourable outcome or the gaining of fame or prosperity. Favourable outcomes in construction projects, however, mean different things to different people. Different engineering companies, project teams and professionals in the industry have different perspectives on project success (Parfitt & Sanvido, 1993). Clients, consultants, contractors, quantity surveyors, suppliers and sub-contractors have their own objectives and different criteria for measuring project success. Project type, size and complexity may also change some perspectives of project success (Chan, 2001).

Definitions of project success also vary throughout different phases of construction projects. Atkinson (1999) defines project success during different phases of construction, namely the delivery stage and the post delivery stage. Success indicators for the delivery stage are typically more focused on the project construction team, where the indicators of the post delivery stage are more focused on the client and the operation team (Atkinson, 1999).

Literature have shown that the most common project success indicators in the construction industry are that of time, cost, quality, client satisfaction, environmental performance, socio-economic aspects (labour) and safety, as presented in Figure 2.2 (Chan & Chan, 2004), (Shrnhur, Levy & Dvir, 1997), (Atkinson, 1999), (Lim & Mohamed, 1999).

Although overall project success is measured by all the indicators displayed in Figure 2.2, project success has and still is dominated by the conventional measures of time, cost and quality (Toor & Ogunlana, 2010). For many years, time, cost and quality have been the most popular indicators for evaluating project success. Clients, contractors, consultants and project managers acknowledge the fact that there are many other success indicators as stated above, however the so-called iron triangle for measuring project success remains the fundamental indicators of project success (Atkinson, 1999), (Khosravi & Afshari, 2011), (Lombard, 2011).

2.2.1 The iron triangle

Atkinson (1999) mentioned that the iron triangle was originally developed as an outline to assist project managers in evaluating and determining the demands of cost, time and quality in construction projects. The triangle, however, became a method for measuring project success. Project managers defined project success on these criteria (Ebbesen & Hope, 2013). Figure 2.3 represents the iron triangle of time, cost and quality.

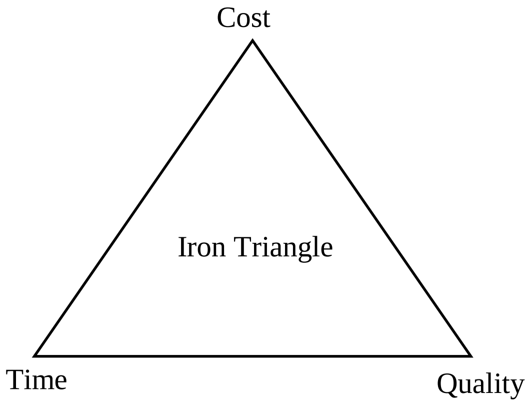

Figure 2.3: The iron triangle (Atkinson, 1999), (Ebbesen & Hope, 2013)

The iron triangle is also used for the indication of dependency between the three indicators (Ebbesen & Hope, 2013). Project cost is more likely to be high when projects are constructed at a rapid pace with high quality. When rapid construction with minimal costs take place, on the other hand, it may be difficult to deliver a product of high quality. And projects that are constructed with minimal cost and good quality might be time consuming. Project managers therefore strive to deliver the "ideal project", where a high-quality project is delivered on time, within budget. Figure 2.4 is a presentation of the dependency between the iron triangle indicators. It is important to consider these indicators in relation with each other, as they have an indirect impact on each other.

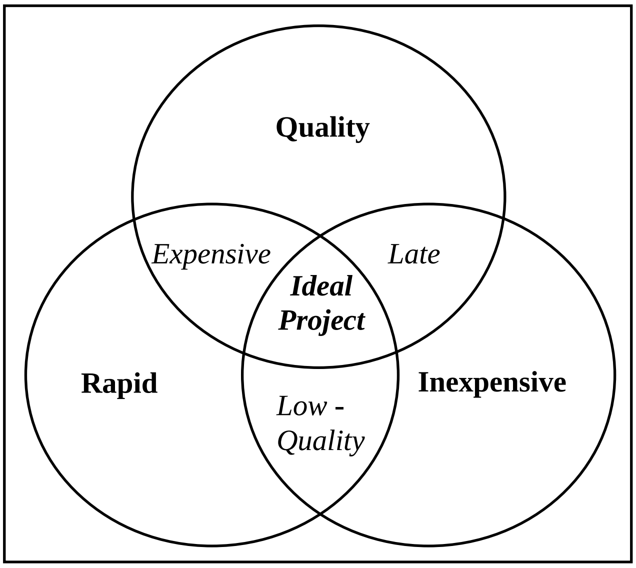

Figure 2.4: Dependence model of the iron triangle (Ebbesen & Hope, 2013), (Lombard, 2011)

2.2.2 Project cost

Cost in construction projects remains the principle indicator of success (Khosravi & Afshari, 2011). However, to measure cost in construction projects is not that simple. Construction projects consist of various phases, such as the design phase, construction phase and the operation and maintenance phase. All these phases add to the sum of total project cost, also known as life cycle cost (LCC). Goodchild & Glass (2004) established that the structure of a building represents typically only 10 % of the construction cost. It is therefore important to consider the total LCC of construction projects. It is also important to consider the output costs at the end of a structures life in the estimation of project cost. Table 2.1 presents typical long-term costs of concrete buildings according to Goodchild & Glass (2004).

Table 2.1: Long-term costs of buildings (Goodchild & Glass, 2004)

CAPITAL COST = 1	**COST IN USE = 5**	**BUSINESS COSTS = 200**
To operate and maintain the building will cost five times the capital costs over the life of the building. However, the cost to the business, including salaries and staff productivity, of occupying the asset is 200 times the capital cost. In some quarters this has been extended by attributing 0.1 to the cost of design and 1000 to the cost of the outputs from the building.		

Woodward (1997) presented a graph of life cycle cost during the different phases of a construction project in his article, “Life cycle costing”. Figure 2.5 presents his graph. Engineering and development cost, as indicated on the graph, represents the design cost, where production and implementation cost represents the construction cost, and the operating cost represents that of operation and maintenance cost. The LCC is the sum of all the costs from the initial phase to the disposal phase of construction projects. Cost factors are often difficult to quantify and vary throughout the different phases. It is important to consider the life cycle cost in the decision between various construction methods (Woodward, 1997).

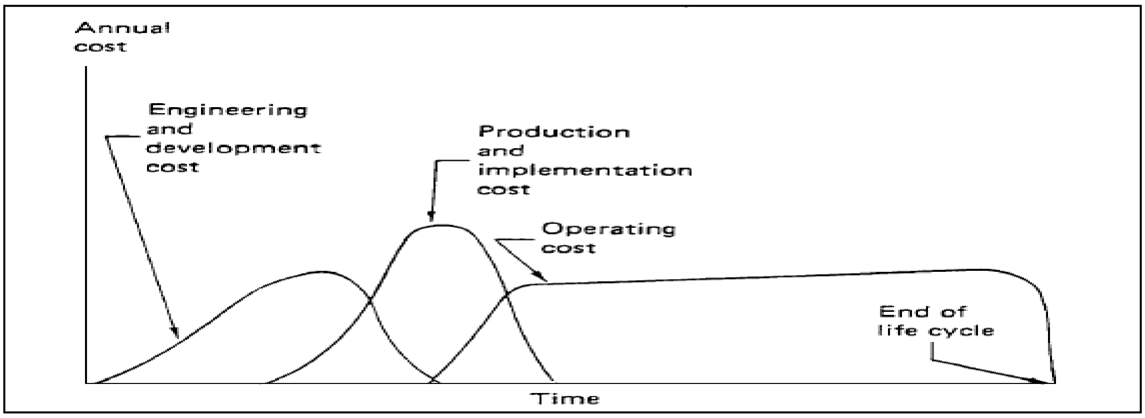

Figure 2.5: Life cycle cost of construction projects (Woodward, 1997)

2.2.3 Project time

In the construction industry, time is referred to as money. Construction time is one of the principle factors of construction cost. According to Driscoll (2013), time in construction projects, with its related costs, is important to all the parties involved in construction projects. Effective time management is important to avoid time and cost overruns (Driscoll, 2013).

As mentioned in section 2.2.1, time has an indirect impact on cost. Baker (1991) classified construction cost in two categories, namely direct cost and indirect cost. Direct cost is necessary for implementation and includes costs, such as, labour, material and equipment cost. Direct cost can therefore be allocated to each activity on the project (Baker, 1991).

Indirect cost, on the other hand, includes management, office overheads, revenue, financing and the cost of inflation. The total indirect cost of construction projects increases with time. Indirect cost can therefore not be divided between activities due to the continuous increase in cost throughout the duration of a project (Baker, 1991).

Figure 2.6 presents the typical relationship of indirect cost and time, throughout the duration of a construction project. The actual shape of the graph is dependent on various factors. Therefore, the relationship of the curve may not necessarily be linear as indicated in the graph; nonetheless it shows the continuous growth of indirect cost over the duration of a construction project (Baker, 1991).

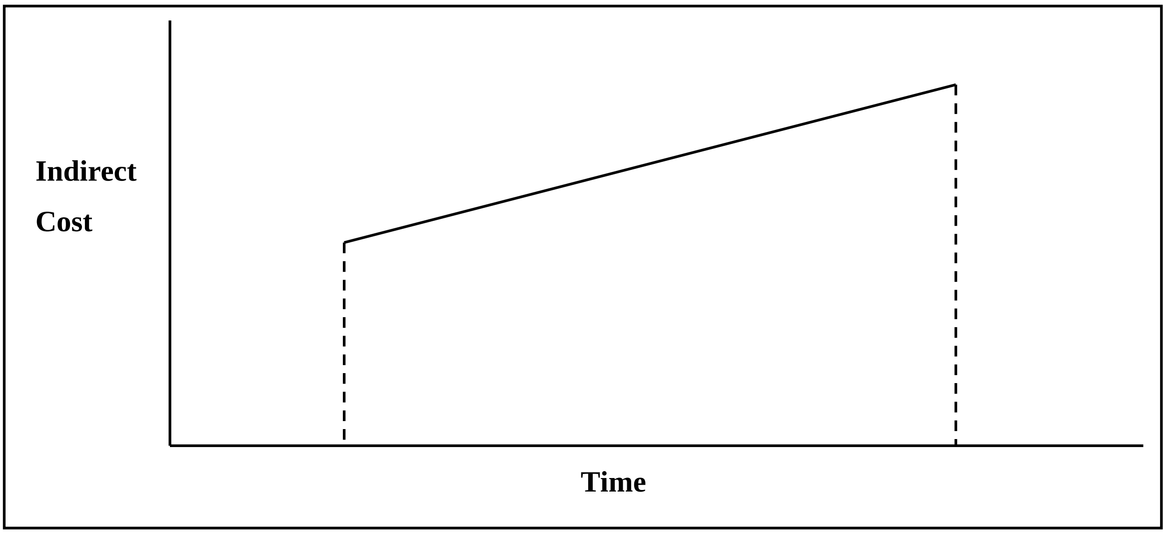

Figure 2.6: Increasing indirect cost showing the effect of time on cost (Baker, 1991)

Contractors usually use credit or borrow money in order to finance construction projects (Atkinson, 1999). The interest rate has an effect on the indirect cost of construction projects. The overall cost of construction projects increases with time during the duration of a project, due to the impact of interest rates (Baker, 1991). The value of time should therefore be considered in the decision between various construction methods.

2.2.4 Project quality

Construction quality is an essential aspect in the construction industry. Lombard (2011) mentioned that construction quality has the ability to reduce potential time and cost savings when the quality aspects of applications in construction are overlooked. Quality, therefore, has an indirect influence on the time and cost of construction projects and is an important factor in the success of a project.

Different definitions of construction quality have been formulated throughout the years. One of the many definitions, “conformance to, or meeting requirements”, was developed by Conrick in the early 90’s (Conrick, 1991). Rwelamila & Wiseman (1995) established that quality can not be observed in the absence of durability. Durable construction applications usually execute its future purpose over its design life. Long term quality of construction applications, therefore, includes durability. Lombard (2011) also added to the definition of quality by identifying different scopes of quality. These terms were described as long and short term quality, where the construction phase of a project typically represents the short term quality and the operational phase the long term quality of a project.

Soetato *et al* (2004) mentioned that precast elements can potentially achieve higher quality standards than in-situ concrete construction. This statement was also confirmed by the Concrete Network (2014). The main reason for this is the ability to apply more efficient quality control in controlled environments (precast factories), compared to operations taking place on site. Quality control of precast elements in controlled environments includes accurate cover dimensions and precise concrete mixtures. In HCC projects it is, however, not only the precast elements that contribute to the structure, but also the application of in-situ concrete. All structural applications should therefore meet the quality requirements throughout the project to produce a durable product.

To measure quality in construction projects is a complicated task. It is difficult to quantify measures of quality. Several systems and codes regarding quality requirements are implemented to achieve and maintain a certain standard of quality (Lombard, 2011). The factor of quality should not be overlooked and is important in the decision between various construction methods as it has an indirect impact on project time and cost.

2.2.5 Project success conclusion

This section illustrated that the factors of time, cost and quality are dependent on each other. These factors have an indirect impact on one another. It is important to consider these factors in relation with each other when the budget of a project is estimated.

2.3 Background on concrete construction

The application of concrete in construction is virtually everywhere, but the role it plays in society of today is often easily overlooked. The benefits that concrete holds for our society are vast, where it is implemented to construct a large number of current infrastructure. This infrastructure includes apartment blocks, schools, hospital clinics, bridges, dams, tunnels, pavements, roads, sewage systems and more (Cement Sustainability Initiative, 2012). Concrete is said to be the most used artificial material in the world. It was estimated by the Cement Sustainability Initiative (2012) that nearly three tons of concrete are used annually per person. It was also estimated that twice as much concrete is used around the world in comparison with the total of all other building materials, including wood, plastic and aluminium. Concrete as material in construction remains the benchmark in terms of effectiveness, price and performance (Cement Sustainability Initiative, 2012).

2.3.1 Concrete construction methods

The construction industry is a competitive market and contractors need to keep up-to-date with new construction methods and technologies. Modern methods of construction (MMC) were developed to reduce construction time, improve the quality of construction, insure cost savings and promote sustainable development (The Concrete Centre, 2009). The concrete industry encourages innovation and MMC to meet these benefits of concrete construction (The Concrete Centre, 2009). The most common methods of concrete construction are in-situ and the application of precast concrete in construction.

In-situ concrete construction was for years the most common method of construction and is still known as the conventional method in the construction industry in South Africa. Although many contractors in South Africa are moving towards the use of precast systems, especially above ground level, the traditional form of in-situ concrete construction remains dominant (CCANZ, 2013a), (Lombard, 2011). Designers in South Africa prefer in-situ concrete construction due to years of experience. Designers also appreciate beneficial qualities that this familiar method of construction has to offer. In-situ concrete has the ability to be cast in monolithic building elements, such as walls, columns, beams, floor slabs and roof elements which are attractively detailed and appeal to many designers in the construction industry (CCANZ, 2013a).

In developed parts in the world, such as the US and Europe, it is often difficult to compete in the construction industry, using the conventional method of in-situ concrete construction. HCC has proved to be cost effective and contractors realise the benefits that HCC has to offer (CCANZ, 2013b). In-situ concrete construction is in some projects, however, still the ideal structural material, such as construction sites with challenging accessibility and projects with limited occurrence of standardization (CCANZ, 2013b).

Several precast techniques have been developed to improve the application of concrete in construction. Precast concrete has not been used to its potential in the construction industry until the past decade, and is still not being used to its full potential in South Africa. The main reason for this is the lack of design experience in the industry (Jurgens, 2008), (Hanekom, 2011). This material, however, has shown itself to be effective in cost and time savings in developed countries over the years. It also produces high quality structures in construction projects, since the casting is done in a controlled environment (CCANZ, 2013b).

Concrete precast systems were established in the United States early in the 20th century (CCANZ, 2013b) . The South African construction industry is well developed and precast construction has been on the increase during the past five years. There are currently sufficient supplies of the raw materials and technology in some parts of the country, but in order to use this material to its potential, more technology and supplies are required (Lombard, 2011).

Although it is possible, structures are not often constructed entirely of precast elements, especially in South Africa. The combination of precast and in-situ concrete in construction (HCC) is, however, more prevalent. The two concrete construction methods, namely, in-situ concrete construction and hybrid concrete construction are further discussed in the following sections of this chapter.

2.3.2 In-situ concrete construction

The application of in-situ concrete in construction is a construction method where the concrete is cast on site. This construction method is where fresh concrete is poured into formwork where it is required to be hardened as part of the final structure. This method of construction is said to be a method that has been, and still is one of the most common forms of construction (PCA, 2014). In-situ concrete construction is displayed in Figure 2.7.

Figure 2.7: In-situ concrete construction (Dawson, 2003)

2.3.2.1 History of in-situ concrete construction

The technology of casting concrete in removable forms dates back to the 1850s. This application of reinforced concrete originated soon after Portland cement was patented in 1853 (PCA, 2014). Removable forms were primarily used for basement walls of single-family homes. One of the first to recognise the potential benefits of in-situ concrete applications above ground level was Thomas Edison. He introduced this technology through demonstration projects more than 100 years ago, where buildings were constructed entirely of in-situ reinforced concrete (PCA, 2014).

These projects led to innovations in forming and placing techniques which in turn made concrete construction using removable forms a well-accepted construction method (PCA, 2014).

2.3.2.2 The benefits of in-situ concrete construction

In-situ concrete is often referred to as cast in place (CIP) concrete. The application of CIP concrete in construction has numerous benefits to offer. The benefits of CIP concrete in construction are mentioned and described below.

Familiarity

The application of in-situ concrete in construction has been and still is the most used technique in construction. Designers and contractors are confident in using this technique. There are numerous design guidelines that have been tried and tested throughout the years. Design engineers favour designing in-situ concrete structures with the use of these guidelines, due to years of experience (Goodchild & Glass, 2004).

Monolithic Construction

CIP concrete has the advantage of monolithic construction. This is where larger solid structures are erected, which requires fewer joints. The frame of monolithic reinforced concrete also has the ability to resist heavy loads. These structures are reliable in seismically active regions (Sandt, 2003).

Easy use for two way structural systems

In-situ concrete encourages longer spans with the ability to bare heavy loads. Two way structural systems reduce the dead load of the structure due to present voids in the elements. This is an attractive method of construction which produces good vibration resistance (Tesit, 2012).

Late adjustments are possible

Adjustments to the design can be made up unto the last minute, just before casting the concrete. The application of in-situ concrete in construction has the advantage of making late changes to the project, since casting concrete will only take place on-site. The design of in-situ concrete structures is said to be more or less flexible (Sandt, 2003).

No additional skills & material required

Subcontractors and local labour are familiar with the use of in-situ concrete in construction. Contractors are therefore confident in using local labour and local material suppliers (Sandt, 2003).

Smaller cranes

The use of in-situ concrete in construction requires cranes with a smaller load bearing capacity when compared to the use of precast concrete in construction. For the use of in-situ concrete construction, cranes are only required to move concrete buckets, reinforcement and other required materials. These cranes are required when site accessibility might be challenging, or when construction take place at heights (Sandt, 2003).

Insulation

CIP concrete provides a high degree of insulation. This insulation includes thermal insulation, which prevents moisture from the earth to penetrate through the structures. This also includes insolation against sound, insects, mold and mildew. Since there are no gaps between sections in the structure, it makes it difficult to penetrate (Hartman, 2011).

Positive drainage

It is said that in-situ concrete applications have the ability to provide better overall drainage when compared to precast concrete construction (Ceco, 2012).

Adequate lighting

More lighting in structures from fewer fixtures are allowed with the wide spans that the application of in-situ concrete in construction has to offer. Adequate lighting provides for the increase of safety and visibility of signage. It also reduces potentially high initial costs associated with lighting a precast structure (Ceco, 2012).

2.3.2.3 The barriers of in-situ concrete construction

CIP concrete is the conventional technique of concrete construction, but it does, however, have a few limitations. The following descriptions are known as the barriers of CIP concrete in construction.

Labour intensive

CIP concrete in construction requires a large quantity of labourers. Three separate labour teams are required for the application of in-situ concrete construction. The tasks of these teams start once the earthworks are completed. Firstly the steel fixers position the steel, known as the reinforcement. After the steel is in position the team responsible for placing the formwork starts to function. Once the formwork and steel are set the concrete team pours the concrete. Each of these teams may involve different labourers, requiring exclusive skills. CIP concrete in construction, therefore, requires various teams of labourers (Illingworth, 2002).

Time consuming

To erect the formwork and positioning the reinforcement of the structure is a time consuming process. In the case where one of these activities is behind schedule, the activities to follow will also be affected (Illingworth, 2002).

Quality control

Since the concrete is not manufactured in a controlled environment, and sometimes in awkward positions at great heights, it is difficult to control the quality of in-situ concrete on-site (Illingworth, 2002).

Weather

When concrete is poured in its form to set, it requires time for curing. Weather conditions can create difficulties for curing, and for construction itself. Weather is also known as a safety hazard to labourers in the application of CIP concrete in construction (Illingworth, 2002).

Buildability

Superstructures and structures constructed at great heights may be difficult to construct with the application of in-situ concrete. To set the formwork, position the steel and pour the concrete at great heights may be a challenge (Goodchild & Glass, 2004).

Safety

Labourers working with formwork and reinforcement often work in awkward positions and at great heights. To construct with in-situ concrete in construction may therefore be a safety hazard to labourers in the construction industry (Goodchild & Glass, 2004).

Waste

The application of in-situ concrete in construction tends to produce more waste when compared to the application of precast concrete. Bison (2011) mentioned that the use of in-situ concrete in construction can produce up to 50 % more waste when compared to precast concrete techniques.

2.3.2.4 Applications of in-situ concrete construction

The application of in-situ concrete construction is known as the conventional method in the construction industry in South Africa. Consultants and contractors are confident to design and construct with the use of in-situ concrete. The flexibility of in-situ concrete provides various application options of this robust material. Various standard forms are available to cast in-situ concrete. Designers therefore have the ability to design structures of almost any shape in using in-situ concrete construction and include applications, such as, beams, columns, walls, foundations, etc. (Goodchild & Glass, 2004).

2.3.3 Hybrid concrete construction

The application of precast concrete in construction is where the concrete has been prepared for casting, cast and cured in a controlled environment at a location which is not its final destination (Elliott, 2002). These precast elements are then transported to the construction site where it is erected to form part of the main structure. New technologies have shown that it is possible to construct total precast structures, however, most structures are usually constructed with a combination of precast and in-situ concrete construction. The combination of these two methods is also known as hybrid concrete construction (HCC) (Lombard, 2011), (Goodchild & Glass, 2004).

The Concrete Centre (2005) mentioned that hybrid concrete construction is a method of construction where in-situ concrete is combined with precast elements to benefit from the supreme advantages of their different inherent qualities. The flexibility and economy of in-situ concrete can be combined with the speed, accuracy and high-quality construction of precast systems (The Concrete Centre, 2005).

Glass (2005) mentioned that clients can be given better value with the use of precast concrete in construction. This method has proved to produce simple buildable and competitive structures. Figure 2.8 is an illustration of HCC, where precast elements are placed in its final location.

Figure 2.8: Precast concrete construction (Gibb & Isack, 2001)

2.3.3.1 The history of hybrid concrete construction

There is no specific date recorded of the first official design of HCC. The combination of in-situ concrete and precast concrete was used many years ago, although it was never referred to as HCC. The origin of the term hybrid concrete construction was developed after the Ronan Point building collapse (Hanekom, 2011).

Much criticism was levelled at the United Kingdom’s construction industry after the collapse of the Ronan Point building (Hanekom, 2011). Project teams ignored precast concrete in construction because the industry was criticized for the lack of precast design standards and safety measures, especially after the collapse (Hanekom, 2011). These criticisms resulted in various studies of the construction industry in order to define the industry problems for the government of the United Kingdom.

Sir Michael Latham (1994) was the author of the first breakthrough report, "Constructing the team". He was followed by Sir John Egan (1998) with "Rethinking Construction", which provided additional guidelines for improving the construction industry (Hanekom, 2011). Both these reports commented on methods to improve the utilisation of precast concrete in construction. This inturn led to the publication of "Best Practise Guidance for Hybrid Concrete Construction" by Goodchild & Glass (2004).

The publication of Goodchild & Glass (2004) was founded on previous successful projects where HCC methods had been used successfully in construction projects. Goodchild & Glass (2004) found that HCC was broadly cost neutral, and time of construction was equal or reduced when compared to conventional construction methods and offered more potential benefits. The acceptance and widespread use of HCC was, however, still hindered by the lack of experience and guidance (Goodchild & Glass, 2004), (Gibb & Isack, 2001).

The aim of the publication was therefore to provide guidance on the design and implementation of precast concrete. The fundamental output from the report provided information of customer requirements, design concerns, construction business processes and supply chain issues (Goodchild & Glass, 2004).

2.3.3.2 The benefits of hybrid concrete construction

The combination of in-situ and precast concrete has numerous benefits in the construction industry. The one material compensates for the drawback of the other. In-situ concrete construction is known as the most economic framing option, while precast construction promotes time savings on construction and better product quality. Combining these two materials provides for greater overall economy (Goodchild & Glass, 2004). The following descriptions are reported benefits of construction with the implementation of HCC (Concrete Network, 2014).

Quality

Quality of the structural elements can be controlled and monitored since precast concrete is manufactured in a controlled environment (precast yards and factories). It is therefore easier to control the mix, position the steel and cast the concrete. The desired temperature for the curing of concrete can also be achieved in some of these factories (Concrete Network, 2014), (Goodchild & Glass, 2004).

Reduced construction schedule

On site operations can advance more rapidly with the construction of precast elements. The manufacturing of precast elements is moved from site into a controlled environment to reduce the activities performed on site. Precasting is independent of the activities on site and can continue in the factory, while site procedures are in progress. One example is that there is no waiting period on site required for the curing of concrete. Precast concrete can be installed immediately. The modularity of precast products also increases the tempo of installation (Concrete Network, 2014), (Goodchild & Glass, 2004), (Lombard, 2011).

Reduced temporary works

The Irish Concrete Federation (2011) mentioned that formwork and scaffolding are reduced when compared to in-situ concrete construction. The reliance on wet trades and on-site supervision by contractors are also reduced with the use of HCC techniques. Economies are generated through these factors (Goodchild & Glass, 2004).

Earlier return on investment

Project cost and time are directly linked. Faster project completion therefore means earlier return on investment, lesser interest expenses, reduced construction preliminaries and, consequently, ideal development cost (Goodchild & Glass, 2004), (Irish Concrete Federation, 2011).

On site labour

Fewer labour teams are required with the use of HCC. Only one team is required on site. This team is responsible to lift and place the elements. The team usually consist of a crane operator, an assistant helping with navigation, and a crew that does the placing. No specific labour skills are required in the application of HCC, except for the crane operators. As mentioned in section 2.3.2.3, in-situ concrete construction may require up to three separate teams (Concrete Network, 2014), (Goodchild & Glass, 2004).

Buildability

It is more convenient to construct with the use of precast concrete compared to certain in-situ concrete applications, especially when construction takes place at heights. The application of precast concrete mostly consists of the placing of elements. In the case of in-situ concrete, the erection of formwork, positioning of steel and the pouring of concrete at heights may be a challenging task. Precast frames may therefore ease construction buildability (Irish Concrete Federation, 2011), (Dawson, 2003).

Repeatability

It is easy to produce a large number of the same precast elements. By maximizing repetition of precast elements, more value from the moulds and set-up can be achieved. This also increases the speed of construction (Concrete Network, 2014), (Jurgens, 2008).

Waste

Much less waste is generated with precast systems compared to the use of in-situ concrete. With most of the manufacturing being done in the factory, materials, such as formwork panels, are reused to its maximum usage. The controlled environment produces less waste than on-site operations. This also reduces the risk of on-site theft due to less material (Irish Concrete Federation, 2011), (Lombard, 2011).

Weather

The weather factor is eliminated when precast elements are manufactured in a controlled environment. Casting of concrete can take place during any time of the project, without considering weather conditions. This ensures more reliable concrete mixtures and methods (Concrete Network, 2014), (Goodchild & Glass, 2004).

2.3.3.3 The barriers of hybrid concrete construction

The implementation of HCC does have certain shortcomings. The following aspects are reported barriers in the use of HCC.

Experience

Design engineers have more experience in designing structures with the conventional method of in-situ concrete. Although research on precast concrete has increased significantly, the majority of designers in South Africa still prefer to design in-situ concrete applications (Barrett, 2003), (Harcourt, 2011), (Lombard, 2011), (De Klerk, 2013).

Guidance

There are not sufficient HCC guidelines available for engineers to use. The industry also has a dearth of professional mentors with experience in this field to assist engineers in their choice and use of precast concrete (Lombard, 2011), (Harcourt, 2011).

Connections

Structural connections for precast systems in combination with the use of in-situ concrete in construction have the possibility to cause design and construction problems. Some design engineers may find connection design for HCC systems somewhat complex. Several engineers are not familiar with this concept and experience a lack of confidence with the connection design of HCC systems (CPCI, 2007), (Jurgens, 2008).

Flexibility

Planning in collaboration with all parties involved is essential for HCC. Planning as well as strategizing is done in detail during the initial stages of a project. This reduces the flexibility in later stages of the project. For example, once the elements have been manufactured off site, it would be a costly procedure to change the design and remanufacture the elements. There is therefore not much flexibility in the implementation of HCC (Harcourt, 2011), (Hanekom, 2011).

Market conditions

Suppliers of precast elements determine the cost of their elements according to the current state of national need for the product. Due to an unstable market and fluctuation of product cost, it may be difficult to determine the cost of construction in advance with the use of precast elements that are supplied by manufacturers. The availability of precast manufactures may also be a concern in some parts of South Africa (Lombard, 2011), (Hanekom, 2011), (De Klerk, 2013).

Transportation

To transport large elements may become challenging, especially if precast members are transported over great distances. Sizes of elements are also limited in the use of HCC due to maximum weight specifications by the road agencies (Barrett, 2003). Accessibility to sites with large transportation vehicles may also be a challenge, due to limited space and accessibility to site (CPCI, 2007), (Harcourt, 2011).

Cranes and equipment

Cranes and special lifting devices are required to erect precast elements. Operational plans and special lifting devices must be developed and designed before construction takes place. This may be a time consuming process. Special attention is required to hire cranes and equipment during the planning phase of projects. Contractors usually hire these cranes and equipment per day. Special attention is required to insure that they are not hired for unnecessary days (Lombard, 2011), (De Klerk, 2013).

The erection of precast elements is highly dependent on cranes. Windy conditions may easily affect these cranes and may cause time delays in projects.

Uncertainties

The risk of uncertainty always proves to be increased when new methods are implemented (Jurgens, 2008). The vagueness of new methods causes a risk of incorrect application and is usually rather avoided. As an unknown author once said, “it has to be tested to be trusted”.

Other risks of this method include the following (Lombard, 2011), (Jurgens, 2008):

- safety
- technical risks
- late changes
- price instability
- availability of elements and transport

Lombard (2011) also mentioned that as the number of parties involved in a project increases, the risk of schedule and budget overruns will also increase. These additional risks are currently some of the main reasons why consultants prefer to design according to conventional methods. These risks will, however, reduce as the application of this method increases. The barrier of unexpected risks can therefore be overcome once this method has proven to be successful over a period of time (Lombard, 2011), (Jurgens, 2008).

2.3.3.4 Applications of hybrid concrete construction

A wide range of applications of precast elements are available and used in South Africa. Precast concrete has developed to a point where it is possible to construct total precast structures, where precast elements and prestressed concrete are combined to erect entire structures (De Klerk, 2013). This method of construction is not widely implemented in South Africa. In South Africa, HCC is a more common method of construction when compared to total precast construction (Lombard, 2011).

The flexibility of precast elements allows it to be manufactured in a variety of shapes and sizes. Standard precast elements, where the same formwork is repeatedly used, are often manufactured to gain supreme benefits of speed and cost (Goodchild & Glass, 2004). Precast manufacturers therefore supply a number of usual precast elements that meet the traditional challenges in the construction industry. It is, however, possible to design and manufacture custom precast elements as required. It may, however, not be economical when a great variety of custom precast elements are manufactured. When these custom elements can't be standardized it may sacrifice the time related benefits of HCC (De Klerk, 2013), (Gibb & Isack, 2001).

The following applications of precast concrete in construction are being used in the construction industry in South Africa (Corestruc, 2013), (ECHO, 2014), (TopFloor,2013),:

- Hollow core slabs
- columns (square, rectangular, circular, bull nose and T reinforced columns)
- prestressed columns (8m +)
- beams (I-beams, T-beams, L-beams, D-beams, stadium raker beams)
- prestressed beams (reinforced rectangular beams)
- staircases
- pavilions
- bridge beams & barriers
- slabs (Rib and block slabs, hollow core slabs etc.), and
- a variety of special applications

In addition to these various elements, is the construction method of tilt up systems. This is where precast concrete elements, typically walls and columns, are manufactured on the ground and are tilted into its final locations. Several projects have been constructed using this method of construction. One of these projects is the Cape Town dispatch plant and is discussed in Chapter 5.

2.4 Chapter conclusion

2.4.1 Previous and current investigations

HCC has been successfully used in developed countries of the world. The applications of this method are, however, limited in the construction industry in South Africa. Stellenbosch University therefore investigates this field to identify the current obstacles that prevent the utilization of this method in South Africa and to provide possible solutions for these obstacles.

The first investigation into this topic was performed by Jurgens (2008). Jurgens performed an investigation on the feasibility of hybrid concrete construction in South Africa. This was followed by an investigation of the decision making between in-situ and hybrid concrete construction by Lombard (2011). Various project success factors that play a role in the decision were identified. These factors included time, cost, quality, socio-economic aspects (labour), environmental performance, safety and client satisfaction.

Hanekom (2011) followed on the investigation of Jurgens (2008) by proposing solutions to increase the utilization of precast concrete construction in South Africa. De Klerk (2013) combined the outcomes of Jurgens, Hanekom and Lombard to perform an investigation of precast modular construction for schools in South Africa.

This thesis is an outflow of these investigations. The thesis focuses on the factors that have an influence on the time and cost, that need to be considered, for a decision between in-situ concrete construction and HCC.

2.4.2 Project success

The construction industry of South Africa acknowledges the fact that there are numerous success factors that indicate the success of a project. Project success measurement has and still is, however, dominated by the conventional measures of time, cost and quality, where cost remains the principle success indicator. Both time and quality in construction projects have an indirect impact on the cost. It is therefore important to consider these two indicators in relation with project cost.

It is also mentioned that the structure of a building represents typically only 10 % of the total construction cost. It is therefore important to consider the life cycle cost (LCC) of construction projects when deciding between various construction methods. The life cycle with the various phases of a construction project is further discussed in Chapter 3.

2.4.3 Background on concrete construction methods

The construction industry is a competitive market and contractors need to keep up-to-date with new construction methods and technologies. The application of in-situ concrete in construction is the conventional method for concrete construction in South Africa. The implementation of precast elements in construction has increased during the past decade, where contractors and clients have realized the time, cost and quality benefits that this method has to offer. It is, however, not often that a structure is constructed fully of precast elements. Hybrid concrete construction (HCC) is a combination of in-situ concrete and precast elements. HCC is slow to enter the construction market due to a lack of information and guidance. Many professionals in the industry, however, acknowledge the fact that there is a future for the use of HCC and that this method may be a solution for time and cost overruns in the construction industry in South Africa. Table 2.2 is a summary of the reported benefits and barriers of in-situ concrete construction and HCC.

Table 2.2: Benefits and barriers of in-situ and hybrid concrete construction

In-situ concrete construction		**Hybrid concrete construction**	
Benefits	**Barriers**	**Benefits**	**Barriers**
- Familiarity -Monolithic construction -Easily applied for two way structural systems -Flexibility/late adjustments are possible -No additional skills & materials required -Smaller cranes -Insulation -Positive drainage - Adequate lighting	-Labour intensive -Time consuming -Quality control -Weather -Buildabiliy -Safety -Waste	-Quality -Reduced construction schedule -Reduced temporary works -Earlier return on investment -Labour -Buildability -Repeatability -Waste -Weather	-Experience -Guidance -Flexibility -Market conditions -Transportation -Cranes & equipment -Uncertainties

2.4.4 Following chapters

This thesis details an investigation on the factors that may have an influence on the time and cost for a decision between in-situ concrete construction and HCC during the respective life cycle phases of a project. These phases are the design phase, construction phase and maintenance phase. Furthermore an investigation of the impact that time has on cost is also discussed. The chapter divisions are as follows:

Chapter 3: Construction life cycle

Chapter 4: Design phase

Chapter 5 & 6: Construction phase

Chapter 7: Maintenance phase

Chapter 3

Construction life cycle

The previous chapter provided an overview of literature on the implementation of in-situ concrete construction and HCC. It also discussed the various project success indicators with special reference to the importance of project time and cost.

Construction projects consist of various phases, which form a project life cycle. In order to identify and investigate the various factors that have an influence on the time and cost of construction projects, it is important to consider all phases throughout the life cycle of construction projects. The objectives of this chapter are therefore to perform:

1. An investigation on the literature of construction life cycle. This investigation provides a background on life cycle management and how it can be used to decide between various construction methods, such as in-situ concrete construction and HCC. It also describes the various life cycle phases in construction projects.
2. An investigation on life cycle cost and the importance thereof in the decision between various construction methods. It also discusses the methods for estimating life cycle cost.
3. A life cycle cost comparison between a theoretical in-situ concrete construction and HCC project. This comparison investigates the effect of reduced construction time on life cycle cost, the effect of varying construction costs on the life cycle cost and the effect of an increase in maintenance cost for construction projects.

Figure 3.1 presents the chapter outline.

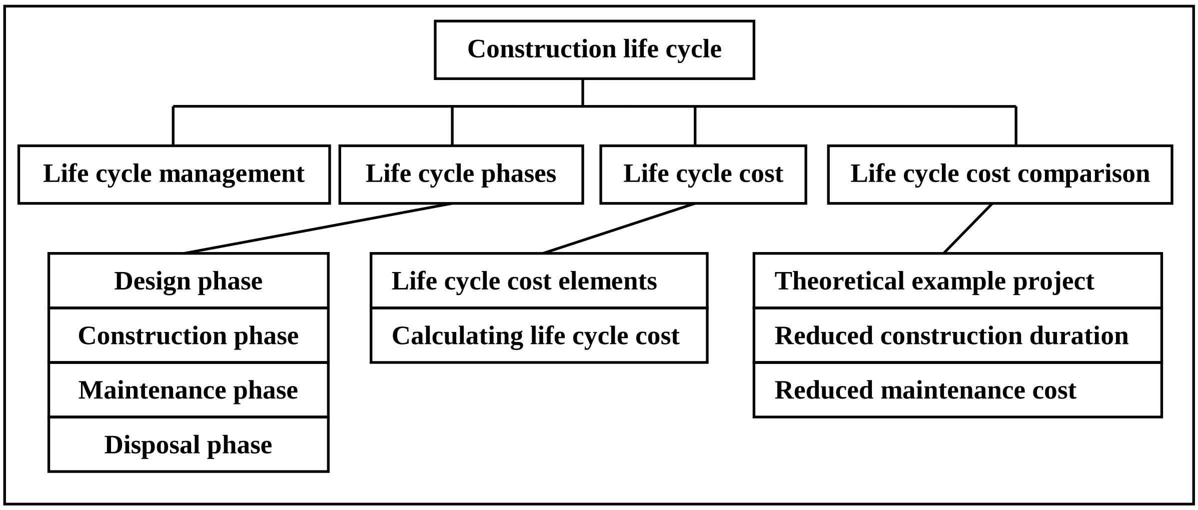

Figure 3.1: Chapter 3 outline

3.1 Life cycle management

Life cycle management (LCM) is a process that is developed to manage the total life cycle of products, services and methods. It can be used in the construction industry to decide between various construction methods. LCM has proved to offer cost savings and to improve the service to clients over the years (Xie & Simon, 2006). LCM can typically be used in deciding wether the use of in-situ concrete construction or HCC will be more beneficial for a construction project (Guo, Li & Skitmore, 2009).

Project management in the construction industry is usually separated into various phases. These phases are known as the design, construction, operational and disposal phases of a project. When construction projects are managed without a life cycle approach, these phases are implemented independently with little communication and interaction between participants in each phase (Fuller, 2010). This is often the case in the construction industry in South Africa, where contractors are only involved after the detail design of a project has been completed. The application of LCM, however, encourages project teams to work in collaboration with one another. LCM therefore motivates integration of phases that leads to information sharing and communication between clients, consultants and contractors (Xie & Simon, 2006). The collaboration between parties ensures sufficient constructability that is in line with the requirements of the client and is more likely to result in life cycle cost and project time savings in construction projects (Sullivan, Wicks & Luxhoj, 2009),(Leland, 2012).

Figure 3.2 presents the sequence of the typical phases in a construction project. The phases can be broken down into three primary phases known as the design, construction and maintenance phases, and are discussed in section 3.2.

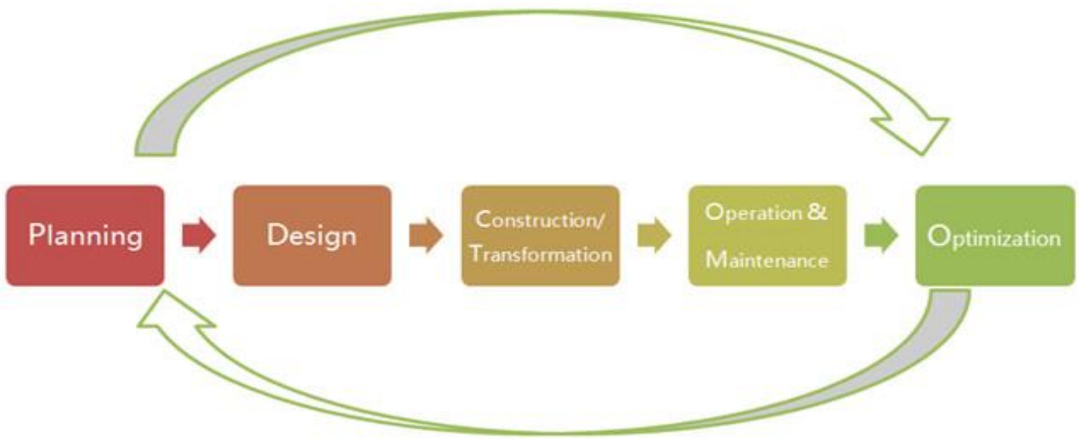

Figure 3.2: Construction life cycle phases (Xihua, 2014)

LCM is an important procedure in the decision between in-situ concrete construction and HCC. In the construction industry in South Africa, it is often the case that consultants are responsible for the choice of the construction method. In numerous projects alternatives are, however, proposed by contractors, which may generate potential time and cost savings. When these proposals are accepted, the consultants must spend additional time on changing the initial design. LCM can assist project teams to make collaborative decisions during the early stages of construction projects. These decisions can prevent unnecessary rework, such as redesigning (Xihua, 2014), (Leland, 2012).

In order for HCC to reach the ultimate benefits in a project, early involvement by the contractor and collaborative planning with the consultant are essential (De Klerk, 2013). LCM can assist project teams to achieve these benefits by encouraging collaboration between the various parties.

3.2 Life cycle phases

As mentioned in the previous section, the primary LCM phases in the construction industry are known as the design phase, construction phase and maintenance phase. These phases are presented in Table 3.1. The table subdivides the primary phases into secondary phases that represent the activities taking place during the respective primary phases of construction projects.

Table 3.1: Primary and associated secondary phases of LCM in construction projects (Guo et al, 2009)

Design	**Construction**	**Maintenance**	**Disposal**
• Client's conception • Planning in collaboration with designer • Conceptual design • Feasibility study • Detailed design	• Evaluate constructability • Reviewing alternative building methods • Feasibility study • Construction	• Project completion evaluation • Operating the facility • Maintenance	• Project disposal or recycle

3.2.1 Design phase

Construction projects usually commence with the client's conception. The ideas and the requirements of the client are then usually formulated with guidance from the consultants during the planning phase of a project. The planning phase is said to be the first phase during the design phase of construction projects. Clients and consultants work in collaboration to develop a rough design of the client's thoughts. Once the client's requirements have been developed, a concept design with a feasibility study is prepared to estimate possible outcomes of the project. When the project proves to be feasible, the consultants start with the detail design of the project. The detail design is the primary secondary phase during the design phase. This is where all elements are designed and specified for construction.

All these secondary phases form part of the design phase and is summarized in the first column of Table 3.1(Guo et al, 2009), (Xie & Simon, 2006).

Consultants and clients often rush through these phases due to limited time. This makes it challenging for designers to evaluate alternatives. Designers are therefore often comfortable in choosing to design with conventional methods of construction, such as in-situ concrete construction, without investigating the potential benefits of HCC. Chapter 4 elaborates further on this issue and identifies and investigates the design factors that may have an influence on the time and cost for a decision between in-situ concrete construction and HCC.

3.2.2 Construction phase

Following the design phase is the construction phase. Traditionally, the first step during this phase is where the contractor evaluates the constructability of the design. Alternative methods, promoting more convenient and economical constructability are investigated here and proposed to the client or consultant. This is often the case with the implementation of precast systems in the construction industry in South Africa (Lombard, 2011). Structural applications are usually designed for the conventional method of in-situ concrete construction. Contractors may then propose alternative building methods, such as the implementation of HCC. In some circumstances, these alternatives are accepted and need to be re-evaluated and designed by the consultants (Le Roux, 2013).

This is a timely and costly procedure, since the alternative ideally has to be reviewed from the first phase in the LCM process. Nevertheless, the alternative may hold other benefits during the construction phase, such as potential time savings. It is therefore important that consultants include the insight of contractors early, during the design phase of construction projects, to avoid the possibility of rework. Popular procurement strategies, however, often prevent the optimum collaboration at an early stage in the construction industry in South Africa (Sullivan et al, 2009), (Leland, 2012), (Fliss, 2013).

The physical construction remains the primary component during this phase. Construction starts once the alternative methods have been reviewed, proved to be feasible and accepted by the consultants. It is during this phase where the benefits of various construction methods are mostly recognised. These benefits consequently effect the subsequent phases in the life cycle. For example, when the construction duration is reduced, the client gains the benefit of a faster return on investment, therefore increasing the client’s income (Sullivan et al, 2009), (Leland, 2012).

The construction factors that have an influence on the time and cost for a decision between in-situ concrete construction and HCC are identified and discussed in Chapter 5 and Chapter 6.

3.2.3 Maintenance phase

The last primary phase is known as the operation and maintenance phase of a project. The primary function of the maintenance phase includes the operation and maintenance of a structure. This is done over the entire usage period of the structure, which is determined during the design phase of a project. Usage periods of structures in South Africa vary between 20 and 50 years, depending on the external surroundings (Guo et al, 2009) ,(Sullivan et al, 2009).

The maintenance factors that may have an influence on the time and cost for a decision between in-situ concrete construction and HCC are further discussed in Chapter 7.

3.2.4 Disposal phase

The disposal phase in construction projects involves the disposal or recycling of the project. Recycling can also be defined as the upgrading of the facility. This phase is mentioned but will not be discussed in this report.

This section provided an introduction of the various phases of a LCM process for construction projects. The influential time and cost factors during the design, construction and maintenance phases are discussed from Chapter 4 to Chapter 7.

3.3 Life cycle cost

There are several factors that determine the success of construction projects. Cost, however, remains the principle success indicator for construction projects (Atkinson, 1999), (Chan, Scott & Lam, 2002). All the different phases, as mentioned in the previous section, add to the sum of project life cycle cost (LCC). It is important to consider the complete life cycle cost, by estimating the associated cost for every phase during the life cycle, when estimating project cost. LCC should be the principle basis for choosing construction methods (Xihua, 2014), (Chow, Heaver & Henriksson, 1994).

Sullivan *et al.* (2011) presented a graph of life cycle cost throughout the different phases of a construction project. The graph was combined with the various phases identified by Guo *et al.* (2009) to produce Figure 3.3. The graphs in Figure 3.3 present the quantitative project cost and potential cost savings throughout the life cycle of construction projects.

As seen in Figure 3.3, the potential for LCC savings is reduced with time. In order to benefit from potential LCC savings, economic analysis and strategies have to be incorporated during the early phases of a project. Savings on LCC depend on many factors, therefore effective engineering design and economic analysis during the design phase of construction projects are essential in increasing potential LCC savings (Guo et al, 2009),(Sullivan et al, 2009).

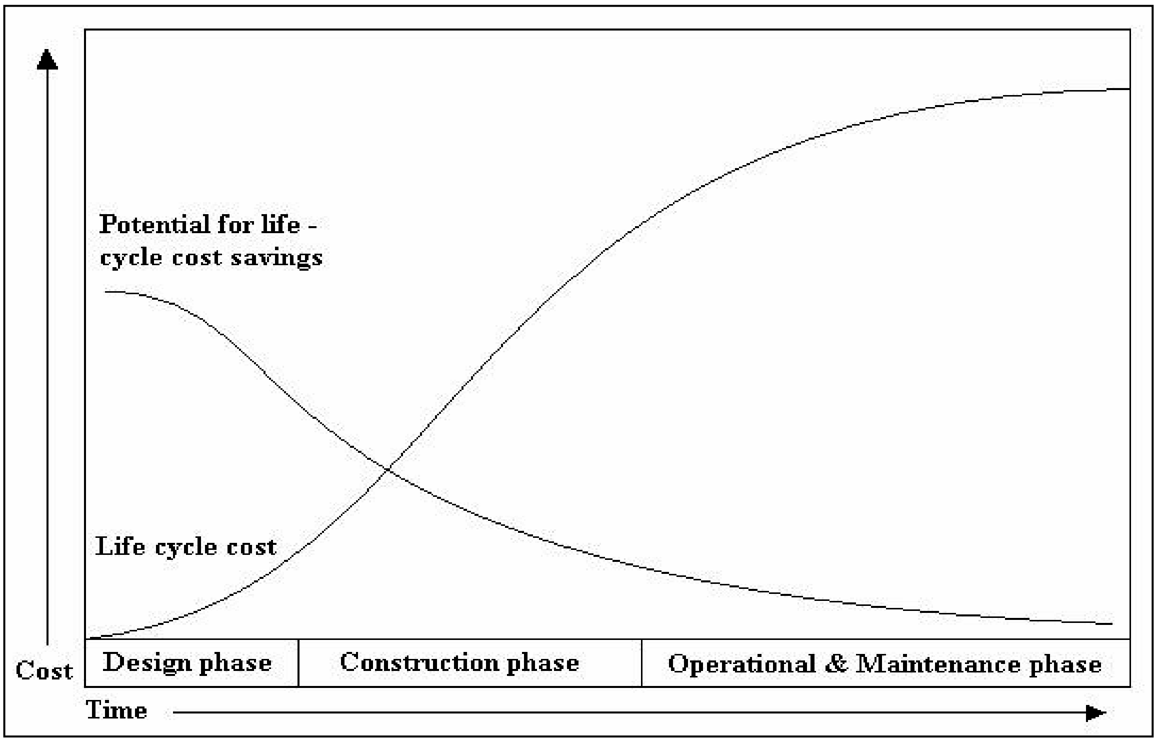

Figure 3.3: Quantitative life cycle cost throughout the various phases (Guo et al, 2009)

In the construction industry in South Africa, alternative construction methods are often only considered at the start of the construction phase. The potential for LCC savings are reduced when compared to when the decision is made at the start of the project. Efficient planning during the design phase is therefore critical to benefit from potential cost savings. This evaluation of LCC in construction projects can assist clients and consultants in their decision between various construction methods, such as in-situ concrete construction and HCC (Guo et al, 2009), (Sullivan et al, 2009).

A life cycle cost analysis for construction projects can be implemented as a method where the total cost of a structural application or infrastructure is estimated for alternative construction methods (Fuller, 2010), such as in-situ concrete construction and HCC. These estimations are then used to compare the alternative construction methods, which can assist in choosing the economical option for a project.

3.3.1 Life cycle cost elements

The estimation of life cycle cost includes various elements that need to be considered. These elements will vary for different situations. Because of their common use, several basic life-cycle cost categories are defined in this section (Leland, 2012). These elements are the investment cost, working capital, operation and maintenance cost and disposal cost (Leland, 2012).

The *investment cost* is the capital that is required from the client for most of the activities during the design and construction phases of a project. A series of expenditures over a time frame could typically be incurred. This method of costing is often referred to as a *capital investment* (Leland, 2012), (Fuller, 2010).

The subsequent cost is the *operational and maintenance cost*. These forms of payment include annual expenses that are associated with the maintenance and operational phase of construction projects. It includes both direct and indirect cost of operation and maintenance, and include the resources such as people, materials, energy and machines. These are the primary resources and are important components of the cost in this category (Leland, 2012), (Fuller, 2010).

The last form of cost is known as the *disposal cost*. These costs include the nonrecurring cost of the disposal of assets and shutting down the operation at the end of the life cycle. The most general costs in this category are associated with personnel, materials, transportation and once off special activities. These costs will be offset in some instances by receipts from the sale of assets with remaining market value (Leland, 2012).

3.3.2 Calculating life cycle cost

The life cycle cost of a project is usually calculated as the value of the whole project at the start of the project. This value is known as the present value. All payments during each phase in the life cycle of a project contribute to the present value of a project (Lombard, 2011). Figure 3.4 presents a cash flow diagram with associated values of each activity during the life cycle of a construction project. It can be seen that the present value is determined at the start of the project.

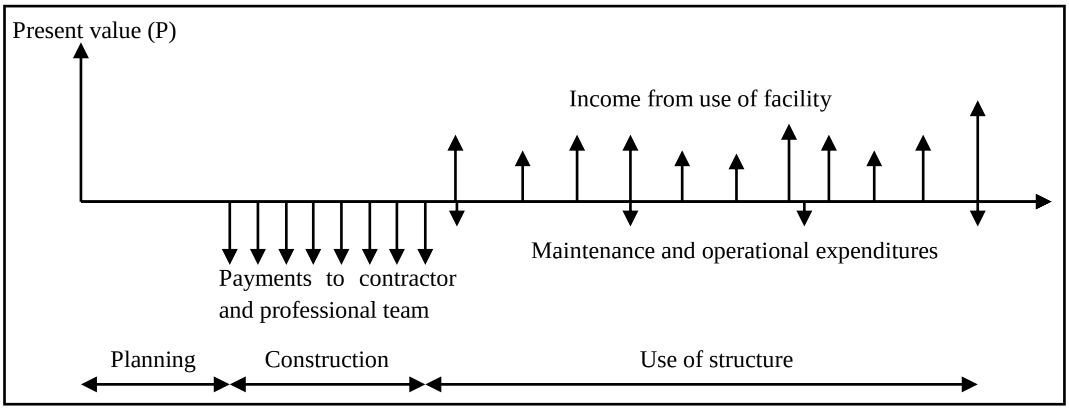

Figure 3.4: Cash flow diagram of a typical construction project (Lombard, 2011)

The present value (P) for a single payment is determined by the following equation (Leland, 2012):

$$P = F\left[\frac{1}{(1+i)^n}\right]$$

Where:

- P is the present value for a given future value F
- i is the interest rate; and
- n is the number of periods in weeks, months or years

The present value (P) for a uniform series of payments is determined by the following equation (Leland, 2012):

$$P = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right]$$

Where:

- A is the value of the uniform series

These equations assist project teams in determining the present value of two alternatives in order to decide which option would be the most economical over their life cycle.

3.3.3 Section conclusion

This section provided a background on LCC and the associated cost elements. The LCC analysis can furthermore be used to compare construction methods in order to evaluate which method will be more economical. These comparisons are done by using present worth values (Fuller, 2010). The following section provides a theoretical life cycle cost comparison between in-situ concrete construction and HCC.

3.4 Life cycle cost comparison

It is mentioned in literature that the use of HCC has the ability to reduce construction time and subsequently life cycle cost (Goodchild & Glass, 2004). The aim of this section is to estimate the effect of time savings during the construction phase, varying construction costs, and increased maintenance cost on the life cycle cost of a project. A theoretical comparison of life cycle costs for in-situ concrete construction and HCC is conducted in this section. This comparison will show the value of time in construction projects. The example is only a theoretical example with fictional values to show the effect of construction time and cost and maintenance time, on the life cycle cost of a project.

3.4.1 Theoretical example project

An example project has been formulated to show the effect of time savings during the construction phase on the life cycle cost of a project. For the example project an in-situ concrete construction project was compared to a HCC project. The objective of this comparison is to estimate the value of time, therefore to determine the effect of time saved during the construction phase on project life cycle cost. Detailed calculations for this example can be found in Appendix A.

For the example project, it is assumed that the duration and cost of the design phase and maintenance phase are the same for in-situ concrete construction and HCC. It is also assumed that the construction cost for both methods is equal. The only difference for the two construction methods is the duration of the construction phase. For in-situ concrete construction the duration of the construction phase is 15 months, whereas for the HCC method the duration of the construction phase is 12 months. The example therefore aims to estimate the effect of the 3 months construction time saved on the life cycle costs of the project. The estimation is done by calculating the yearly income required in order to break even after a usage period of 30 years, with the use of a present value comparison.

It was assumed that the design cost for the project was R 4,200,000. The project construction cost was R 54,000,000 with an additional monthly running cost of R 360,000. The usage period of the structure was 30 years with annual maintenance costs of R 540,000. The monthly interest rate was 0.75 % over the lifetime of the project. Figure 3.5 and Figure 3.6 present the cash flow diagrams for the two respective methods of in-situ concrete construction and HCC.

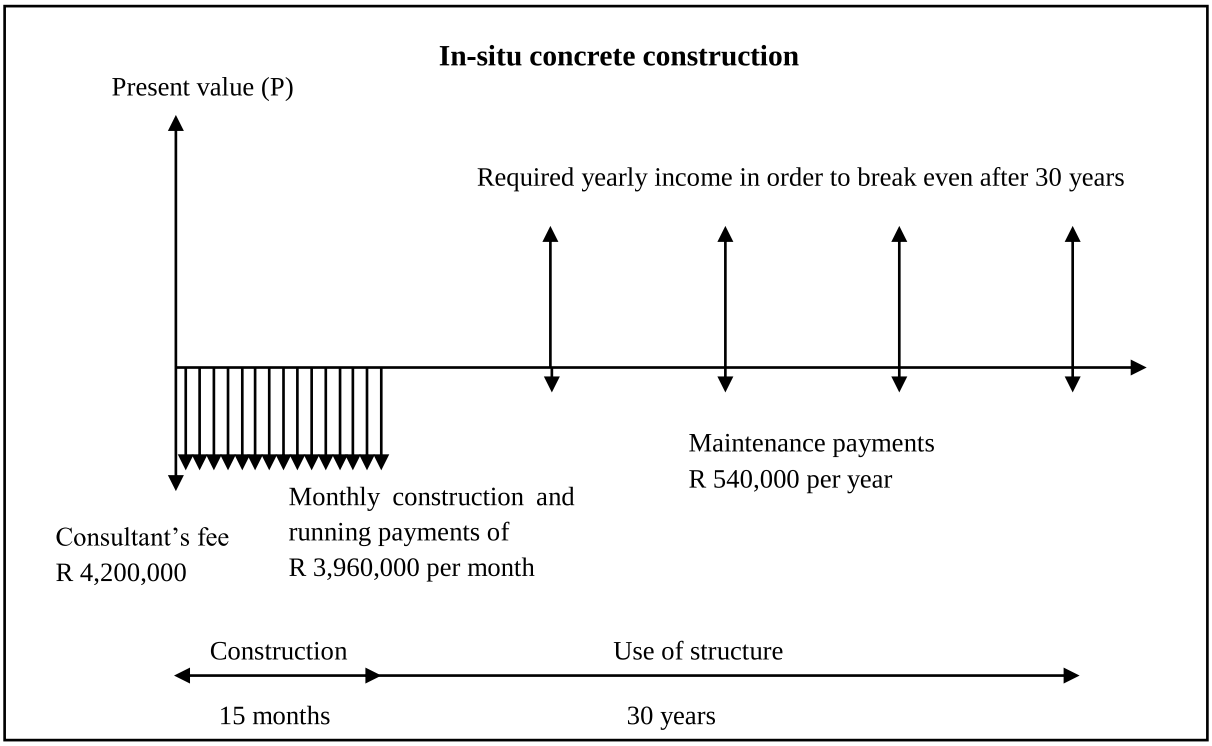

Figure 3.5: Cash flow diagram for in-situ concrete construction of example project

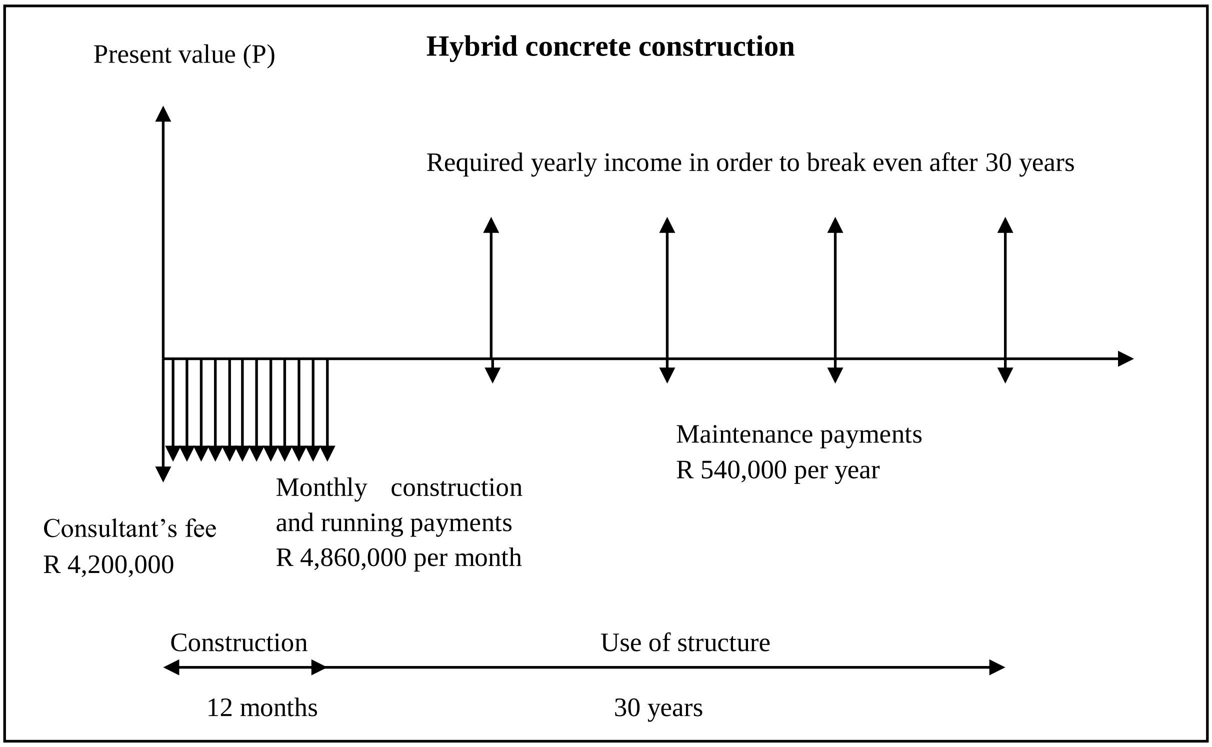

Figure 3.6: Cash flow diagram for HCC of example project

The required yearly income in order to break even for the project constructed with in-situ concrete was calculated to be R 7,315,039. When HCC is used, a yearly income of R 7,119,856 is required. Therefore, R 196 183 less yearly income is required for the HCC method to break even for a usage period of 30 years. This is 2.67 % less yearly income required than that of in-situ concrete construction. This shows the effect of time savings during the construction period on project life cycle cost.

3.4.1.1 Reduced construction durations

A further evaluation was performed, where the same calculation was done for various construction durations. Figure 3.7 presents the graph obtained from the results. The figure shows the reduced annual income required in order to break even as a function of the construction time saved. These calculations and results can be found in Appendix A.

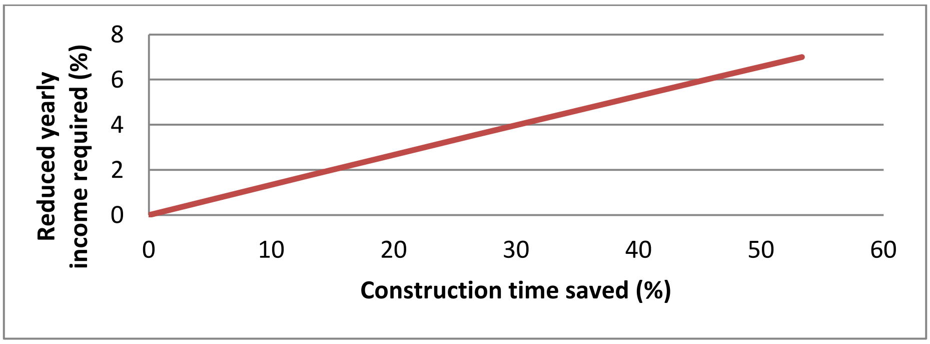

Figure 3.7: Reduced yearly income required vs. construction time saved

3.4.1.2 Varying construction costs

A further evaluation was performed, where the same calculation was done for varying construction costs. Figure 3.8 presents the effect of varying construction costs on the LCC of the project. The figure shows the percentage of reduced or increased annual income required, for the HCC project (with reduced construction duration of three months), in order to break even as a result of an increase or reduction in construction cost. It can be seen that 6.9 % less yearly income is required in the case where the construction cost is 5 % less than that of the in-situ project and 1.9 % more yearly income is required in the case where the construction cost is 5 % more than that of the in-situ project.

For this project it can be seen that the construction cost can increase up to 3 % to reduce the yearly income required in the case where the construction period is reduced by 3 months. These calculations and results can be found in Appendix A.

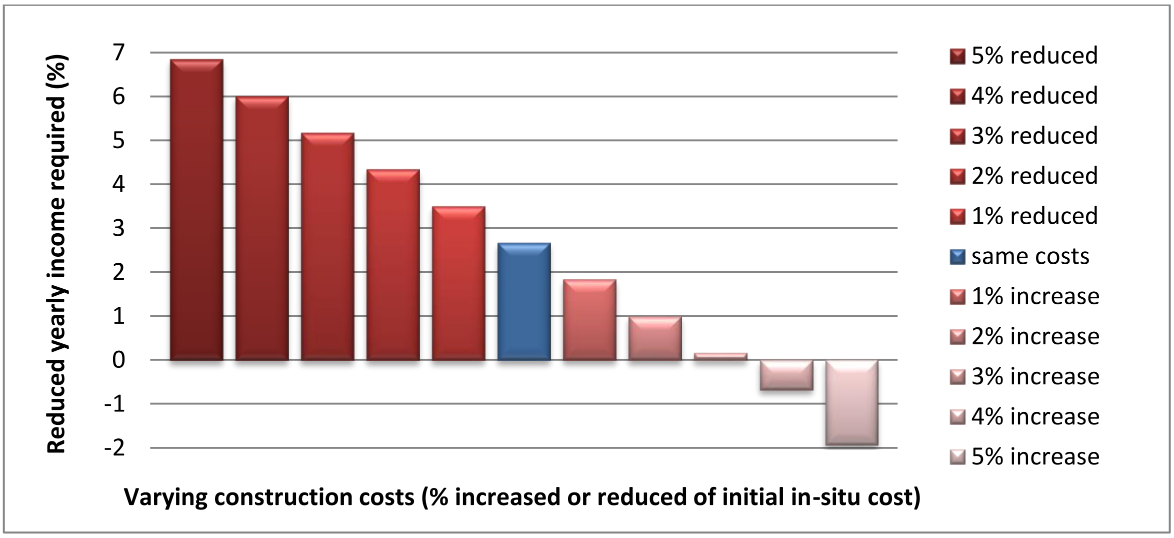

Figure 3.8: The effect of varying construction cost on life cycle cost

3.4.1.3 Reduced maintenance cost

Another evaluation was performed where the same calculation was done for various maintenance values for the HCC project with a reduced construction period of three months.

The project constructed with HCC methods, with a construction time saved of three months, was calculated for different maintenance percentages. It is believed that HCC has the potential to provide higher quality and consequently less maintenance when compared to the conventional method of in-situ concrete construction (Goodchild & Glass, 2004). The reduced yearly income required in order to break even was therefore calculated for different maintenance percentages of the initial project cost. Figure 3.9 presents the graph obtained from the results. The figure shows the reduced annual income required in order to break even as a function of an increase in maintenance cost, as a percentage of the initial cost. These calculations and results can be found in Appendix A.

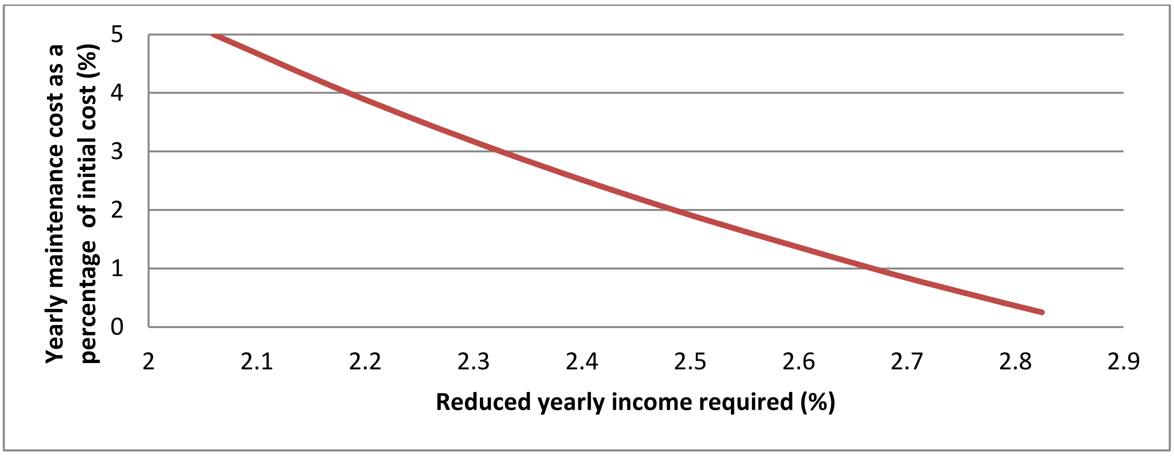

Figure 3.9: Maintenance cost vs. reduced yearly income

3.5 Chapter conclusion

The chapter defined life cycle management and the importance of collaboration between the various project participants. This collaboration is critical to benefit from potential cost savings during the early stages of a project. The various life cycle phases and associated costs were then identified and discussed. The section also discussed how LCC analysis can assist project teams in their decision between various construction methods, such as in-situ concrete construction and HCC.

The section finally presented a life cycle cost comparison of a theoretical project drawing a comparison between in-situ concrete construction and HCC. This comparison showed the effect of reduced construction duration on life cycle cost. For the chosen example, it is showed that 2.67 % less yearly income is required to break even when the construction duration is reduced by 20 %.

Further evaluations were performed for reduced construction durations, varying construction cost and reduced maintenance cost to observe the effect thereof on the life cycle cost of a project. It was shown that a shorter construction time, reduces the required yearly income in order to break even (Figure 3.7), and an increase in construction cost, increases the yearly income required to break even (Figure 3.8). It was also shown that as the maintenance cost increases as a percentage of the initial cost, an increase in yearly income is required to break even (Figure 3.9).

It is however well known that shorter construction schedules often results in more expensive construction costs. Figure 3.8 addresses this issue where the effect of varying construction costs on the LCC of a project is presented. The figure shows the percentage of reduced or increased annual income required, for the example HCC project (with reduced construction duration of three months), in order to break even as a result of an increase or reduction in construction cost. It was found that 6.9 % less yearly income is required in the case where the construction cost is 5 % less than that of the in-situ project and 1.9 % more yearly income is required in the case where the construction cost is 5 % more than that of the in-situ project. For this project it has been estimated that the construction cost of the HCC project can increase up to 3 % (compared to the in-situ project) to reduce the yearly income required in the case where the construction period is reduced by 3 months.

It is thus demonstrated that project teams should consider the effect of time savings and reduced maintenance cost on the life cycle cost of a project in the decision between various construction methods.

For each of the life cycle phases, the associated factors which may have an influence on the time and cost in construction projects are identified, and are discussed in the following chapters. These factors will be used to produce the framework that project teams can use, to assist them, for a decision between in-situ concrete construction and HCC.

Chapter 4

Design phase

The previous chapter presented an investigation on the project life cycle of construction projects. Chapter 4 investigates the various factors that may have an influence on the time and cost for a decision between in-situ concrete construction and HCC during the design phase of a project's life cycle.

Structured interviews were conducted with professional consultants in the industry to identify and discuss the various factors. The information obtained from the interviews is qualitative information and are used in discussions throughout this chapter. The structured interviews can be found in Appendix B. The questions were developed to identify and discuss the various factors that have an influence on project time and cost during the design phase of a project. Figure 4.1 is a presentation of the chapter outline addressing the identified factors during the design phase of a construction project's life cycle.

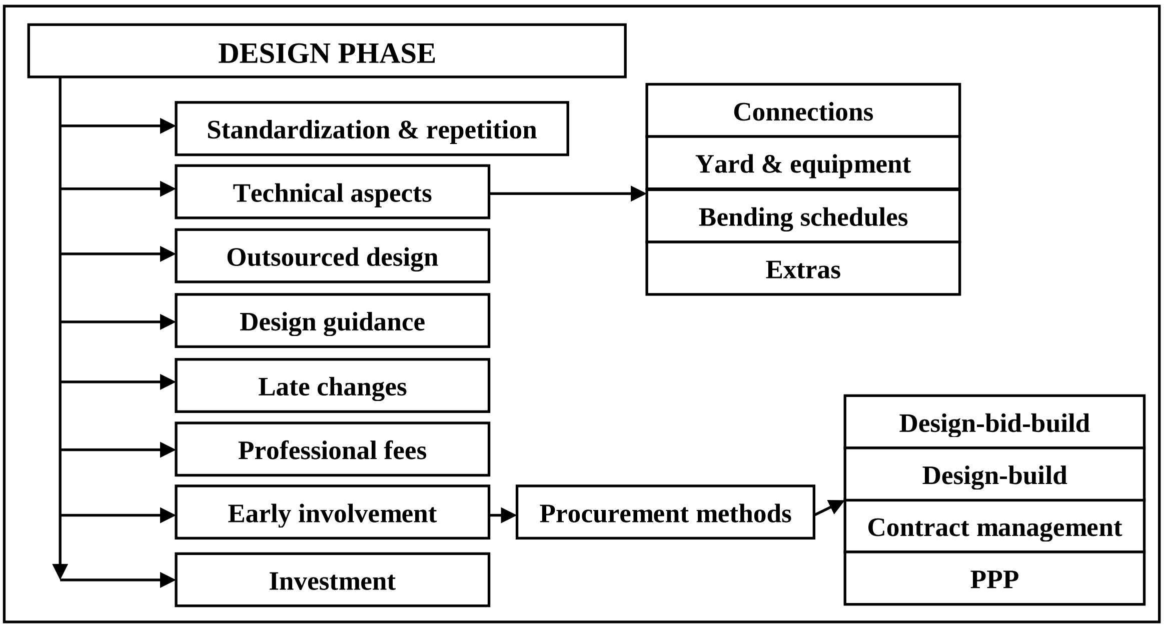

Figure 4.1: Chapter 4 outline

4.1 Standardization and repetition

Fliss (2013) mentioned that HCC is only economically viable when sufficient standardization occurs. Gibb (2001) also mentioned that implementation of precast concrete in construction must be applied with standardization and repetition to gain the supreme economical advantages thereof. When precast concrete construction is used on its own, with limited standardization and repetition, it may not be as effective (De Klerk, 2013).

Standardization is defined as the extensive application of processes and components in which there is consistency, repetition and an environment of success (Gibb & Isack, 2001a). It is also defined as the repeated use of processes, components and methods (De Klerk, 2013). Standardized design for HCC can therefore be defined as the design of precast elements with similar dimensions that are erected in the same sequence that promote repeatability.

Several consultants have mentioned that there are certain shortcomings in the application of standardization. Some consultants argue that precast elements, such as beams and columns, are often over designed in the implementation of standardization (De Klerk, 2013), (Fliss, 2013), (Botha, 2013). The over design of elements consequently increases the material cost. Gibb & Isack (2001) conducted an investigation on the implications of standardization. In their investigation, senior staff from major construction clients were asked to describe what comes to mind when the word standardization is mentioned. They stated that 15 % of the respondents were negative towards standardization. Standardization has been criticized for a lack of flexibility and creativity, and that standardized designs may lead to dull standard buildings (Gibb & Isack, 2001a).

Fliss, Botha, Ronne & Jordaan (2013), however, mentioned that when standardized designs are applied with good knowledge, an innovative spirit, experience and drive, it will result in a project with potential time and cost savings. During the investigation by Gibb & Isack (2001), a large number of the respondents mentioned that standardization could lead to a quality product that results in time and cost savings. Best practice guidelines are also developed in some countries, where standardization is motivated with creativity. These guidelines have shown that it is possible to provide flexible designs with the use of standardized components (James, 2011).

In addition to these arguments, several projects have shown to result in time and cost savings when standardization was implemented. One example of these projects is school construction by Laing O'Rourke and Atkins, well known firms in the UK (De Klerk, 2013). In collaboration, they had developed a model where standardized precast components were used for school construction. The standardized components model for school construction has shown to produce up to 30 % cost savings, and has also shown to save between 25 % and 35 % time on the construction schedule when compared to conventional methods of school construction (De Klerk, 2013).

In the investigation by Gibb & Isack (2001), the respondents have mentioned that lower cost, faster construction durations and quicker delivery times with better quality are achieved by implementing standardized precast designs. Many of the respondents have mentioned that up to 30 % cost savings are possible, and construction times can be reduced by 25 %. It is therefore evident than standardization can be used successfully in construction projects that may result in potential time and cost savings.

Standardization is known to be more economical for manufacturers and consultants in the implementation of mass production. For manufacturers an increase in production will lower the cost per element. The same applies for designers. In the implementation of standardized designed, the more the design concepts are reused, the more value is added to the initial design. In Chapter 5, a case study on the construction of an HCC coal bunker is presented. The implementation of HCC in coal bunker construction has resulted in time and cost savings for the project. In addition to these benefits, is the fact that the design has been completed and the concept can be reused for future coal bunkers. This form of standardization can therefore be considered as an investment. The first design might be time consuming, however, consultants and manufacturers benefit when the concepts are reused.

Standardization during the design phase of HCC should therefore be seen as an investment (Fliss, 2013). When standardization is applied for the first time, it might require more time for planning and designing. However, once the method of HCC has been tried and tested, the consultant will not only benefit from project time and cost savings, but will also gain a reputation for competence and innovative culture, thereby attracting a better position in the market (Fliss, 2013), (Botha, 2013).

Standardization is the primary motivation for the implementation of HCC (Fliss, 2013), (Botha, 2013), (Goodchild & Glass, 2004). Project teams should therefore consider the potential of standardization during the early phases of a project when HCC is considered as an alternative. In the case where standardization can be applied effectively, the use of precast concrete in construction has shown to be successful for several projects in terms of time and cost. However, in the case where standardization is limited for a project, the use of in-situ concrete construction might be more beneficial.

4.2 Technical aspects

This section includes a discussion on the technical aspects, obtained from the interviews (Appendix B), which might have an influence on the time and cost when HCC is considered for projects. The technical aspects include connection design, yard and equipment design, the detailing of reinforcement and the related precast design extras that need to be considered.

4.2.1 Connection design

During the interviews conducted with professionals in the industry (Appendix B), it was found that additional time is required for the design of precast concrete connections. Many of the respondents mentioned that the design of precast connections may be a time consuming and challenging process (Botha, 2014), (Fliss, 2013), (Ronne, 2014).

Connection design is a critical component in the implementation of HCC. The design of connections is one of the motivations why the design of precast concrete might be more time consuming when compared to the design of in-situ concrete applications. The reason for this increase in time is that precast connections are required to meet a broad spectrum of design and performance criteria. The primary objective of connection design is to transfer forces across construction joints to produce proper interaction between precast elements. Other criteria that add to a more time consuming design include the consideration of (Jurgens, 2008):

- water tightness
- fire protection
- lightning protection
- durability
- aesthetics
- seismic activities , and
- the manufacturing and erection methods (tolerances etc.)

Due to the various criteria that need to be considered, it is evident that precast connection design is a time consuming process. Although many of the mentioned criteria also apply for the design of in-situ concrete applications, consultants are familiar with in-situ methods and are therefore more comfortable in designing for in-situ concrete applications. Several professionals have mentioned during the interviews (Appendix B) that in-situ concrete design eliminates the risks associated with the design of precast connections (Pretorius, 2013), (Visagie, 2014).

There are, however, several construction projects where connections for precast concrete have proven to be successful over the years. Nonetheless, the additional time and experience required for the design of precast connections should be considered for a decision between in-situ concrete construction and HCC.

4.2.2 Yard and equipment design

HCC requires a precast yard and associated equipment for the manufacturing of precast elements. Yard and equipment design include the design of the precast yard, associated equipment, and the planning of the sequence, methods and processes during the manufacturing and transportation stages of a project. Additional time is required for the design of a precast yard and associated equipment (Pretorius, 2013).

Figure 4.2 presents an example of equipment needed for a construction project constructed with HCC techniques. This specific project entailed the construction of an HCC coal bunker. The lifting clamp and associated elements had to be designed together during the initial phases of the project, as well as the precast yard. A case study on the HCC coal bunker is presented in Chapter 5.

Figure 4.2: Clamps erecting precast elements at the Shondoni coal bunker

In some projects the additional time required for the design of the precast yard and equipment may be negligible. In other projects, however, it may be challenging and time consuming. This additional time and cost should therefore be considered during the early stages of a project for a decision between in-situ concrete construction and HCC.

4.2.3 Detailing of bending schedules

Many of the professionals during the interviews have mentioned that more time is spent on reinforcement detailing and bending schedules for in-situ concrete as compared to the design of precast elements (Botha, 2014), (Fliss, 2013). The reason for this is that there are various standard precast elements available that already contain these details. The consultants therefore simply choose the applicable elements. Consultants often outsource the work to the contractor's specialist, and the design duration (by the consultant) is therefore reduced (De Lange, 2014).

4.2.4 Extras

During the interviews, some of the consultants mentioned that the design duration, in terms of elements, is similar for in-situ and precast concrete. In addition to precast connections, other aspects that might be time consuming in the design of HCC are considered as the related extras (Fliss, 2013). These extras include the planning and design of adequate lighting, drainage and power supply cables in HCC structures. These additional extras may often be challenging and time consuming, especially when the consultant is inexperienced in designing for the implementation of HCC. Once the consultant has gained sufficient experience, it would be more convenient and faster to design. These extras need to be planned and designed well in advance, before construction commences, to prevent unnecessary rework and design changes. Early information is needed from other disciplines, which traditionally provide such information much later (Fliss, 2013).

This allowance for services by other disciplines need to be considered in the decision between in-situ concrete construction and HCC, especially in unique structural applications where the extras might be challenging and time consuming.

4.3 Outsourced design

When constructing with HCC, the design of precast elements are either done by appointed consultants or it can be outsourced to the contractor's specialists, which are often precast suppliers. Precast suppliers often offer their own standardized designs, equipment and precast yard facilities. Therefore, most of the technical aspects discussed in the previous section do not need to be considered by the consultants. It remains the responsibility of the consultant to coordinate the design of suppliers by making sure that the design complies with the project criteria and with the rest of the design concept, and that the correct loading conditions have been used. Nonetheless, the design duration (of the consultant) is reduced (De lange, 2014), (Ronne, 2014). The supplier's cost for the design and manufacturing of precast elements may, however, be higher in comparison with the professional fees of the consultant in certain cases (Visagie, 2013).

Although the method of outsourcing designs might save time during the design phase, the associated costs are often higher. Project teams should consider the additional costs and possible time savings in appointing specialist subcontractors when HCC is considered for a project.

4.4 Design guidance

The consultants in the South African industry are not familiar with the specifications of HCC designs (Jurgens, 2008). The primary motivation for this is a shortage of local precast design manuals (Hanekom, 2011). Designers are therefore required to design precast elements from first principles. This may increase the time to complete precast designs and mostly requires additional design input. During an investigation in the United Kingdom, Soetanto *et al.* (2004) mentioned that a lack of exposure and a high level of inexperience with the design of precast concrete was the main cause for the limited applications of precast concrete within the country (Hanekom, 2011), (Soetanto, Glass, Dainty & Price, 2007).

Computer packages and tools that can assist project teams in the designs of precast elements and the decision making process between in-situ concrete construction and HCC remain to be developed locally (Hanekom, 2011). Current available design packages may not be able to assist consultants with the complex design of connections between elements (Elliott, 2002), (Hanekom, 2011), (Ronne, 2014).

In addition to the above mentioned constraints, the ability of consultants to design precast elements is also challenged. It was mentioned during the interviews that designers are required to be creative and innovative when designing for HCC. Consultants in South Africa are often characterized as being unable to conform to new construction methods and technologies (Pretorius, 2013), (Fliss, 2013), (Soetanto et al, 2007).

The lack of precast design criteria and assistance are still regarded as a barrier to the utilization of HCC in South Africa. It is, however, improving and innovative ideas are coming to the fore. This factor should be considered when HCC is considered for a project, especially in unique structural applications where the design might be time consuming (Hanekom, 2011).

4.5 Late changes

An important factor to consider in a cost effective analysis is the minimising of the impact of design changes throughout the life cycle of a project. Sullivan et al (2011) mentioned that the cost of design changes increases by a multiple of approximately 10 with each phase, as shown in Figure 4.3. All the respondents in the interviews indicated that HCC would be more time consuming and expensive, in the case where design changes occur.

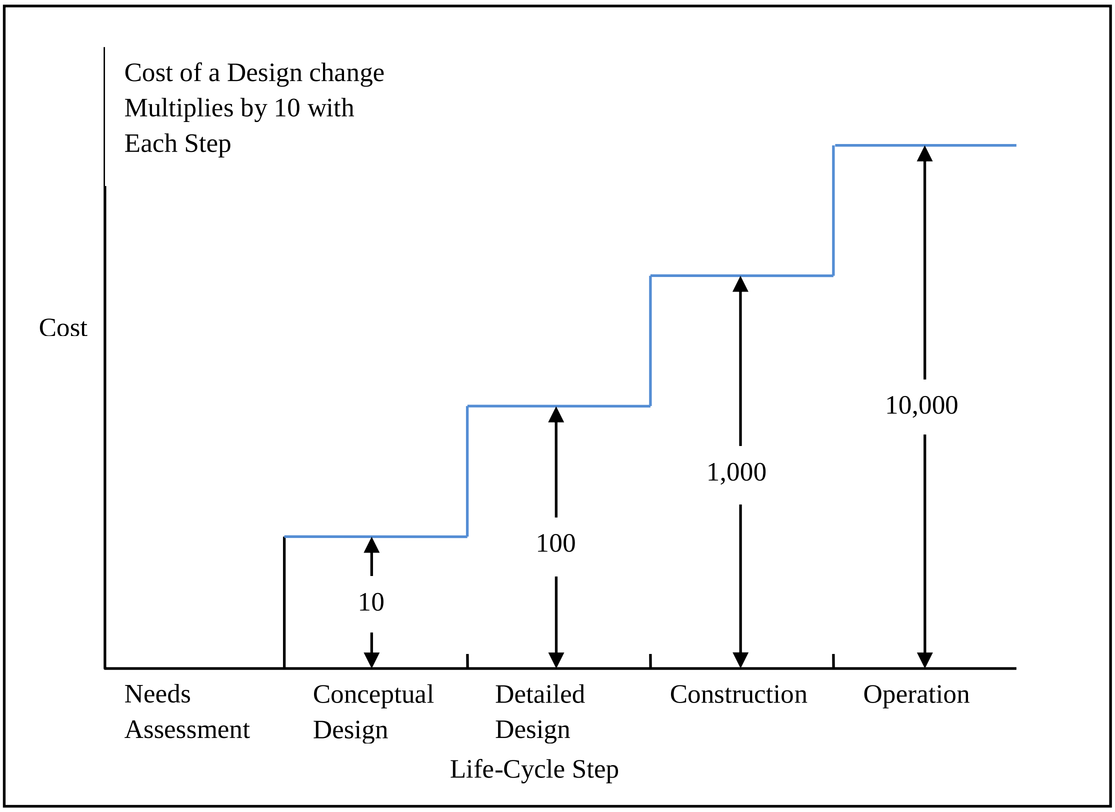

Figure 4.3: Impact of design changes on project life cycle cost (Sullivan et al, 2009)

Time and caution are therefore required to develop a quality preliminary design. A quality preliminary design should reduce the potential of changes to occur during later stages in the life cycle of construction projects. Early completion of designs can prevent design changes, potentially resulting in reduced cost overruns in construction projects (Sullivan et al, 2009).

Complex designs often complicate the construction process. Early involvement from contactors is therefore essential during the early stages of the design. Many projects in South Africa are initially designed for the conventional method of in-situ concrete construction. However, due to construction constraints and proposals from contractors, projects are sometimes altered towards HCC, which may result in time and cost savings (Hanekom, 2011).

Figure 4.4 shows the impact of changes on the project costs throughout the various phases (Perrine, 2007). It can be seen that the cost of project change increases as the project progresses through the various phases. Likewise, as the project progresses, it becomes more challenging to accommodate change or to accomplish the expected change (Hanekom, 2011). Therefore it is economically more beneficial to apply changes early in a project. The cost of these changes is lower and it is easier to accomplish these changes.

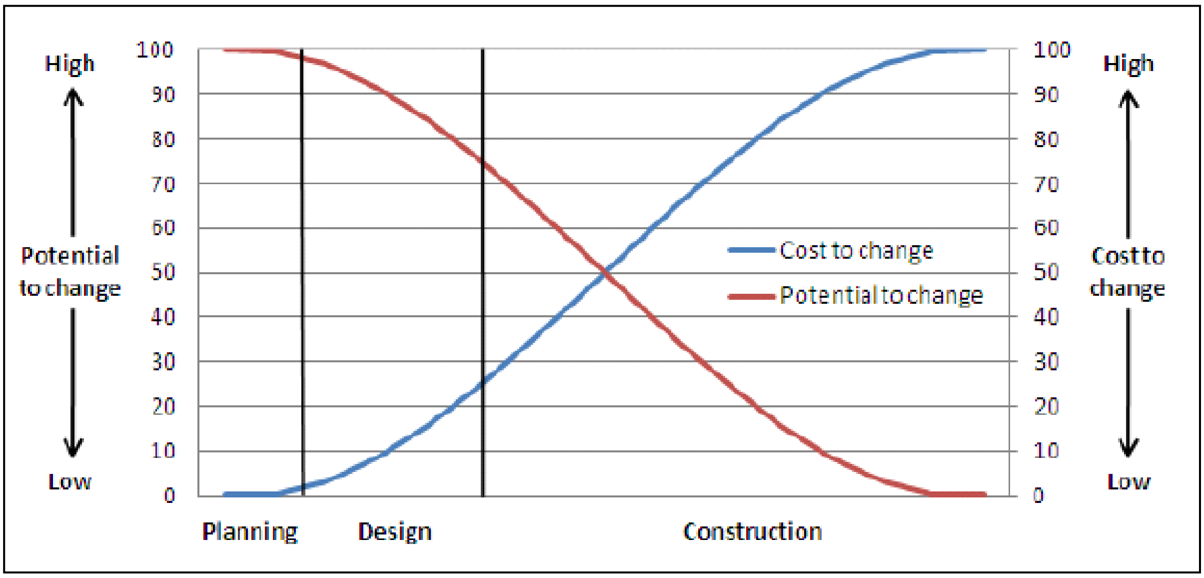

Figure 4.4: Influence of design changes on project cost (Hanekom, 2011)

HCC is known to be less flexible than the conventional method of in-situ concrete construction (Gibb & Isack, 2001b). Late changes will therefore have a greater impact on HCC when compared to in-situ concrete construction. As mentioned above, the involvement of the contractor during the early stages of a HCC project is critical to reduce potential late design changes (Glass et al, 2000).

The construction industry has conformed to the habit of generating late changes by making decisions on-site instead of in the office (Botha, 2014), (De Lange, 2014), (Gibb & Isack, 2001b). This is possible for in-situ concrete construction as consultants often design according to the contractor’s programme. For HCC, these changes are not possible, since the design needs to be completed before construction commences or precast elements are manufactured.

Although certain time savings are generated during the construction phase of a project, the planning during the early stages of a project may be more time consuming for HCC. The factor of potential late changes should be considered for a decision between in-situ concrete construction and HCC.

4.6 Professional fees

Professional fees can either be based on the cost of works, can be time based fees, or can be a lump sum. In the construction industry in South Africa, the fees are usually based on the cost of works and typically represent 1 % to 2 % of the life cycle cost of construction projects (ECSA, 2013). In the case of a lump sum, the ECSA fee rates are often used as a reference point to determine fees (Ronne, 2014).

There is not much literature available on the time spent and associated professional fees for the design of HCC. During the interviews with professionals, 50 % of the respondents mentioned that precast concrete designs are more time consuming, whilst the other 50 % mentioned that precast concrete design is faster when compared to in-situ concrete design. The same results were obtained when the professionals were asked whether professional fees play a role in the decision between HCC and in-situ concrete construction. Some of the professionals said it does not affect the decision, whilst other professionals mentioned that it does play a role. Arguments about professional fees were, however, identified during these interviews and are discussed in this section.

One of the arguments that were mentioned was that time is often limited during the tender stages of a project. Several consultants mentioned that they have limited time to investigate alternative construction methods during the tendering stages of a project. They therefore often choose to design with the conventional method of in-situ concrete construction. In this case it would be ideal if the client requests for HCC. This is not always possible in the industry of South Africa, where the client's requirements are usually not finalised by the time of tender (De Lange, 2014), (Visagie, 2014).

The second argument that was mentioned during the interviews was that the design of HCC is more laborious and time consuming when compared to conventional methods of construction. Consultants therefore argue that the professional fees should be higher for the design of HCC. Consultants then often negotiate the fees with the client. There are, however, no guidelines on estimating professional fees for precast design, which often makes it difficult to come to negotiable rates (Fliss, 2013), (Botha, 2014), (Jordaan, 2014). Although the professional fee scales from ECSA (ECSA, 2013) allow for more complicated designs, it remains the consultant's responsibility to convince the client.

Another argument that arose was that precast design can result in potential time and cost savings on a project's cost of works, which subsequently reduces the professional fees. Some consultants therefore argued that there is no benefit for them in lowering the cost of works and in some cases the time required for the design. Although this reduction in the cost of works and design duration benefits the client, the percentage of professional fees of the consultant may be reduced. Some consultants therefore choose to design for the conventional method of in-situ concrete construction (Visagie, 2014), (De lange, 2014).

Fliss (2013) commented on these arguments, mentioning that the design for precast concrete should be seen as an investment. The first time, the design might be more time consuming, and the professional fees might even be the same or lower when compared to conventional methods of construction. However, when time is spent and knowledge and understanding is gained for the design of HCC, the design duration might be shorter in subsequent projects. In addition to this, the consultant will gain from the benefit of a good reputation in the market for an innovative design. Fliss (2013) further suggested that consultants should approach clients by negotiating the professional rates on the basis of possible time and cost savings during the construction phase of a project.

This topic is however still open for discussion and future investigations are suggested. This factor should be considered in the decision between in-situ concrete construction and HCC.

4.7 Early involvement & collaboration

Referring to Chapter 3, Figure 3.3, early involvement and collaboration between the respective parties are essential to promote potential time and cost savings during the life cycle of construction projects. Early involvement and collaboration amongst parties assist project teams to decide between various construction methods and building materials during early stages of a project. HCC is said to be more dependent on early involvement and collaboration between the various parties when compared to the conventional method of in-situ concrete construction (Gibb & Isack, 2001b).

Early involvement encourages professionals to work in collaboration within the construction team. Collaboration in turn develops trust amongst the respective parties (Egan, 1998). The good relationships then produce the best value project to the client. Clients, consultants, contractors and manufacturers learn from each other, therefore increasing the knowledge of construction methods and materials to provide a product with reduced effects of fragmentation in construction projects (Hanekom, 2011). Collaboration also aids the client to continuously measure the project performance. Egan (1998) mentioned that the end product is dependent on the early involvement of the client in a project team.

In addition to the importance of early involvement in a project, is the importance to understand the various procurement methods that motivate early involvement and collaboration amongst parties. The following section elaborates on the procurement methods used in the construction industry in South Africa and their impact on early involvement and collaboration.

4.7.1 Procurement methods in South Africa

Table 4.1 provides a summary of the commonly used procurement methods in South Africa. These methods are further discussed in this section.

Table 4.1: Procurement contract methods in South Africa (De Klerk, 2013)

Contract method	Description
Design-Bid-Build	The design-bid-build method is also known as the traditional method. During this method, the contractor is only responsible for the construction, where the designs are issued by the client.
Design-Build	During a design-build contract, the client appoints one entity who takes responsibility for the design and construction of the project. This is done in accordance with the client's brief and the required tender specifications, usually for a lump sum price.
Develop and Construct	The develop and construct contract is similar to the design-build contract. However, for this contract the client issues the concept design on which the tenders are based.
Contract Management	A contract management is where a main contractor is appointed to appoint and administer a number of subcontractors to complete construction on the basis of designs issued by the client. The subcontracts are between the main contractor and the subcontractors.
Construction Management	This contract is similar to a contract management; however the client appoints the subcontractors and therefore the subcontracts are between the client and the subcontractors.
Public Private Partnerships	A public private partnership (PPP) is a contract between a public sector authority and a private party. Here the private party provides a service or project on their expenses and operates and maintenains the project for a certain time frame as stated in the contract.
Target price contracts	This form of contract is based on two aspects, namely the target price and the cap. The cap is the maximum amount of the client. The target price is lower than the cap, which gives both parties a financial incentive to meet the target. Both the savings (under the target) and extra cost (over the target, up unto the cap) are equally shared between the client and contractor. Over the cap is treated as fixed price.

The traditional procurement contract strategy of design-bid-build is the most used method in the construction industry in South Africa. Although this method requires early collaboration amongst the parties to be successful, the other methods in Table 4.1 appear to be more successful, especially in other countries, such as the UK and Canada (De Klerk, 2013). The main motivation for this is the lack of early involvement and collaboration in the application of the design-bid-build contract strategy. Contractors are only involved after the design has been completed (Glass et al, 2000), (Hanekom, 2011).

Due to the similarities between the design-build and develop and construct methods; and the contract management and construction management approach, this section only discusses the traditional (design-bid-build), design-build, contract management, PPP and target price contract methods of procurement contract strategies.

4.7.1.1 Design-bid-build

The design-bid-build approach is the traditional method of tendering and is based on the separation of the design and construction phases. In this method the client appoints a consultant after the feasibility study has been completed. The team of consultants develop the design where all drawings, specifications and bill of quantities are prepared. The design is completed before the tendering procedures for the interested contractors commences. In South Africa, the contracts are usually awarded to the tender with the lowest bid price, although some of the clients are moving towards a range of criteria that might be of more value than the tendered price. The contractor is then responsible for all the construction works and related activities. The contractors often subcontract some of the works. The consultant acts on the client's behalf to ensure that the desired quality is achieved. Figure 4.5 is a basic presentation of the traditional method of tendering (De Klerk, 2013).

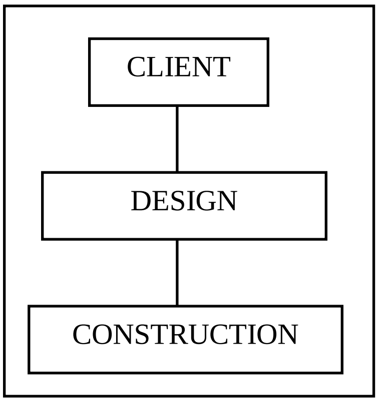

Figure 4.5: Traditional procurement contract strategy (De Klerk, 2013)

The principle idea of this procurement contract strategy is that the design and construction are done by separate firms and that the construction only starts after the design has been substantially completed. Early involvement by the contractor is therefore often not possible. This method has proved to result in little collaboration between the various parties (De Klerk, 2013).

4.7.1.2 Design-build

The design-build approach is an integrated procurement method, where one entity undertakes the contract for both the design and construction of a project. The client often appoints a contractor to be responsible for the entire project that includes the design and construction. The contractor may however sacrifice quality in favour of profit. It is therefore the client's responsibility to ensure the desired quality is achieved. This method of procurement is widely used in developed countries, such as the UK, United States and Japan, and has proved to result in a quality product with potential time savings. This method is also starting to gain favour in South Africa, where provincial departments used this strategy for 29 % of their projects in 2011 (Marx, 2012). Figure 4.6 graphically presents the design-build method (Goodchild & Glass, 2004), (De Klerk, 2013).

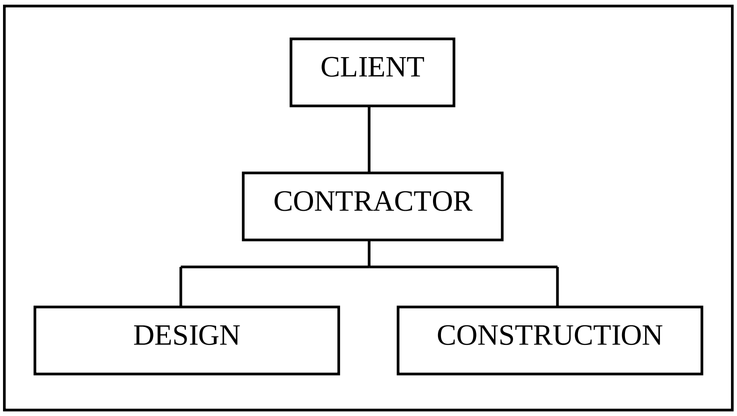

Figure 4.6: Design-build procurement contract strategy (De Klerk, 2013)

The implementation of this method encourages early involvement and collaboration between the designers and contractors (De Klerk, 2013). They can share ideas to produce the best value project to the client. It is argued that this procurement method is still not used to its potential in South Africa. Clients, contractors and consultants appreciate the cost certainty and quality with the use of the design-build procurement contract strategy. Consultants, however, feel more pessimistic about this approach, as they argue that it may result in a lack of systematic design (Goodchild & Glass, 2004), (Hanekom, 2011).

This method may result in potential time and cost savings due to early involvement and close collaboration amongst parties, and should therefore be considered, especially in the applications of HCC.

4.7.1.3 Contract management

Management orientated procurement contract strategies are where the client agrees in a contract with an external management organization to take responsibility for the management of the design and construction of a project. The subcontractors can either be appointed by the client or the management contractor. Figure 4.7 graphically presents the structure of management contracting (De Klerk, 2013).

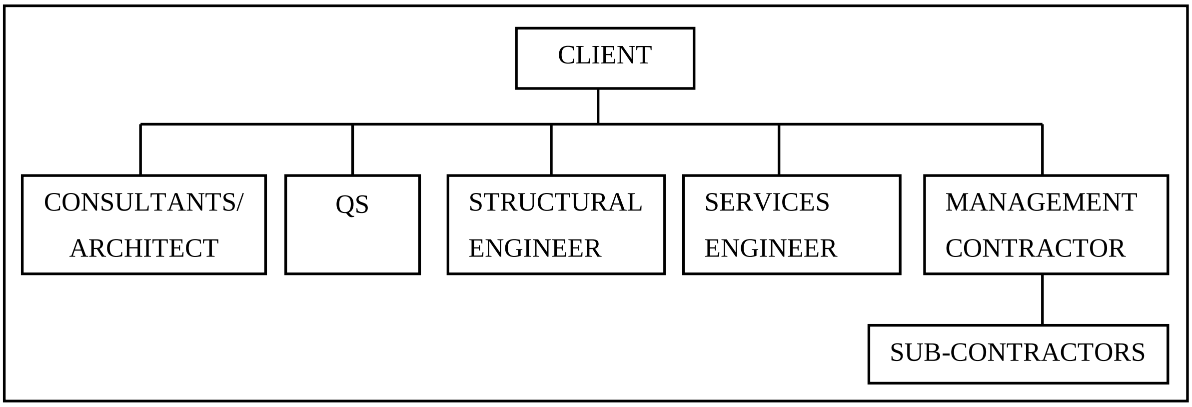

Figure 4.7: Contract management procurement contract strategy (De Klerk, 2013)

Contract management is not a popular procurement method in the construction industry in South Africa. The method is, however, the preferred method of procurement in the UK (Hanekom, 2011). The clients in the UK remain confident in using this method of procurement as it provides the best value for the client, where the tendering process is avoided (De Klerk, 2013). This method of procurement motivates early involvement in order to ensure a best value product for the client (Hanekom, 2011). Contract management requires an educated client since he has to manage all the related disciplines. This is becoming increasingly difficult for government due to the loss of their engineers.

The contract management method may result in potential time and cost savings with the use of precast techniques in the UK (Goodchild & Glass, 2004). Project teams in South Africa should therefore consider this method when HCC is the preferred method of construction.

4.7.1.4 Public private partnerships

A PPP is implemented by public clients to construct large projects where the required management resources and funds are not available. It is similar to Design-build, except that the private party (contractor) would provide some of the financing. A PPP is usually a long project, typically 30 years. During the initial stages of the project, both the private and public partners invest in the project. The project is the responsibility of the private partner for the agreed life of the project. When the life of the project has passed, the public partner takes over the responsibility of the project. This method of procurement motivates early involvement and collaboration amongst the various parties in order to ensure a best value product for the client (Hanekom, 2011).

PPPs are not often used in the construction industry in South Africa. Nonetheless, it has proven to be successful in the UK, where early involvement and collaboration between parties are encouraged.

4.7.1.5 Target price contracts

One of the principle benefits of target price contracts is that the contract aligns the objectives of the respective parties. Contractors and clients are therefore encouraged to work in collaboration to control costs by sharing the risk and benefit of over and under target price expenditures (Huemer, 2004). The target price contract gives the client access to the accounts of the contractor. This open book approach builds trust between the client and contractor. A target price contract is also agreed upon at an earlier stage when compared to conventional contract strategies and therefore allows an earlier start to the project (Perry & Barnes, 2000), (Chan et al, 2011).

It may be difficult to predict the final cost and the distribution thereof in the implementation of target price contracts. This may consequently cause financial problems to the client. The implementation of the target price contract is limited in South Africa (Huemer, 2004). Nonetheless, due to the encouragement of early involvement and collaboration, this contract strategy should be considered when HCC is considered as an alternative for a project.

4.7.1.6 Procurement methods conclusion

For HCC, early involvement and collaboration between parties are important to avoid late changes and to promote potential life cycle cost savings, as discussed in Chapter 3. Although all the discussed procurement contract strategies can be implemented for HCC, it is advised to use the design-build, contract management, PPP or target price contract as a procurement method. These methods encourage early involvement and collaboration amongst parties to provide the best value project for the client. Early involvement also gives contractors the opportunity to propose more buildable projects (Glass et al, 2000), (Hanekom, 2011).

It is also advised that clients should be more involved during the procurement methods of construction projects. Clients have the most influential role in a project, and are therefore encouraged to promote early involvement and collaboration amongst the various parties during the early stages of a project (Egan, 1998), (Hanekom, 2011).

The procurement contract strategies can have a significant impact on the time and life cycle cost of a construction project. Project teams should therefore consider the various procurement contract strategies in their decision between in-situ concrete construction and HCC.

4.8 Investment

Many professionals have mentioned during the interviews (Appendix B), that the design for HCC should not be seen as a time consuming venture, but rather as an investment (Botha, 2014),(Fliss, 2013),(Ronne, 2014). Fliss (2013) mentioned that HCC design might be time consuming during the first attempt, however, will be faster once sufficient experience and knowledge have been gained. Botha (2014), an experienced HCC designer, confirmed this statement when he mentioned that in-situ concrete design is more time consuming when compared to HCC design.

Fliss (2013) stated: "the reward is professional satisfaction when the structure is successfully completed and the client is satisfied with its performance. To the consultancy the reward is high reputation for their competence and innovative culture, to thus attract a better position in the market."

The design of HCC should therefore be seen as an investment, where consultants may be rewarded with a good reputation for their innovative culture. Consultants should therefore consider the long term benefit during the decision between in-situ concrete construction and HCC. However, the best value for the client should remain the principle motivation for the choice of construction method.

4.9 Chapter Conclusion

This chapter identified and discussed the various time and cost factors that may play a role in the decision between in-situ concrete construction and HCC during the design phase of a construction project. HCC is more dependent on standardization and repetition when compared to the conventional design of in-situ concrete construction. Therefore, when standardization and repetition are substantial, HCC might be the preferred method of construction. However, when standardization and repetition are limited in a construction project, in-situ concrete construction might be the preferred method of construction.

It is still argued that sufficient guidance on the design of HCC is limited in South Africa. HCC designs are therefore required to be designed from first principles which are time consuming. Many consultants therefore choose to design for the conventional method of in-situ concrete construction.

There are certain factors that may increase the construction schedule and budget in the implementation of HCC that need to be considered. These factors include the technical aspects, such as connection design, yard and equipment design and the related extras. It was, however, concluded that once sufficient knowledge and experience are gained, the duration of HCC design might be shorter or similar when compared to in-situ concrete construction.

Another key factor that needs to be considered in the decision between in-situ concrete construction and HCC is early involvement and collaboration amongst the various parties involved. Late changes to a project may have a larger effect on HCC when compared to in-situ concrete construction. Early involvement and collaboration are therefore important in order to eliminate these late changes to the project. Contract strategies that encourage early involvement and collaboration are therefore important in reducing late project changes, especially in the implementation of HCC.

These design cost and time factors can assist project teams in their decision between in-situ concrete construction and HCC. Table 4.2 summarizes the identified design factors. The following two chapters identify the cost and time factors during the construction phase for a decision between in-situ concrete construction and HCC.

Table 4.2: Design phase factors for a decision between in-situ concrete construction and HCC

Factors	In-situ concrete construction	HCC
Standardization & Repetition	In the case where limited standardization and repetition occurs, in-situ construction will be more beneficial in terms of time and cost.	Greater potential for standardization and repetition. Result in more time and cost savings when compared to in-situ concrete construction.
Technical aspects: • **Connection design** • **Precast yard design** • **Equipment design** • **Detailing** • **Extras**	Technical aspects might be less time consuming when compared to the technical aspects of HCC.	Technical aspects might be more time consuming when compared to in-situ concrete design.
Outsourced design	Not applicable	Reduced time required for design, however, associated costs are often higher
Design guidance	Sufficient guidance available, may result in time savings in terms of the design	Sufficient guidance is limited, may result in time consuming designs
Late changes	Late changes more possible, reduced impact on time and cost	Possibility of late changes is reduced. Late changes have a greater impact on the time and cost when compared to in-situ concrete construction.
Professional fees	May be lower for the design of in-situ construction when compared to HCC	May be higher for the design of HCC applications
Early involvement and collaboration	Require early involvement and collaboration in order to provide the best value project for the client, however, less dependant on early involvement and collaboration when compared to HCC.	More dependant on procurement strategies that promote early involvement and collaboration.
Investment	Not applicable	May result in a good reputation and innovative culture.

Chapter 5

Construction phase: Identification

Chapter 5 and Chapter 6 present the construction phase during the life cycle of construction projects. The primary objective of these two chapters is to identify and discuss the factors that potentially have an influence on the time and cost during the construction phase of projects in South Africa where HCC is considered. These factors, in addition to the identified factors during the design phase (Chapter 4), are used to create a framework that can assist project teams in their decision between in-situ concrete construction and HCC.

The construction phase consists of a part 1, where the factors are identified, and a part 2, where the various factors are discussed, as shown in the construction phase outline presented in Figure 5.1. Chapter 5 includes part 1, where the various factors are identified. Chapter 6 subsequently includes part 2, where the identified factors are further discussed.

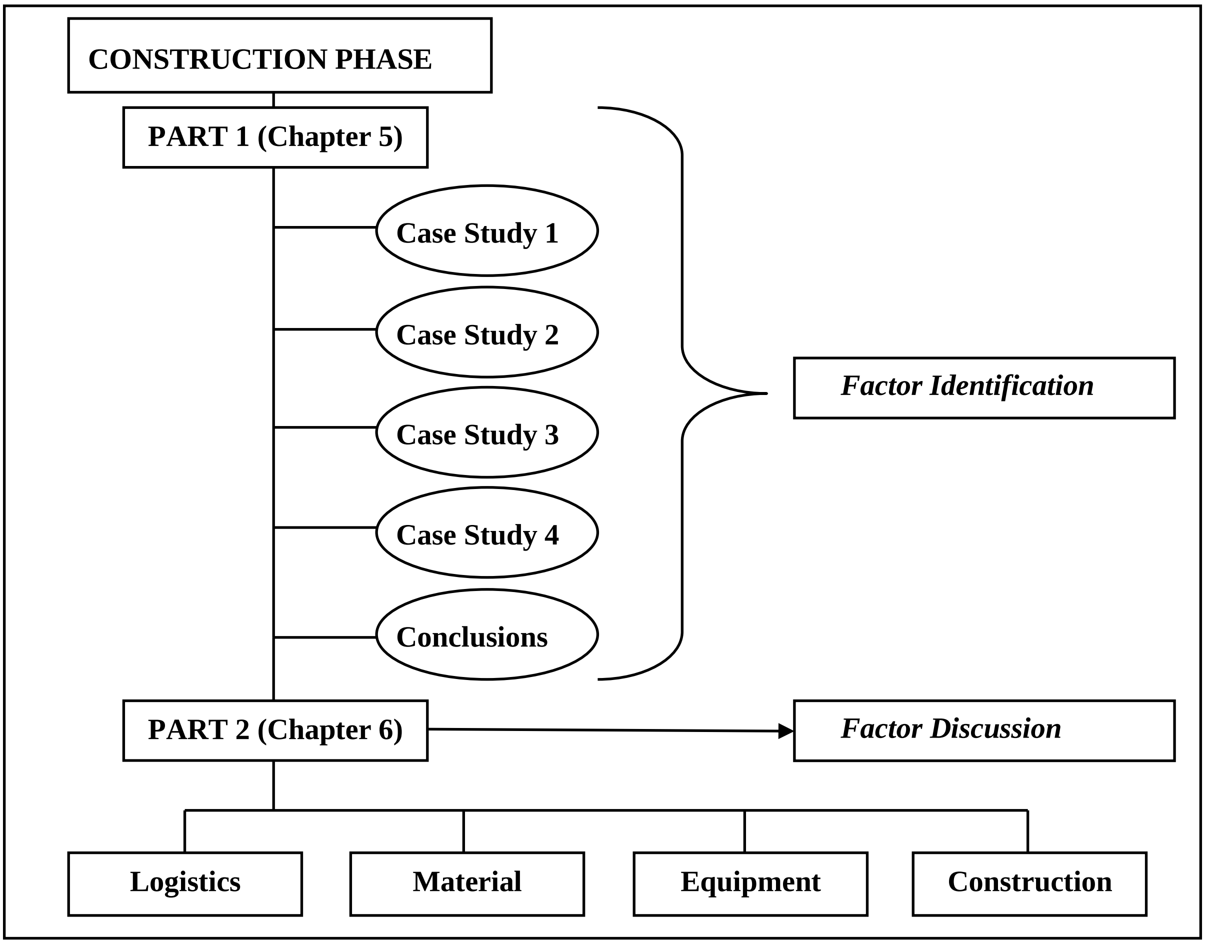

Figure 5.1: Construction phase outline

Part 1 (Chapter 5) of the construction phase includes a variety of projects, which were constructed over the last decade with the implementation of HCC in South Africa. These projects were investigated and are introduced in this chapter with the use of case studies. The information on these case studies was obtained through site visits to the various projects and through discussions with a representative from the respective project teams. Discussions with the representatives are provided in Appendix C. The following projects were investigated:

- Case Study 1: Grootegeluk and Shandoni coal bunkers by Stefanutti Stocks
- Case Study 2: Cape Town dispatch plant for Value logistics by Group five
- Case Study 3: Bloemfontein Longridge reservoir by Ruwacon
- Case Study 4: VWSA paint shop by Grinaker LTA

The time and cost factors are identified in this chapter through the study of these case studies and discussions with the various project teams. These case studies are presented with reference to the project aspects as shown in Figure 5.2.

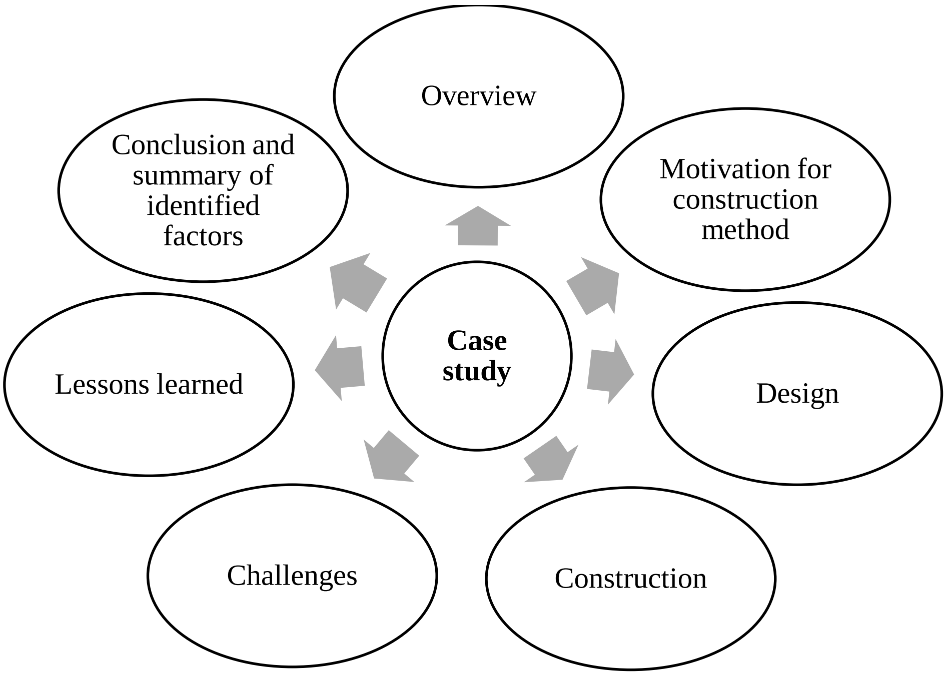

Figure 5.2: Case study format, displaying respective sections

5.1 Case Study 1: Grootegeluk and Shandoni coal bunkers by Stefanutti Stocks

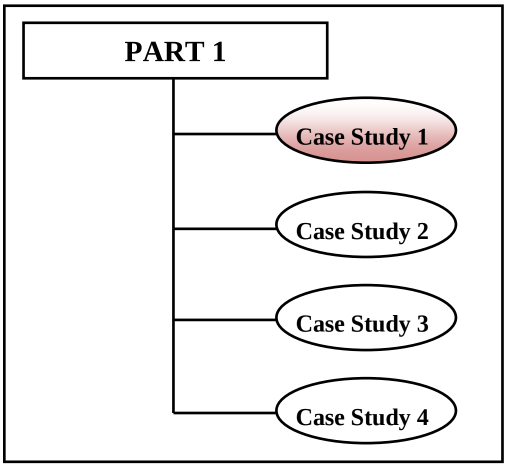

Figure 5.3: Chapter 5 outline - Case study 1

Stefanutti Stocks, a well known South African construction firm, providing services to the mining industry, was responsible for constructing coal bunkers in two separate projects. The first project, Grootegeluk coal bunkers, was constructed with the implementation of in-situ concrete. In the second project, Shandoni coal bunker, the bunker was constructed with the implementation of HCC techniques. These two projects are studied and compared to learn from failures and successes, and to identify the various time and cost factors that may play a role for a decision between in-situ concrete construction and HCC.

5.1.1 Grootegeluk coal bunker

Figure 5.4: Grootegeluk coal bunker (Stefanutti Stocks, 2013)

Overview:

The Grootegeluk expansion project included the construction of two coal bunkers. The two coal bunkers can be seen in Figure 5.4. The contract was undertaken as a joint venture between Stefanutti Stocks Civils and Stefanutti Stocks Civils KZN. The value of the project was estimated to be R 805 million (Stefanutti Stocks, 2013).

Motivations for the implementation of in-situ concrete construction:

For this specific project the client requested to construct with the use of in-situ concrete construction. The Stefanutti project team proposed an alternative method where they suggested the implementation of HCC techniques. The principal motivation for this was to increase the rate of construction by transferring the activities taking place at heights to ground level, which in turn would lead to a shorter construction schedule with better quality control. The alternative was based on a previous project, the Isibonelo bunker, constructed by Murray and Roberts in 2005. The client, however, rejected the proposal and Stefanutti Stocks had no choice but to construct with the original design of in-situ concrete construction.

Design:

The two coal bunkers were designed as the two largest coal bunkers in South Africa with a capacity of 48 000 ton and 31 000 ton respectively. The larger bunker measures 142 m long by 26.8 m wide and 38.5 m high. The discard bunker is 100 m long by 27 m wide and 41.5 m high. Some of the structural elements in the bunkers are up to two metres thick, such as the elevated walls (Stefanutti Stocks, 2013).

Some of the quantities of the bunkers and Plant Civils (including tunnels) were:

- Formwork: 126 000m^2
- Concrete: 136 000m^3
- Reinforcing: 18 800 ton
- Cast in items: 930 ton

The larger bunker consisted of 32 000 m^3 concrete with 365 kg/m^3 reinforcement and the discard bunker consisted of 27 000 m^3 concrete with 480 kg/m^3 reinforcement (Stefanutti Stocks, 2013). The design was based on conventional methods of in-situ concrete designs.

Construction:

The duration of the project was just over 3 years. The scope of works included earthworks, civil works and structural steel work. The earthworks consisted of bulk and restricted earthworks as well as several retaining walls. The civil works included the construction of the two coal bunkers. The structural steelwork included the manufacture and installation of chutes (Stefanutti Stocks, 2013).

The in-situ method of construction for these bunkers had a workforce of 750 labourers and 130 staff. During some stages of construction, up to 4 cranes were used. Much work took place at heights and made construction difficult, especially during windy conditions. Labourers often worked in awkward positions and in difficult conditions that resulted in rework. Rework of approximately 2 % was required on the structure. This amount of rework added to time and cost overruns on the project.

A formwork system, comprising of floating tables for the sloping walls and elevated slabs, were used for potential time savings and for reduced staging. Several take up towers and transfer towers were also constructed for the bunkers (Stefanutti Stocks, 2013). The success of this method was, however, limited as much rework on these sloping walls and elevated slabs was required.

Figure 5.5 displays rework that was required on one of the sloping walls of the structure to repair honeycombing which occurred as a result of casting concrete in sloping formwork.

Figure 5.5: Rework on the Grootegeluk bunkers due to honeycombing

Challenges of the Grootegeluk coal bunkers:

1. These bunkers were constructed to be the largest coal bunkers in Southern Africa and were a new challenge to the construction team. Many unforseen risks were identified during the project. These risks included on-site theft (due to the bulk quantities of materials and equipment); operation and managing of the cranes, staff and labourers; and safety of the workforce working in difficult conditions and in awkward positions at great heights.

2. Many cranes in an overlapping area were used for construction. Operating and managing these cranes were challenging. Tower cranes were mostly used to lift and move the material (reinforcement, concrete buckets, equipment, etc.) required for construction at heights. These cranes are easily affected by wind, which made it impossible to supply materials at these heights on certain days.
3. In-situ casting in sloping formwork resulted in honeycombing and inadequate concrete compaction during the construction of some of the side walls. Honeycombing makes a 30 MPa concrete vulnerable to the abrasive nature of sliding coal. In-situ concrete bunkers therefore require 50 mm thick steel plates or rail liners in order to add wear protection. The sloping walls are 2 m thick, which made constructability difficult at these heights. Construction of the sloping walls required planning, designing and erection of support structures in order to carry the weight of the formwork and fresh concrete until sufficient strength has been reached. The challenges, planning and construction of the sloping walls added to the construction schedule and total project cost.
4. A large workforce was required to construct the Grootegeluk bunkers. Managing the labourers and overseeing the productivity of these labourers was a challenge. More staff than originally anticipated for were therefore appointed to oversee the labourers, which added to the total cost of the project.
5. After the erection of the bunkers, it was estimated that approximately 2 % of the structures required rework. This added to the total time and cost overruns of the project.
6. Working at heights affected the following:
    - *Quality*. Labourers often worked in awkward positions on harnesses at great heights. Quality control was difficult to apply; therefore insufficient quality on certain parts of the structure was evident, such as the required rework on the elevated walls as presented in Figure 5.5.
    - *Safety*. Working at height is a safety risk to the labourers and in turn to the contractor. Applying the necessary safety rules and legislations were time consuming and added to the cost and schedule of the project.
    - *Time delays*. Working at heights caused numerous time delays. Tower cranes are easily affected by windy conditions. This caused occasions where materials couldn’t be supplied to the various teams. Working in awkward positions also required more time when compared to working at ground level. These factors made it easy for the project to fall behind schedule.

The schedule and budget for these bunkers were a challenge from the start. Due to various complications and challenges, as discussed, this project was not completed on time nor within budget.

5.1.2 Shondoni coal bunker

Figure 5.6: Shondoni coal bunker

Overview:

Stefanutti Stocks Civils is busy with the construction of the Shondoni bunker project at Kinross, Mpumalanga, which can be seen in Figure 5.6 (June 2014). This is the second coal bunker of this scale that the company is constructing for Sasol Mining. The first project was the Twistdraai project where a 15 000 ton coal bunker was constructed. The first project was constructed by the use of in-situ concrete, with similar methods as for the Grootegeluk coal bunkers, whilst the Shondoni coal bunker is being constructed with the implementation of HCC (Stefanutti Stocks, 2014).

The Shondoni project included the construction of a 15 000 ton coal bunker with the implementation of HCC. Vermeulen (2013) mentioned that the unique aspect of this project is that all precast construction elements, weighing up to 19.8 ton are erected in sequential order (Stefanutti Stocks, 2014).

The precast yard, responsible for the manufacturing of the precast elements, has been established near the Secunda plant, with its own batch plant run by Afrisam. The duration of the project was estimated to be one year. Six months into the project, the team had achieved an overall progress of 18 %, improving the set progress target of 16 % by 2 %. The project is currently ahead of schedule and within budget (June 2014), (Stefanutti Stocks, 2014).

Motivations for the implementation of HCC:

As mentioned in the project overview, this is the second bunker of this scale that Stefanutti Stocks is constructing for Sasol Mining. For the first coal bunker (Twistdraai project), a 15 000 ton bunker was constructed with the use of in-situ concrete. The timeline to complete the Twistdraai bunker was challenging and Stefanutti Stocks proposed an alternative method of HCC. The HCC method was previously used successfully in an 8 000 ton bunker, constructed by Murry and Roberts. The alternative for the Twistdraai project was, however, not accepted by the client.

Due to some time, cost and quality challenges in the Twistdraai project and an on-going relationship between Stefanutti Stocks and Sasol Mining, Stefanutti Stocks attempted for the second time to convince Sasol Mining of the alternative of using HCC techniques. The proposal was accepted for the Shondoni coal bunker project. The principle motivation for the implementation of HCC was to improve quality, reduce wastage and to stay within budget and on schedule (Stefanutti Stocks, 2014).

Design:

The Shondoni bunker is 20 m wide, 80 m long and 28 m high. A 3D model of the precast design can be seen in Figure 5.7. All the columns and foundations were cast in-situ. The in-situ columns were formed with 40 MPa concrete and are 7.5 m apart. The longitudinal and transverse elements were designed to be constructed with the implementation of precast concrete elements.

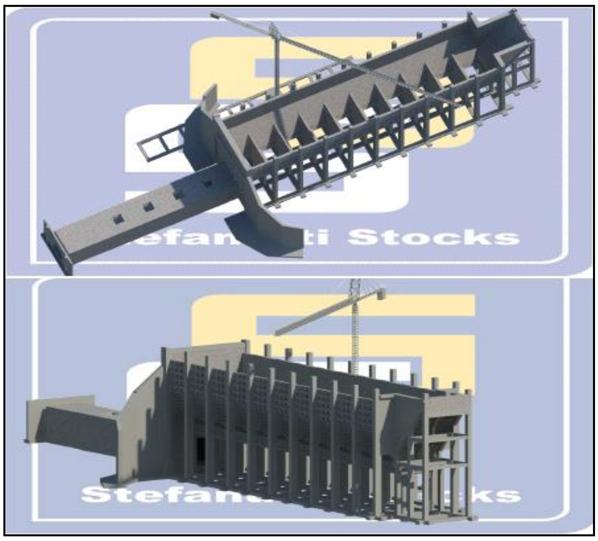

Figure 5.7: 3D model of the precast Shondoni coal bunker (Stefanutti Stocks, 2014)

The designer of the Shondoni coal bunker mentioned that the precast elements are manufactured in a controlled environment where it is possible to reach a high strength concrete of 60 MPa (Fliss, 2013).

The manufacturing process provides a smooth finish to the elements that improves the flow of the coal as it is being discharged from the chutes. In the conventional method of in-situ concrete construction the bunkers are usually constructed using a 30 MPa concrete in uncontrolled casting environments and usually requires an internal lining to improve the discharge of the coal. The implementation of precast elements therefore has the potential to provide more sufficient quality for coal bunker construction (C&CI, 2013).

The various precast elements were designed with reinforcement protruding from the elements. The elements were then placed with overlapping reinforcement and tied together. After the elements have been tied together, in-situ concrete is poured to complete the connection. This form of HCC connection eases the design and construction when compared to conventional precast connections (Vermeulen, 2013). This form of connections is presented in Figure 5.8.

Figure 5.8: HCC connection for Shodoni coal bunker

Construction:

The columns and foundations were cast using in-situ concrete. The horizontal bottom slab was cast in-situ on precast beams, which in turn is supported by the columns. The remainder of the bunker, including inclined and vertical wall panelling, as well as sloping beams, were all constructed using precast concrete elements. The largest precast element weighed up to 19.8 tons (Stefanutti Stocks, 2014).

At the same time, while excavation works and in-situ columns, horizontal floor slabs and foundations were constructed, the precast elements were manufactured (Stefanutti Stocks, 2014), (C&CI, 2013). The precast elements were manufactured at a precast yard approximately 15 km from the construction site. Figure 5.9 presents the precast yard with the associated formwork and precast panels.

Figure 5.9: Precast moulds and elements for the Shondoni project

In Figure 5.9, on the left, a precast mould and some of the completed elements are displayed. On the right hand side of the figure the same moulds are shown with void forms having been placed into the moulds. These precast elements with voids were used for the sloping walls of the coal bunker. This leads to significant concrete and reinforcement savings when compared to the conventional method of in-situ concrete construction. For the Grootegeluk project these walls were mentioned to be 2 m thick. In this case, material was saved in using precast elements (Vermeulen, 2013).

Since all elements were erected in sequential order, it was important that the precast yard stay on schedule with the fabrication of the elements. In order to simplify the operation, the reinforcement was fixed using pre-manufactured reinforcement moulds, as seen in the Figure 5.10. The moulds also add to the accuracy and precise fixing of the reinforcement, ensuring that the specified cover was reached. This system allowed repeatability and proved to be convenient, especially after the workforce had become familiar with the concept.

Figure 5.10: Pre-manufactured reinforcement placement mould

When the precast elements were transported to site, they were often double handled. The elements were transported to the site, stacked and then again transported to the crane for installation. For this project it was necessary to design special lifting equipment also known as special clamps. These clamps are responsible for the lifting and placing of the various elements. Figure 5.11 shows the transportation and erection of one of the side beams, being lifted and placed with a special clamp.

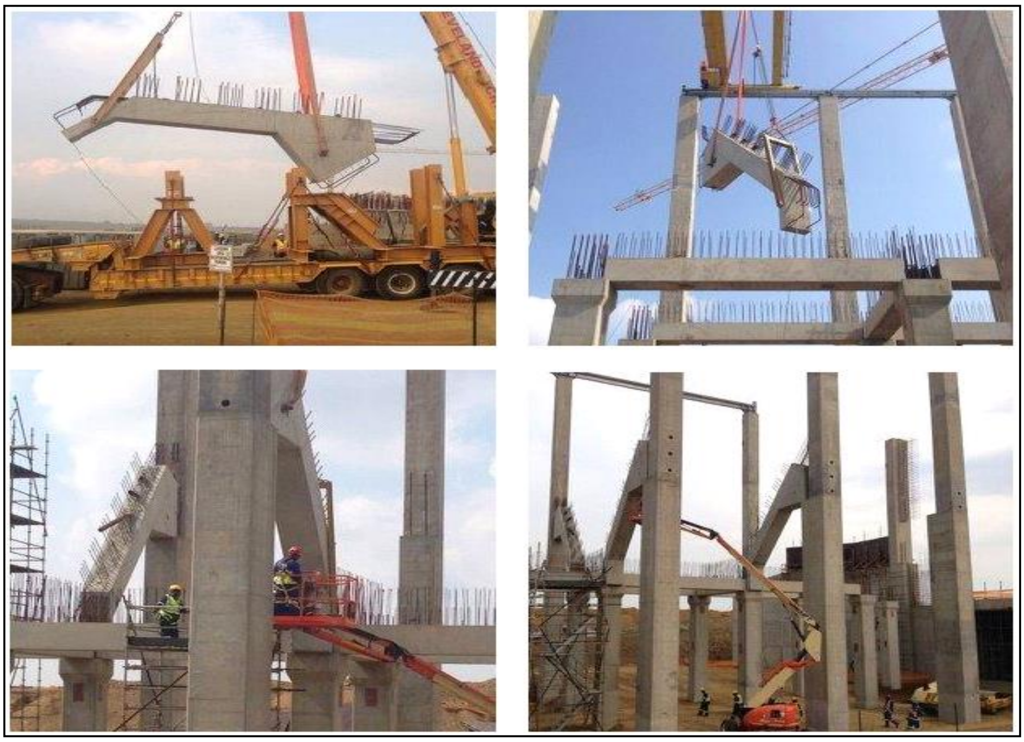

Figure 5.11: Placing of precast beams with special clamp

For the placement of the beam presented in Figure 5.11, a crane operator and four labourers were required. As mentioned in the Grootegeluk case study, many labourers were required for the implementation of in-situ concrete construction. Vermeulen (2013) mentioned that far fewer labourers are required for the implementation of HCC when compared to in-situ concrete construction for coal bunker construction.

The duration of the 15 000 ton Twistdraai project, constructed using in-situ concrete, was little under two years. The 15 000 ton Shondoni bunker, constructed with the implementation of HCC, is on schedule and the duration of this project is estimated to be one year. In this case, the construction duration when using precast elements is almost 50 % of the duration required when constructing with the use of the conventional method of in-situ concrete construction.

Challenges for the Shandoni coal bunker:

1. Special forms are required for the shutters of the precast moulds. The moulds need to be designed and ordered for manufacturing well in advance. Planning during the early stages of the project was therefore important for the consideration of this aspect.

2. The precast yard that was used for the Shondoni project was set up by Murray & Roberts in 2005. The precast yard, however, required to be repaired and upgraded for the Shondoni project.
3. Precast elements needed to be double handled. The precast units were typically transported from the precast yard to the site, stacked on site and then again transported to the crane for installation. The elements therefore needed to be handled with caution in order to prevent damage to the elements, which might increase the possibility of repair work.
4. There is a small margin for error when placing the precast elements into their final locations. Accuracy of connections and measurements of the various elements therefore need to be precise in order to prevent rework.
5. Late adjustments and repair work are difficult to apply on precast elements. Accurate levelling was therefore essential during the starting phases of construction to ensure that the elements were not out of tolerance.
6. Transportation of the elements is always a risk in terms of time and cost. Heavy elements were required to be transported to site. Although the elements were transported over small distances, the weight of the elements required special transportation methods. This added to the construction cost of the project.
7. Special lifting devices or clamps were required to be designed and manufactured during the initial phases of the project for the erection of some of the precast elements.

Lessons learned from the in-situ concrete construction and HCC coal bunkers:

1. When using precast concrete in coal bunker construction much less material is required. For the Grootegeluk coal bunker, the concrete walls were 2 m thick with 480 kg/m^3 reinforcement. For the Shondoni coalbunker it was established that much less concrete and reinforcement were required. When the 15 000 ton precast Shondoni coal bunker was compared to the 15 000 ton Twistdraai in-situ coal bunker, it was estimated that approximately 30 % less concrete and reinforcement were required. Reduced material in the implementation of HCC can result in potential cost savings in coal bunker construction, depending on the nature of the project (Vermeulen, 2013).
2. Less wastage is generated in the implementation of HCC. The precast yard has shown to be a more controlled environment when compared to on-site conditions. It is easier to reduce wastage on a precast yard. The transportation and disposal of wastage in construction projects add to the project schedule and budget. Due to less wastage, construction time and cost can be reduced.
3. For this case, the workforce required for the implementation of HCC is much smaller when compared to in-situ concrete construction. Fewer labourers in turn reduced the total project cost.

4. One of the principle benefits in the implementation of HCC for coal bunkers is that the activities taking place at heights are transferred to ground level. This generates many benefits, such as:
    - *Safety*. The Medupi coal bunker required many off the ground activities. Labourers therefore had to work in awkward positions at great heights. For the Shondoni project, most activities were done at ground level. The risk of accidents is therefore reduced. Safety on site is an important component in the construction industry. When a construction project does not satisfy the safety requirements, it can lead to project closure, which will have a significant impact on the construction schedule.
    - *Fewer temporary works required*. Due to fewer activities taking place at height, fewer support and access structures are required. Much less scaffolding is required for the Shondoni coal bunker. The erection time of these temporary structures is saved in the implementation of HCC. These structures add to the total cost and schedule of the project. Therefore, possible cost savings may occur in using fewer support and temporary structures with the implementation of HCC.
    - *Rapid construction*. Construction takes place at a more rapid pace. The erection of formwork, placing of reinforcement and pouring of concrete are done at ground level, which is more convenient and faster than constructing at heights in awkward positions. Since the same moulds are re-used for the concrete, it takes less time to prepare the formwork. On site activities can also take place while the precast elements are being manufactured. The construction duration of the 15 000 ton Twistdraai coal bunker was just under two years, whilst the construction duration of the 15 000 ton Shondoni coal bunker is estimated to be just under a year. The implementation of HCC in coal bunker construction has the potential to reduce the construction schedule by 50 % in this case. This reduction in time, however, depends on numerous aspects, such as project size, location, etc.
    - *Quality*. Better quality control can be performed at ground level in a controlled environment when compared to working at heights. Casting in sloping formwork often leads to honeycombing. Less rework may therefore be required with the implementation of HCC.
5. Standardization and repetition is an essential factor in the implementation of HCC. Pre-manufactured and standardized reinforcement moulds were erected to enhance the speed of the precast yard. Standardization and repetition may result in potential time and cost savings.
6. Cranes are hired for a shorter duration and for this case, fewer cranes were required in the implementation of HCC. Cranes are expensive and are hired per day. Due to a shorter construction period and fewer cranes, cost savings were possible.

Case Study 1 Conclusion:

In the case of coal bunker construction, it is evident that the implementation of HCC offers numerous benefits that in turn results into potential time and cost savings. There are, however, a few factors that need to be considered during the initial phases of the project, such as the availability of a precast yard, site accessibility, etc., to insure that this method of construction would be economically viable. The project team mentioned that the programme activities for the implementation of in-situ concrete construction and HCC is similar for coal bunker construction. The schedule duration for HCC is, however, shorter when compared to in-situ concrete construction. The factors that may have an influence on the time and cost for a decision between in-situ concrete construction and HCC for case study 1 is identified in Table 5.1. The table provides a short description of the factors for the implementation of HCC when compared to in-situ concrete construction. The factors are further discussed in Chapter 6.

Table 5.1: Identified time and cost factors for Case study 1

Factor	Impact	HCC compared with in-situ concrete construction
Precast yard erection	time & cost	Additional time and cost for precast yard erection
Lifting devices	cost	Additional installation cost (eg. gantry crane)
Property	cost	Additional property purchase/renting cost
Labourers	cost	Reduced labourers, therefore reduced labour cost
Transportation	time & cost	Additional time and cost required for transportation methods
Concrete & reinforcement	cost	Reduced material (concrete & reinforcement) cost
Wastage	cost	Less waste generated, therefore reduced cost
Temporary works	time & cost	Fewer temporary works, therefore reduced time and cost
Precast moulds	time & cost	Reduced formwork for precast moulds, therefore reduced cost and reduced time required for mould setup
Material theft	cost risk	Less on-site material, therefore smaller risk of theft
Equipment theft	cost risk	More plant & equipment, therefore increased risk of theft
Cranes	cost	Fewer cranes & shorter duration, therefore reduced cost
Handling devices	cost	Additional manufacturing cost
Plant	cost	Additional plant cost may be required
Connections	time	Connections may be time consuming
Rework	time & cost	Reduced rework time and cost
Repetition	time & cost	Repetition may result in time and cost savings
Working at heights	time & cost	Transferring activities to ground, therefore reduced time & cost
Safety	time & cost	Safer method of construction, therefore reduced risk
External risks	time & cost	Less affected by weather conditions
Earlier site access	time	Earlier site access, therefore reduced construction schedule
Return on investment	cost	Faster return on investment, increased income

5.2 Case Study 2: Cape Town Dispatch plant for Value logistics

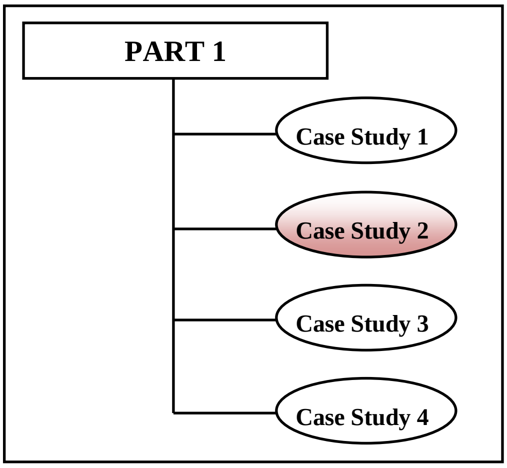

Figure 5.12: Chapter 5 outline- Case study 2

Overview:

The Value logistics group requested a new dispatch plant for Cape Town and the Cape Winelands area. The plant is located near Kraaifontein industrial area on the Sandringham road next to the N1 highway. A dispatch plant of 140 000 m^2 is constructed with the implementation of precast tilt up systems. At the time of the site visit (April 2014), the project was still under construction and was showing to be successful in budget and ahead of schedule. The total tendered price of the project was R 180 million. Figure 5.13 displays the plant where a precast wall is being tilted in position at the construction site.

Figure 5.13: Value logistics dispatch plant, tilt up wall

Motivations for the use of precast tilt up systems:

The client constructed a previous project with the implementation of precast tilt up systems. He was familiar with the use of this construction method and the associated benefits thereof, such as time, quality and safety. When the project went out on tender, the client (Value logistics) requested to construct with the implementation of precast tilt up systems (Bergh, 2014).

Design:

Loudon Perry Anderson Architects were appointed as the architects for the project. The design of the structure was done by Sutherland consultants in collaboration with Tilt Up Systems.

The architectural precast concrete components comprised of:

- 181 columns with the longest length of 17 m and cross sections of: - 450 × 600, and
  - 600 × 600
- ± 170 walls with panel sizes of: - 6 000 × 8 000
  - 7 000 × 5 000, etc.

The precast elements, moulds, connections and tilt up systems were primarily designed and manufactured by Tilt Up Systems. Tilt Up Systems were also responsible for the erection of the columns and walls in using the tilt up method during the construction phase of the project (Bergh, 2014).

Construction:

By the time of the site visit, the columns had been cast and placed into their final locations and the precast wall panels were still under construction. The duration of the project was estimated to be 11 months.

Group 5 was the main contractor for the project and had appointed Tilt Up Systems as specialist subcontractor to design and construct the precast tilt up columns and walls. The subcontractor was also responsible for the tilting and therefore to supply the crane, formwork and labourers for the placing of the elements. The concrete was supplied by Group 5.

The precast elements were cast on site by placing the column moulds on concrete blindings, to provide a smooth surface for the elements. Four moulds were used for the casting procedure of the columns, where a total of four columns were cast per day. Better quality control was possible by manufacturing the precast elements at ground level when compared to constructing these elements at heights. Some columns reached heights of up to 17 m. Quality control at these heights in awkward positions may have been a challenge. The wall panels were also cast on concrete blindings. Five wall panels had been cast on top of each other by using a non adhesive layer between panels in order to separate them from each other. Figure 5.14 shows the moulds of the columns on top of the concrete blinding.

Figure 5.14: Precast column moulds on concrete blinding

After the casting had been completed, the columns were tilted and placed into their final locations. The placing was done by a mobile crane and six trained labourers that were familiar with the system. Up to 30 columns were tilted and positioned per day. Figure 5.15 displays the tilting and positioning of one of the columns.

Figure 5.15: Value Logistics dispatch plant, tilt up column

Challenges:

1. There is a small margin for error in titling precast elements into their final locations. The connections and measurements of the precast elements need to be manufactured with great precision in order for the elements to fit into their various connections. In the case where the accuracy of elements are out of tolerance, some of the elements may need to be disposed of or remanufactured.

2. Late adjustments and repair work are difficult to apply on precast elements. Accurate levelling was therefore essential during the starting phases of construction to ensure that the elements are not out of plumb.

Lessons learned:

1. The principle benefit in the implementation of precast tilt up systems is that the concrete is cast at ground level. This generates many benefits, such as:
    - *Safety*. Working at heights is a risk to labourers and subsequently to contractors. Working at ground level reduces the risk of accidents, which in turn reduces the risk of project time and cost overruns.
    - *No temporary supports required*. The structural elements (precast columns/walls) are removed from the moulds and left to cure until sufficient strength is reached. Scaffolding and support structures are not required to support the formwork and wet concrete. Another benefit is that no accessibility structures are required for activities taking place at heights, since all activities are carried out at ground level.
    - *Rapid construction*. Construction takes place at a more rapid pace. The erection of formwork, placing of reinforcement and pouring of concrete are done at ground level. Since the same moulds are repeatedly used for the concrete, it takes less time to prepare the formwork. Bergh (2014) mentioned that the project would take approximately 3 months longer if the conventional method of in-situ concrete construction was to be implemented.
    - *Quality*. Better quality control can be performed at ground level when compared to working at heights. The concrete for a 17 m column would have been cast in two to three lifts in the implementation of in-situ concrete construction, whilst it can be poured once at ground level with the implementation of precast tilt up systems.
2. Less material is required for precast tilt up systems. In this case only four moulds were used to construct the columns. With most of the work being carried out at ground level, it eliminates the need for scaffolding, formwork and temporary support structures.
3. Due to less on site material, less wastage is generated. The construction site is also located in an area where theft is considered as high risk. The possibility of theft is therefore reduced due to less on the site material and equipment.
4. Time is gained by standardization of column sizes and the repetitive erection of columns and walls in the implementation of precast tilt up systems (HCC).
5. One crane was used for the erection of the columns. For the implementation of in-situ concrete construction either a crane or a truck mounted concrete pump would have been used to cast concrete at these heights.

Case Study 2 Conclusion:

Precast tilt up systems were used for this project and proved to be successful in terms of the construction schedule and budget. HCC is, however, not always the economical option. When repetition is limited, and the size of the project is smaller, the implementation of in-situ concrete construction may be more economical. For this project, a large quantity of walls and columns needed to be manufactured. Repetition of erecting these elements have shown that precast tilt up systems have many benefits in terms of time and cost and are possible in the construction industry in South Africa. The factors that may have an influence on the time and cost for a decision between in-situ concrete construction and precast tilt up systems for Case study 2 are identified in Table 5.2. The table provides a short description of the factors for the implementation of HCC when compared to in-situ concrete construction. The factors are further discussed in Chapter 6.

Table 5.2: Identified time and cost factors for case study 2

Factor	Impact	HCC compared with in-situ concrete construction
Precast yard erection	time & cost	Additional time and cost for precast blindings
Precast supplier	cost	Additional cost to the precast supplier (specialist subcontractor)
Labourers	cost	Reduced labourers, therefore reduced labour cost
Precast yard disposal	time	Additional time required for the disposal of concrete blindings
Wastage	cost	Less waste generated, therefore reduced cost
Temporary works	time & cost	Fewer temporary works, therefore reduced time and cost
Precast moulds	time & cost	Reduced formwork for precast moulds, therefore reduced cost and reduced time required for mould setup
Material theft	cost risk	Less on-site material, therefore smaller risk of theft
Site preparation	time	More time required for precise preparations
Connections	time	Connections may be time consuming and challenging
Rework	time & cost	Reduced rework time and cost
Repetition	time & cost	Repetition may result in time and cost savings
Working at heights	time & cost	Transferring activities to ground, therefore reduced time & cost
Safety	time & cost	Safer method of construction, therefore reduced risk
Earlier site access	time	Earlier site access, therefore reduced construction schedule

5.3 Case Study 3: Bloemfontein Longridge Reservior

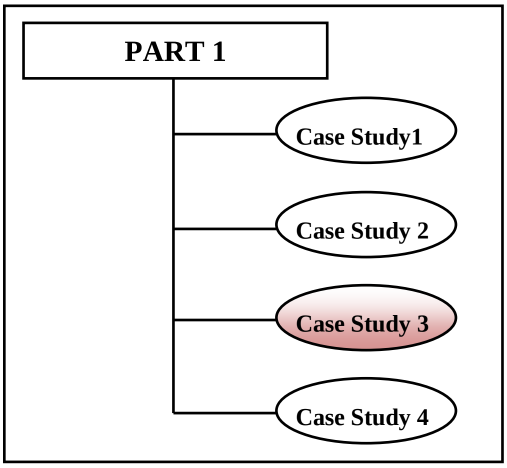

Figure 5.16: Chapter 5 outline - Case study 3

Overview:

Ruwacon was appointed as main contractor to undertake the construction of the 45Ml Longridge reservoir in Bloemfontein. Bigen Africa was appointed as the consulting engineer. The duration of the project was estimated to be one year. Le Roux (2013) mentioned that 3 months were saved with the implementation of HCC when compared to the original design of in-situ concrete construction. The reservoir is 11 m high with a diameter of 78 m. The capital cost of the reservoir was R 55 million (Theunissen, 2012). The Longridge reservoir under construction can be seen in Figure 5.17.

Figure 5.17: 45Ml Longridge reservoir

Motivations for the use of HCC:

The municipality prioritized the construction of the 45Ml Longridge reservoir to meet the water demand in the area. The initial design of the project was done for the implementation of in-situ concrete construction. The construction schedule was tight and Ruwacon proposed an alternative. The alternative was to construct with the implementation of HCC. The primary motivation for the implementation of HCC was to enhance the pace of construction. The client accepted the request and the reservoir was constructed with the implementation of HCC.

One of the alternatives for the construction of the roof was a floating roof. This concept is based on the principle of lifting the roof by using water. The roof floats on top of the water while water is being pumped into the reservoir. The roof therefore lifts as the structure is being filled with water. This option was, however, turned down because of the increasing cost of water. The cost of water for this method was estimated to be in the vicinity of R 260 000. The proposal of a precast roof design was therefore accepted (Theunissen, 2012).

Design:

The design of the structure was done by Bigen Africa in collaboration with Corestruc. The walls were designed for the conventional method of in-situ concrete construction. The columns, beams and roof slabs were designed for the implementation of precast elements (Theunissen, 2012). These elements can be seen in Figure 5.18.

Figure 5.18: Precast columns, beams and slabs for the Longridge reservoir

Construction:

The construction of reservoirs is usually done by a standard construction sequence, starting with the construction of the walls, columns and then the roof. However, in the construction of the Longridge HCC reservoir, the columns and beams were first completed. After the completion of the columns and beams the roof was constructed. When the roof was 90 % completed, the floors were poured and the walls constructed (Theunissen, 2012).

The construction of the roof and various elements were subcontracted to Corestruc. Coreslab, a subsidiary of Corestruc, prefabricated the slabs, columns and beams in Polokwane, a distance of 720 km from the construction site. Coreslab transported the elements from Polokwane to the construction site in Bloemfontein. Le Roux (2013) mentioned that it was estimated to be financially more viable to use a roof subcontractor from Polokwane and transporting the elements when compared to local suppliers. It was, however, mentioned that only suppliers with good reputations were considered (Theunissen, 2012).

The columns were lowered and erected by a mobile crane onto the foundations and bolted into place. The beams and slabs then followed. The walls of the structure were constructed by the conventional method of in-situ concrete construction and were poured with two lifts in 20 m long sections and a height of 5.5 m. The walls were placed on rubber bearings that allow horizontal movement. These bearings were in turn placed on a reinforced concrete ring foundation, founded on rock (Theunissen, 2012).

Challenges:

1. There is only a small margin for error in placing the precast elements into their final positions. The connections and measurements of the various elements therefore need to be manufactured precisely and in tolerance to prevent rework.
2. Late adjustments and repair work are difficult to apply on precast elements that are out of tolerance. Accurate levelling was therefore essential during the start-up phases of construction.
3. The transportation of the elements increases the total cost of the project. Transport related risks are, however, carried by the subcontractor.
4. Precast elements are often required to be double handled. Special care is therefore required in handling and transporting the elements.
5. On of the main concerns of the HCC reservoir was the construction of the roof. After the roof had been completed it showed leakage at some locations. The project team are investigating the potential causes. This is a time consuming and costly procedure.

Lessons learned:

1. Constructing the HCC reservoir has shown to require less material when compared to the conventional method of in-situ concrete construction. Le Roux (2013) mentioned that the following quantities were reduced when compared to the original bill of quantities of the in-situ reservoir:
    - Formwork to columns and column heads
    - Formwork to beams and roofslab
    - Reinforcement to columns and column heads
    - Reinforcement to beams and roofslab
    - Concrete to columns and column heads
    - Concrete to beams and roofslab
    - Post tensioning to roofslab
2. Much less wastage is generated in the implementation of HCC when compared to the conventional method of in-situ concrete construction. It is however difficult to quantify and estimate the cost saved thereof.
3. Fewer labourers are required for the construction of a HCC reservoir. Corestruc used their own skilled labourers for the erection of the precast elements. Fewer labourers may result in potential cost savings.
4. Reservoir construction takes place at a more rapid pace in the implementation of HCC when compared to in-situ concrete construction. In this case, the construction duration was reduced by 3 months with the implementation of HCC
5. All elements are constructed in a controlled environment at ground level, enhancing the quality of the elements and also improving the safety on site. Less rework is therefore required in the implementation of HCC for reservoirs.
6. Weather conditions had little influence on the schedule of the project. With the use of in-situ concrete construction weather may have had a larger impact on the schedule of the project.
7. Time is gained by standardization and repetition in the erection phase of the columns, beams and roofslabs.

Case Study 3 Conclusion:

The implementation of HCC for the construction of reservoirs has shown to be successful on several projects (Botha, 2014). The success of the Longridge project was, however, troubled by leakages in the roof structure. The project team is investigating possible causes and solutions of the existing leakage in the roof structure. This challenge has added to the cost and schedule of the project and possible cost savings may have been reduced. There are, however, numerous factors that influence the time and cost in the decision between in-situ concrete construction and HCC for reservoir construction. The identified factors are displayed in Table 5.3. The table provides a short description of the factors for the implementation of HCC when compared to in-situ concrete construction. The factors are further discussed in Chapter 6.

Table 5.3: Identified time and cost factors for case study 3

Factor	Impact	HCC compared with in-situ concrete construction
Precast supplier	cost	Additional cost for precast supplier (transportation included)
Labourers	cost	Reduced labourers, therefore reduced labour cost
Concrete & reinforcement	cost	Reduced material (concrete & reinforcement) cost
Wastage	cost	Less waste generated, therefore reduced cost
Temporary works	time & cost	Fewer temporary works, therefore reduced time and cost
Precast moulds	time & cost	Reduced formwork for precast moulds, therefore reduced cost and reduced time required for mould setup
Material theft	cost risk	Less on-site material, therefore smaller risk of theft
Site preparations	time	More time required for precise preparations
Connections	time	Connections may be time consuming
Rework	time & cost	Reduced rework time and cost
Repetition	time & cost	Repetition may result in time and cost savings
Working at heights	time & cost	Transferring activities to ground, therefore reduced time & cost
Safety	time & cost	Safer method of construction, therefore reduced risk
External risks	time & cost	Less affected by weather conditions
Earlier site access	time	Earlier site access, therefore reduced construction schedule

5.4 Case Study 4: VWSA Paint Shop

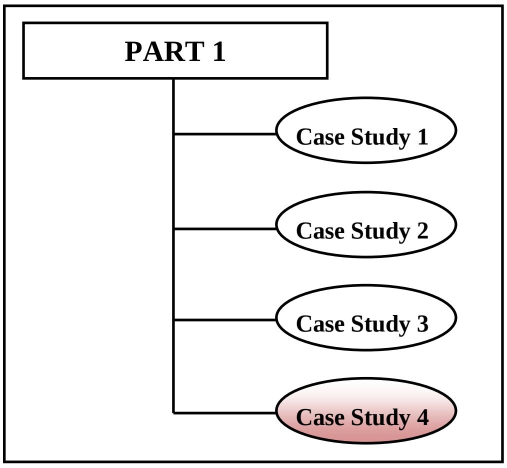

Figure 5.19: Chapter 5 outline – Case study 4

Overview:

In 2005, Volkswagen South Africa (VWSA), requested to upgrade the Uitenhage automotive paint shop. The capital cost of the project was R 750 million. The VWSA paint shop project consisted of the construction of an automotive paint shop with a service area of 45 000 m^2 that doubled the capacity of the original plant to paint 1200 vehicles per day. The paint shop was constructed through the use of HCC to complete the project in a tight schedule of just over one year (Jurgens, 2008). Figure 5.20 display the construction of the VWSA paint shop.

Figure 5.20: Construction of the VWSA Paint Shop (Jurgens, 2008)

Motivations for the use of HCC:

The German clients of the project are well familiar with constructing through the implementation of HCC. The client therefore requested the project to be constructed with HCC methods. The client used this method of construction for a similar project in Germany and had already completed the feasibility study before appointing the contractor. The main contractor evaluated the proposal of HCC. According to the contractor, the project cost for an in-situ structure might have been lower. The method of in-situ concrete construction would, however, make it impossible to meet the strict expected project deadline and the client therefore accepted the more expensive but faster construction method of HCC. The client mentioned that a faster return on investment is more valuable than the cost savings resulted from a longer construction duration (Jurgens, 2008).

Design:

The VWSA project was constructed as a design-build venture. Grinaker LTA was appointed as the main contractor where the design was handled by ARQ consulting engineers. A bill of quantities and a re-measurement clause were the principle aspects included in the tendering process. The design-build venture improved collaboration amongst the different parties and it is believed that the management of the project may have had complications if the design team and architect had been outsourced (Jurgens, 2008), (Sigma consulting, 2006).

The design of the structure included a precast frame that consisted of precast foundations and beams. The columns were cast in-situ and the composite slabs were designed with precast planks which were used as permanent formwork and topped with in-situ concrete to form the slab. The connections in the structure were designed as corbels and half-joints with rubber bearings (Sigma consulting, 2006), (Jurgens, 2008).

Construction:

Figure 5.21: Structural frame of VWSA paint shop (Jurgens, 2008)

The columns of the paint shop were constructed with the use of in-situ concrete. Jurgens (2008) mentioned that during his site visit to the paint shop the project team has claimed that multi-storey continuous precast columns may have been more beneficial in terms of the schedule of the project. Nonetheless, the columns were constructed with in-situ concrete construction. The foundations, slabs and beams were constructed with precast elements and some of the beams and slabs can be seen in Figure 5.21. The composite slabs were constructed with precast planks as permanent formwork for the structured in-situ concrete topping (Jurgens, 2008).

The largest element had a mass of up to 35 ton and measured 26 m in length. Some of these elements had to be placed at a height of 18 m above ground level. The placing and handling of these heavy elements were challenging at these heights (Jurgens, 2008). The contractor did not have much experience in the method of HCC. This made the construction process even more challenging. The elements were mostly post-tensioned and were cast with a concrete strength of 35 MPa. The elements were handled and placed by using 2 tower cranes and two mobile cranes, located at each corner of the construction site (Jurgens, 2008).

Grinaker LTA constructed a temporary precast yard on site. All the precast elements were manufactured in the yard from where it was lifted and placed by crane. Although constructing the yard may have been time consuming and costly, time was saved due to more rapid construction (Jurgens, 2008). The on-site precast yard also avoided the elements from being double handled and transported over long distances. Although the on-site precast yard can not be seen in the light of a controlled environment, as a precast factory, the quality thereof can be controlled more effectively when compared to in-situ concrete construction taking place at heights (Jurgens, 2008).

Challenges:

1. The design had not been completely finalized by the time construction commenced. Over 400 different precast beam compositions were required due to late design adjustments. This complicated the operation at the precast yard and had a significant impact on the construction schedule and material cost. If better care had been taken during the design phase of the project, standardization could have eased the precast operation and the project schedule would have benefited.
2. Communication and collaboration between the designers and contractors were not effective. This lack of communication and collaboration led to confusion and unnecessary rework that could have been prevented.
3. The contractor had to train labourers some necessary skills for the project. For this project shutter workers were trained as riggers. This was a timely process and added to the overall cost of the project.
4. At the start of the project, crane operators were only comfortable with lifting concrete buckets and transporting the necessary materials. They had insufficient experience in high precision work with the crane and it took them some time to gain experience and confidence in placing the elements with speed and accuracy (Jurgens, 2008).

5. Construction problems occurred due to overstressed pre-stressed precast beams. These beams caused formation of discontinues joints where the slabs in the different directions connected. This required rework and adjustments in some instances (Jurgens, 2008).
6. The establishment of the precast yard added to the construction schedule and budget. The HCC method, nevertheless, reduced the overall construction period of the VWSA paint shop.

Lessons learned:

1. The logistics and location of the precast yard, which was on site, reduced a great amount of risks related to the schedule, especially in terms of transportation. The elements were not double handled as mentioned in the previous case studies.
2. Another principle benefit of the precast yard is that the concrete was cast at ground level. This generated benefits, such as:
    - *Safety*. Working at heights with in-situ concrete construction is a risk for labourers and contractors. Working at ground level reduces the risk of accidents. The heavy precast elements in the air was, however, a new method of construction for many of the labourers and was therefore a risk by itself.
    - *Fewer temporary works required*. As mentioned in the construction section of this case study, the concrete slabs were constructed as composite slabs, whilst the precast elements served as permanent formwork. In addition to this, less scaffolding, formwork and temporary supports structures were required to support the structure during the casting phase. Less temporary works were therefore required.
    - *Rapid construction*. HCC takes place at a more rapid pace when compared to in-situ concrete construction. As mentioned, there is much less temporary works required for the implementation of HCC. The erection of formwork, placing of reinforcement and pouring of concrete are done at ground level, which was more convenient than constructing at heights in awkward positions.
    - *Quality*. Better quality control can be performed at ground level when compared to working at heights.
3. Although 400 different precast element compositions were manufactured, possible cost savings were generated through material savings. These materials include scaffolding, formwork, reinforcement and concrete.
4. Time was gained by repetition in the precast yard and during the erection phase. More time savings could have been possible if standardized designs were promoted.
5. Due to less on site material, less wastage was generated. The transportation and disposal of wastage in construction projects add time and cost to the project. Less wastage therefore contributes to potential time and cost savings.

6. The weather had an influence on the precast yard, where the yard was exposed to open air. Tower cranes are also easily affected by the wind; therefore time was lost during unpleasant weather conditions.

Case Study 4 Conclusion:

The VWSA paint shop was constructed on schedule at a rapid pace. The client requested for HCC primarily for the reason of early completion. Although the project cost was higher when compared to the conventional method of in-situ construction, the client argued that the return on investment is more valuable than the capital cost, and that this return will generate sufficient income. It proved to be the more economical option when compared to the lower cost, but longer method of in-situ concrete construction. More cost savings could, however, been generated during the design phase of the project by the implementation of standardization. As mentioned, more than 400 different precast compositions were manufactured. Another challenge during this project was the number of late changes and adjustments to the design during the construction phase of the project. Therefore, considerable amount of cost and time can be saved during the design phase of a project when accurate and quality planning is conducted. The factors that may have an influence on the time and cost for a decision between in-situ concrete construction and HCC for case study 4 are identified in Table 5.4. The table provides a short description of the factors for the implementation of HCC when compared to in-situ concrete construction. The factors are further discussed in Chapter 6.

Table 5.4: Identified time and cost factors for Case study 4

Factor	**Impact**	**HCC compared with in-situ concrete construction**
Precast yard erection	time & cost	Additional time and cost for precast yard erection
Labourers	cost	Reduced labourers, therefore reduced labour cost
Skill development	time & cost	Additional time and possible cost for skill development
Precast yard disposal	time	Additional time required for the disposal of precast yard
Wastage	cost	Less waste generated, therefore reduced cost
Temporary works	time & cost	Fewer temporary works, therefore reduced cost
Precast moulds	time & cost	Reduced formwork for precast moulds, therefore reduced cost and reduced time required for mould setup
Material theft	cost risk	Less on-site material, therefore smaller risk of theft
Cranes	cost	Shorter duration, therefore possible reduced cost
Handling devices	cost	Additional manufacturing cost
Connections	time	Connections may be time consuming
Rework	time & cost	Reduced rework time and cost
Repetition	time & cost	Repetition may generate time and cost savings
Working at heights	time & cost	Transferring activities to ground, therefore reduced time & cost
Safety	time & cost	Safer method of construction, therefore reduced risk
External risks	time & cost	Affected by weather conditions, may require additional cost
Earlier site access	time	Earlier site access, therefore reduced construction schedule
Return on investment	cost	Earlier return on investment, increased income

5.5 Chapter conclusions

This section summarises the identified factors from the various case studies and presents the concluding remarks of this chapter.

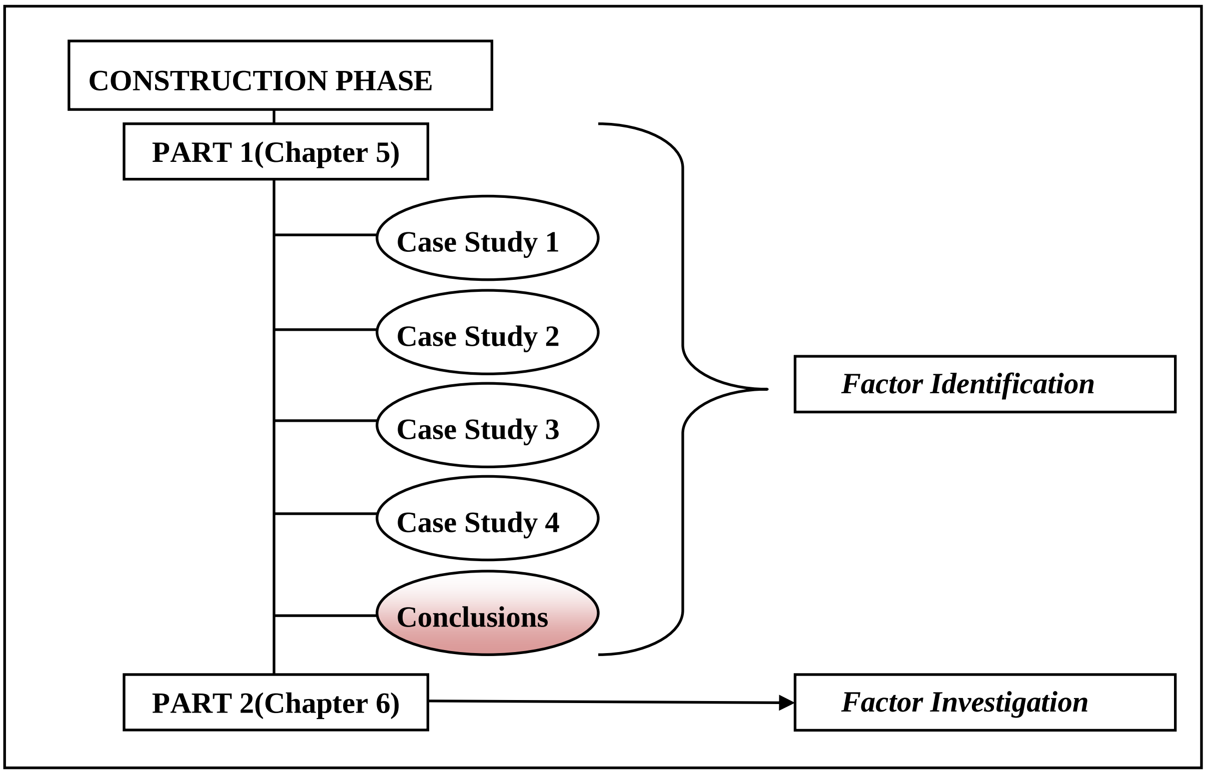

Figure 5.22: Chapter outline - conclusions

It is evident that the implementation of HCC has the potential to allow for faster construction, under certain conditions, when compared to the conventional method of in-situ concrete construction. The case studies have shown that the implementation of HCC has potential time and cost savings in the construction industry in South Africa. There are, however, certain cases where HCC will not be the most viable method for construction. The main objective of this chapter is to identify the time and cost related factors during the construction phase that need to be considered for a decision between HCC and in-situ concrete construction.

The case studies were investigated to identify these factors. The factors are categorized as logistics, materials, equipment and construction. The outcome of these factors will vary for different projects. For example, when the precast yard is not under a roof, weather conditions will still impact the project, whereas if the yard is under a roof, weather will not impact the manufacturing of the precast elements. Therefore, it is suggested that these factors be evaluated for each project to assess which method of in-situ concrete construction or HCC would be economically more viable. The time and cost factors are summarized in Table 5.5 and are further discussed in Chapter 6.

Table 5.5: Identified construction time and cost factors for a decision

Category	Factor	Possible impact on
Logistics	Precast supplier	cost
	Precast yard erection	time & cost
	Lifting devices	cost
	Property	cost
	Transportation	cost
	Labourers & skill development	cost
	Precast yard disposal	time
Material	Concrete and reinforcement	cost
	Wastage generated	cost
	Disposal of wastage	time
	Temporary works and scaffolding	time & cost
	Precast moulds	time & cost
	Theft	cost
Equipment	Cranes	cost
	Handling devices	cost
	Plant	cost
	Theft	cost
Construction	Site preparations	time
	Connections	time & cost
	Rework	time & cost
	Repetition	time & cost
	Working at heights	time & cost
	Safety	time & cost
	External risks	time & cost
	Earlier site access	time
	Return on investment	coat

Chapter 6

Construction phase: Discussion

In Chapter 5, the various time and cost factors that play a role in the decision for HCC were identified from four case studies. This chapter provides a discussion to assist project teams to gain a better understanding of these time and cost factors. The identified factors have been categorized into four categories, namely, logistics, material, equipment and construction. The objective of this chapter is to gain knowledge of the time and cost factors that play a role in the construction phase for a decision between in-situ concrete construction and HCC. Figure 6.1 provides the chapter outline that includes the various identified factors. These factors are shown in each section to assist the reader throughout the chapter.

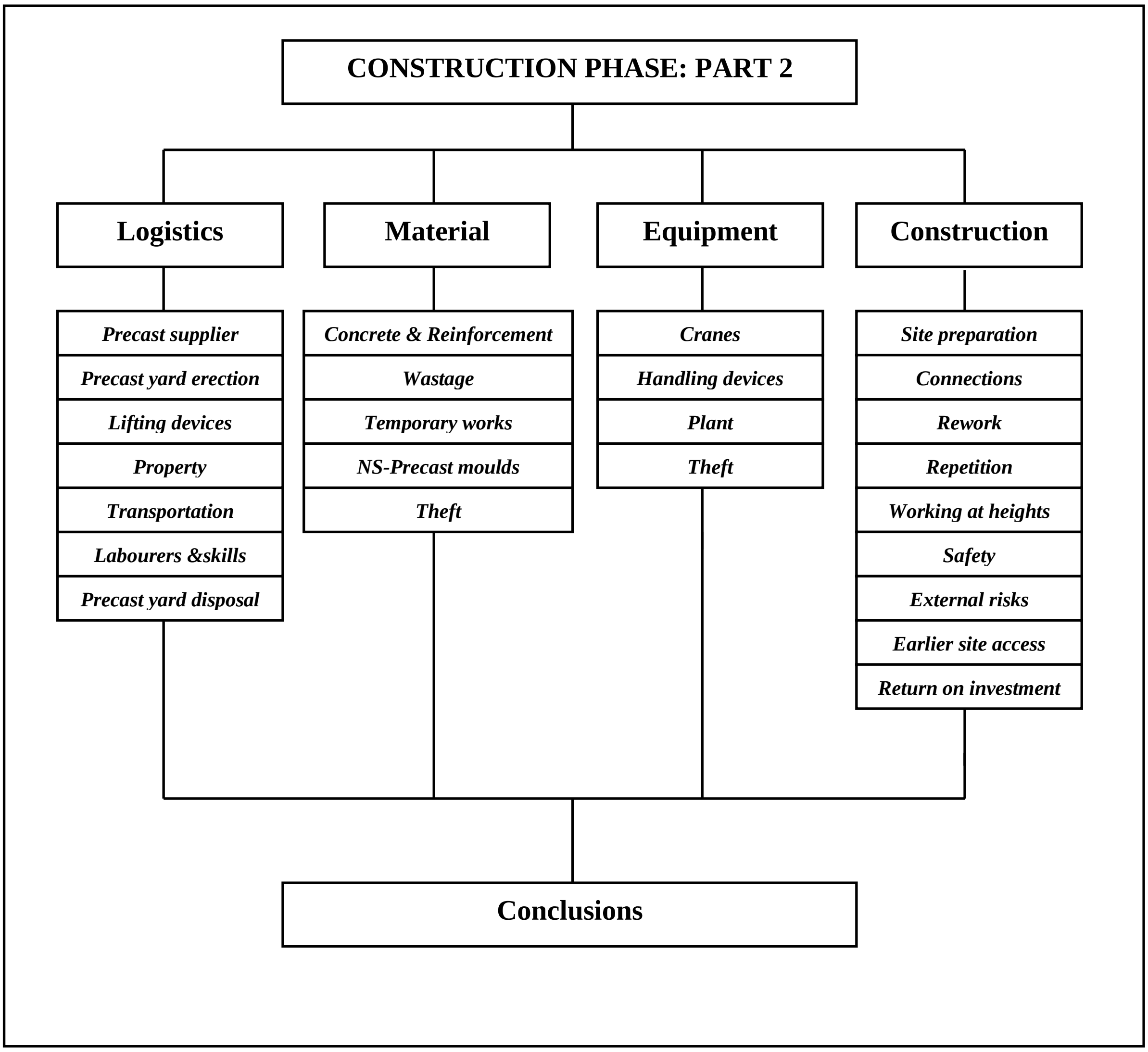

Figure 6.1: Chapter 6 outline and identified time and cost factors (construction phase)

NS-Precast moulds = non-standard precast moulds

6.1 Logistics

This section discusses the time and cost factors categorized under the logistics section of the construction phase. Logistics can be defined as the planning, management and processing of systems and methods (Chow, Heaver & Henriksson, 1994). It is often referred to as getting things done. The logistics for the construction phase, therefore, include the planning and management of certain aspects during the construction phase. The factors discussed in terms of logistics for a decision between in-situ concrete construction and HCC can be seen in Figure 6.2.

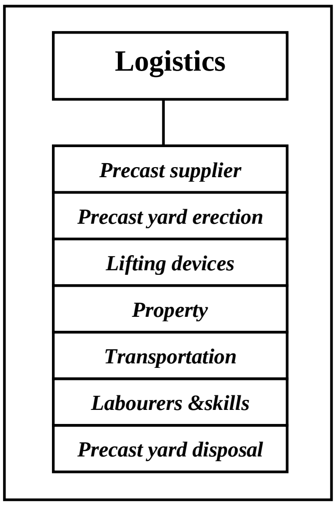

Figure 6.2: Logistical time and cost factors

6.1.1 Precast supplier

One of the first decisions to make in the implementation of HCC, is the decision between appointing a precast supplier (specialist subcontractor), and the contractor taking own responsibility by manufacturing the precast elements. In the case studies presented in Chapter 5, both these methods were implemented. For the Value logistics dispatch plant (Case study 2) and the Longridge reservoir (Case study 3), Tilt Up Systems and Corestruc were appointed accordingly as specialist subcontractors and were responsible for the manufacturing of the precast elements. However, for the Shondoni coal bunker (Case study 1) and the VWSA paint shop (Case study 4), a precast yard was erected, where the contractor took own responsibility for the manufacturing of the precast elements. Both methods have resulted in time and cost benefits.

This section addresses the cost and time implications and possible benefits in appointing a precast supplier as specialist subcontractor, such as in the cases of the Longridge reservoir (Case study 3) and the Value logistics dispatch plant (Case study 2). The following section (Section 6.1.2), provides a discussion on the associated implications and benefits of erecting a precast yard and taking own responsibility.

The principle benefit of appointing a specialist subcontractor is that the tendered price of the specialist subcontractor usually includes the manufacturing of elements, the delivery (transportation costs) of elements, the erection of elements and potentially the design of elements (Corestruc, 2013),(ECHO, 2014),(Tilt Up Systems, 2014). Precast suppliers are also familiar and experienced in designing and constructing precast elements. Clients therefore occasionally request a precast supplier as a specialist subcontractor (Botha, 2014). The main consultant is, however, still responsible for the detail design and should confirm that the design of the specialist subcontractor satisfies the project specifications (Botha, 2014). Nevertheless, the included factors in the tendered price and the reduced risk of a lack of experience in appointing a specialist subcontractor may be beneficial to the client.

Appointing precast concrete suppliers to complete the associated precast works are, however, not always the most economical option. Since the use of precast is expanding in a competing South African market, it is evident that market demand will play a role in the estimation of product prices (Goodchild & Glass, 2004). Lombard (2011) also confirmed this by mentioning that precast rates are often unstable and may fluctuate due to the market conditions in South Africa. Many consultants in the industry prefer to avoid precast suppliers as they argue that they often over price their products (Fliss, 2013), (Pretorius, 2013), (De Lange, 2014).

Lombard (2011) performed a cost evaluation for floor systems in South Africa. In the evaluation, costs of normally reinforced and post tensioned in-situ concrete slabs were compared with hollowcore and rib-and-block precast slabs. It was concluded that rib-and-block floors are between 8 % and 30 % more expensive than the in-situ concrete floor with the lowest cost. Hollowcore floors were even more expensive, being between 22 % and 32 % more expensive than the in-situ concrete floor with the lowest cost. Although, concrete and reinforcement volumes were less for the precast options, the precast options were more expensive due to the rates of the manufacturers. This evaluation confirmed that the use of precast suppliers may often result in more expensive projects (Lombard, 2011).

The availability of precast suppliers is another concern in the construction industry. Although precast suppliers have increased in number during the last decade in South Africa, some parts of the country are still lacking the availability of precast suppliers, such as Limpopo and the Northen Cape province. The shortage of precast suppliers also affects the price of precast elements. For the Longridge reservoir (Case study 3), precast elements were transported from Polokwane to Bloemfontein. The elements were therefore transported over a distance of 720 kilometres. The reason for this was that the price of Corestruc in Polokwane was economically more viable compared to local and closer precast manufacturers (Theunissen, 2012). The project team of Ruwacon, however, mentioned that only experienced precast suppliers with a good reputation were considered (Le Roux, 2013). This example illustrates that a shortage of precast suppliers may have an affect on the price of the product. A list of some precast suppliers in the various provinces in the construction industry in South Africa can be found in Appendix D. This list shows that there are regions in South Africa that are currently still experiencing a shortage of precast suppliers.

Although it is evident that a precast supplier may save project time during the design and construction phases, the associated costs are often higher (Bargstädt, 2013). Project teams should therefore take care in deciding whether it would be economically viable to appoint a precast supplier for the design and manufacturing of the precast elements. Table 6.1 presents the benefits and barriers in appointing a precast supplier as a specialist subcontractor for a project.

Table 6.1: Potential benefits and barriers of a specialist subcontractor

Benefits	• Experienced design and construction of precast elements
	• Required plant and cranes may be provided by specialist subcontractor
	• Total tentered price include various cost aspects, such as:
	  ○ Labour cost
	  ○ Material cost (concrete, reinforcement and temporary works)
	  ○ Transportation cost
	  ○ Design cost
	  ○ Construction cost
	• Reduced risk of implementation

Barriers	• Often over priced • Shortage of availability

6.1.2 Precast yard erection

This section provides a discussion on the time required and associated costs to construct a precast yard. Most of the case studies presented in Chapter 5 included the erection of a precast yard that was either on, or near the construction site. The required time and associated costs can be considered for three different options.

The first option is a basic open air precast yard, constructed using concrete blindings and associated formwork, such as the precast yard that was erected for the Value logistics dispatch plant (Case study 2). During the construction of the dispatch plant only walls and columns with similar dimensions have been manufactured. The variety of precast elements for this option is small. The erection of such a precast yard requires minimum time, in terms of planning and erection, with low associated costs (Bergh, 2014).

The second option is similar to the first option, but requires more time to plan and erect with higher associated costs. This option can be described as a precast yard constructed in open air, either on or near the construction site, where a larger variety of precast elements are manufactured when compared to an option one precast yard. Additional time is required for designing the yard, so as to ensure that all required elements can be manufactured and handled in the yard. The Shondoni coal bunker (Case study 1) and the WVSA paint shop (Case study 4), are examples of an option two precast yard (Vermeulen, 2013).

The first two options are often used in the construction industry in South Africa (Chapter 5, case studies). The third option is where a precast factory is installed, and where a large variety of precast elements can be manufactured under a roof, in a controlled environment. This option has been used for the Gautrain project, and for projects in Europe, however, is not popular in the construction industry in South Africa. The Gautrain project is the only project in South Africa where the precast yard can be categorized under the third option of a precast factory. The Gautrain project consisted of the biggest precast plant in Africa (Beer, 2009). Precast factories require a great amount of time and cost to design and erect (Vollert, Brandt and Kaspar, 2012).

In the case where elements are required to be manufactured in a controlled environment, such as an option 3 precast yard, specialist subcontractors are rather appointed. It is not often viable to erect a precast factory for one single project. Project teams should investigate the scale and variety of precast elements required for a given project in order to estimate the required time and cost associated in erecting a precast yard. The options discussed are summarized in the Table 6.2.

Table 6.2: Different precast yards

Precast yard construction	
Option 1	Basic open air precast yard, manufacturing a small variety of precast elements. Not much time and cost required for the planning and erection of the yard.
Option 2	Basic open air precast yard, adequate to manufacture a large variety of precast elements. More time consuming and higher cost required for the erection than for an option 1 precast yard.
Option 3	Option 3 yard requires the installation of a precast factory (controlled environment). Expensive to construct and requires much time for the design and construction of this precast factory.

6.1.3 Lifting devices

Lifting devices include the additional cost required to hire or invest in a gantry crane or associated equipment for the handling of precast elements on the precast yard. The Shondoni coal bunker project (Case study 1) made use of a Gantry crane for the handling of precast elements on the precast yard. For the Value logistics dispatch plant (Case study 2), mobile cranes were used and for the VWSA paint shop (Case study 4), tower cranes were used to handle the elements. Therefore, the type of lifting device that is required may vary for each project. Project teams should consider the type of lifting device and the associated costs required when HCC is considered as an alternative for a project.

6.1.4 Property

The first and most feasible option in terms of location is to erect the precast yard on the construction site. When the yard is located on the construction site, it is not necessary to transport the elements, and there are no property rental costs required. The precast yard was erected on the construction site for the VWSA paint shop (Case study 4). Potential renting costs were therefore avoided.

For the Shondoni coal bunker (Case Study 1), the yard was located a distance of 15 km from the construction site. For this project, Stefanutti Stocks purchased a precast yard previously owned and used by Murray and Roberts for a similar project in the region. In the feasibility study, Stefanutti Stocks estimated that an existing precast plant near Secunda could be an investment for the company and that the precast yard could be used for other projects in the future. Stefanutti Stocks therefore invested in the precast yard (Vermeulen, 2013).

Property renting costs may have added to the Shondoni coal bunker project cost if the contractor didn't invest in the precast yard. The location and possible renting costs should be assessed and considered in estimating the project budget when HCC is considered as an alternative for a project.

6.1.5 Transportation

The innovative ideas and development of specialized precast elements as designed by consultants have made the transportation of these elements a challenge (Gibb & Isack, 2001a). The design of precast structures is often limited by the ability to transport large precast elements. It is therefore necessary to evaluate the transportation of precast elements during the preliminary stages of a project (De Klerk, 2013).

Although it is possible to transport precast elements by rail, most precast elements are transported by road in the construction industry in South Africa. The allowable specified mass and dimensions specified by the national highway agency limits the size of precast elements. The evaluation of transportation for precast elements therefore needs to include the consideration of respective masses and sizes of various precast elements. The limitation of the size of precast elements in turn limits the design of the consultant. Consultants need to evaluate the possibility of transporting the designed elements, and whether the solution is economically viable (Arditi, Ergin & Günhan, 2000), (Gibb & Isack, 2001a).

De Klerk (2013) mentioned that the transportation costs of precast elements are calculated by the factors of size, weight, transportation method and distance travelled. The transportation costs of precast elements are usually directly proportional to the distance transported to the construction site (Arditi, Ergin & Günhan, 2000). De Klerk (2013) also mentioned that 200 kilometres of travelling distance are the average where transportation remains a feasible option. The Longridge reservoir (Case

Study 3), however, contradicts De Klerk's (2013) statement. Precast elements for the Longridge reservoir were transported from Polokwane to Bloemfontein, a distance of over 700 kilometres, and were proven to be economically viable. It is therefore suggested that the transportation of precast elements should be further investigated in future studies.

The time required for transporting elements is also included in the construction schedule. Transportation of precast elements is an important factor that may have an influence on the time and cost, and needs to be considered during the early stages of construction projects.

The factors that may have an influence on the transportation cost of precast elements include the following:

- transportation method (rail or road)
- size of precast elements
- mass of precast elements, and
- distance transported

It is suggested that the field of transportation of precast concrete elements in South Africa be further investigated in future research studies.

6.1.6 Labourers & skills

During all the case studies presented in Chapter 5, the respective project teams mentioned that much less labour and skills were required for the use of HCC when compared to in-situ concrete construction. Chan (2013) estimated that approximately 4 times less labourers are required for the implementation of HCC when compared to the conventional method of in-situ concrete construction. The reason for this is that much less activities take place during the implementation of HCC. For HCC, only a crane operator and a few labourers are required to install the various elements, whereas for in-situ concrete construction, three sperate teams are required. These teams include the shutter workers, steel fixers and concrete workers, which may consist of many labourers (Le Roux, 2013).

Another factor that reduces the labour cost for HCC is that the construction schedule of a project is usually shorter when compared to in-situ concrete construction (Gibb & Isack, 2001a). A shorter construction schedule in turn reduces the labour cost (Elbeltagi, 2010). On site labour and labour cost are therefore reduced for the implementation of HCC when compared with in-situ concrete construction (Bergh, 2014), (Vermeulen, 2013), (Le Roux, 2013).

On the other hand, Botha (2014) has mentioned that there is a shortage of skilled labour for the implementation of in-situ concrete construction in South Africa. Training labourers to gain sufficient skills are both expensive and time consuming.

The cost benefit that HCC has to offer in terms of fewer on site labourers is, however, not always the best solution in the construction industry in South Africa. Reduced on site labour is a major concern in South Africa, as the country experience a high unemployment rate of 24 % (Lombard, 2011). In addition to the high unemployment rate, there is the shortage of skilled labour (De Klerk, 2013). One of the principle objectives of the Department of Labour is therefore to contribute to employment creation and skill development. South African industries attempt to apply construction methods that are labour intensive, especially in the public sector (Lombard, 2011). This is, however, not always possible as most projects are required to be constructed in a tight budget (Bergh, 2014), (Le Roux, 2013).

In terms of skills development for the implementation of HCC, additional time and costs may be required. It was mentioned in the case of the VWSA paint shop (Case study 4) that the crane operator took some time to gain confidence and experience in erecting the precast elements with precision. Additional training time may therefore be required in the construction of precast elements (Hanekom, 2011), (Lombard, 2011). In-situ concrete construction, however, requires more skill, and skills development will be more important when compared to HCC (Botha, 2014), (Pretorius, 2013). Sufficient information is not available on the cost of labour and skills development for in-situ concrete construction and HCC. Future research in this field is therefore suggested.

It is evident that the implementation of HCC will result in potential cost saving in terms of fewer labourers required. This factor should be considered when deciding between in-situ concrete construction and HCC. The following aspects should be considered in the estimation of labour cost:

- number of labourers
- duration of working period (days, weeks, months, etc.), and
- additional skills development cost

6.1.7 Precast yard disposal

Precast yard disposal may require additional time and cost for the disposal of the precast yard. In some cases, such as the case of the VWSA paint shop (Case study 4), the precast yard was located on the construction site. The disposal of the precast yard is therefore included in the construction schedule. The additional time and cost that contributes to the disposal of a precast yard should be considered when HCC is considered as an alternative for a project.

6.1.8 Logistics conclusion

In this section the various logistical factors that may have an influence on the time and cost for a decision between in-situ concrete construction and HCC during the construction were discussed. Table 6.3 presents the logistical factors and the impact thereof on in-situ concrete construction and HCC.

Table 6.3: Logistical factors for a decision between in-situ concrete construction and HCC

Factors	In-situ concrete construction	HCC
Precast supplier	Not applicable	Additional cost
Precast yard erection	Not applicable	Additional time and cost
Lifting devices (Precast yard)	Not applicable	Additional cost
Property	Not applicable	Additional cost
Transportation	Not applicable	Additional time and cost
Labourers and skills development	More time and cost required	Reduced time and cost
Precast yard disposal	Not applicable	Additional time and cost

6.2 Material

This section discusses the time and cost factors categorized under the material category during the construction phase that need to be considered for a decision between in-situ concrete construction and HCC. The first factor in the material category includes a discussion on the required concrete and reinforcement for in-situ concrete construction and HCC. The following factors include discussions on the waste generated, temporary works required, non-standard precast moulds required, and the risk of theft for in-situ concrete construction and HCC. The identified factors under the material category are presented in Figure 6.3.

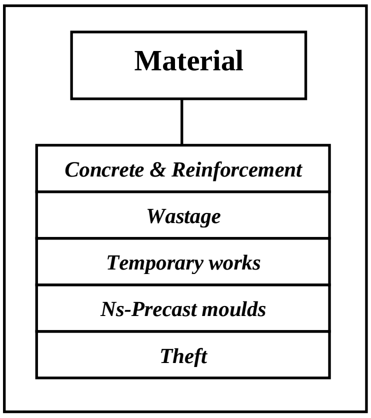

Figure 6.3: Material time and cost factors
Ns = Non standard

6.2.1 Concrete & Reinforcement

During the case studies presented in Chapter 5 it was mentioned that a large quantity of materials, especially in terms of concrete and reinforcement, can be saved with the use of HCC. In the case of the Shondoni coal bunker (Case study 1), it was mentioned that approximately 30 % less concrete and reinforcement were required for the construction of the 15 000 ton HCC Shondoni coal bunker when compared to the 15 000 ton in-situ Twistdraai coal bunker (Stefanutti Stocks, 2014). Le Roux (2013) also mentioned that much less concrete and reinforcement were required for the HCC reservoir when compared to a conventional in-situ reservoir. This section provides a discussion on the required concrete volumes for in-situ concrete construction and HCC.

Alfred Yee (2001) investigated potential savings of concrete and reinforcement that prestressed precast concrete has to offer. In his investigation he concluded that a composite slab (HCC), consisting of a prestressed precast slab topped with in-situ concrete, has the potential to produce material savings when compared to a conventional in-situ concrete slab. The results of his investigation on slabs are presented in Figure 6.4. Yee (2001) further investigated structural beam elements where he concluded that a prestressed precast concrete beam with a composite in-situ slab can result in maximized strength and minimized material quantity requirements, resulting in structural efficiency and economy. This method of beam construction has the ability to offer material savings when compared to the conventional method of in-situ concrete construction (Yee, 2001). The results obtained by Yee are shown in Figure 6.4.

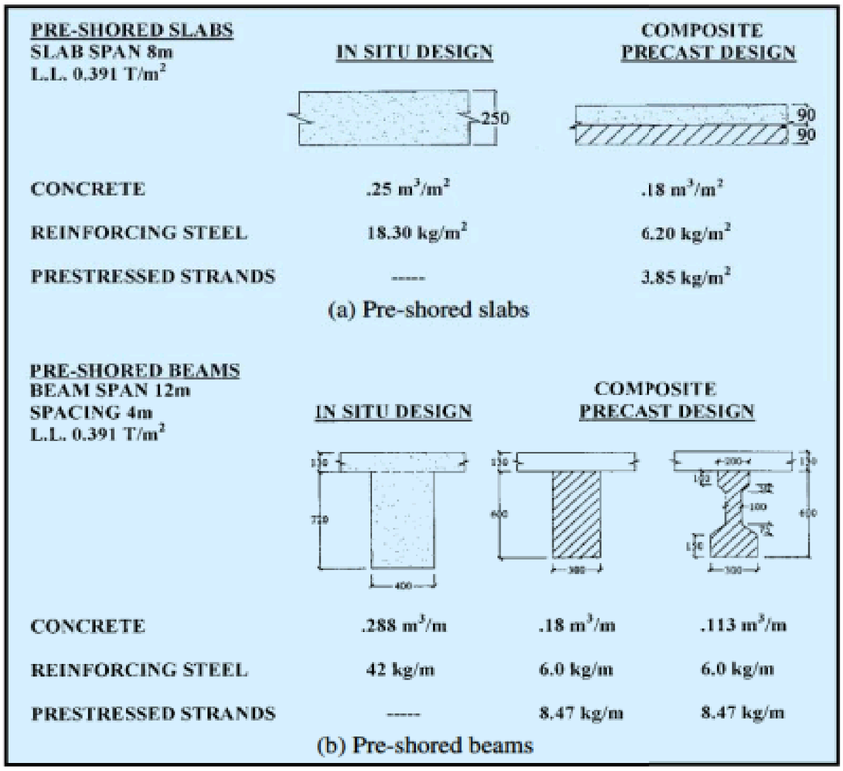

Figure 6.4: Material savings using HCC beams (Yee, 2001)

It can be seen that much volume of concrete and mass of reinforcement can be saved with the implementation of HCC. Yee went further to confirm his statement by investigating the Dalian Xiwang Building in Dalian City, China. This building is located in a high seismic zone. A HCC solution did not only save material but also resulted in lower building dead weight and subsequently lower shear forces due to seismic loads. It was estimated that 40 % concrete and 50 % reinforcement were saved with the method of HCC beams when compared to conventional in-situ concrete beams (Yee, 2001).

Lombard (2011) also estimated possible concrete and reinforcement savings for the construction of floor slabs. Lombard compared material required for a conventional reinforced in-situ floor slab with hollow core precast slabs. She estimated that hollow core slabs can save up to 35 % in concrete material. In addition to concrete savings, Lombard estimated that between 35 % and 60 % more reinforcement is required for the conventional method of in-situ concrete construction when compared to hollow core precast slabs (Lombard, 2011).

These material savings can potentially result in cost savings when the contractor takes ownership in the manufacturing of the precast elements. As mentioned in section 6.1.1, precast suppliers often over price their products (Fliss, 2013). Therefore, in order to benefit from cost savings due to reduced concrete and reinforcement, contractors might be required to take self ownership in manufacturing precast elements (Fliss, 2013), (Botha, 2014).

It is evident that the use of HCC may result in material savings and subsequently cost savings (Goodchild & Glass, 2004), (Jaillon, Poon & Chiang, 2009). There are, however, other factors that also play a roll in the estimation of concrete cost, such as the price associated with the strength of concrete. Precast concrete is often manufactured of high-strength concrete (concrete with a compressive strength greater than 40 MPa), which is more expensive when compared to normal strength concrete (De Lange, 2014).

Project teams should consider all the discussed aspects in estimating the quantities of concrete and reinforcement required for a project to determine the potential cost savings when deciding between in-situ concrete construction and HCC.

6.2.2 Wastage

During the construction of the Longridge reservoir (Case study 3), the project team mentioned that one of the principal benefits of using precast concrete for reservoir construction is the amount of reduced wastage (Le Roux, 2013). Construction wastage was also shown to be reduced during the other case studies presented in Chapter 5. This section discusses the factor of material wastage on construction sites for the use of in-situ concrete construction and HCC.

Jallion *et al* (2009) investigated waste management by quantifying the waste reduction potential in the construction industry of Hong Kong. In the investigation, Jallion *et al* (2009) identified various factors that are considered to be the most waste producing components. These factors include formwork, packaging and protection, finishing work, masonry work, scaffolding, concrete work, material handling and hoarding. The choice of construction method (eg. HCC or in-situ concrete construction) may have an impact on these factors. The choice of construction method may consequently reduce or increase material wastage (Poon, Yu & Jaillon, 2004), (Jaillon *et al* ,2009).

During the quantitative analysis performed by Jallion *et al* (2009), the results indicated that temporary works generate the highest amount of wastage on construction sites. It was estimated that formwork was the main contributor to waste generation and accounted for 30 % of the identified factors. Concrete was considered as the second highest contributor, accounting for 20 % of the total construction wastage. Another contribution to the generation of waste that was not mentioned by Jallion *et al* (2009) is design changes, as discussed in Chapter 4 (Baldwin, Poon, Shen, Austin & Wong, 2009), (Poon et al, 2004).

Jallion *et al* (2009) concluded that the reduction of waste on construction sites could be one of the major drivers for the selection of HCC. It was estimated that an average of 57 % less waste is generated and a reduction of 70 % formwork can be achieved with the implementation of HCC (Jaillon et al, 2009), (Baldwin et al, 2009).

Therefore, waste reduction may result in potential cost savings, especially in the reduction of temporary works and concrete. Less time is also required for the disposal of wastage. The factors that contribute to reduced construction wastage for the implementation of HCC include (Le Roux, 2013):

- less on site temporary works (scaffolding, formwork, support structures, est.)
- less on site material (reinforcement and concrete), and
- manufacturing takes place in a controlled environment, where less wastage is generated.

6.2.3 Temporary works

The respective project teams, of the case studies presented in Chapter 5, mentioned that the use of HCC can potentially reduce the amount of temporary works (Le Roux, 2013), (Vermeulen, 2013), (Bergh, 2014). Temporary works include formwork, falsework, scaffold or other temporary structures, designed to provide support or access during construction (Burgess, 2013), (Guo, 2002). The potential cost and time savings generated from reduced temporary works, through the use of HCC, are discussed in this section.

Jallion *et al.* (2009) mentioned that up to 70 % of formwork and scaffolding can be saved when HCC is used over in-situ concrete construction (Sultan, 2009). The principal reason for this is that precast moulds are used for an optimum amount of usages. In composite structures, the precast elements are often used as permanent formwork, therefore, also reducing the quantity of required formwork, scaffolding and temporary support structures. Reduced temporary works in turn lead to reduced construction costs (Sultan, 2009), (Vermeulen, 2013).

In addition to potential cost savings, there is also the reduction of construction time. For in-situ concrete construction, formwork and scaffolding need to remain in place until concrete has reached sufficient strength (Burgess, 2013). Table 2 in the SANS 2001-CC1 code provides the time required before formwork can be removed for various structural applications, such as walls, beams, slabs and support structures. Burgess (2013), summarized the information of Table 2 (SANS 2001-CC1), which is presented in Table 6.3. This additional waiting period adds to the construction schedule for the method of in-situ concrete construction. The implementation of HCC can therefore potentially reduce the construction time due to a smaller amount of temporary works that are required to be erected and removed, especially for the construction of multi-storey precast buildings (Burgess, 2013), (Goodchild & Glass, 2004).

Table 6.4: Required days before formwork can be removed (Burgess, 2013)

Structural application	Required days before formwork can be removed
Wall formwork	0.5 – 4 days
Slab formwork	2 – 10 days
Beam formwork	3 – 17 days
Support work	5 – 17 days plus (after concrete has achieved sufficient strength)

During the Value logistics dispatch plant (Case study 2); one mould was used to manufacture five wall panels at a time. This method reduced the construction duration and material costs by preventing the formwork to be placed and removed separately for the manufacturing of all five wall panels. This was done for up to 80 wall panels, therefore saving a great amount of construction time and cost (Bergh, 2014).

The required formwork is project dependent, and the reduction percentage thereof will be different for each situation. However, project teams should consider the amount of potential cost and time savings due to the reduction of temporary works in the decision between in-situ concrete construction and HCC.

6.2.4 Non-standard precast moulds

The beam elements for the side walls of the Shondoni coal bunker (Case study 1), were unique and standard precast moulds were not available. Non-standard precast beam moulds had to be designed and manufactured. The design and manufacturing of these moulds require time and need to be completed during the early stages of a project. Vermeulen (2013) mentioned that the manufacturing of non-standard moulds may be expensive, especially in the case where variability of elements is prominent.

It is suggested that designers should attempt to use precast moulds with standard sizes and dimensions. However, in cases where it is not possible, such as in the case of the Shondoni coal bunker, the required time and cost to manufacture these non-standard moulds need to be considered when HCC is considered as an alternative for a project.

6.2.5 Theft

Theft and vandalism on construction sites can directly impact the success on construction projects and reduce potential profitability (Farinloye et al., 2013). It is indicated by Statistics South Africa (2014) that South Africa is amongst the top twenty countries in the world with the highest crime rate.

The use of HCC reduces the amount of on-site material when compared to the conventional method of in-situ concrete construction (Le Roux, 2013), (Bergh, 2014). Due to less on site material, the risk of material theft is reduced. Bergh (2014), mentioned that the risk associated with material theft was reduced for the Value logistics dispatch plant (Case study 2), due to the implementation of precast tilt up systems, with reduced on-site material. Material theft had been a concern for the project team, as the construction site was located in a region where crime is considered to be a high risk. Le Roux (2013) also mentioned that the risk of material theft was reduced for the Longridge reservoir (Case study 3).

Although the risk of theft does not have a direct impact on the time or cost of a construction project, the impact thereof may have an influence on the project budget. Therefore, project teams need to consider the risk associated with material theft in their decision between in-situ concrete construction and HCC, especially in high crime regions.

6.2.6 Material conclusion

In this section the various material factors that may have an influence on the time and cost for a decision between in-situ concrete construction and HCC during the construction phase have been discussed. Table 6.5 presents the material factors and the impact thereof on in-situ and HCC.

Table 6.5: Material factors for a decision between in-situ concrete construction and HCC

Factors	**In-situ concrete construction**	**HCC**
Concrete	More concrete volume required, therefore potentially more cost	Reduced concrete volume required, therefore potentially reduced cost
Reinforcement	More reinforcement required, therefore potentially more cost	Reduced reinforcement required, therefore potentially reduced cost
Wastage	More wastage generated, therefore potentially more time and cost required	Reduced wastage generated, therefore potentially reduced time and cost required
Temporary works	More temporary works required, therefore potentially more time and cost required	Reduced temporary works required, therefore potentially reduced time and cost required
Non-standard precast moulds	Not applicable	Additional time and cost
Material theft	Greater risk of material theft	Reduced risk of material theft

Not much literature is available on the quantification of the factors presented in Table 6.5. It is often difficult to quantify these factors, as they are usually project dependent. Future studies are suggested in this field, to quantify, or provide methods and guidelines in order to quantify these factors.

6.3 Equipment

This section discusses the time and cost factors categorized under the equipment category during the construction phase that need to be considered for a decision between in-situ concrete construction and HCC. It includes the factors of cranes and associated handling devices required to lift and place the precast elements during construction. This section also discusses additional plant required to transport and erect precast elements. Other factors that are discussed are the risk of vandalism and theft of equipment, and the consideration between purchasing equipment and renting equipment. The identified factors under the equipment category are presented in Figure 6.5.

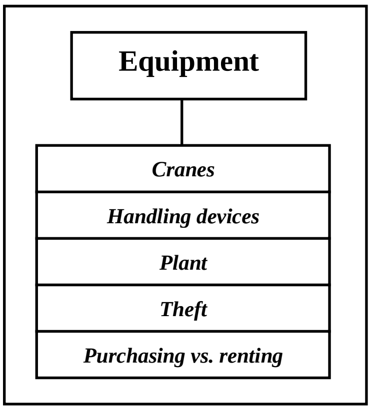

Figure 6.5: Equipment time and cost factors

6.3.1 Cranes

The cost for hiring cranes represents a large amount of the equipment cost in construction projects. Much literature is available on the usage and economical scheduling of cranes (Bargstädt, 2013), (Andam & Knapton, 1980), (Tam, Deng & Zeng, 2002). The available literature provides guidelines on crane scheduling that can be used to generate potential cost savings in construction projects. Various factors and decision making models were identified and suggested during these investigations (Hanna & Lotfallah, 1999).

However, not much literature is available on the comparison between the crane requirements and cost for in-situ concrete construction and HCC. Bargstädt (2013) mentioned that both methods of in-situ concrete construction and HCC require cranes for construction. The main differences between crane requirements for in-situ concrete construction and for HCC are the differences in crane capacities and types of cranes required. For the erection of precast elements, it was recorded that an average capacity of 20 tons is required, depending on the weight of the heaviest element. For in-situ concrete constructions, an average crane capacity of 2.5 tons is required in order to lift and move required equipment and material (Bargstädt, 2013). The other factors that might have an impact on the cost of crane selection are the required reach, the number of cranes required and the duration for which the cranes are used (Hanna & Lotfallah, 1999).

There is not much literature available on the factors that have an influence on the cost of cranes for the implementation of HCC. Nonetheless, Table 6.6 provides the factors that may influence the cost of crane selection that need to be considered for in-situ concrete construction and HCC.

Table 6.6: Factors affecting cost in crane selection

Crane capacity
The hiring cost of a crane increases as the crane capacity increases. As mentioned, precast elements often require cranes with higher capacities when compared to the conventional method of in-situ concrete construction (Bargstädt, 2013). The cost required for cranes will therefore be higher in the implementation of HCC when compared to the cost required for in-situ concrete construction in terms of crane capacity.
Number of cranes required
Tam *et al.* (2002) evaluated the effect of the number of cranes on construction time for in-situ concrete construction vs. HCC for high rise housing in Hong Kong. Tam *et al*. (2002) mentioned in the evaluation that the number of cranes can be increased for the implementation of HCC to produce more rapid construction, therefore saving on the construction schedule. During the investigation, the construction of an apartment block was considered for three different scenarios. The scenarios differed in construction methods (in-situ vs. HCC) and by material handling input (number of cranes). For the first scenario, one crane for in-situ concrete construction was considered. For the second scenario, one crane for HCC was considered and the results have shown that the project duration of the second scenario was reduced by 20 % when compared to the first scenario. For the third scenario, three tower cranes were considered for HCC and the results showed that the project duration was reduced by 40 % when compared to the first scenario. The hiring of more cranes increases the fixed costs for equipment. However, when more cranes are hired, the construction schedule may be reduced for the implementation of HCC, consequently assuring a faster return on investment. A feasibility study to determine the optimum number of cranes vs. the minimum number of cranes required is suggested per project. This feasibility study can assist project teams in evaluating the more economical option.
Duration
The construction duration in the implementation of HCC is usually reduced when compared to in-situ concrete construction (Glass et al, 2000). The period for which cranes are required is therefore reduced for HCC. The cost in terms of the construction duration for which the cranes are hired is consequently lower for HCC when compared with in-situ concrete construction.
Types of cranes
There are many types of cranes available to use for construction purposes. These types include overhead cranes, mobile cranes and fixed cranes, and are usually selected based on the site layout and required crane capacity. The cost varies for the various types of cranes (Hanna & Lotfallah, 1999). Project teams should investigate the type(s) of cranes required for a construction project when deciding between in-situ concrete construction and HCC.

Case study example

During Case study 1, presented in Chapter 5, many more cranes were required for the in-situ coal bunker when compared to the HCC coal bunker. For the in-situ Grootegeluk coal bunker, 4 cranes were used for construction and for the HCC Shondoni coal bunker, one overhead crane was used for the installation of the precast elements. In this case, cost savings were generated due to fewer cranes required and a shorter duration for which the cranes were hired. It was also mentioned that tower cranes for the Grootegeluk project was easily affected by the wind. These conditions made it easy for the project to fall behind schedule, as it was difficult to supply material on certain days of the project (Vermeulen, 2013).

Section conclusion

Effective crane hiring for construction projects can result in potential cost savings. The comparison of crane selection and scheduling for in-situ concrete construction and HCC is, however, difficult to quantify. Future studies are suggested in the field of crane selection for HCC vs. in-situ concrete construction.

Project teams should investigate and compare the types and number of cranes required for in-situ concrete construction and HCC to determine the more economical option. This factor needs to be considered for a decision between in-situ concrete construction and HCC.

6.3.2 Handling devices

Figure 6.6: Lifting clamp for Shondoni coal bunker project (C&CI, 2013)

For the Shondoni coal bunker (Case study 1), special lifting clamps were designed and manufactured to handle and erect the precast elements. Figure 6.6 presents an example of one of the lifting clamps that was used for the Shondoni coal bunker project. When standard precast elements are manufactured for implementation, lifting clamps may not be required. However, for specially designed precast elements, such as the beam presented in Figure 6.6, special lifting clamps are required to be designed and manufactured. The additional time and cost required for the manufacturing of special lifting clamps need to be evaluated when HCC is considered as an alternative for a project.

6.3.3 Plant

Additional machinery and plant may be required for HCC. Figure 6.7 presents one of the plants used to transport precast beams for the Shondoni coal bunker project (Case study 1). Project teams should identify and consider the additional plant and machinery required for HCC to evaluate the additional cost that may be required.

Figure 6.7: Transportation plant for Shondoni coal bunker

6.3.4 Theft

As mentioned in Section 6.2.5, theft and vandalism on construction sites can directly impact the success of construction projects and reduce potential profitability (Farinloye et al., 2013). It was estimated that South Africa spends roughly R 1 billion annually on theft of equipment and tools in the construction industry (Brown, 2012). It was further mentioned that only 6 % of stolen construction equipment, including machinery and plant, is recovered (Brown, 2012).

Additional equipment required for HCC may increase the risk associated with equipment theft. Although this risk might be difficult to quantify, it is suggested that project teams evaluate the potential impact of the risk in deciding between in-situ concrete construction and HCC, especially in regions where crime is expected to be a challenge.

6.3.5 Purchase vs. renting

When equipment is considered for construction projects, contractors have the choice of either renting the equipment or making a capital investment by purchasing the equipment. When equipment is purchased, contractors are responsible to generate sufficient income in order to operate and maintain the equipment (Elbeltagi, 2010).

The preference between renting or purchasing equipment generally depends on the operation time of the equipment. Therefore, when equipment is used often and can be reused for future projects, it may be viable to purchase equipment. However, for HCC it is not always viable to purchase the required equipment. HCC projects are often unique and require the associated equipment only for the duration of one project. In these cases, where the operational time of the equipment is limited, renting the equipment might be more viable (Elbeltagi, 2010).

There are, however, certain precast applications where the equipment can be used and reused multiple times, such as in the case of the Value logistics dispatch plant (Case study 2). For the construction of the Value logistics dispatch plant, the subcontractor (Tilt Up Systems) had their own crane, precast moulds and lifting clamps to manufacture and erect the precast elements (Bergh, 2014).

It is therefore the contractor's decision to decide between renting or purchasing equipment. The following table provides some of the benefits of purchasing and renting equipment for construction projects.

Table 6.7: Advantages of renting and purchasing equipment (Elbeltagi, 2010)

Renting	**Purchasing**
No associated time and cost required to maintain equipment	More control on the use and disposition of the equipment
Access to latest available equipment	Marketing advantage in tendering for projects
No warehouse or storage facility required.	Always available when required
Equipment cost accounting is simpler	No renting charges

The choice between renting or purchasing equipment may affect the cost of construction projects. This is, however, the contractor's decision of which option would be economically more viable for a project.

6.3.6 Equipment conclusion

In this section the various equipment factors that may have an influence on the time and cost for a decision between in-situ concrete construction and HCC during the construction phase have been discussed. Table 6.8 presents the equipment factors and the impact thereof on in-situ concrete construction and HCC.

Table 6.8: Equipment factors for a decision between in-situ concrete construction and HCC

Factors	In-situ concrete construction	HCC
Cranes	Depends on crane capacity, type, number and duration; and is therefore project dependant	Depends on crane capacity, type, number and duration; and is therefore project dependant
Handling devices	Not applicable	Additional manufacturing cost required
Additional HCC Plant and machinery	Nor applicable	Additional cost may be required for renting or purchasing plant and machinery
Theft	Reduced risk of equipment theft	Greater risk of equipment theft
Purchasing additional HCC equipment	Not applicable	Dependent on number of usages
Renting additional HCC equipment	Not applicable	Additional renting cost required in the case where equipment is not purchased

In terms of equipment during the construction of a project, additional cost may be required for the implementation of HCC.

6.4 Construction

This section discusses the time and cost factors categorized under the construction category that need to be considered for a decision between in-situ concrete construction and HCC. The construction category includes the factors of site preparation, connections, rework, repetition, working at heights, safety, external risks, earlier site access, and return on investment. The identified factors under the construction category are demonstrated in Figure 6.8.

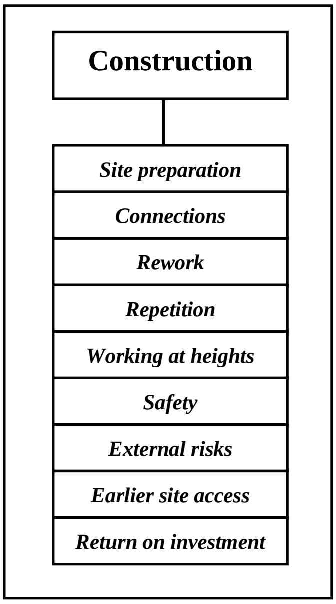

Figure 6.8: Construction time and cost factors

6.4.1 Site preparation

Bergh & Vermeulen (2013) mentioned that the planning and preparations of the site layout for HCC require more thought than in-situ concrete construction. The primary reason for this is that HCC has a small margin for error and will result in costly errors if much rework is required (Bergh, 2014). The Value logistics dispatch plant (Case study 2), had a situation where some of the precast elements were disposed of due to quality constraints. The reason for these constraints was that one of the concrete blindings, on which the precast elements were manufactured, was not levelled to specification. This caused some of the elements to be out of tolerance. As a result, these elements and the concrete blinding had to be remanufactured and reconstructed. Vermeulen (2013) mentioned that site preparations are critical, and therefore require sufficient time to ensure time savings during later stages of the construction period, especially for the implementation of HCC.

In some cases, the site layout can make it impossible to construct with the use of HCC. These cases include construction sites where the accessibility, for cranes and other related plant, might be challenging. For these projects, in-situ concrete construction is the preferred method of construction.

However, more time and caution are required for the preparation of the site layout for HCC. Site layout preparations need to be considered for a decision between in-situ concrete construction and HCC.

6.4.2 Connections

The representatives of the case study projects, presented in Chapter 5, mentioned that the constructability of precast and hybrid concrete connections can be implemented with minimum constraints (Vermeulen, 2013), (Bergh, 2014), (Le Roux, 2013) . Le Roux (2013) mentioned that the main risk in the construction of precast and hybrid concrete connections is accuracy, therefore, signifying that construction of connections must be carried out with precision. In the case where reinforcement protruding from precast elements is slightly out of tolerance, costly rework might be required. Quality control in the precast yard is therefore essential to prevent rework due to potential constraints of reinforcement being out of tolerance (Bergh, 2014).

Marsh (2011) has mentioned that the construction of precast and hybrid concrete connections is one of the factors in HCC that promotes a faster construction schedule. However, the risk of rework due to connections, especially in terms of remanufacturing of precast elements, may have a major impact on the construction schedule and cost (Marsh, 2011).

It is important that project teams investigate the type of connections, and assess the associated risk, before constructing the various connections. Precast connections are primarily a design consideration, as discussed in Chapter 4. Quality precast and hybrid concrete connection design promote constructability and may result in potential time savings. Project teams should consider the details and implications of connections when HCC is considered as an alternative for a project. The factors that need to be considered include (Le Roux, 2013):

- tolerances and specifications
- associated risks and potential impact thereof
- constructability, and
- experience and reputation of the contractor

6.4.3 Rework

The term rework has numerous definitions in the construction industry. Love *et al.* (2000) defined rework as the unnecessary work of rebuilding applications that were executed incorrectly the first time. Another definition of rework is to remove and repair the activities that were incorrectly installed in a project (Burati, Farrington & Ledbetter, 1992).

Research has shown that the cost associated with rework represents an average of 5 % of the total construction cost (Hwang, Thomas, Haas & Caldas, 2009). Rework in construction projects is separated into four primary causes. These causes are known as design deviations, construction deviations, fabrication deviations and transportation deviations (Burati et al, 1992). This section only includes a discussion on construction related rework. Burati *et al.* (1992) mentioned that approximately 20 % of rework is caused by construction deviations. Construction deviations are defined as construction errors resulting from incorrect construction methods and procedures.

Vermeulen (2013) mentioned that much less rework was required for the HCC coal bunker when compared to the in-situ concrete construction coal bunkers (Case study 1). Rework for the in-situ Grootegeluk coal bunker represented 2 % of the construction cost. The HCC Shondoni coal bunker required much less rework than the in-situ Grootegeluk coal bunker. The main reason for the reduced rework was the difficulties to cast in-situ concrete in awkward positions at heights during the construction of the Grootegeluk coal bunkers. The elements which were cast at ground level for the Shondoni project reached much better quality and did not require rework (Vermeulen, 2013).

The use of HCC can result in potential cost savings due to less rework when compared to in-situ concrete construction. The main reason for this is that precast concrete elements are manufactured in a controlled environment (Gibb & Isack, 2001b). However, in the case where HCC requires rework, the impact thereof might be more severe and consequently more costly when compared to that of in-situ concrete construction (Le Roux, 2013), (Bergh, 2014).

In order to avoid rework, sufficient planning and design during the early stages of a project is required. There is not sufficient literature available on the rework of HCC. Future studies are therefore suggested in this field. Project teams should consider the factor of rework and the impact thereof in their decision between in-situ concrete construction and HCC.

6.4.4 Repetition

Factory products are usually not appropriate for once off applications, and primarily rely on bulk demands in order to be economically viable. More cost savings are possible when a large quantity of precast elements is manufactured. Variability in precast elements, on the other hand, will affect the delivery time and cost of a product. This concept therefore means that many of the same elements (precast concrete) must be manufactured to reap the supreme benefits of time, cost and quality (De Klerk, 2013). Gibb (2001) confirmed this concept when he mentioned that repetition has the ability to lower project cost, reduce construction time and improve product quality (Gibb & Isack, 2001b).

It is evident that repetition and HCC are inseparable (Gibb & Isack, 2001a). Although HCC can be applied separately, the supreme benefits thereof are gained when it is implemented with repetition. Bergh (2013) mentioned that a construction duration of approximately 20 % was saved for the Value logistics dispatch plant (Case study 2), primarily due to the repetition that precast tilt up systems had to offer. Le Roux (2013) mentioned roughly the same percentages of savings on the construction schedule for the Longridge reservoir (Case study 3), with the principal motivation of repetition and standardisation. Figure 6.9 presents the relationship between cost and repetition for precast concrete cladding in terms of units (Gibb & Isack, 2001a).

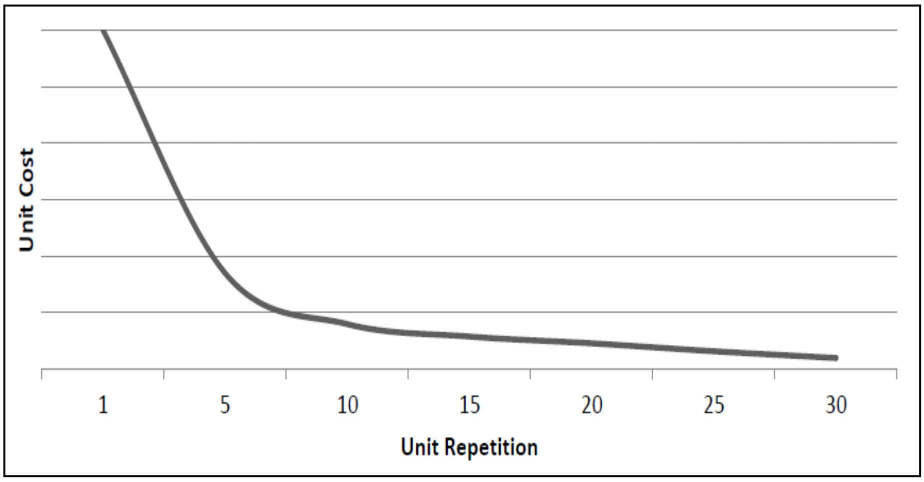

Figure 6.9: The relationship of unit costs and unit repetition for precast concrete cladding (Gibb & Isack, 2001a), (De Klerk, 2013)

Figure 6.9 illustrates the potential cost benefits when repetition occurs. As the number of unit repetition increases, the unit cost reduces, therefore, resulting in cost savings when maximum repetition is endorsed.

Contractors should work in collaboration with design teams to identify where repetition can be maximised to reap the benefits thereof. Repetition in HCC may result in time and cost savings when compared to the conventional method of in-situ concrete construction (De Klerk, 2013). This is an important factor that needs to be considered for a decision between in-situ concrete construction and HCC. In order to maximize repetition that may result in cost savings, the following factors need to be considered:

- Bulk demand of elements
- Minimum variability
- Early involvement and collaboration amongst contractors and consultants

6.4.5 Working at heights

Reducing activities taking place at heights, and transferring it to the ground may have a significant impact on the time and cost in construction projects. Transferring activities to ground level by using HCC can potentially generate the following savings (Quinn, 2012):

- Up to 75 % less formwork required
- Up to 80 % less scaffolding required
- 80 % less loose reinforcement and material that must be moved to these heights, and
- 90 % less wet concrete, which means that there is no waiting period for the concrete to cure.

Figure 6.10 is illustrated to explain the motivations for these savings. The figure presents a mobile crane that is placing precast beam elements in the construction of a multi-storey building.

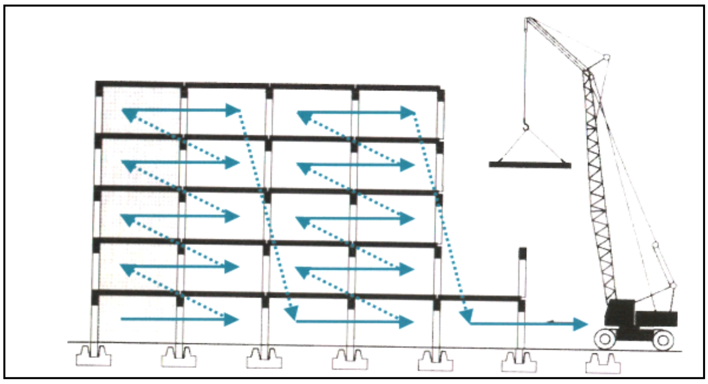

Figure 6.10: Precast beam assembly (Bargstadt, 2013)

When in-situ concrete construction is applied for the multi-storey building, the following steps are followed. First the temporary works are erected. After the temporary works have been erected, the steel reinforcement and formwork is placed into position and erected. After this, the concrete is poured, which requires sufficient time to reach the specified strength before the formwork can be removed. After the removal of the formwork, another waiting period is required to ensure that the concrete is strong enough to bear the necessary loads for the construction of the following levels. In addition to this, labourers are usually required to work in awkward positions at great heights which make it difficult to stay on schedule (Goodchild & Glass, 2004), (Quinn, 2012), (Vermeulen, 2013).

For HCC, the precast elements are manufactured at ground level. Therefore, much less temporary works are required. It is more convenient to work at ground level, which promotes faster construction when compared to working in awkward positions at heights. After the precast elements have been manufactured, they are placed into their final position. This is usually done in sequence, as illustrated in Figure 6.10 to promote repetition. In the case of multi-storey building construction, up to 60 % of the construction schedule can be reduced by transferring activities to the ground where repetition is prominent (Quinn, 2012), (Goodchild & Glass, 2004), (Vermeulen, 2013).

During the case studies presented in Chapter 5, significant time and cost savings occurred due to activities that had been transferred to the ground. The HCC Shondoni coal bunker (Case study 1) saved 50 % on the construction schedule when compared to the In-situ Tiwistraai coal bunker (Vermeulen, 2013). The principal motivations for these savings were that most of the activities had been transferred to ground level and that sufficient repetition had occurred (Vermeulen, 2013).

When numerous activities in construction projects take place off the ground, it is suggested that project teams investigate the possibility of constructing with repetitive precast concrete elements. Working at ground level does not only result in potential time and cost savings. The quality of the structural application and on-site safety is also improved. It is evident that HCC may be the preferred alternative when it comes to repetitive off-the-ground construction, such as multi-storey building construction.

Working at heights is an important factor that needs to be considered for a decision between in-situ concrete construction and HCC. Transferring activities taking place at heights to the ground generates the following benefits (Goodchild & Glass, 2004), (Vermeulen, 2013):

- Reduced formwork, scaffolding and support structures
- reduced loose material
- reduced wet concrete
- promotes repetition
- more rapid construction
- better quality control, and
- improved safety (reduced risk of on-site accidents)

6.4.6 Safety

Health and safety has become one of the biggest concerns in the construction industry in South Africa (Le Roux, 2013). On-site accidents can lead to site closure in the case where the necessary safety rules and legislations are not applied. Construction sites in general, are safety hazards and contractors need to apply the necessary safety rules and legislations to prevent the risks associated with on-site safety. The impact of accidents on construction sites can potentially have an influence on the time and cost of a project, and are therefore considered as an indirect time and cost factor for a decision between in-situ concrete construction and HCC (Shapira & Lyachin, 2009).

Figure 6.11 is a presentation of recorded fatal injuries for the manufacturing industry vs. the construction industry in Great Brittain. It was found that fatal injuries are twice as likely to happen in the construction industry when compared to the manufacturing industry (HSE, 2011). The blue line represents the construction industry and the red line represents the manufacturing industry. The CIDB (2009) conducted a similar investigation where it was found that one in every five fatality claims takes place in the construction industry (De Klerk, 2013). It is therefore evident that accidents are more likely to occur in the construction industry when compared to other industries, such as the manufacturing industry (CIDB, 2009), (HSE, 2011), (De Klerk, 2013).

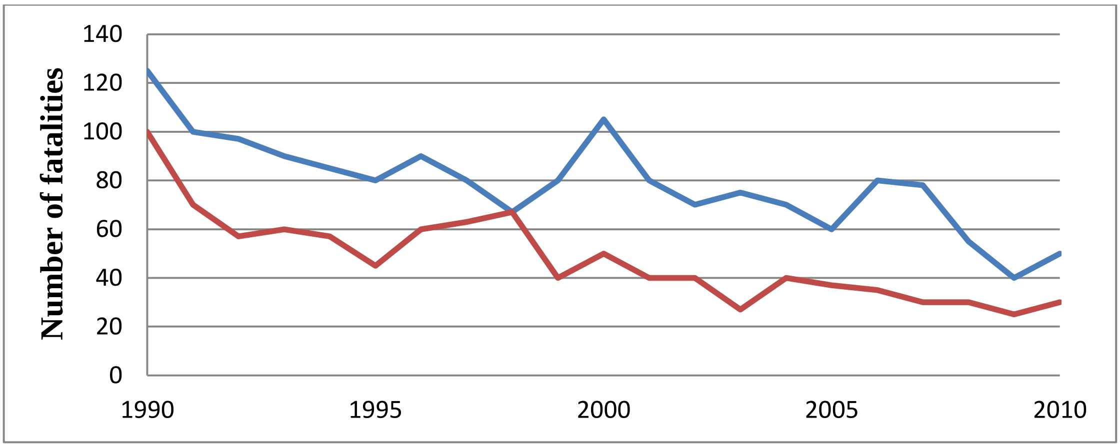

Figure 6.11: Industry fatalities in the UK (De Klerk, 2013), (HSE, 2011)
Blue – construction industry
Red – manufacturing industry

The use of prefabrication in construction projects has shown to reduce the on-site activities and consequently reducing safety risks (Gibb & Isack, 2001a), (Le Roux, 2013). Many of the construction activities are transferred to a controlled environment for the implementation of HCC (Goodchild & Glass, 2004). It is easier to control the exposure of safety hazards in a controlled environment when compared to on-site conditions. The reduction of working at heights also reduces the risk of accidents (Vermeulen, 2013).

The use of HCC has shown to result in a safer working environment (Lombard, 2011), (De Klerk, 2013). There are, however, certain safety risks associated with HCC that need to be considered, such as the moving of heavy overhead elements and risks associated with cranes. Project teams should investigate and evaluate the impact of potential safety risks in their decision between in-situ concrete construction and HCC. The following aspects need to be considered for both methods of construction and compared, for the decision:

- quantity of on-site activities
- activities taking place at heights
- risk associated with cranes, and
- risk associated with heavy overhead elements

6.4.7 External risks

The external risk factor refers to the risk of unfavourable weather conditions. Much literature on HCC has mentioned that unfavourable weather conditions do not affect the construction schedule of HCC (Goodchild & Glass, 2004), (Gibb & Isack, 2001a). The main reason for this is that the precast elements are cast and manufactured under a roof in a controlled environment (Glass *et al*, 2000). This is, however, only true when the elements are manufactured under roof. For the case studies presented in Chapter 5, the precast yards were subjected to open air. Rainy conditions can therefore still affect the construction schedule (Vermeulen, 2013). However, the impact thereof is smaller when compared to on-site procedures.

Tower cranes are also easily affected by the wind. For the construction of coal bunkers (Case study 1), it was mentioned that the wind had a significant impact on the construction schedule for the in-situ Grootegeluk coal bunker. For the HCC Shondoni coal bunker, the wind did not have an effect on the installed overhead crane (Vermeulen, 2013).

The risk of unfavourable weather conditions should be considered by project teams for a decision between in-situ concrete construction and HCC, especially in areas where rainfall is prominent.

6.4.8 Earlier site access

One of the factors that promotes faster construction with the use of HCC is earlier site access. As mentioned in section 6.4.5, the use of formwork, scaffolding and the amount of wet concrete is reduced when HCC is used (Goodchild & Glass, 2004). Therefore, once the precast elements have been installed, the subsequent construction activities can continue. For the case of in-situ concrete construction, additional time is required for the concrete to reach sufficient strength and to remove the temporary works.

Project teams should consider the factor of earlier site access in their decision between in-situ concrete construction and HCC.

6.4.9 Return on investment

For the VWSA paint shop (Case study 4), the client requested the method of HCC, primarily for the reason of a faster return on investment. Although the client was aware that the precast option might be more expensive compared to in-situ concrete construction for that specific project, he opted for a faster construction period to gain the economical benefit of a faster return on investment (Jurgens, 2008).

In Chapter 3, cost calculations were performed to evaluate the effect that time has on cost. Two projects with similar cost but different construction durations were compared. It was assumed that the construction time for an in-situ project was 15 months, where the duration of an HCC project was 12 months. Therefore, a construction time of three months (20 %) was saved. The estimation concluded that the HCC method required 2.7 % less yearly income in order to break even after a usage period of 30 years when compared to in-situ concrete construction. The value of money increases over time, and a faster return on investment will therefore increase the amount of return (Leland, 2012). Refer to Chapter 3 for more information.

Project teams should therefore consider the client's needs in deciding between in-situ concrete construction and HCC. For some projects it might be to construct a project with lower cost but a longer schedule, where in other projects it might be to complete the construction as fast as possible to gain the benefit of a faster return on investment. Project teams should understand the client's needs in order to make appropriate decisions between in-situ concrete construction and HCC (Lombard, 2011).

6.4.10 Construction conclusion

In this section the various construction factors that may have an influence on the time and cost for a decision between in-situ concrete construction and HCC were discussed. Table 6.9 presents the construction factors and the impact thereof on in-situ concrete construction and HCC.

Table 6.9: Construction factors for a decision between in-situ concrete construction and HCC

Factors	In-situ concrete construction	HCC
Site preparation	May be the preferred method of construction in cases where crane accessibility is limited	Requires more time and caution for the preparations of the site layout
Connections	Time consuming construction, however reduced impact for the risk of rework	Faster construction, however increased impact for the risk of rework
Rework	Represents up to 5 % of the total construction cost.	Reduced rework, however the impact of rework for HCC might be more severe
Repetition	Reduced potential for repetition, therefore increase in construction time	Increased potential for repetition, therefore reduced construction time production cost
Working at heights	Numerous activities taking place at heights, therefore insufficient quality control and slower construction duration	Reduced activities taking place at heights, therefore reduced time and cost, and better quality control
Safety	Accidents more likely to occur	Reduced risk of on-site accidents
External risks	Likely to affect project time	Reduced impact of external risks
Earlier site access	Waiting period for concrete to reach sufficient strength	Earlier site access, therefore reduced construction duration
Return on investment	Slower return on investment	Faster return on investment

6.5 Chapter Conclusion

In this chapter the various factors that may have an influence on the time and cost for a decision between in-situ concrete construction and HCC during the construction phase were discussed. The factors were identified by literature and by the case studies presented in Chapter 5. The factors were categorized into four categories namely logistics, equipment, material and construction. Table 6.10 presents the factors and the impact thereof on in-situ concrete construction and HCC.

Table 6.10: Construction phase factors for a decision between in-situ concrete construction and HCC

Logistical factors		
Factors	**In-situ concrete construction**	**HCC**
Precast supplier	Not applicable	Additional cost
Precast yard erection	Not applicable	Additional time and cost
Lifting devices (Precast yard)	Not applicable	Additional cost
Property	Not applicable	Additional cost
Transportation	Not applicable	Additional time and cost
Labourers and skills development	More time and cost required	Reduced time and cost
Precast yard disposal	Not applicable	Additional time and cost
Material factors		
Factors	**In-situ concrete construction**	**HCC**
Concrete	More concrete volume required, therefore potentially more cost	Reduced concrete volume required, therefore potentially reduced cost
Reinforcement	More reinforcement required, therefore potentially more cost	Reduced reinforcement required, therefore potentially reduced cost
Wastage	More wastage generated, therefore potentially more time and cost required	Reduced wastage generated, therefore potentially reduced time and cost required
Temporary works	More temporary works required, therefore potentially more time and cost required	Reduced temporary works required, therefore potentially reduced time and cost required
Non standard precast moulds	Not applicable	Additional time and cost required
Material theft	Greater risk of material theft	Reduced risk of material theft
Equipment factors		
Factors	**In-situ concrete construction**	**HCC**
Cranes	Depends on crane capacity, type, number and duration; and is therefore project dependant	Depends on crane capacity, type, number and duration; and is therefore project dependant
Handling devices	Not applicable	Additional manufacturing cost required
Additional HCC Plant and machinery	More wastage generated, therefore potentially more time and cost required	Reduced wastage generated, therefore potentially reduced time

		and cost required
Theft	Reduced risk of equipment theft	Greater risk of equipment theft
Purchasing additional HCC equipment	Not applicable	Dependent on number of usages
Renting additional HCC equipment	Not applicable	Additional renting cost required in the case where equipment is not purchased
Construction factors		
Factors	**In-situ concrete construction**	**HCC**
Site preparation	May be the preferred method of construction in cases where crane accessibility is limited	Requires more time and caution for the preparations of the site layout
Connections	Time consuming construction, however reduced impact for the risk of rework	Faster construction, however increased impact for the risk of rework
Rework	Represents up to 5 % of the total construction cost.	Reduced rework, however the impact of rework for HCC might be more severe
Repetition	Reduced potential for repetition, therefore increase in construction time	Increased potential for repetition, therefore reduced construction time production cost
Working at heights	Numerous activities taking place at heights, therefore insufficient quality control and slower construction duration	Reduced activities taking place at heights, therefore reduced time and cost, and better quality control
Safety	Accidents more likely to occur	Reduced risk of on-site accidents
External risks	Likely to affect project time	Reduced impact of external risks
Earlier site access	Waiting period for concrete to reach sufficient strength	Earlier site access, therefore reduced construction duration
Return on investment	Slower return on investment	Faster return on investment

In conclusion, the factors discussed during this chapter primarily depend on the client's needs. In some cases the client may pay more to benefit from a faster return on investment, such as the case of the VWSA paint shop (Case study 4). In other cases, clients will opt for an economical option that might be more time consuming during the construction phase.

HCC may result in time and cost savings when many activities are transferred to ground level. Therefore, when construction takes place at heights, and sufficient standardization and repetition is possible, HCC is the preferred method of construction and may result in time and cost savings.

Table 6.9 and the related discussions throughout the chapter can assist project teams for a decision between in-situ concrete construction and HCC during the construction phase of a project.

Chapter 7

Maintenance phase

Civil engineers design concrete structures that are required to perform safely for decades. The design of concrete structures has a significant impact on the durability of a structure, however, all concrete structures deteriorate over time. Concrete structures require lifetime maintenance and repair expenses to increase the life of a structure. It is difficult to estimate and quantify future maintenance cost. However, a maintenance programme may assist teams in making appropriate decisions at critical times, to minimize the maintenance cost of concrete structures (Gupta & Shui, 2014), (NPA, 2004).

It is said that HCC has the potential to result in more durable structures, due to more efficient quality control in the manufacturing of precast elements (Goodchild & Glass, 2004), (Glass, 2005). Although the quality might be better controlled for precast elements when compared to in-situ concrete, there is not sufficient literature available on the comparison of the maintenance cost of these two construction methods. Therefore, the primary objective of this chapter is to identify the factors that may have an influence on the project time and cost for a decision between in-situ concrete construction and HCC during the maintenance phase of a project. The case study projects that were investigated in Chapter 5 had similar maintenance procedures than that of in-situ concrete construction. The factors have therefore been identified from available international literature on concrete maintenance. The chapter outline and identified maintenance factors are presented in Figure 7.1.

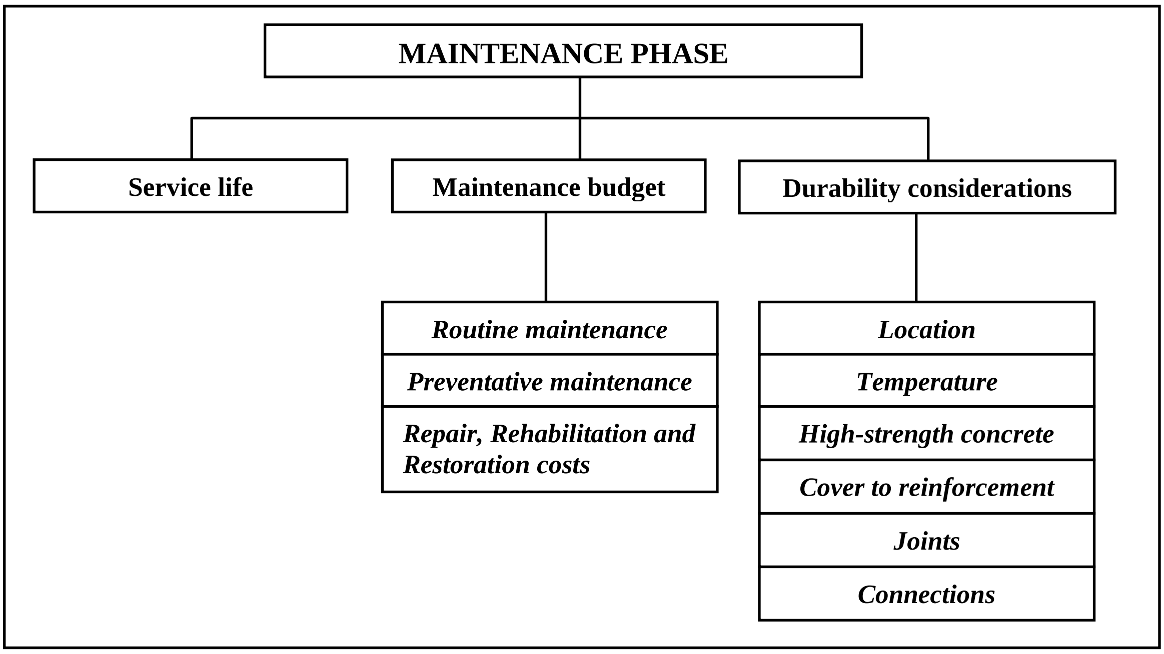

Figure 7.1: Maintenance time and cost factors

7.1 Service life of concrete structures

Structural buildings usually deteriorate slowly over their life cycle. The reason for this is that closed buildings do not undergo a rapid change in loads and environmental conditions when compared to exposed structural applications (Gupta & Shui, 2014). This form of deterioration is presented by the normal curve in Figure 7.2. Exposed concrete structures, such as parking structures, coal bunkers and spectator pavilions are subjected to thermal movement and dynamic loads, but are also exposed to the atmosphere. These structures undergo a more accelerated rate of deterioration. The relationship between deterioration and repair costs during the service life of exposed structures is demonstrated by the curves in Figure 7.2 (Gupta & Shui, 2014), (NPA, 2004), (PCI, 2003).

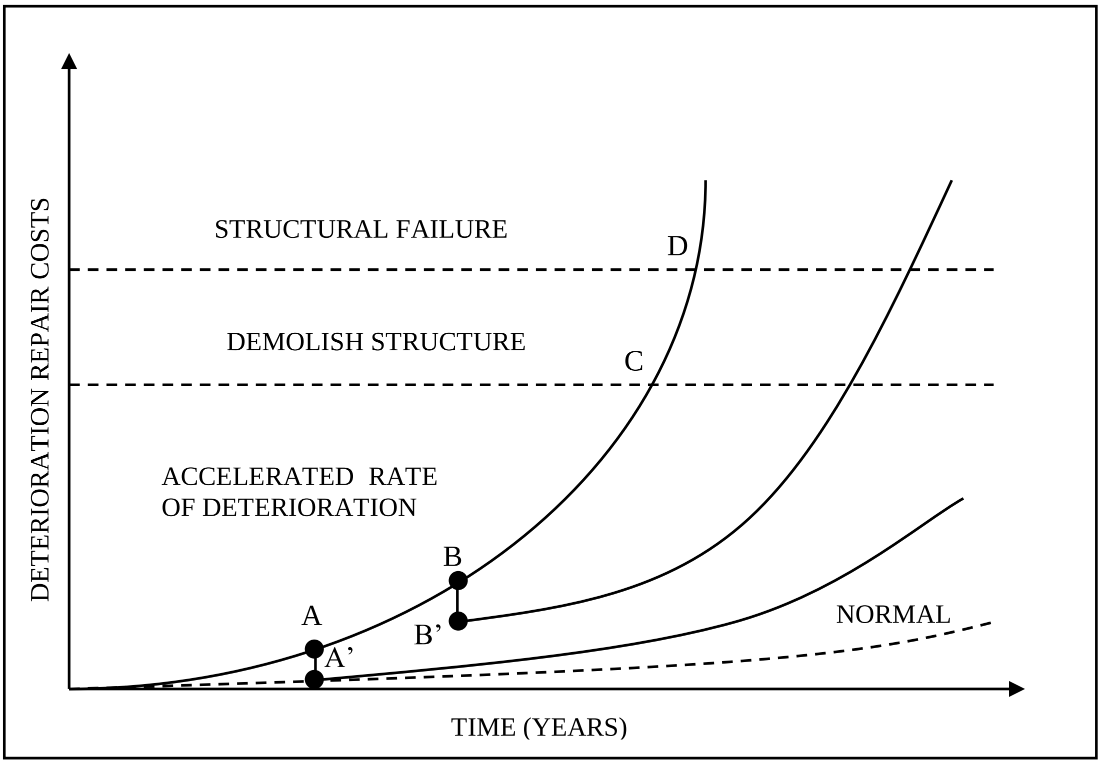

Figure 7.2: Rate of deterioration repair cost over time (NPA, 2004), (Gupta & Shui, 2014)

Exposed concrete structures follow the normal deterioration rate during the initial stages of their life cycle. After these structures have been used for a number of years, the deterioration rate accelerates. This accelerated deterioration rate is caused by a combination of repeated temperature changes and dynamic loads with exposure to chlorides and moisture, which in turn leads to the corrosion of reinforcement and resultant cracking of concrete. As shown between points A and B, the curve deteriorates at an accelerated rate after a few years of usage (NPA, 2004), (Gupta & Shui, 2014). It can also be seen that the curve deteriorates at a more accelerated rate when timely maintenance repairs are not conducted at times A and B. This causes the structure to lose integrity and to become a safety hazard, as shown between points B and C. Further along the curve, the structure might fail (C-D). This curve (A-B-C-D), therefore presents an exposed structure where no maintenance is performed during the life cycle of the structure (NPA, 2004), (Gupta & Shui, 2014).

Effective repair and maintenance strategies decrease the rate of deterioration and result in a longer life cycle. These strategies prevent moisture and chlorides from penetrating through the concrete, consequently reducing the corrosion of reinforcement and cracking of concrete. The rate of deterioration reduces and becomes more like the normal rate of deterioration (NPA, 2004). The maintenance and repair strategies are presented by the vertical lines between points A and A’, and B and B’. It can also be seen that early repairs and maintenance (A-A’) is more effective, and cost less, compared to maintenance and repairs during later stages of the service life (B-B’) (NPA, 2004), (Gupta & Shui, 2014).

Figure 7.3 presents the maintenance cost over the service life of exposed concrete structures construction with in-situ concrete construction and HCC. Kimbrey (2014) mentioned that the concrete repair strategies for in-situ concrete construction and HCC will be the same specification and therefore the same costs. The only difference is that, generally, HCC has a longer life span before repair work is required.

The service and repair cost for the two construction methods might be similar. HCC may, however, require less maintenance and repair work, due to a longer service life than in-situ concrete construction (Kimbrey, 2014). The reason for this is that HCC is manufactured in more controlled circumstances compared to in-situ concrete construction (Goodchild & Glass, 2004).

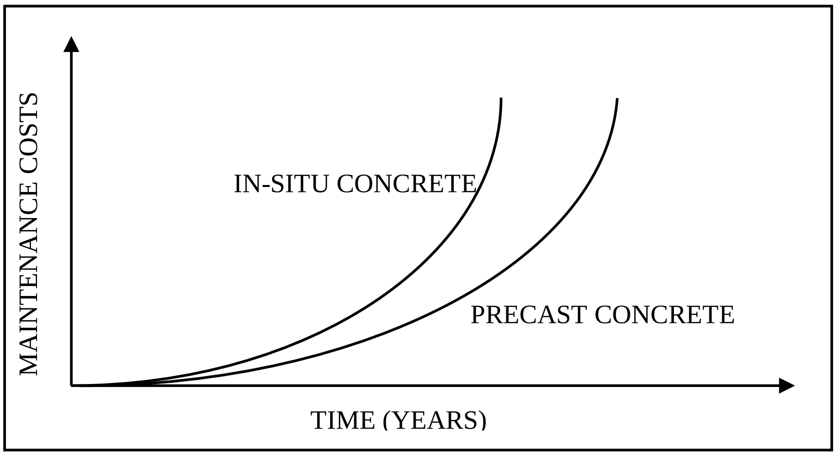

Figure 7.3: Maintenance cost for in-situ and HCC structures (Gupta & Shui, 2014)

7.2 Maintenance budget

It is important to incorporate maintenance and repair programmes during the initial stages of the operational phase. Maintenance and repair programmes aid project teams to establish an annual maintenance budget. Maintenance budgets usually commence on the first day of the operation phase and accounts for all operating, routine maintenance, preventative maintenance and structural repairs, replacement, rehabilitation and restoration expenses (NPA, 2004), (Gupta & Shui, 2014).

Effective budgeting for the repair and maintenance of concrete structures includes the following types of maintenance cost (NPA, 2004):

1. Routine and preventative maintenance
2. Repair and replacement maintenance

Routine maintenance cost and preventative maintenance cost mostly include similar activities. These two costs are, however, not duplicates, as the frequency and timing of the two cost mechanisms are different. Initial costs can be listed as preventative maintenance, while annual cleaning, inspections and repairs are considered as routine maintenance (NPA, 2004).

The two primary components in the programme of repair and maintenance are therefore repair and preventative maintenance, and structural repairs and replacement maintenance (Gupta & Shui, 2014).

7.2.1 Routine and preventative maintenance cost

Routine and preventative maintenance include many activities that should at least be carried out once a year. This includes a walk-through inspection and wash of the structure in order to identify any active leakages and cracks in the structure (PCI, 2003). Areas of concern, such as leaks, joint failures, cracks and concrete surface deterioration are then recorded per floor by the use of checklists. An example of such a checklist for concrete parking structures can be found in Appendix E. Similar types of checklists are used for other exposed concrete applications (PCI, 2003), (NPA, 2004).

Routine and preventative maintenance cost of a structure constructed with HCC is similar to that constructed with in-situ concrete (Gupta & Shui, 2014). The same aspects apply, and the same inspections are required for both structures. Although the possibility of cracks and open reinforcement is less for precast concrete, other aspects, such as joints and connections require inspection (PCI, 2003), (Gupta & Shui, 2014).

7.2.2 Repairs, rehabilitation and restoration costs

After a certain number of years, usually 5 to 10 years, engineers are appointed to perform a comprehensive inspection of the condition of a structure. These inspections may require destructive and laboratory material testing, depending on the age and condition of a structure, to better evaluate future concerns (NPA, 2004). Typical repair types of this phase include concrete restoration, repairing of waterproofing, sealing of cracks, performing joint and sealant controls, replacing expansion joints, and covering of exposed reinforcement, metals and concrete surfaces (Gupta & Shui, 2014), (NPA, 2004).

In the case where the concrete, reinforcement steel bars, or post tensioning system show to have damage, a more thorough restoration programme is required. This is done to prevent the structure from deteriorating at an accelerated rate and to bring the structure to the normal curve of deterioration, as shown in Figure 7.2. In other cases it might be necessary to perform major structural repairs. For parking structures, water-retaining structures, coal bunkers and pavilions, a specialist contractor, experienced in waterproofing and structural repairs is appointed. Major structural repairs are an expensive and time consuming process, depending on the possible impact of the concern (Gupta & Shui, 2014), (NPA, 2004).

As mentioned in the previous section, structures constructed with HCC require the same maintenance and repair procedures when compared to in-situ concrete techniques. The only difference, however, is that structures constructed with HCC have a longer service life. Therefore, less repairs, rehabilitation and restoration work may be required for structures constructed with HCC (Kimbrey, 2014).

However, certain aspects in the maintenance of structures constructed with HCC require much attention, such as the maintenance of construction joints and connections. Joints and connections between precast elements might be expensive and difficult to maintain (Goodchild & Glass, 2004).

The maintenance budget of a project can assist project teams for a decision between in-situ concrete construction and HCC.

7.3 Durability considerations

The maintenance of concrete applications is dependent on the quality of the concrete. Lombard (2011) mentioned that quality can not be observed in the absence of durability. Therefore, when a product is durable, it is known as a quality product. Long term quality of concrete structures includes durability (Lombard, 2011).

It is said that precast concrete elements reach a higher quality when compared to in-situ concrete applications. The main reason for this is that manufacturing of precast elements is carried out in a controlled environment (Goodchild & Glass, 2004), (Gibb & Isack, 2001). Better quality control can be performed, when compared to on-site procedures. There are, however, certain durability aspects that remain questionable for the use of HCC, such as precast joints and connections. Table 7.1 provides a list of the durability factors that need to be considered for a decision between in-situ concrete construction and HCC.

Table 7.1: Durability factors of concrete construction

Durability considerations		
The controlled environment	Location	For HCC the manufacturing of elements take place at ground level, this is easily accessible. For on site in-situ applications, the concrete is often poured at heights, and in awkward positions, making it difficult to reach the desired quality.
	Temperature & weather conditions	The temperatures can be controlled in precast factories, therefore providing perfect conditions for the curing of concrete. Site conditions are in contrast with this. The temperatures and weather conditions are not controllable on construction sites. Cold temperatures and wet weather conditions can greatly affect the curing process of the concrete, and consequently the quality.
	High-strength concrete	Precast concrete is usually manufactured with high-strength concrete. This reduces potential cracks that may occur on the surface of the concrete.
	Cover to reinforcement	Better control in placing the reinforcement to provide adequate cover can be performed for precast elements in a controlled environment. This also reduces the possibility of future cracking.
	Joints & Connections	This includes expansion joints, control joints, construction joints and construction connections between precast elements. In-situ concrete is more homogeneous when compared to precast elements. Precast applications therefore consist of more joints and connections when compared to in-situ concrete applications. These joints and connections might require more maintenance when compared to the joints of in-situ applications.

These aspects of durability are dependent on the design and construction phase of the project. Another aspect that affects the durability considerations is the argument of precast yards vs. precast factories. In the construction industry in South Africa, contractors often erect their own precast yards. The quality of these yards does not reach the same standards compared to precast factories (Vermeulen, 2013). These yards often manufacture the elements at a rapid pace, within a tight schedule. Although the precast yards provide better quality compared to on-site procedures, they are often exposed to weather conditions and does therefore not produce the same quality than that of precast factories. These durability aspects are more beneficial when manufacturing takes place inside a precast factory (Vermeulen, 2013).

The identified durability aspects should be investigated during the initial stages of a project. These factors can assist project teams for a decision between in-situ concrete construction and HCC, in terms of maintenance.

7.4 Chapter conclusion

This chapter identified and discussed the cost and time factors for a decision between in-situ concrete construction and HCC during the maintenance phase of a project.

It is concluded that similar maintenance and repair techniques are required for structures constructed with in-situ concrete and HCC. The main difference is that the service life, before maintenance is required, is longer for structures constructed with HCC. HCC therefore require less maintenance and repair work over the lifespan period when compared to structures constructed with in-situ concrete.

It has also been established that a maintenance budget during the initial stages of the operational phase is important in order to estimate future maintenance costs.

HCC is said to deliver more durable structures when compared to in-situ concrete construction. The reason for this is that precast elements are manufactured in controlled circumstances. This chapter identified the various factors that may have an influence on the durability of structures constructed with in-situ concrete and HCC. Table 7.2 provides the factors that need to be considered for a decision between in-situ concrete construction and HCC during the maintenance phase of a project.

Table 7.2: Maintenance phase factors for a decision between in-situ concrete construction and HCC

Factors		**In-situ concrete construction**	**HCC**
Service life		Shorter lifespan before maintenance is required	Longer lifespan before maintenance is required
Routine and preventative maintenance		Similar maintenance activities required	Similar maintenance activities required
Repairs, rehabilitation and restoration costs		Similar activities, however shorter life span. Therefore potentially more cost required	Similar activities, however longer life span. Therefore potentially less cost required
Durability considerations	**Location**	Difficult to reach similar quality standards on construction sites	More controlled environment, better quality
	Temperature & weather conditions	Affected by temperature and weather conditions	Not affected by temperature and weather conditions
	High-strength concrete	Usually normal strength concrete	Increased strength, however more expensive
	Cover to reinforcement	Often difficult to control due to difficult site conditions.	Easy to control concrete cover
	Joints & Connections	Less complex to maintain, potentially reduced cost	More complex to maintain, potentially more cost

Chapter 8

Conclusions

This chapter presents a summary of the main findings that were obtained in the study.

8.1 The state of the South African construction industry

The construction industry is a competitive market and contractors need to keep up-to-date with new construction methods and technologies. The application of in-situ concrete in construction is the conventional method for concrete construction in South Africa. The implementation of precast elements in construction has, however, increased during the last decade, where contractors and clients realize the time, cost and quality benefits that this method of construction has to offer. It is not often that a structure is constructed fully of precast elements. Hybrid concrete construction (HCC) is a combination of in-situ concrete and precast concrete elements. The applications of this method are, however, hindered in the construction industry of South Africa. Some of the obstacles that hinder the implementation of HCC are a lack of sufficient information and guidelines for the use thereof. Many professionals in the industry, however, acknowledge the fact that there is a future for the use of HCC and that this method may be a solution for time and cost overruns in the construction industry in South Africa.

8.2 The importance of time, cost and quality

The construction industry in South Africa acknowledges the fact that there are numerous success factors that indicate the success of a project, such as time, cost, quality, environmental performance, socio economic aspects (labour), safety and client satisfaction. Project success measurement has and still is, however, dominated by the conventional measures of time, cost and quality, where cost remains the principle success indicator. Both time and quality in construction projects have an indirect impact on the cost. It is therefore important to consider these two indicators in relation with project cost. It was also mentioned that the structure of a building represents typically only 10 % of the total construction cost. It is therefore important to consider the whole life cycle cost of construction projects when deciding between various construction methods.

8.3 The decision

Project teams are usually required to make decisions during the early stages of construction projects. These decisions often need to be made in a short time period, and include the decision between various construction methods, such as the decision between in-situ concrete construction and HCC. Due to insufficient information available on the use of HCC, project teams often decide to construct with the conventional method of in-situ concrete construction, without investigating the alternative of HCC. This study therefore investigated and discussed the factors that might have an influence on the time and cost for a decision between in-situ concrete construction and HCC.

8.4 Life cycle cost

Construction projects consist of various phases which form part of a project life cycle. In order to identify and discuss the various factors that have an influence on the time and cost of construction projects, all phases throughout the life cycle were investigated. These phases include the design phase, construction phase and maintenance phase.

A theoretical example project was formulated in the study to show the effect of time savings during the construction phase on the life cycle cost of a project. This example has shown that the yearly income required in order to break even after a usage period of 30 years can be reduced by 2.67 % when the construction duration is reduced by 20 %. Further evaluations were performed for reduced construction durations, varying construction cost and reduced maintenance cost, to observe the effect thereof on the life cycle cost of a project. It was shown that a shorter construction time, reduces the required yearly income in order to break even, and an increase in construction cost, increases the yearly income required to break even. It was also shown that as the maintenance cost increases as a percentage of the initial cost, an increase in yearly income is required to break even.

These examples were not exact project values, however, it demonstrated that project teams should consider the effect of time savings, construction cost savings and reduced maintenance cost on the life cycle cost of a project in the decision between various construction methods.

8.5 Design time and cost factors

The design factors that have an influence on the time and cost for in-situ concrete construction and HCC were identified through interviews, conducted with professional consultants in the industry. It was found that HCC is more dependant on standardization and repetition when compared to the conventional design of in-situ concrete construction. Therefore, when standardization and repetition is limited in a construction project, in-situ concrete construction might be the preferred method of construction.

It is still argued that sufficient guidance on the design of HCC is limited in South Africa. HCC designs are therefore required to be designed from first principles, which may be time consuming. Many consultants, therefore, choose to design for the conventional method of in-situ concrete construction. There are certain factors that may result in additional time and cost in the implementation of HCC that need to be considered. These factors include the technical aspects, such as, connection design, yard and equipment design and the related extras.

Another key factor during the design phase is early involvement and collaboration amongst the various role players. Late changes to a project may have a larger effect on HCC when compared to in-situ concrete construction. Early involvement and collaboration are important in order to eliminate potential late changes in a project. Contract strategies that encourage early involvement and collaboration, such as the design-build approach, are therefore important in reducing project changes, especially for the implementation of HCC.

8.6 Construction phase

A variety of projects in South Africa, which were constructed over the last decade with the implementation of HCC have been investigated and introduced in this study with the use of case studies. The information on these case studies was obtained through site visits to the various projects and through discussions with a representative from the respective project teams. These case studies were used to identify the construction factors that have an influence on the time and cost for the decision between in-situ concrete construction and HCC. The identified factors were categorised under four categories, namely logistics, material, equipment and construction. The impact on these factors was found to be project dependant, and the results therefore may vary for each situation. The primary motivation for the use of HCC is the result of a shorter construction period. The factors in the construction phase therefore depend on the client's needs. In some cases the client may pay more to benefit from a faster return on investment. In other cases, clients will opt for an economical option that might be more time consuming during the construction phase.

8.7 Maintenance phase

Maintenance and repair techniques required are similar for structures constructed with in-situ concrete and HCC. The main difference is that the service life, before maintenance is required, is usually longer for structures constructed with HCC. HCC is also said to deliver more durable structures, due to precast elements being manufactured in controlled circumstances. The maintenance factors that have an influence on time and cost for in-situ concrete construction and HCC are presented in Figure 8.1.

8.8 Preliminary framework for the decision between HCC and in-situ concrete construction

Figure 8.1, displays the identified factors throughout the life cycle of construction projects that may have an influence on the time and cost of a project. This framework can be used to assist project teams in their decision between in-situ concrete construction and HCC.

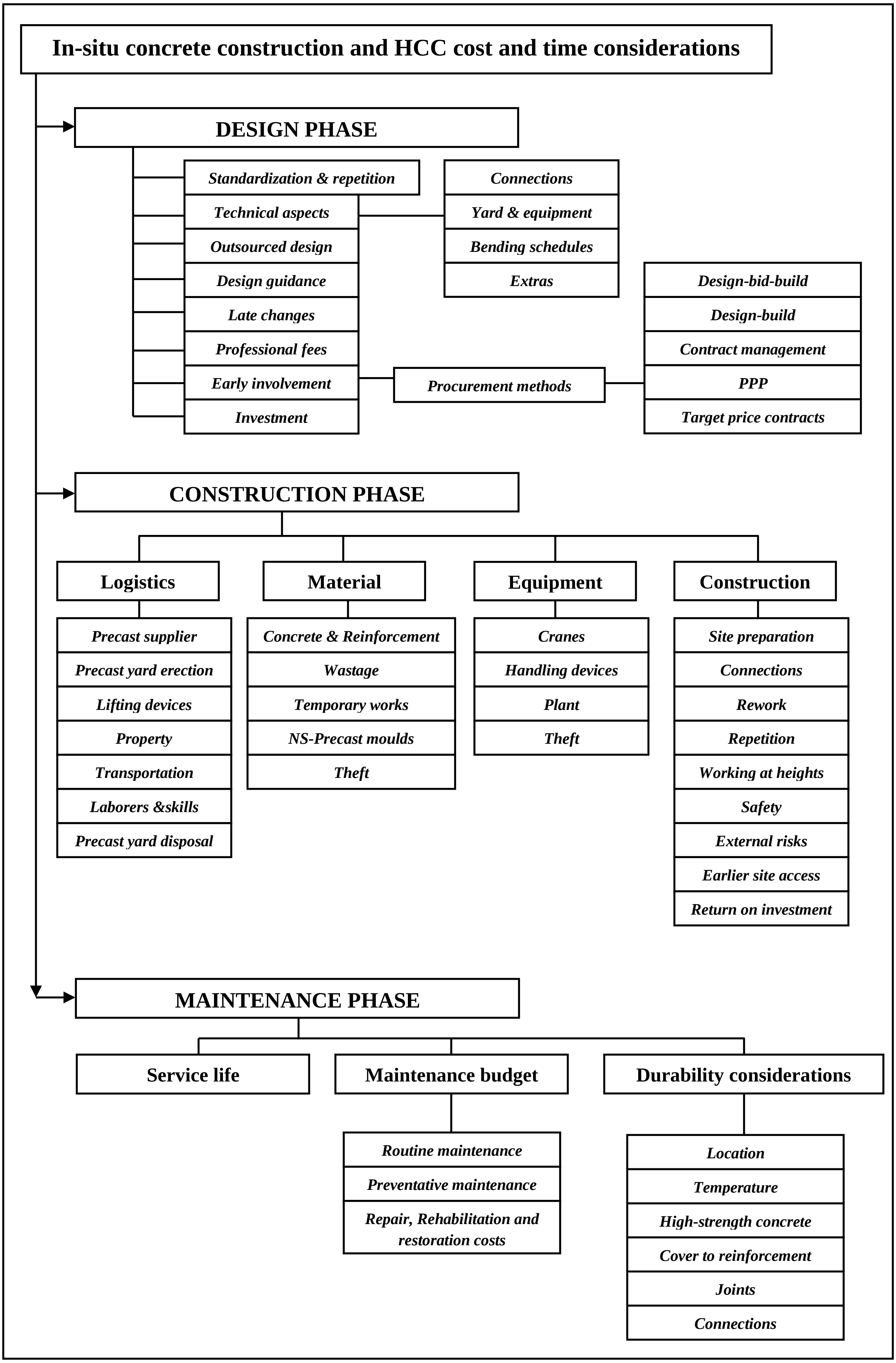

Figure 8.1: Framework of influential time and cost factors

Chapter 9

Recommendations

This study investigated the time and cost factors for a decision between in-situ and hybrid concrete construction. Based on the findings of this study, the following recommendations are made.

9.1 Recommendations for the South African construction industry

9.1.1 Guidance

Many professionals in the industry have mentioned that sufficient guidelines and information are limited on the implementation of HCC. The SANS 10100:2000 provides limited guidance on the topic of precast concrete and hybrid concrete construction (HCC). It is therefore suggested that the SANS 10100:2000 code, be updated. The updated code should include all the required design aspects and considerations on precast concrete and HCC. The updated code could improve the utilization of HCC in South Africa. In addition, it is suggested that precast design needs to be incorporated in the education and training of all structural design engineers, so that the concept can be confidently investigated as an alternative during the initial stages of a project.

9.1.2 Procurement strategies

The design-bid-build approach is the traditional method of tendering and is based on the separation of the design and construction phases. In the construction industry in South Africa, most designs are done for the conventional method of in-situ concrete construction. Once the design has been completed, the contractor occasionally requests to construct with an alternative method of HCC. When the alternative is accepted, the designs need to be redesigned or adjusted. This could have been prevented if the contractor was involved during the initial stages of the project. Therefore, it is advised to use the design-build, contract management, PPP or target price contract procurement methods. These methods encourage early involvement and collaboration amongst parties to provide the best value project for the client. Early involvement also gives contractors the opportunity to propose more buildable projects.

9.1.3 Maintenance considerations

The information available on maintenance cost and requirements for HCC vs. in-situ concrete construction is limited. Therefore, it is suggested that maintenance and overall failures should be monitored for structures constructed with HCC and in-situ concrete. These results can assist to compare the maintenance requirements, and consequently the durability of in-situ concrete and HCC applications.

9.1.4 South African database

All projects constructed with the implementation of precast concrete elements and HCC methods should be recorded on a database that can be used for future projects. This database can assist project teams during the initial stages of a project to make informed decisions on the design and use of HCC. The following information for the database will be useful:

- Description of the project
- Precast elements used
- Procurement method selected and motivations
- Challenges and potential guidelines during the design phase
- Challenges and potential guidelines during the construction phase
- Problems encountered during the use phase
- Maintenance requirements and associated costs

9.2 Future research suggestions

9.2.1 Transportation of precast elements in South Africa (Section 6.1.5)

De Klerk (2013) mentioned that 200 kilometres of travelling distance are the average where transportation of precast elements remains a feasible option. The Longridge reservoir (Case Study 3), however, contradicts De Klerk's (2013) statement. Precast elements for the Longridge reservoir were transported from Polokwane to Bloemfontein, a distance of over 700 kilometres, and have shown to be a feasible option. It is therefore suggested that the transportation of precast elements be further investigated. This investigation should determine to which point, in terms of distance, does it remain viable to transport precast elements. Such an in investigation should also determine the transportation cost as a percentage of the total project cost, and should investigate how manufacturers determine these costs. Limitations to the sizes of precast elements, as specified, can also be investigated.

9.2.2 HCC labour requirements, in South African context (Section 6.1.6)

Labour is a major concern in South Africa, as the country experiences a high unemployment rate of 24 %. One of the principle objectives of the Department of Labour is therefore to contribute to employment creation and skills development. Although South African industries attempt to apply construction methods that are labour intensive, the budgets of construction projects are often too tight to appoint more labourers. Therefore, it is suggested to investigate labour requirements for HCC and to compare the results with the requirements of in-situ concrete construction. Such an investigation should also address the impact that this concern might have on socio economic aspects, such as community development.

9.2.3 Quantification of factors (Section 6.2.6)

Many factors that have an influence on the time and cost for a decision between in-situ concrete construction and HCC have been identified in this study. It is, however, difficult to quantify these factors. Future investigations are therefore suggested in this field to quantify, or to provide methods and guidelines in order to quantify these factors. A useful addition would be the prioritization of the identified factors in Figure 8.1.

9.2.4 Crane selection for HCC vs. in-situ concrete construction (Section 6.3.1)

Effective crane hiring for construction projects can result in potential cost savings. There is not much literature available on the factors that have an influence on the cost of cranes for the implementation of HCC. Future studies are therefore suggested in the field of crane requirements for the implementation of HCC vs. in-situ concrete construction. This comparison of crane selection and scheduling should show which method is economically more viable in terms of crane selection, and should indicate the impact that crane scheduling has on the construction time and cost of construction projects.

9.2.5 Rework of HCC (Section 6.3.1)

Rework represents up to 5 % of the total construction cost for structures constructed with in-situ concrete. The literature available on rework required for HCC is limited. Future studies are therefore suggested in this field. Such an investigation should monitor the amount of rework required on structures constructed with HCC in order to compare the short-term quality of in-situ concrete construction and HCC. This investigation would also assist project teams in identifying the primary causes of rework, so that these issues can be addressed.

9.2.6 Precast yards vs. precast factories (Section 7.3)

In the construction industry of South Africa, contractors often erect their own precast yards. It is argued that these yards do not reach the same quality standards compared to precast factories. These yards often manufacture the elements at a rapid pace, in a tight schedule. It is therefore suggested to investigate and compare the quality of in-situ concrete construction, precast concrete elements, as constructed on precast yards during construction projects, and precast factory elements, as manufactured by precast suppliers. This investigation will show the quality standards of the three different methods of manufacturing concrete elements.

Chapter 10

References

1. Akinsola, A., Potts, K., Ndekugri, I. & Harris, F. 1997. Identification and Evaluation of Factors Influencing Variations on Building Projects. *International Journal of Project Management*, 15(4):263-7.
2. Aksorn, T. & Hadikusumo, B. 2008. Critical Success Factors Influencing Safety Program Performance in Thai Construction Projects. *Safety Science*, 46(4):709-27.
3. Andam, K. & Knapton, J. 1980. Optimum Cost Design of Precast Concrete Framed Structures. *Engineering Optimization*, 5(1):41-9.
4. Arditi, D., Ergin, U. & Günhan, S. 2000. Factors affecting the use of Precast Concrete Systems. *Journal of Architectural Engineering*, 6(3):79-86.
5. Atkinson, R. 1999. Project Management: Cost, Time and Quality, Two Best Guesses and a Phenomenon, its Time to Accept Other Success Criteria. *International Journal of Project Management*, 17(6):337-42.
6. Baker, R.D. 1991. *Time-Cost Relationships in Construction, University of Florida.*
7. Baldwin, A., Poon, C., Shen, L., Austin, S. & Wong, I. 2009. Designing Out Waste in High-Rise Residential Buildings: Analysis of Precasting Methods and Traditional Construction. *Renewable Energy*, 34(9):2067-73.
8. Baloyi, L. & Bekker, M. 2011. Causes of Construction Cost and Time Overruns: The 2010 FIFA World Cup Stadia in South Africa. *Acta Structilia*, 18(1):51-67.
9. Bargstädt. Complementary construction elements: Course for construction management. 2013, Stellenbosch University
10. Barrett, P. 2003. Hybrid Concrete: Improved Processes and Performance. *Structures & Buildings*, 156(2):193-203.
11. Beer, D. 2009. Gautrain Precast Concrete Yard-Achieving More with Less. *Civil Engineering= Siviele Ingenieurswese*, 17(6):46-9.
12. Bergh, G. Site visit interview with regards to cape town dispatch plant. 2014, Group five, Cape Town, South Africa
13. Bison, Concrete Limited. 2014. *Precast concrete construction.* [Online]. Available: http://www.wrap.org.uk/sites/files/wrap/Offsite%20Precast%20concrete.pdf [18 February]
14. Botha, P. Personal interview with regards to precast concrete design. 2014, VBL Consultants, Pollokwane, South-Africa
15. Brown, J. 2014. *Construction and plant hire - investigation service.* [Online]. Available: http://www.investigators.co.za/construction.html [May]

16. Bubshait, A.A. & Almohawis, S.A. 1994. Evaluating the General Conditions of a Construction Contract. *International Journal of Project Management*, 12(3):133-6.

17. Burati Jr, J.L., Farrington, J.J. & Ledbetter, W.B. 1992. Causes of Quality Deviations in Design and Construction. *Journal of Construction Engineering and Management*, 118(1):34-49.

18. Burgess, V. 2013. Temporary Works. Paper presented at Construction Management module. Stellenbosch. August 2013.

19. C&CI. 2014. *Promoting precast concrete usage – also for structural engineering.* [Online]. Available:http://www.idconline.com/technical_references/pdfs/civil_engineering/Promoting_precast_concrete_usage.pdf [20 May]

20. CCANZ. 2014. *Concrete answers.* [Online]. Available: http://www.ccanz.org.nz/page/Precast-Concrete.aspx [22 January]

21. CCANZ. 2014. *Concrete answers.* [Online]. Available: http://www.ccanz.org.nz/page/In-Situ-Concrete.aspx [22 January]

22. Ceco. 2014. *Advantages for cast in place parking structures.* [Online]. Available: http://www.cecoconcrete.com/Resources/WhyConcrete_Files/CIP%20Advantages%20to%20Parking%20Structures.pdf [18 February]

23. Cement Sustainability Initiative. 2014. *Sustainability benefits of concrete.* [Online]. Available: http://www.wbcsdcement.org/index.php/about-cement/benefits-of-concrete [21 January]

24. Chan, A. 2001. Framework for Measuring Success of Construction Projects. *Benchmarking: An International Journal*

25. Chan, A.P. 1996. Determinants of Project Success in the Construction Industry of Hong Kong. *Benchmarking: An International Journal*

26. Chan, A.P. & Chan, A.P. 2004. Key Performance Indicators for Measuring Construction Success. *Benchmarking: An International Journal*, 11(2):203-21.

27. Chan, A.P., Scott, D. & Lam, E.W. 2002. Framework of Success Criteria for design/build Projects. *Journal of Management in Engineering*, 18(3):120-8.

28. Chan, D.W., Chan, A.P., Lam, P.T. & Wong, J.M. 2011. An Empirical Survey of the Motives and Benefits of Adopting Guaranteed Maximum Price and Target Cost Contracts in Construction. *International Journal of Project Management*, 29(5):577-90.

29. Chan, TK. 2014. *Mechanisation in construction – A Malaysian perspective.* [Online]. Available: http://www.conference.net.au/cibwbc13/papers/cibwbc2013_submission_111.pdf [January 2014]

30. Chen, M. & Wang, S. 2010. A Hybrid Delphi-Bayesian Method to Establish Business Data Integrity Policy: A Benchmark Data Center Case Study. *Kybernetes*, 39(5):800-24.

31. Chow, G., Heaver, T.D. & Henriksson, L.E. 1994. Logistics Performance: Definition and Measurement. *International Journal of Physical Distribution & Logistics Management*, 24(1):17-28.

32. CIDB. 2014. *Synthesis review of the South African construction industry and its development.* [Online].Available:http://www.cidb.org.za/Documents/KC/cidb_Publication/Ind_Reps_other/Ind_reps_status_report_2004.pdf [9 January 2014]

33. Claase, J. 2010. *Achieving Alignment of the Objectives of the Role Players in a Typical Construction Industry,*

34. Concrete Network. 2014. *Advantages of precasting.* [Online]. Available: http://www.concretenetwork.com/precast-concrete/advantages.html [19 February]

35. Corestruc. 2014. *Concrete elements.* [Online]. Available: http://www.corestruc.co.za/concrete-elements/ [27/0302014]

36. CPCI. 2014. *Precast concrete construction.* [Online]. Available: http://faculty.delhi.edu/hultendc/A220-Week5-Lecture.htm [25 January]

37. Dawson , Susan. 2014. *Cast in concrete.* [Online]. Available: http://www.britishprecast.org/documents/CastinConcrete.pdf [19 February]

38. De Klerk, D. 2013. *Precast Modular Construction of Schools in South Africa, Unpublished, MEng at Stellenbosch University, South Africa*

39. De Lange, J. Personal interview with regards to precast concrete design. 2014, BVI consulting engineers, Cape Town, South Africa

40. Dictionary, O.E. 2008. *Oxford English dictionary online.* Oxford University Press, Oxford, UK http://www.oed.com

41. Driscoll , Thomas J. 2014. *Managing the time factor.* [Online]. Available: http://www.constructionadvisoryreport.com/home/blog/2013/09/11/managing-the-time-factor/ [26 March 2014]

42. Ebbesen, J.B. & Hope, A. 2013. Re-Imagining the Iron Triangle: Embedding Sustainability into Project Constraints. *PM World Journal,* 2(III):

43. ECHO. 2014. *Pioneers of hollowcore in South Africa.* [Online]. Available: http://www.echo.co.za/ [June 2014]

44. ECSA. 2013. Government Gazette Staatskoerant. Paper presented at South African professional fees. 37102. 2014.

45. Egan, J. 1998. The Egan Report-Rethinking Construction. *Report of the Construction Industry Task Force to the Deputy Prime Minister.London,*

46. Elbeltagi, Emad. 2014. *Cost of construction labor and equipment.* [Online]. Available: http://osp.mans.edu.eg/elbeltagi/Cost%20Ch4.pdf

47. Elliott, K. 2002. *Precast concrete structures.* Elsevier

48. Estes, A.C. & Frangopol, D.M. 2001. Minimum Expected Cost-Oriented Optimal Maintenance Planning for Deteriorating Structures: Application to Concrete Bridge Decks. *Reliability Engineering & System Safety,* 73(3):281-91.

49. Farinloye et al. 2013. Theft and Vandalism Control Measures on Building Sites in Lagos, Nigeria. *Journal of Engineering, Project, and Production Management*, 3(1):9-21.

50. Fliss, L. Personel interview with regards to precast concrete design. 2014, Lyonell FLiss and associates, Johannesburg, South Africa

51. Fuller, S. 2010. Life-Cycle Cost Analysis (LCCA). *National Institute of Building Sciences, an Authoritative Source of Innovative Solutions for the Built Environment*, 1090

52. Gibb, A.G. & Isack, F. 2001. Client Drivers for Construction Projects: Implications for Standardization. *Engineering Construction and Architectural Management*, 8(1):46-58.

53. Gibb, A.G. & Isack, F. 2001. Client Drivers for Construction Projects: Implications for Standardization. *Engineering Construction and Architectural Management*, 8(1):46-58.

54. Glass, J. 2005. A Best Practice Process Model for Hybrid Concrete Construction . *Construction Management and Economics*, Volume 1[Online], Available: 169-184file:///H:/Meesters/Theusis/Artikels/0144619042000326756.pdf27 February, 2014

55. Glass, J., Federation, B.P.C. & British Cement Association. 2000. *The future for precast concrete in low-rise housing.* British Precast Concrete Federation Leicester

56. Goodchild, C. & Glass, J. 2004. Best Practice Guidance for Hybrid Concrete Construction. *The Concrete Centre, Camberley*,

57. GPS Precast Concrete. 2014. *Precast concrete - history*. [Online]. Available: http://www.gpsprecastconcrete.co.uk/blog/precast-concrete-history/ [19 February]

58. Guo, H., Li, H. & Skitmore, M. 2009. Life-Cycle Management of Construction Projects Based on Virtual Prototyping Technology. *Journal of Management in Engineering*, 26(1):41-7.

59. Guo, S. 2002. Identification and Resolution of Work Space Conflicts in Building Construction. *Journal of Construction Engineering and Management*, 128(4):287-95.

60. Gupta, P.R. & Shui, N.B. 2014. Effective Repair and Maintenance Strategies for Parking Structures. *Concrete Repair Bulletin*, 1ste volume(July/August):

61. Hanekom, R. 2011. *Increasing the Utilisation of Hybrid Concrete Construction in South Africa, Unpublished,MEng at Stellenbosch University, South Africa*

62. Hanna, A.S. & Lotfallah, W.B. 1999. A Fuzzy Logic Approach to the Selection of Cranes. *Automation in Construction*, 8(5):597-608.

63. Harcourt, Port. 2014. *Advantages and disadvantages of precast concrete construction.* [Online]. Available:http://cw2011workshop05.wordpress.com/2011/09/22/advantages-and-disadvantages-of-precast-concrete-construction/ [February 25]

64. Hartman, Denis. 2014. *The advantages and disadvantages of cast-in-place concrete.* [Online]. Available:http://www.ehow.com/info_12165031_advantages-disadvantages-castinplace-concrete.html [18 February]

65. Hewitt, M. & Gambatese, J. 2003. Automation Consideration during Project Design. *Nist Special Publication Sp*, 197-204.

66. HSE. 2014. *Health & safety statisctics.* [Online]. Available: http://www.hse.gov.uk/statistics/ [June]
67. Huemer, L. 2004. Activating Trust: The Redefinition of Roles and Relationships in an International Construction Project. *International Marketing Review*, 21(2):187-201.
68. Hussin, A.A. & Omran, A. 2009. Roles of Professionals in Construction Industry.
69. Hwang, B., Thomas, S.R., Haas, C.T. & Caldas, C.H. 2009. Measuring the Impact of Rework on Construction Cost Performance. *Journal of Construction Engineering and Management*, 135(3):187-98.
70. Illingworth, J.R. 2002. *Construction methods and planning.* CRC Press
71. Irish Concrete Federation. 2014. *Benefits of precast.* [Online]. Available:http://www.irishconcrete.ie/benefits_of_precast.html [19 February]
72. Jaillon, L., Poon, C. & Chiang, Y. 2009. Quantifying the Waste Reduction Potential of using Prefabrication in Building Construction in Hong Kong. *Waste Management*, 29(1):309-20.
73. James, S. 2011. Review of Education Capital, *Gov.UK.*
74. Jari, A.J. & Pankaj, P.B. 2013. To Study Critical Factors Necessary for a Successful Construction Project. *International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075*, Volume 2(Issue 5):
75. Jhonson. 2014. *Jhonson crane hire south africa.* [Online]. Available: http://www.jch.co.za/projects.php [February]
76. Jordaan, T. Personal interview with regards to precast concrete design. 2014, LMV consultants, Bloemfontein, South Africa
77. Jurgens, C.J. 2008. *An Investigation into the Feasibility of Hybrid Concrete Construction in South Africa, Unpublished, MEng at Stellenbosch University, South Africa*
78. Khosravi, S. & Afshari, H. 2011. A Success Measurement Model for Construction Projects. *International Proceedings of Economics Development & Research*, 11
79. Kimbrey, K. Email descussion on maintenance cost for in-situ and precast concrete structures
80. Latham, M. 1994. Constructing the Team: Final Report of the government/industry Review of Procurement and Contractual Arrangements in the UK Construction Industry. *The Stationery Office, London,*
81. Le Roux, G. Site visit interview with regards to the precast longridge reservior. 2014, Ruwacon, Bloemfontein, South Africa
82. Leland, B. 2012. *Engineering economy.* New York: Mcgraw Hill
83. Lim, C. & Mohamed, M.Z. 1999. Criteria of Project Success: An Exploratory Re-Examination. *International Journal of Project Management*, 17(4):243-8.
84. Lombard, A. 2011. *Decision Making between Hybrid and in-Situ Concrete Construction in South Africa, Unpublished, MEng at Stellenbosch University, South Africa*

85. Mangaung Municipality. 2014. *Total number of househould in mangaung metropoltan municipality*. [Online]. Available: http://www.mangaung.co.za/wp-content/uploads/2014/03/MANGAUNG-SERVICE-DELIVERY-LEAFLET.pdf [April 2014]

86. Marsh, M.L. 2011. *Application of accelerated bridge construction connections in moderate-to-high seismic regions.* Transportation Research Board

87. Marx, H. 2012. Results of the 2011 Survey of the CIDB Construction Industry Indicators, *CIDB.*

88. Miles, W.R. and Bergman, D.J. 1993. Comparison of Cast-in-Place Concrete Versus Precast Concrete Stay-in-Place Forming Systems for Lock Wall Rehabilitation. Paper presented at Us Army corps of engineers. 1st. October 1993.

89. NPA. 2004. Parking Garage Maintenance Manual. *Parking Garage Maintenance Manual, Guide for Maintenance and Repair,* (fourth edition):

90. Oladinrin, T., Ogunsemi, D. & Aje, I. 2012. Role of Construction Sector in Economic Growth: Empirical Evidence from Nigeria. *FUTY Journal of the Environment,* 7(1):50-60.

91. Parfitt, M. & Sanvido, V. 1993. Checklist of Critical Success Factors for Building Projects. *Journal of Management in Engineering,* 9(3):243-9.

92. Parmenter, D. 2010. *Key performance indicators (KPI): Developing, implementing, and using winning KPIs.* John Wiley & Sons

93. PCA, Americas Cement Manufacturers. 2014. *Building systems.* [Online]. Available: http://www.cement.org/think-harder-concrete-/homes/building-systems [20 January]

94. PCI. 2014. *Life cycle costs.* [Online]. Available: http://www.gcpci.org/index.cfm/precast_solutions/life [10 July]

95. Perrine, R. 2013. *Project management.* [Online]. Available: http://www.robertperrine.biz/Perrine2004/Perrine_PM_Notes.html [June]

96. Perry, J.G. & Barnes, M. 2000. Target Cost Contracts: An Analysis of the Interplay between Fee, Target, Share and Price. *Engineering Construction and Architectural Management,* 7(2):202-8.

97. Poon, C., Yu, A.T. & Jaillon, L. 2004. Reducing Building Waste at Construction Sites in Hong Kong. *Construction Management and Economics,* 22(5):461-70.

98. Pretorius, S. Personal interview with regards to precast design. 2014, Aurecon, Bloemfontein, South Africa

99. Quinn, C. 2014. *Precast concrete.* [Online]. Available: http://www.irishconcrete.ie/downloads/Precast_concrete_frames_guide.pdf [April]

100. Ronne, H. Personel interview with regards to precast concrete design. 2014, SMEC consulting engineers, Bloemfontein, South Africa

101. Sadeh, A., Dvir, D. & Shenhar, A. 2000. The Role of Contract Type in the Success of R&D Defense Projects Under Increasing Uncertainty. *Project Management Journal,* 31(3):14-22.

102. Sandt, E. 2014. *Structural concrete design*. [Online]. Available: http://www.slideshare.net/gloryglow/structural-system-overview [17 February]

103. Shapira, A. & Lyachin, B. 2009. Identification and Analysis of Factors Affecting Safety on Construction Sites with Tower Cranes. *Journal of Construction Engineering and Management*, 135(1):24-33.

104. Shen, L., Tam, V.W. & Li, C. 2009. Benefit Analysis on Replacing< i> in situ</i> Concreting with Precast Slabs for Temporary Construction Works in Pursuing Sustainable Construction Practice. *Resources, Conservation and Recycling*, 53(3):145-8.

105. Shrnhur, A.J., Levy, O. & Dvir, D. 1997. Mapping the Dimensions of Project Success. *Project Management Journal*, 28(2):5-13.

106. SIGMA CONSULTING. 2014. *VWSA new paint shop*. [Online]. Available: http://www.sigmaconsulting.co.za/Projects/VWSA.htm [2006]

107. Singhose, W.E., Porter, L.J. and Seering, W.P. 1997. Input Shaped Control of a Planar Gantry Crane with Hoisting. Paper presented at Proceedings of the American Control Conference.

108. Soetanto, R., Glass, J., Dainty, A. & Price, A. 2007. Structural Frame Selection: Case Studies of Hybrid Concrete Frames. *Building Research and Information*, 35(2):206-19.

109. StatsSA. 2014. *Crime statstics in south africa*. [Online]. Available: http://www.crimestatssa.com/

110. Stefanutti Stocks. 2014. *Stefanutti stocks constructs 15 000 ton precast coal bunker for sasol mining*. [Online]. Available: http://www.stefanuttistocks.com/Medianews/PressOffice/tabid/146/articleType/ArticleView/articleId/196/Stefanutti-Stocks-constructs15-000-ton-precast-coal-bunker-for-Sasol-Mining.aspx [20 May]

111. Stefanutti Stocks. 2014. *Finishing touches made to groote exxaro grootegeluk medupi expansion*. [Online]. Available: http://www.stefanuttistocks.com/Medianews/PressOffice/tabid/146/articleType/ArticleView/articleId/193/Finishing-touches-made-to-Exxaro-Grootegeluk-Medupi-expansion.aspx [Jul 2013]

112. Sullivan, W.G., Wicks, E.M. & Luxhoj, J.T. 2009. *Engineering economy*. Pearson Prentice Hall

113. Sultan, Munir. 2014. *Precast concrete*. [Online]. Available: http://www.cmguide.org/archives/2006

114. Swan, W. & Kyng, E. 2005. An Introduction to Key Performance Indicators. *Manchester: Centre for Construction Innovation.[Links]*,

115. Tam, C., Deng, Z. & Zeng, S. 2002. Evaluation of Construction Methods and Performance for High Rise Public Housing Construction in Hong Kong. *Building and Environment*, 37(10):983-91.

116. Tesit. 2014. *Crane dependant and slip formwork*. [Online]. Available: http://slipformwork.com/proizvodstvo_opalubki [17 February]

117. The Concrete Centre. 2014. *Modren methods of construction.* [Online]. Available: http://www.concretecentre.com/technical_information/building_solutions/modern_methods_of_construction.aspx [4 February 2014]

118. The Concrete Centre. 2014. *Hybrid concrete construction.* [Online]. Available: http://www.concretecentre.com/technical_information/building_solutions/frame_elements/hybrid_concrete_construction.aspx [9 January]

119. Theunissen, N. 2012. Top-Down Acceleration. *The civil engineering contractor*, (36). http://www.myvirtualpaper.com/doc/brookepattrick/the_civil_engineering_contractor_october_2012_ebook/2012100301/36.html#36May 2014

120. Toor, S. & Ogunlana, S.O. 2010. Beyond the 'iron Triangle': Stakeholder Perception of Key Performance Indicators (KPIs) for Large-Scale Public Sector Development Projects. *International Journal of Project Management*, 28(3):228-36.

121. Value Group. 2014. *About value group.* [Online]. Available: http://www.value.co.za/about.aspx [22 May]

122. Van Leeuwen, J. & Fridqvist, S. 2006. An Information Model for Collaboration in the Construction Industry. *Computers in Industry*, 57(8):809-16.

123. Vermeulen, F. Site visit interview with regards to coal bunker construction. 2014, Stefanutti Stocks,Secunda, South Africa

124. Visagie, C. Personal interview with regards to precast concrete design. 2014, MVD Mangaung,Bloemfontein, South Africa

125. Vollert, H., Brandt, B. & Kaspar, A. 2014. *For your precast concrete production you want a partner who can offer you customized plant concepts and state-of-the-art machine technology.* [Online]. Available: http://www.vollert.de/fileadmin/inhalte/de/02-unternehmen/05_info-center/02_media_downloads/Ausgabe_BR_Betonfertigteile_EN_web.pdf [May 2014]

126. Woodward, D.G. 1997. Life Cycle costing—theory, Information Acquisition and Application. *International Journal of Project Management*, 15(6):335-44.

127. Xie, X. & Simon, M. 2006. Simulation for Product Life Cycle Management. *Journal of Manufacturing Technology Management*, 17(4):486-95.

128. Xihua. 2014. Green Energy-Saving, Modular Deployment——Data Center Service Solution. *ZTE Technologies*, (Number 4):

129. Yee, A.A. 2001. Structural and Economic Benefits of precast/prestressed Concrete Construction. *PCI Journal*, 46(4):34-43.

Appendix A

Life cycle cost comparison

This appendix includes a theoretical comparison of the life cycle cost for in-situ and hybrid concrete construction.

Example project:

An example project has been formulated to show the effect of time savings during the construction phase on the life cycle cost of a project. For the example project an in-situ concrete construction project was compared to a HCC project. The objective of this comparison is to estimate the value of time, therefore to determine the effect of time saved during the construction phase on project life cycle cost.

For the example project it is assumed that the duration and cost of the design phase and maintenance phase is the same for both in-situ concrete construction and HCC. It is also assumed that the construction cost for both methods are equal. The only difference for the two construction methods is the duration of the construction phase. For in-situ concrete construction the duration of the construction phase is 15 months, whereas for the HCC method the duration of the construction phase is 12 months. The example aims to estimate the effect of the 3 months construction time saved on the life cycle cost of the project. This estimation is done by calculating the yearly income required in order to break even after a usage period of 30 years. The following fictional values are used for the example project:

Construction cost: The construction cost for the material of both projects is R 54, 000,000. This amount is paid in equal monthly payments over the construction phase of the project.

The monthly running cost of the project is estimated to be an additional R 360,000. This is applied for both construction methods of in-situ concrete construction and HCC. The total running costs throughout the duration of the construction phase is 10 % of the construction costs.

Construction cost: The duration of in-situ concrete construction is 15 months.

The duration of HCC is 12 months.

Design cost: The design cost for both methods of construction is R 4,200,000. This is estimated as 7 % of the project cost.

Maintenance: The annual maintenance cost for both the construction methods is R 540,000. This is estimated as 1 % of the project cost.

Interest rate: The monthly interest rate is 0.75 %.

Structure usage: The use phase of the structure is 30 years.

Figures 3.5 and Figure 3.6 presents the cash flow diagrams of in-situ concrete construction and HCC respectively. These diagrams include the various costs and durations throughout the life cycle of the project.

In-situ concrete construction

Figure 3.5, presented in Chapter 3, is a presentation of the cash flow diagram for the project constructed with in-situ concrete. The monthly construction payment for the 15 months is R 54,000,000/15 + R 360,000 = R 3,960,000.

The present value for the construction costs of the project is:

$$P_{\text{construction}} = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] = R\ 3{,}960{,}000\left[\frac{(1+0.0075)^{15} - 1}{0.0075(1+0.0075)^{15}}\right] = R\ 55{,}982{,}500$$

The calculated present value for the annual maintenance after the first year of usage is:

$$P_{\text{maintenance(year 1)}} = F\left[\frac{1}{(1+i)^n}\right] = R\ 540{,}000\left[\frac{1}{(1+0.0075)^{27}}\right] = R\ 441{,}344$$

The calculated present value for maintenance is then determined for each year respectively, up to 30 years. The total maintenance present value is then:

$$P_{\text{maintenance}} = R\ 4{,}796{,}806$$

The total present value is therefore:

$$\begin{aligned} P_{\text{total}} &= P_{\text{design}} + P_{\text{construction}} + P_{\text{maintenance}} \\ &= R\ 4{,}200{,}000 + R\ 55{,}982{,}500 + R\ 4{,}796{,}806 \\ &= R\ 64{,}979{,}306 \end{aligned}$$

The present value of the required yearly income in order to break even after a usage period of 30 years is similarly calculated as the present value for the maintenance. The present value for the yearly income after the first year of usage is:

$$P_{\text{yearly income(year 1)}} = F\left[\frac{1}{(1+i)^n}\right] = F\left[\frac{1}{(1+0.0075)^{27}}\right] = 0.817F$$

The calculated present value of the yearly income after 30 years is therefore:

$$P_{\text{yearly income}} = 8.883F$$

In order to breakeven after 30 years:

$$P_{\text{yearly income}} = P_{\text{total}}$$

Therefore, the required yearly income to break even after a usage period of 30 years is:

$$\begin{aligned} P_{\text{total}} &= 8.883\ F \\ R\ 64{,}979{,}306 &= 8.883\ F \\ F &= R\ 7{,}315{,}039 \end{aligned}$$

The yearly income required to break even after 30 years for the use of in-situ concrete construction is R 7,315,039.

Precast concrete construction

Figure 3.6, presented in Chapter 3, is a presentation of the cash flow diagram for the project constructed with HCC. The monthly construction payment for the 12 months is R 54,000,000/12 + R 360,000 = R 4,860,000. HCC and in-situ concrete construction has the same project cost, however due to a shorter construction period it will be noted that the monthly construction payments are higher for HCC.

The same steps that were undertaken during the calculation for the construction method of in-situ concrete construction are followed here:

$$P_{\text{construction}} = A\left[\frac{(1+i)^n - 1}{i(1+i)^n}\right] = R\ 4{,}860{,}000\left[\frac{(1+0.0075)^{12} - 1}{0.0075(1+0.0075)^{12}}\right] = R\ 55{,}573{,}676$$

$$P_{\text{maintenance(year 1)}} = F\left[\frac{1}{(1+i)^n}\right] = R\ 540{,}000\left[\frac{1}{(1+0.0075)^{24}}\right] = R\ 451{,}349$$

$$P_{\text{maintenance}} = R\ 4{,}905{,}546$$

$$\begin{aligned} P_{\text{total}} &= P_{\text{design}} + P_{\text{construction}} + P_{\text{maintenance}} \\ &= R\ 4{,}200{,}000 + R\ 55{,}573{,}676 + R\ 4{,}905{,}546 \\ &= R\ 64{,}679{,}222 \end{aligned}$$

$$P_{\text{yearly income(year 1)}} = F\left[\frac{1}{(1+i)^n}\right] = F\left[\frac{1}{(1+0.0075)^{24}}\right] = 0.836F$$

$$P_{\text{yearly income(total)}} = 9.084\ F$$

$$P_{\text{yearly income(total)}} = P_{\text{total}}$$

$$P_{\text{total}} = 9.084\ F$$

$$R\ 64{,}679{,}222 = 9.084\ F$$

$$F = R\ 7{,}119{,}856$$

The yearly income required to break even after 30 years for the use of HCC is estimated as R 7,119,856.

Comparison

The required income in order to break even for the project constructed with in-situ concrete was estimated as R 7,315,039. When HCC is used, a yearly income of R 7,119,856 is required to break even after 30 years. Therefore, R 196 183 less yearly income is required with the use of HCC. This is 2.67 % less yearly income required than that of in-situ concrete construction. This shows the effect of time savings during the construction phase on the life cycle cost of a project.

Reduced construction durations

A further evaluation was performed, where the same calculation was done for various construction durations. The yearly income required in order to break even after a usage period of 30 years was calculated for the construction durations as seen in the Table A.1. The table shows the construction duration, construction time saved, yearly income required in order to break even after 30 years and the percentage of the reduced yearly income required.

Figure 3.7, presented in Chapter 3, presents the graph obtained from the results. The figure shows the reduced annual income required in order to break even as a function of the construction time saved.

Table A.1: Effect of construction time saved on the required yearly income for break even

Construction duration	Construction time saved	Yearly income required	% saved on yearly income
15 months	0 %	R 7,315,039	0 %
14 months	6,67 %	R 7,249,544	0.9 %
13 months	13,33 %	R 7,184,484	1.78 %
12 months	20 %	R 7,119,856	2.67 %
11 months	26.67 %	R 7,055,656	3.55 %
10 months	33,33 %	R 6,991,882	4.42 %
9 months	40 %	R 6,928,530	5.28 %
8 months	46,67 %	R 6,865,598	6.14 %
7 months	53,33 %	R 6,803,083	7 %

Varying construction durations

A further evaluation was performed, where the same calculation was done for varying construction costs. The yearly income required in order to break even after a usage period of 30 years for the HCC project with a reduced construction period of 20 % was calculated for varying construction costs as seen in the Table A.2. The table shows the increase or reduction of construction cost (in terms of the initial in-situ project cost) and the yearly income required in order to break even after a usage period of 30 years.

Table A.2: Effect of varying construction cost on required yearly income for break even

Varying construction costs in terms of initial in-situ construction cost	**Reduced or increased yearly income required (%)**
5 % reduced	6.85 % reduced
4 % reduced	6.01 % reduced
3 % reduced	5.18 % reduced
2 % reduced	4.34 % reduced
1 % reduced	3.50 % reduced
same cost	2.67 % reduced
1 % increased	1.83 % reduced
2 % increased	1 % reduced
3 % increased	0.16 % reduced
4 % increased	0.68 % increased
5 % increased	1.93 % increased

Figure 3.8, presented in Chapter 3, presents the graphs obtained from the results. The figure shows the effect of varying construction costs on the LCC of the project.

Reduced maintenance cost

A further evaluation was performed, where the same calculation was done for various maintenance costs. The yearly income required in order to break even after a usage period of 30 years was calculated for the maintenance cost as a percentage of the initial cost as seen in the Table A.3. The table shows the yearly maintenance cost as a percentage of the initial project cost and the percentage of the reduced yearly income required.

Figure 3.9, presented in Chapter 3, presents the graph obtained from the results. The figure shows the reduced annual income required in order to break even as a function of maintenance cost, as a percentage of the initial cost.

Table A.3: Effect of reduced maintenance cost on the required yearly income for break even

Yearly maintenance cost as a percentage of initial cost	Reduced yearly income required (%)
0.25 %	2.82 %
0.5 %	2.77 %
1 %	2.67 %
2 %	2.48 %
3 %	2.32 %
4 %	2.18 %
5 %	2.06 %

During this evaluation it has shown that a reduction in construction duration and maintenance cost can generate more income due to a faster return on investment. Project teams should evaluate the effect of construction time and cost saved, and reduced maintenance cost on the life cycle cost of projects for a decision between in-situ concrete construction and HCC.

Appendix B

Consultant interviews

This appendix includes structured interviews with consultants in the industry. The consultants interviewed have 5 or more years experience and most of them are registered as professional engineers. These conversations were used to identify the time and cost factors for a decision between in-situ concrete construction and HCC during the design phase of a construction project. The following consultants were interviewed:

Table B.1: Names and company of consultants interviewed

Name	**Company**	**Experience in precast design**
Lyonell Fliss	Lyonell Fliss & Associates	yes
Harold Ronne	SMEC South Africa	yes
Paul Botha	VBL Consulting Engineers	yes
Theuns Jordaan	LMV Consulting Engineers	yes
Etienne Van der Klashorst	Stellenbosch University	yes
Johan de Lange	BVI Consulting Engineers	yes
Stephan Pretorius	Aurecon	yes
C.J.B Visagie	MVD Mangaung	yes
Anonymous	WorleyParsons	yes

Name: Lyonell Fliss

Company: Lyoynel Fliss and Associates

1. Have you designed structures by using precast concrete construction? What type of structures? What were the main motivations for choosing precast?
- *Many. Industrial in particular as I specialized in Industrial Civil Engineering. Motivations: better engineering.*

2. What are generally the principle motivations for you as consultant to design using precast construction?
- *The general good engineering practice motivations : Quality, Cost , Time*

3. To what extent do you consider precast as an option when conceptualizing a project? What are the important factors to consider out of a consultant perspective? For you as consultant? Not necessary the client.
- *Always as first option. Precast is an option when one can feel that one of the 3 motivations above can be achieved , but for this you need : a. knowledge, b. imagination, c. experience, d. dedication*

4. Do professional fees play a role when deciding between the design of precast and in-situ?
- *Yes. Precast design is more laborious, so the professional fees should be higher. This is compensated by substantial saving in construction costs.*

5. Is there a difference in the time required to design for precast and in-situ construction? Which method will be more time consuming? And by roughly what percentage? Why is the one method more time consuming during the design phase?
- *During the first designs, precast might take longer. But once sufficient experience is gained in precast design, the design for precast is faster. The reason for this is that there is less detailing of reinforcement. The extras might be time consuming, such as the lighting, drainage ect.*

6. What cost related factors do you consider when deciding between precast and in-situ during the design phase? Answer this for both the benefit of the consultant and client?
- *Repetition , modularization , difficulties to construct in situ at heights, superior quality required , availability of lifting equipment and transport, etc…….*

7. If it is cheaper for the client to design for precast, will you design for it? Or may there be disadvantages for you as consultants?
- *Yes, see question 4*

8. What are the risks considered when designing with precast rather than in-situ?
- *If the designer is inexperience there are many risks, the main risk being in the design of connections. There are other risks as well with the contractor who may not have the adequately qualified and experienced personnel.*

9. What are the design advantages considered when designing with precast rather than in-situ?
- *Repetition and standardization*

10. To what extent is the structural concept (precast vs in-situ) determined by you as structural designer? Also indicate type of structure (civil, commercial, industrial, mining)

- *The structural designer can propose the concept he sees most advantageous, but this concept should be accepted by the contractor and finally by the Client. Precasting applies to all the fields of reinforced and un-reinforced concrete applications, provided that you can prove the advantages against in-situ.*

11. As a structural designer what would you prefer, precast or in-situ? Specify principle reason(s) for the answer?

- *Preference should be supported by advantages. You don't start with a preconceived preference or just a feeling without justifying it with facts. Bunkers for example in precast are : more economical, faster to construct and of superior in quality and performance than cast in-situ Of course when I designed the first precast bunker it took some time to assess the advantages and it was a higher degree of responsibility to guarantee success. Once the first one was successfully built it give you more confidence for the following once even if they are at a larger scale.*

12. Are you as a consultant (team) in a position at the conceptual phase to estimate the advantages of using precast on a project? If not, what type of information would you need to do so?

- *Precast design required from the conceptual phase close co-operation between consultant and contractor, what it is called Design and Construct. Design in isolation from construction is not adequate for precast. Together the consultant and contractor establish the methodology based on contractor's resources of equipment and personnel and can estimate and compare the advantages of one system or another.*

13. In terms of TIME indicate which method will be more time consuming and comment if applicable. If there is no difference just mark both.

	Precast	**In-situ**
Design of elements (walls, beams, columns est.)	X	X
Design of connections	X	
Late changes and adjustments	X	
Working in collaboration		X

14. In terms of COST indicate which method will be more expensive and comment if applicable. If there is no difference just mark both.

	Precast	**In-situ**
Design of elements (walls, beams, columns est.)	X	X
Design of connections	X	
Late changes and adjustments	X	
Working in collaboration		X

15. Any other comment?
- *The key of success for using precasting is in correctly assessing the structural and geometric conditions, ability to visualize the precast configuration and providing best constructability conditions.*
- *To get to that is needed: a good knowledge of structural reinforced (and sometime prestressed) concrete analysis and technology, attention to detail and precision, innovative spirit, drive, interest in direct site supervision, experience in design and construction. The reward is professional satisfaction when the structure is successfully completed and the client is satisfied with its performance. To the Consultancy the reward is high reputation for their competence and innovative culture, to attract thus a better position in the market.*

Name: Harald Ronne

Company: SMEC South Africa

1. Have you designed structures by using precast concrete construction? What type of structures? What were the main motivations for choosing precast?
- *Yes, usually used for smaller buildings such as double storey house floors or manhole chamber covers. Also beneficial for concrete barriers on parking garages and bridges. The construction method is much faster with no formwork erection and curing times.*

2. What are generally the principle motivations for you as consultant to design using precast construction?
- *The construction method is much faster with no formwork erection and curing times. These precast slabs are usually design and supply by specialist, qualified suppliers and as such we as consultant save a lot of time by only developing concrete drawings and not the reinforcement bending schedules thereof. Unfortunately this also implies that we lose out on those fees as the design fees go to the supplier's in-house engineers. Main advantage would be the decreased construction period.*

3. To what extent do you consider precast as an option when conceptualizing a project? What are the important factors to consider out of a consultant perspective? For you as consultant? Not necessary the client.
- *Personally I would only consider precast concrete slabs when the supports are loadbearing brickwork and the imposed loading of a minimal nature. Not comfortable with using the precast units with multi storey buildings as moment connections can get complicated when relying on structural stiffness between columns and slabs for overall stability.*

4. Do professional fees play a role when deciding between the design of precast and in-situ?
- *Yes, it unfortunately does.*

5. Is there a difference in the time required to design for precast and in-situ construction? Which method will be more time consuming? And by roughly what percentage? Why is the one method more time consuming during the design phase?
- *I believe the design itself takes very similar time, however the reinforcement detailing should take longer for the in-situ members as there are usually more reinforcement to detail than with precast units. Precast unit design capacities are also usually calculated beforehand and the length of the panels specified to accommodate architect's layout.*

6. What cost related factors do you consider when deciding between precast and in-situ during the design phase? Answer this for both the benefit of the consultant and client?
- *The main benefit is to the client if they get a competitive quote from a supplier. They then save on time (and in turn costs on P&G's) as well as on formwork. The rest of the construction can also commence almost immediately as these slabs have already cured in the factory and no back propping are required. For very small structures i.e. small double storey houses, manhole covers etc. the profit made by the consultant on the in-situ slab design does not justify the time spend.*

7. If it is cheaper for the client to design for precast, will you design for it? Or may there be disadvantages for you as consultants?
- *You would be willing to design the precast units, however it would be difficult to compete against a company that have optimized these designs over years of daily production.*

8. What are the risks considered when designing with precast rather than in-situ?
- *You have to calculate the stresses in the wires/reinforcement very accurately which also relates back to the loadings and spans. As many of these panels are duplicated, one mistake can cause several panels to be precast incorrectly.*

9. What are the design advantages considered when designing with precast rather than in-situ?
- *Precast panels have a much better span/depth ratio which implies the panels can span much further than in-situ members. The precast members are also usually constructed with voids, which makes the units also much lighter thereby possibly decreasing foundation sizes.*

10. To what extent is the structural concept (precast vs in-situ) determined by you as structural designer? Also indicate type of structure (civil, commercial, industrial, mining)
- *Civil – Mainly determined by engineer*
- *Commercial – Mainly determined by Quantity Surveyor and Client in conjunction with Architect and Engineer*
- *Industrial - Mainly determined by Quantity Surveyor and Client in conjunction with Engineer*
- *Mining - Mainly determined by Quantity Surveyor and Client in conjunction with Engineer*

11. As a structural designer what would you prefer, precast or in-situ? Specify principle reason(s) for the answer?
- *I would choose In-situ from a fees point of view.*

12. Are you as a consultant (team) in a position at the conceptual phase to estimate the advantages of using precast on a project? If not, what type of information would you need to do so?

- *Yes, usually the client and QS indicates their preference at prelim design stage. However, with the bigger structures they do consult with the engineer first on his motivation why one type would be beneficial over the other.*

13. In terms of TIME indicate which method will be more time consuming and comment if applicable. If there is no difference just mark both.

	Precast	**In-situ**
Design of elements (walls, beams, columns est.)	X	X
Design of connections	X	
Late changes and adjustments	X	
Working in collaboration		X

14. In terms of COST indicate which method will be more expensive and comment if applicable. If there is no difference just mark both.

	Precast	**In-situ**
Design of elements (walls, beams, columns est.)	X	X
Design of connections	X	
Late changes and adjustments	X	
Working in collaboration		X

15. Any other comment?

- *NA*

Name: Paul Botha

Company: VBL Consulting Engineers CC

1. Have you designed structures by using precast concrete construction? What type of structures? What were the main motivations for choosing precast?
   - *Yes. Reservoir roofs, water purification works, buildings such as office blocks, residential buildings, educational buildings like laboratory facilities. Time saving on overall construction period.*

2. What are generally the principle motivations for you as consultant to design using precast construction?
   - *Time saving in both design and construction stages.*
   - *Better quality control under factory conditions.*
   - *Pre-cast normally goes with pre-stressing which optimizes the strength properties of concrete and high-strength steel.*

3. To what extent do you consider precast as an option when conceptualizing a project?
   What are the important factors to consider out of a consultant perspective? For you as consultant? Not necessary the client.
   - *I always consider pre-cast as first option. The first priority for any Consultant should be the interest of the client. The most important factors are speed of delivery, quality and cost effectiveness.*

4. Do professional fees play a role when deciding between the design of precast and in-situ?
   - *No.*

5. Is there a difference in the time required to design for precast and in-situ construction?
   Which method will be more time consuming? And by roughly what percentage?
   Why is the one method more time consuming during the design phase?
   - *Yes. Cast-in-situ construction. 50%. In cast-in-situ structures, each structural element has to be designed and detailed individually, while in pre-cast standardized pre-designed elements saves considerable time.*

6. What cost related factors do you consider when deciding between precast and in-situ during the design phase? Answer this for both the benefit of the consultant and client?
   - *For both the consultant and the client there are three important factors, namely time, time and time!*

7. If it is cheaper for the client to design for precast, will you design for it?
   Or may there be disadvantages for you as consultants?
   - *Yes. None*
8. What are the risks considered when designing with precast rather than in-situ?
   - *The risk for designing in pre-cast is less than in cast-in-situ, as the possibility of human errors is reduced considerably.*
   -

9. What are the design advantages considered when designing with precast rather than in-situ?
   - *Time saving and elimination of human errors.*

10. To what extent is the structural concept (precast vs in-situ) determined by you as structural designer? Also indicate type of structure (civil, commercial, industrial, mining)
    - *Civil: Totally determined by the structural Engineer.*
    - *Commercial and industrial: The structural concept is determined by the structural Engineer in close collaboration with the Architect.*

11. As a structural designer what would you prefer, precast or in-situ? Specify principle reason(s) for the answer?
    - *I always prefer pre-cast above cast-in-situ, as it saves design time, construction time and improved quality.*

12. Are you as a consultant (team) in a position at the conceptual phase to estimate the advantages of using precast on a project? If not, what type of information would you need to do so?
    - *Yes.*

13. In terms of TIME indicate which method will be more time consuming and comment if applicable. If there is no difference just mark both.

	Precast	**In-situ**
Design of elements (walls, beams, columns est.)		x
Design of connections	x	
Late changes and adjustments		x
Working in collaboration	x	x

14. In terms of COST indicate which method will be more expensive and comment if applicable. If there is no difference just mark both.

	Precast	**In-situ**
Design of elements (walls, beams, columns est.)		x
Design of connections	x	x
Late changes and adjustments	x	x
Working in collaboration	x	x

15. Any other comment?
    - *Apart from civil structures such as bridges, pre-cast structures is not common in South Africa, the reason being the fact that there are only a few specialist pre-cast contractors in the Country. The availability of a pre-cast specialist is essential for a successful pre-cast structure.*
    - *When designing a pre-cast structure, early contractor (specialist pre-cast) involvement is essential, even during the conceptual stage of the design.*
    - *In terms of cost effectiveness, pre-cast design comes to its right in the repetition of elements. The more elements of the same size and shape in a project, the more competitive the pre-cast structure will be.*
    - *Architects should also understand and embrace the concept of pre-cast construction in order to have a successful pre-cast structure.*
    - *I am in the fortunate position to have a very competent pre-cast contractor at my doorstep. They offer a total pre-cast solution, from pre-cast columns, beams and hollow core slabs, hence my preference towards pre-cast structures.*

In conclusion, I can state that the shortage of skilled labourers in cast-in-situ concrete structures will force the industry towards pre-cast solutions once more specialist pre-cast contractors come into the market.

Name: Theuns Jordaan

Company: LMV CONSULTING ENGINEERS

1. Have you designed structures by using precast concrete construction? What type of structures? What were the main motivations for choosing precast?
   - *Yes, mainly floor slabs for new buildings, but also staircases and roof slabs. Time.*

2. What are generally the principle motivations for you as consultant to design using precast construction?
   - *Time. Easier construction.*

3. To what extent do you consider precast as an option when conceptualizing a project? What are the important factors to consider out of a consultant perspective? For you as consultant? Not necessary the client.
   - *Precast construction forms an integral part of our preliminary designs. Important factors include column layouts, proposed loadings and easy design.*

4. Do professional fees play a role when deciding between the design of precast and in-situ?
   - *No.*

5. Is there a difference in the time required to design for precast and in-situ construction? Which method will be more time consuming? And by roughly what percentage? Why is the one method more time consuming during the design phase?
   - *_Yes, in situ more time consuming. 15-20% Individual bending schedules for in situ slabs are time consuming.*

6. What cost related factors do you consider when deciding between precast and in-situ during the design phase? Answer this for both the benefit of the consultant and client?
   - *Time during design and construction for both the Consultant and the Client. Ease of construction.*

7. If it is cheaper for the client to design for precast, will you design for it? Or may there be disadvantages for you as consultants?
   - *Engineer still takes full responsibility for all designs and the cost difference are not so big as to cause a disadvantage to the Consultant or the Client.*

8. What are the risks considered when designing with precast rather than in-situ?
   - *More difficult to allow for point loads and intricate layouts. Span of floors more limited.*

9. What are the design advantages considered when designing with precast rather than in-situ?
   - *Easier when using uniform distributed loads. Amount of standardization and repetition*

10. To what extent is the structural concept (precast vs in-situ) determined by you as structural designer? Also indicate type of structure (civil, commercial, industrial, mining)
    - *100%. Civil, commercial and industrial.*

11. As a structural designer what would you prefer, precast or in-situ? Specify principle reason(s) for the answer?
    - *Precast where building layouts are simple and uniform distributed loads can be used. Otherwise in situ.*

12. Are you as a consultant (team) in a position at the conceptual phase to estimate the advantages of using precast on a project? If not, what type of information would you need to do so?
    - *Yes, I believe so*

13. In terms of TIME indicate which method will be more time consuming and comment if applicable. If there is no difference just mark both.

	Precast	**In-situ**
Design of elements (walls, beams, columns est.)		X
Design of connections	X	
Late changes and adjustments	X	
Working in collaboration	X	

14. In terms of COST indicate which method will be more expensive and comment if applicable. If there is no difference just mark both.

	Precast	**In-situ**
Design of elements (walls, beams, columns est.)		X
Design of connections	X	
Late changes and adjustments	X	
Working in collaboration	X	X

Name: Etienne Van der Klashorst

Company: Stellenbosch University

1. Have you designed structures by using precast concrete construction? What type of structures? What were the main motivations for choosing precast?
    - *Yes, mostly housing and elements such as beams, floor slabs, columns, bridge balustrades est. Tight schedules and construction parameters were set that construction must take place while the train station were open and used by the public.*

2. What are generally the principle motivations for you as consultant to design using precast construction?
    - *If the client specify for it or when there is a tight schedule for the construction phase.*

3. To what extent do you consider precast as an option when conceptualizing a project? What are the important factors to consider out of a consultant perspective? For you as consultant? Not necessary the client.
   - *Only when there are specific project parameters such as construction schedule. Factors include site accessibility for cranes, the potential of standardization and repetition, the availability of a precast yard and accessibility for the transport. In general for smaller projects with little repetition and standardization much more time is required for precast design, therefore in the busy schedules we face won't often investigate the alternatives for a project.*

4. Do professional fees play a role when deciding between the design of precast and in-situ?
   - *Yes, unfortunately it does. The design for composite structures requires much more time and effort during the investigation and planning phases of the project and fixed cost remains the same, therefore for consultants design time and fees play a crucial role in the decision of precast or in-situ concrete design.*

5. Is there a difference in the time required to design for precast and in-situ construction? Which method will be more time consuming? And by roughly what percentage? Why is the one method more time consuming during the design phase?
   - *When it comes to big industrial structures or multi storey buildings precast may be a viable option for consultants were a lot of standardization and repetition can be applied. However for structures where standardization and repetition is not possible must more time is required to design for the use of precast concrete. It is not necessarily the elements that are time consuming, but all the extras, connections, drainage, lighting est.*

6. What cost related factors do you consider when deciding between precast and in-situ during the design phase? Answer this for both the benefit of the consultant and client?
   - *Transportation cost, element cost and fees towards time spent. If every thing is taken into account, transport est., the cost for mater per m3 will be less for in-situ compared to precast construction. However it may be an investment from the consultant's perspective. Although it is more time consuming to design for precast knowledge is gained for future projects, and the amount of time for those projects will be less when compared to the first precast design. This also builds reputation and relationships between clients and consultant companies.*

7. If it is cheaper for the client to design for precast, will you design for it? Or may there be disadvantages for you as consultants?
   - *If the client specifies it I will design for it. However more time might be required for us as consultants.*

8. What are the risks considered when designing with precast rather than in-situ?
   - *Uncertainty and rework. Especially when it is small projects or a new construction method that may require investigation. The planning phase is very important in designing for the use of precast structures. For in-situ design project teams design as the project progresses. However for precast design late changes are not possible and the design requires time to plan and finalise the design before construction can start.*
   -

9. What are the design advantages considered when designing with precast rather than in-situ?
   - *You gain knowledge for future projects, it can therefore be seen as an investment. Building up repetition for the design when using precast concrete construction.*

10. To what extent is the structural concept (precast vs in-situ) determined by you as structural designer? Also indicate type of structure (civil, commercial, industrial, mining)
    - *Mostly it is in the hands of the client, however we sometimes assist them in their choice of alternatives in concept designs*

11. As a structural designer what would you prefer, precast or in-situ? Specify principle reason(s) for the answer?
    - *I prefer In-situ because I have more experience with it, however I do acknowledge the fact that designers should put in the time investment to understand the specifications of precast design better.*

12. Are you as a consultant (team) in a position at the conceptual phase to estimate the advantages of using precast on a project? If not, what type of information would you need to do so?
    - *Yes we are as mentioned before, accessibility, repetition, standardization build ability and necessary extras.*

13. In terms of TIME indicate which method will be more time consuming and comment if applicable. If there is no difference just mark both.

	Precast	**In-situ**
Design of elements (walls, beams, columns est.)	X	X
Design of connections	X	
Late changes and adjustments	X	
Working in collaboration	X	

14. In terms of COST indicate which method will be more expensive and comment if applicable. If there is no difference just mark both.

	Precast	**In-situ**
Design of elements (walls, beams, columns est.)	X	X
Design of connections	X	
Late changes and adjustments	X	
Working in collaboration	X	

15. Any other comment?
    - *Precast concrete can be beneficial if consultants decide to invest time into the conceptual design phase. This is however not always possible due to time and professional fees.*

Name: Johan de Lange

Company: BVI Consulting Engineers

1. Have you designed structures by using precast concrete construction? What type of structures? What were the main motivations for choosing precast?
- *Yes, Residential additions, on top of garages.*
- *Quick turn around time on site.*
- *No propping*

2. What are generally the principle motivations for you as consultant to design using precast construction?
- *If the conditions are ideal and the benefits of precast are substantive.*

3. To what extent do you consider precast as an option when conceptualizing a project? What are the important factors to consider out of a consultant perspective? For you as consultant? Not necessary the client.
- *Not often. It takes design responsibility away from our main focus of rebar scheduling for in-situ concrete structures.*

4. Do professional fees play a role when deciding between the design of precast and in-situ?
- *Yes*

5. Is there a difference in the time required to design for precast and in-situ construction? Which method will be more time consuming? And by roughly what percentage? Why is the one method more time consuming during the design phase?
- *Not sure, as we outsource the design to the contractors specialist consultant.*

6. What cost related factors do you consider when deciding between precast and in-situ during the design phase? Answer this for both the benefit of the consultant and client?
- *Do not consider this. Main factors are the clients needs. Time compared to cost.*
- *If speed of construction is big and the design is basic addition on top of a garage, then we don't consider in-situ*

7. If it is cheaper for the client to design for precast, will you design for it? Or may there be disadvantages for you as consultants?
- *Not normally, as it will be done by specialist consultants of precast construction.*

8. What are the risks considered when designing with precast rather than in-situ?
- *Water protection, cranage, access for crane, construction sequence for precast may be a factor to consider*

9. What are the design advantages considered when designing with precast rather than in-situ?
- *Can span longer distances with prestressed elements compared to non-prestressed elements. Specialist consultant may be able to provide more examples.*

10. To what extent is the structural concept (precast vs in-situ) determined by you as structural designer? Also indicate type of structure (civil, commercial, industrial, mining)

- *Our preference is in-situ as it gives the client a more durable building in our view. Also the Roman point collapse in UK, is an example of what can go wrong with precast construction in high rise construction. Civil and commercial – in-situ, Industrial precast slabs on steel frames.*

11. As a structural designer what would you prefer, precast or in-situ? Specify principle reason(s) for the answer?

- *Depends on the clients needs, see above*

12. Are you as a consultant (team) in a position at the conceptual phase to estimate the advantages of using precast on a project? If not, what type of information would you need to do so?

- *Yes, as we have extensive experience with precast and in-situ*
- *advantages are mainly speed of construction and clients needs.*

13. In terms of TIME indicate which method will be more time consuming and comment if applicable. If there is no difference just mark both.

	Precast	**In-situ**
Design of elements (walls, beams, columns est.)	X	X
Design of connections	X	
Late changes and adjustments	X	
Working in collaboration	X	

14. In terms of COST indicate which method will be more expensive and comment if applicable. If there is no difference just mark both.

	Precast	**In-situ**
Design of elements (walls, beams, columns est.)	X	X
Design of connections	X	
Late changes and adjustments	X	
Working in collaboration	X	

15. Any other comment?

- *Precast floors are raised above ground level, will help during winter high ground water levels, in low cost housing in Cape. Based on this you would think that all low cost housing should have precast floors. The cost are however higher than a normal surface bed, so a good idea isn't enough unfortunately.*

Name: Stephan Pretorius

Company: Aurecon

1. Have you designed structures by using precast concrete construction? What type of structures? What were the main motivations for choosing precast?
   - *Yes, Community hall, residential buildings, because of time restraints*

2. What are generally the principle motivations for you as consultant to design using precast construction?
   - *If client wants precast, time constraints, cost, contractor to inexperienced to cast in situ*

3. To what extent do you consider precast as an option when conceptualizing a project? What are the important factors to consider out of a consultant perspective? For you as consultant? Not necessary the client.
   - *We mostly consider precast if the client request for it, the factors depends on the type of building, use of the building and the layout. Time required to investigate the alterative, the risk of uncertainty*

4. Do professional fees play a role when deciding between the design of precast and in-situ?
   - *No*

5. Is there a difference in the time required to design for precast and in-situ construction? Which method will be more time consuming? And by roughly what percentage? Why is the one method more time consuming during the design phase?
   - *Precast will be more time consuming. We are use to design for in-situ, therefore we are more comfortable with it.*

6. What cost related factors do you consider when deciding between precast and in-situ during the design phase? Answer this for both the benefit of the consultant and client?
   - *soil/founding condition – potential heaving/movement, loading, span lengths (positions of supports), floor finishes. Planning for precast therefore requires more time. Factors that may promote precast includes the amount of standardization and repetition.*

7. If it is cheaper for the client to design for precast, will you design for it? Or may there be disadvantages for you as consultants?
   - *If it is in the best intrust of the client/project I will design for it, it may be more time consuming, on the other hand we build up a good reputation with extra capabilities.*

8. What are the risks considered when designing with precast rather than in-situ?
   - *Durability (cover to reinforcement of the precast elements) and number of joints/potential movement cracks*

9. What are the design advantages considered when designing with precast rather than in-situ?
   - *Construction time can possibly be reduced when precast is used, building up a good market reputation*

10. To what extent is the structural concept (precast vs. in-situ) determined by you as structural designer? Also indicate type of structure (civil, commercial, industrial, mining)
    - *I would say the client and the architect have the first say, we as structural engineers only advise the client and architect about the pros and cons between the two*

11. As a structural designer what would you prefer, precast or in-situ? Specify principle reason(s) for the answer?
    - *in-situ- our future risks are reduced.*

12. Are you as a consultant (team) in a position at the conceptual phase to estimate the advantages of using precast on a project? If not, what type of information would you need to do so?
    - *Yes we are*

13. In terms of TIME indicate which method will be more time consuming and comment if applicable. If there is no difference just mark both.

	Precast	**In-situ**
Design of elements (walls, beams, columns est.)	X	X
Design of connections	X	
Late changes and adjustments	X	
Working in collaboration	X	

14. In terms of COST indicate which method will be more expensive and comment if applicable. If there is no difference just mark both.

	Precast	**In-situ**
Design of elements (walls, beams, columns est.)	X	X
Design of connections	X	
Late changes and adjustments	X	
Working in collaboration	X	

15. Any other comment?
    - *NA*

Name: C.J.B. Visagie

Company: MVD Mangaung (Pty) Ltd,

1. Have you designed structures by using precast concrete construction? What type of structures? What were the main motivations for choosing precast?
    - *Yes, Floor slabs only. Ease of erection*

2. What are generally the principle motivations for you as consultant to design using precast construction?
   - *When it is the choice of the client or when conventional (in situ) concrete is difficult.*
   - *When ready mix concrete is not available.*

3. To what extent do you consider precast as an option when conceptualizing a project? What are the important factors to consider out of a consultant perspective? For you as consultant? Not necessary the client.
   - *We do not use (or propose) it if conventional concrete is possible. The proposed floor cover is always a factor as we (in the Free State) could not yet prevent cracks in tiles above precast floors. Precast floors are more expensive in the Free State*

4. Do professional fees play a role when deciding between the design of precast and in-situ?
   - *Never has*

5. Is there a difference in the time required to design for precast and in-situ construction? Which method will be more time consuming? And by roughly what percentage? Why is the one method more time consuming during the design phase?
   - *No.* Floors *are easier but the supports require more input. Time lost in support is gained in floors*

6. What cost related factors do you consider when deciding between precast and in-situ during the design phase? Answer this for both the benefit of the consultant and client?
   - *As consultants – none. For the client (in our area) we find no cost advantages, not even time. (It take as much time to construct supporting beams as it takes to construct a whole floor.)_We (as consultants) in the Free State are convinced that precast concrete floors are more expensive.*

7. If it is cheaper for the client to design for precast, will you design for it? Or may there be disadvantages for you as consultants?
   - *Yes, but we will warn them about the negative consequences (appearance, cracks above) and whether all costs – like cranes and screeds – were included in the "cheaper"precast.*

8. What are the risks considered when designing with precast rather than in-situ?
   - *Tiles crack; alterations difficult; floors can span one direction only.*

9. What are the design advantages considered when designing with precast rather than in-situ?
   - *We are not convinced of any except where ready mixed plants are too far away.*

10. To what extent is the structural concept (precast vs in-situ) determined by you as structural designer? Also indicate type of structure (civil, commercial, industrial, mining)
    - *Commercial, industrial, residential. We prefer in situ and find (in the Free State) Architects to be more pro in situ than Engineers because of negative experience regarding precast.*

11. As a structural designer what would you prefer, precast or in-situ? Specify principle reason(s) for the answer?
    - *In situ.*
    - *Cracks in tiles above precast floors. Untidy appearance below precast floors. Extremely irritating reps. Costs, because of (recently) much improved shuttering.*

12. Are you as a consultant (team) in a position at the conceptual phase to estimate the advantages of using precast on a project? If not, what type of information would you need to do so?
    - *We often are, but do not often see the advantages of precast concrete. We also do not try to find it. See above.*

13. In terms of TIME indicate which method will be more time consuming and comment if applicable. If there is no difference just mark both.

	Precast	**In-situ**
Design of elements (walls, beams, columns est.)	X	X
Design of connections	X	
Late changes and adjustments	X	
Working in collaboration	X	

14. In terms of COST indicate which method will be more expensive and comment if applicable. If there is no difference just mark both.

	Precast	**In-situ**
Design of elements (walls, beams, columns est.)	X	
Design of connections	X	
Late changes and adjustments	X	
Working in collaboration	X	

15. Any other comment?
    - *To put our attitude towards precast floors in Bloemfontein into perspective:-Contractors "import" precast floor slabs from Gauteng and P.E. cheaper than the local manufacturer can supply it.*

Name: Anonymous

Company: WorleyParsons

1. Have you designed structures by using precast concrete construction? What type of structures? What were the main motivations for choosing precast?
   - *Yes. Reservoir roofs, water purification works, buildings such as office blocks, residential buildings, educational buildings like laboratory facilities. Time saving on overall construction period.*

2. What are generally the principle motivations for you as consultant to design using precast construction?
   - *When the client request for it*

3. To what extent do you consider precast as an option when conceptualizing a project? What are the important factors to consider out of a consultant perspective? For you as consultant? Not necessary the client.
   - *Not often, due to time constraints. More familiar with in-situ construction methods. Needs to be economically beneficial to client, for us standardization and repetition is important.*

4. Do professional fees play a role when deciding between the design of precast and in-situ?
   - *Yes, precast design is more time consuming*

5. Is there a difference in the time required to design for precast and in-situ construction? Which method will be more time consuming? And by roughly what percentage? Why is the one method more time consuming during the design phase?
   - *Yes precast design requires more time. However if time is invested it might be faster.*

6. What cost related factors do you consider when deciding between precast and in-situ during the design phase? Answer this for both the benefit of the consultant and client?
   - *Standardization and repetition*

7. If it is cheaper for the client to design for precast, will you design for it? Or may there be disadvantages for you as consultants?
   - *Yes,*

8. What are the risks considered when designing with precast rather than in-situ?
   - *Uncertainty and rework. Especially when it is small projects or a new construction method that may require investigation. The planning phase is very important in designing for the use of precast structures..*

9. What are the design advantages considered when designing with precast rather than in-situ?
   - *Time saved due to repetition. And mostly don't need to design bending schedules and reinforcement detailing.*

10. To what extent is the structural concept (precast vs in-situ) determined by you as structural designer? Also indicate type of structure (civil, commercial, industrial, mining)
    - *We always have a say. The client and architect usually determine the concept, we however have the last say in designing the structure since we are held responsible.*

11. As a structural designer what would you prefer, precast or in-situ? Specify principle reason(s) for the answer?
    - *It depends on the type of structure. If standardization and repetition is evident I would prefer precast otherwise in-situ.*

12. Are you as a consultant (team) in a position at the conceptual phase to estimate the advantages of using precast on a project? If not, what type of information would you need to do so?
    - *Yes, we have limited time however.*

13. In terms of TIME indicate which method will be more time consuming and comment if applicable. If there is no difference just mark both.

	Precast	**In-situ**
Design of elements (walls, beams, columns est.)	X	X
Design of connections	X	
Late changes and adjustments	X	
Working in collaboration	X	

14. In terms of COST indicate which method will be more expensive and comment if applicable. If there is no difference just mark both.

	Precast	**In-situ**
Design of elements (walls, beams, columns est.)	X	
Design of connections	X	
Late changes and adjustments	X	
Working in collaboration	X	

15. Any other comment?
    - *NA*

Appendix C

Contractor interviews

This appendix includes the discussions based on the interviews with representatives of the projects during site visits to the various projects discussed in Chapter 5. The representatives interviewed were part of the respective project teams. The following representatives were interviewed:

1. Francois Vermeulen - Grootegeluk Medupi and Shondoni coal bunkers
2. Grant Bergh – Cape Town dispatch plant
3. Gerald Le Roux – Longridge reservoir

The discussions provided are questionaries that were answered by the respective project teams after the interviews were performed. The questionnaires consist of the following questions:

1. Are there projects where you have decided to use precast concrete construction rather than in-situ concrete construction? What type of projects and why?
2. What lessons have been learned from using precast construction in these projects?
3. For these projects, how does the program of precast construction differs from the program of in-situ construction?
4. What risks may arise on the program when precast is used?
5. What risks may arise on the program when in-situ is used?
6. What of these risk factors for both precast and in-situ are difficult to quantify and why?
7. What approach is used to decide between precast and in-situ?
8. In what situations will it be more beneficial to use in-situ rather than precast?
9. What are the pros and cons of precast construction?
10. What are the pros and cons of in-situ construction?

Name: Francois Vermeulen

Company: Stefanutti Stocks

1. Are there projects where you have decided to use precast concrete construction rather than in-situ concrete construction? What type of projects and why?
   - *Yes. Being in construction we as contractors don't make the decisions whether to go precast or not. We build what the client wants. We do however make proposals to clients, but they still have the option which route to follow. That being said, we worked at the In-situ Grootte Geluk project and at the Precast Shondoni project where we were running the pre-cast yard. If we had the choice we would go the pre-cast route. You take away a lot of risk in terms of safety and it requires a smaller workforce. Also if planned properly the pre-cast route can save a lot of construction time. (Projects can be completed quicker than in-situ)*
2. What lessons have been learned from using precast construction in these projects?
   - *Pre-cast construction is a much "simpler" way of building storage bunkers. As mentioned in previous point you take away a lot of the risk. You have a lot more control in the end and able to manage everything to the finest details, especially at the precast yard*
3. For these projects, how does the program of precast construction differs from the program of in-situ construction?
   - *On the projects I have been involved the sequence of the programmes will be similar in most aspects. For example in both cases you have to start with excavations, bases, columns, deck, walls, etc. In Pre-cast construction we are involved at the moment the deck, beams, and walls are pre-cast element, columns and base are done in-situ. In terms of the programme the programme one needs to ensure you deliver the pre-cast units in the order they will need to assemble them. To answer your question, in my opinion the sequence of the programme is the same, just pre-cast construction is quicker.*
4. What risks may arise on the program when precast is used?
   - *Not producing the pre-cast units in time, or the right sequence for installing. Eg having all your wall panels done, but you have not done any beams for the deck, thus you will not be able to install your wall panels.*
5. What risks may arise on the program when in-situ is used?
   - *In-situ relies heavily on a tower crane for material to be lifted (rebar for steelfixers, shutter, etc). If you have 3-4 foreman working in the same area it is impossible for one tower crane to help everybody. Tower cranes are also easily affected by wind, you would get days where you are not able to supply your teams with the material they need due to windy conditions. In short it is easier to fall behind on programme because a lot more*

factors play a role. (As mentioned earlier, there is a lot more control in pre-cast construction)

6. What of these risk factors for both precast and in-situ are difficult to quantify and why?
   - *It is difficult to specifically point out particular risk factors, but as mentioned a lot of risk in terms of safety is decreases using pre-cast construction. Also other risks are decreased for example shuttering in the case of in-situ construction is a lot more difficult because it has to be done in the air using tower cranes to hold the shutter and so forth, where ass in the case of pre-cast construction you doing the majority of the work in pre-cast elements which are done at ground level and thus taking away a lot of the risks.*
7. What approach is used to decide between precast and in-situ?
   - *A big factor these days are safety and obviously the financial aspect. Pre-cast construction is definitely a safer route and it should be financially also the better option, especially in terms of coal bunker construction.*
8. In what situations will it be more beneficial to use in-situ rather than precast?
   - *The circumstances in which you are working will effect this decision: Do you have your own batchplant, is there a batchplant close, can you set up your own bactplant? Then setting up your pre-cast yard. Is there space to set up one, how will you transport your units, can you set up your pre-cast yard close to site? Sometimes it may not be viable to erect a pre-cast yard and everything. The size of the structure will also play a roll. In short if it financially viable to set up a pre-cast yard, and you can have good supply of concrete every day go for pre-cast, otherwise in-situ*
9. What are the pros and cons of precast construction?
   - *Pros:*
     - *Safer production*
     - *More control*
     - *Smaller construction period*
     - *Reduced material*
     - *Repetition*
   - *Cons:*
     - *Specialist material needed in terms of shutters*
     - *Need to set up a pre-cast- can be costly*
     - *Pre-cast units needs to be double handled in some cases. (eg you transport units to the site, stack them and then they need to be transported again to the crane to install the units)*

10. What are the pros and cons of in-situ construction?
    - *Pros:*
        - *Don't have the cost of setting up a pre-cast yard*
        - *Logistical easier not having pre-cast units that need to be transported stacked installed etc.*
    - *Cons:*
        - *More risk involved working at heights*
        - *More reliant on crane hook time, can cause delays*
        - *To do remedial work after is lot more complicated*

Name: Grant Bergh

Company: Group five

1. Are there projects where you have decided to use precast concrete construction rather than in-situ concrete construction? What type of projects and why?
   - *Not other than the dispatch plant. This is the first project that I am part of where the use of precast concrete in construction is applied. The project was constructed with precast elements because the client requested it. His primary motivations were to save time and to ease construction.*
2. What lessons have been learned from using precast construction in these projects?
   - *Pre-cast construction is a faster way of construction if a lot of repetition occurs. It takes away a lot of the risk. There is a lot more control in manufacturing the elements. Much less material required.*
3. For these projects, how does the program of precast construction differs from the program of in-situ construction?
   - *The activities of the programme are the same; the duration of the activities for precast concrete construction is just faster than in-situ concrete construction.*
4. What risks may arise on the program when precast is used?
   - *Manufacturing the elements. Precast elements and the dimensions needs to be manufactured with precision. If elements are manufactured with insufficient quality and out of tolerance, a great amount of rework will be required. Planning and levelling of the precast blindings are therefore important for precast concrete construction.*
5. What risks may arise on the program when in-situ is used?
   - *Casting concrete at these heights increases the risk of safety. It also increases the risk of insufficient quality in casting at these heights. Using in-situ concrete construction for the columns and walls would have placed a huge risk on the schedule and completing in time.*
6. What of these risk factors for both precast and in-situ are difficult to quantify and why?
   - *Safety, cranes required and quality.*
7. What approach is used to decide between precast and in-situ?
   - *The potential of standardization and repetition.*
8. In what situations will it be more beneficial to use in-situ rather than precast?
   - *Where there is little repetition occurring and where site accessibility might be difficult.*

9. What are the pros and cons of precast construction?
   - *Pros:*
     - *Safer production*
     - *Better quality*
     - *More control*
     - *Smaller construction period*
     - *Reduced material*
     - *Repetition*
   - *Cons:*
     - *Specialist material needed in terms of shutters*
     - *Erection of precast blindings must be done to precision*
10. What are the pros and cons of in-situ construction?
   - *Pros:*
     - *Don't have the cost of setting up a pre-cast blindings*
     - *More experience with in-situ procedures.*
     - *Logistical easier not having to plan well in advance*
   - *Cons:*
     - *More risk involved working at heights*
     - *Easily affected by weather conditions*

Name: Gerald Le Roux

Company: Ruwacon

1. Are there projects where you have decided to use precast concrete construction rather than in-situ concrete construction? What type of projects and why?
   - *Yes. Water Reservoirs and Components to concrete structures, such as balustrades- Cost and time saving as well as quality*
2. What lessons have been learned from using precast construction in these projects?
   - *Huge time advantages and cost saving on especially wastage and material savings*
3. For these projects, how does the program of precast construction differs from the program of in-situ construction?
   - *Definite saving on the programme. (We completed the last reservoir 1 month earlier because of the precast option). The activities of the programme however remain the same.*
4. What risks may arise on the program when precast is used?
   - *Sequencing of events usually needs to be changed from an "in-situ" programme*
5. What risks may arise on the program when in-situ is used?
   - *Timing is the biggest risk followed by quality and safety, especially due to the fact of working at heights.*
6. What of these risk factors for both precast and in-situ are difficult to quantify and why?
   - *Cost difference- i.e. it will be difficult to estimate your wastage amount if you would have done it in-situ, to then compare with the costs of precast. Precast might seem more expensive, but when all the factors are considered, it may be cheaper*
7. What approach is used to decide between precast and in-situ?
   - *Comparisons need to be drawn up to take into consideration, costs, delivery dates, programme milestone dates, etc.*
8. In what situations will it be more beneficial to use in-situ rather than precast?
   - *When the quantities will not allow precast to be an option due to production costs.*

9. What are the pros and cons of precast construction?
   - *Each situation will have to be evaluated on its own to answer the question; however the following pros and cons are the more common ones.*
   - *Pros:*
     - *Safer production*
     - *More control*
     - *Smaller construction period*
     - *Reduced material*
     - *Repetition*
     - *Less wastage generated*
     - *Better quality*
   - *Cons:*
     - *Transportation costs*
     - *Pre-cast units needs to be double handled in some cases. (eg you transport units to the site, stack them and then they need to be transported again to the crane to install the units)*
     - *Late changes might be challenging to repair*
10. What are the pros and cons of in-situ construction?
    - *Pros:*
      - *No transportation costs involved*
      - *Logistical easier not having pre-cast units that need to be transported stacked installed etc.*
      - *More experience in constructing with in-situ methods*
    - *Cons:*
      - *More risk involved working at heights*
      - *To do remedial work after is lot more complicated*
      - *Slower construction*
      - *More waiting durations required*

Appendix D

Some South African precast concrete suppliers

Table D.1 provides a list of some precast suppliers in the major cities of the various provinces in South Africa.

Table D. 1: South African precast manufacturers

Province	City	Company	Web site
Eastern Cape	Port Elizabeth	Algoa cement	www.algoacement.co.za
		Cavcon	www.cavcon.co.za
Free State	Bloemfontein	Stabilian	No web page
		360 degrees	No web page
		Rainbow concrete	www.rainbowconcrete.co.za
Guateng	Johannesburg	Echo	www.echo.co.za
		Infraset	www.infraset.co.za
		Ital concrete design	www.italconcrete.co.za
		Elematic	www.elematic.co.za
		Al's Precast	www.alsprecast.co.za
	Pretoria	Vanstone	www.vanstone.co.za
		AAA Concrete	www.aaaconcrete.co.za
KwaZulu-Natal	Durban	Echo	www.echo.co.za
		Tilt Up Systems	No web page
		Infraset	www.infraset.co.za
		CCP	www.ccpconcrete.co.za
		LG Green	www.lggreen.co.za
Limpopo	Polokwane	Corestruc	www.corestruc.co.za
Mpumulanga	Nelspruit	Nyatislabs	www.nyatislabs.co.za
	Secunda	Rolca	www.rolca.co.za
Western Cape	Cape Town	Bobcrete	www.bobcrete.co.za
		Cobute	www.cobute.co.za
		Concrete Units	www.concreteunits.co.za
		Topfloor	www.topfloor.co.za

Appendix E

This appendix presents a typical maintenance check list for parking structures (Gupta & Shui, 2014).

Table E.1: Typical maintenance checklist (Gupta & Shui, 2014)

Floors	• When was the last floor sealer application? (Typically applied every 3 to 5 years) • Are there rips, tears, debonded areas, or signs of embrittlement in the traffic topping? • Are there cracks in the floor slab? If yes, where are they located and how wide are they? • Are there signs of leaking? • Any spalls or delaminations? If yes, how big and where are they located? • Has chloride ion content testing been performed this year?
Beams and columns	• Are there cracks? If yes, are they vertical or horizontal and how wide? • Are there any signs of leaking?
Joints	• Are there any signs of leaking, loss of elasticity or separation from adjacent surfaces? • Expansion joints • Control joints • Construction joints • Tee-to-tee joints
Stair/elevator towers	• Are there any signs of a leaking roof? • Are there any cracks in the exterior brick? • Are there any cracks in the mortar joints? NOTES AND CORRECTIVE ACTION NEEDED:
Architectural sealant	• Are there any signs of leaking, loss of elasticity, or separation from adjacent surfaces? • Between windows and doors • In block masonry • Exterior sealants • Concrete walks, drives, and curb landings
Exposed steel	• Is there any exposed steel? If yes, where is it located and is it rusted?
Masonry	• Are there any cracks in the brick? • Are there any cracks in the mortar? • Are there any brick spalls? If yes, where are they located and how big are they? NOTES AND CORRECTIVE ACTION NEEDED:
Bearing pads	• Are bearing pads squashed, bulging, or out of place? If yes, where? After answering the above questions, please consult a qualified engineer to discuss your answers. NOTES AND CORRECTIVE ACTION NEEDED: