

Investigating the impact of site activities and conditions on concrete quality of in-situ and precast construction methods

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Abstract

Construction of structural concrete frames may take place by using either cast in-situ or precast methods. With the cast in-situ method, these elements are constructed on the construction site as needed. Precast construction on the other hand is more resembles a line. The elements are constructed in a precast yard in a systematic fashion and once completed, they are taken to the construction site where they are to be erected.

This study identifies the aspects and attributes which influence the quality of concrete during the construction phase of these two construction methods. The study is independent from the conceptual or design phase. Information regarding these aspects and attributes were obtained from literature and from contractors in industry through interviews and site visits. The literature review also focuses on quality management techniques and factors that influence quality in the construction environment. The information obtained from the site visits and literature was used to design a survey which was sent out to a number of respondents. A comparison between in-situ and precast construction was made based on the results of the survey.

The synthesis of the research findings can be used by project teams to help them decide on the choice between in-situ and precast construction. It was found that precast construction is better for durability, and fitness for purpose is less complex for the in-situ solution. Recommendations for future studies are provided at the end of the document.

Opsomming

Konstruksie van beton struktuurrame kan plaasvind deur die gebruik van in-situ of voorafvervaardigde metodes. Met die in-situ metode, word hierdie elemente op die terrein gebou soos benodig. Tydens voorafvervaardigde konstruksie aan die ander kant is die konstruksie soortgelyk aan 'n produksielyn. Die elemente word gegiet in 'n voorafvervaardigingsterrein in 'n sistematiese wyse, en sodra dit voltooi is, word dit na die konstruksie terrein geneem waar dit opgerig word.

Hierdie studie identifiseer die aspekte en eienskappe wat 'n invloed op die kwaliteit van beton het tydens die konstruksiefase van hierdie twee konstruksie metodes. Die studie is onafhanklike van die konseptuele of ontwerp fases. Inligting rakende hierdie aspekte en eienskappe is verkry uit die literatuur en van kontrakteurs in die bedryf deur middel van onderhoude en besoeke. Die literatuur fokus ook op die gehalte, bestuurs-tegnieke en faktore van gehalte in die bou-omgewing. Die inligting is verkry deur 'n vraelys wat aan 'n aantal respondente gestuur is. 'n Vergelyking tussen in-situ en voorafvervaardigde konstruksie is vervolgens gemaak op grond van die resultate van die opname.

Die sintese van die bevindinge kan gebruik word deur projek spanne om hulle te help besluit oor die keuse tussen in-situ en voorafvervaardigde konstruksie. Die resultate dui daarop dat voorafvervaardigde konstruksie beter is vir duursaamheid, maar passing op terrein is minder kompleks vir die in-situ oplossing. Aanbevelings vir toekomstige ondersoeke word aan die einde van die studie gemaak.

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List of Abbreviations

CBD	Central business district
DQP	Detailed quality plan
HCC	Hybrid concrete construction
ISO	International organisation of standardisation
m	Metre
Mpa	Mega Pascal
mm	Millimetre
PQP	Project quality plan
QA	Quality assurance
QC	Quality control
RE	Representative Engineer
SANS	South African National Standards
TQM	Total Quality Management

1. Chapter 1 – Introduction

1.1. Background

In the construction industry there are certain constraints which influence a project. These constraints are shown in figure 1.

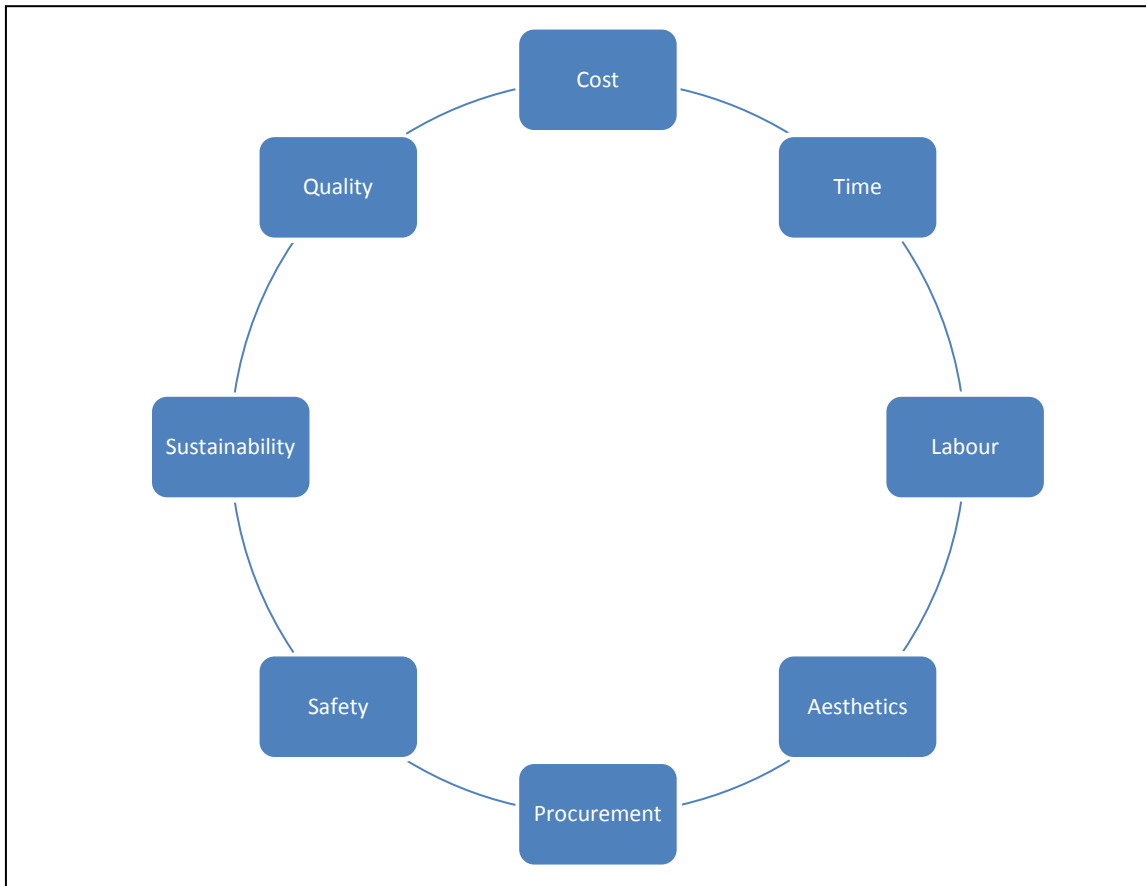


Figure 1: Constraints influencing a construction project (Westney, 2011)

For the purpose of this study, the subject of quality will be investigated for in-situ and precast concrete construction.

On any construction project quality is an important deliverable. In the construction industry owners/clients require that quality of the product conforms to the prescribed specifications. In concrete construction there are many factors that influence quality of a product and thus a contractor can be exposed to many risks. The procedures used for in-situ construction differ from those in precast construction, and in addition there may be a difference in specification. For example, the tolerances specified in SANS 1200G (1982) differ for in-situ and precast construction. In this study an investigation was done to determine the different aspects that play a role in achieving quality, between in-situ construction procedures and precast construction procedures in South Africa. The

investigation was done by studying aspects influencing quality and their consequences. Quality aspects such as durability issues, product tolerances and aesthetics are investigated.

The parameters which determine quality of concrete are well known, however it is not known how site procedures may impact the quality of the concrete. These procedures differ between the in-situ and precast construction options and in this study an investigation is done to determine how certain aspects and attributes impact the quality.

1.2. Purpose of the study

The purpose of this study is to draw a comparison between the quality of concrete using in-situ and precast construction methods. A risk model is proposed which could be used to identify the areas with the major risk and to weigh the precast option against an in-situ option.

In this study the external/secondary factors on the quality of concrete during the construction phase of the project will be investigated. External/secondary factors are also known as aspects. External/secondary factors are indirect factors which play a role and may impact the quality of concrete. Some examples of secondary factors and which are discussed later in the study include management, site factors and labour. The conclusions drawn from the study could be used to aid the decision of a project team in the early stages of the project to minimise potential risk.

1.3. Objectives of the study

The parameters that define quality of concrete structures in the construction environment will be investigated, together with the procedures which are used to control and assure quality throughout the construction phase.

The aspects influencing concrete quality during the construction phase of the project will be identified and investigated to develop an understanding of why they occur, and the consequences thereof. Emphasis will be placed on these parameters throughout the study.

Risk is always present during construction. Expert opinion will be obtained through the use of interviews and site visits to identify the element of risk.

The information obtained will then be used to formulate a survey questionnaire so that the relevant parameters could be ranked and rated as seen from the contractor's perspective. This will be done for both the precast and in-situ construction method, by making use of a qualitative approach. This will enable a comparison to be made between the two methods.

The results will then be used to determine which of the precast or in-situ methods would be the more viable option. This information could be used to assist project teams in the planning stage of the project.

Therefore, in this study, the aim is to investigate how site conditions and certain parameters, directly and indirectly related to concrete construction, influence the quality. The intent of this investigation is therefore to determine whether there are any differences between the quality parameters for the in-situ and precast construction method.

1.4. Research Questions

The research questions for this thesis are:

1. What are the parameters that play a role in achieving concrete quality?
2. How do these factors differ for the precast and in-situ environments?
3. What are the risk implications of these quality issues?
4. What should the project team ask themselves when considering the decision to construct using either precast or in-situ for a specific project as far as quality is concerned?

1.5. Thesis structure

The contents of the thesis structure are briefly discussed in the following paragraphs.

1.5.1. Research Methodology

Chapter 2 describes the approach which was taken to conduct the study.

1.5.2. Quality

Chapter 3.1 provides information on quality and the processes involved during the quality management process.

In chapter 3.1, a brief overview of hybrid concrete construction is given. Concepts of quality are discussed by defining quality and investigating quality in the construction environment. Quality management, total quality management and tools and techniques are discussed. Cause and effect diagrams have also been described here.

1.5.3. Quality aspects and quality in the construction environment

Chapter 3.2 provides information on concrete quality and the factors which play a role in the achievement thereof.

The ingredients needed for concrete quality as well as the aspects indirectly impacting the quality of concrete and their attributes are discussed in chapter 3.2. The concept of rework, a consequence of poor quality, and the causes thereof are also discussed here.

1.5.4. Risk

Chapter 3.3 provides information on risk management in relation to the construction environment.

There exists a correlation between the manner in which risk is managed and achievement of quality respectively. In this study, the manner in which the questionnaire was formulated and the results were analysed follows a risk approach. The content of the risk chapter, chapter 3.3, shows how this may be done. Definitions of risk have been provided and emphasis has been placed on the human factor. Factors that influence decision making and risk management are also discussed here.

1.5.5. Research surveys

There are three types of surveys which may be used to conduct a research study. In chapter 4 these three types of research surveys are discussed with reference to their classification and application.

Chapter 4 also discusses the differences between quantitative and qualitative research. It describes their significance for their respective purposes.

1.5.6. Site visits

Chapter 5 is concerned with interviews and site visits which were conducted, and which served as basis for the formulation of subsequent survey questionnaires. The personal interviews focused on individuals in the construction industry dealing with concrete construction on a daily basis. The subsequent surveys which were conducted were based on a combination of the information that had been obtained in the interviews and in the literature consulted. In this chapter the quality of concrete and the quality management procedures of four companies are discussed. These construction companies include: Cobute, Murray and Roberts (Building), Concor and Botes and Kennedy. Quality procedures followed on the respective construction projects are discussed in this chapter.

1.5.7. Questionnaire and results

In chapter 6, the design of the questionnaire is discussed. Tools and techniques used are further described in this chapter. The results and interpretations thereof are also discussed in the chapter.

1.5.8. Conclusion

Conclusions with reference to the study are provided in chapter 7.

1.5.9. Research findings

In chapter 8, the research questions are answered.

1.5.10. Limitations and recommendations for future study

The limitations and recommendations are discussed in chapter 9.

1.5.11. References

The references used in the study can be found in chapter 10.

2. Research methodology

This chapter provides an overview of the methodology which was followed in this study. Figure 2 below shows the path followed.

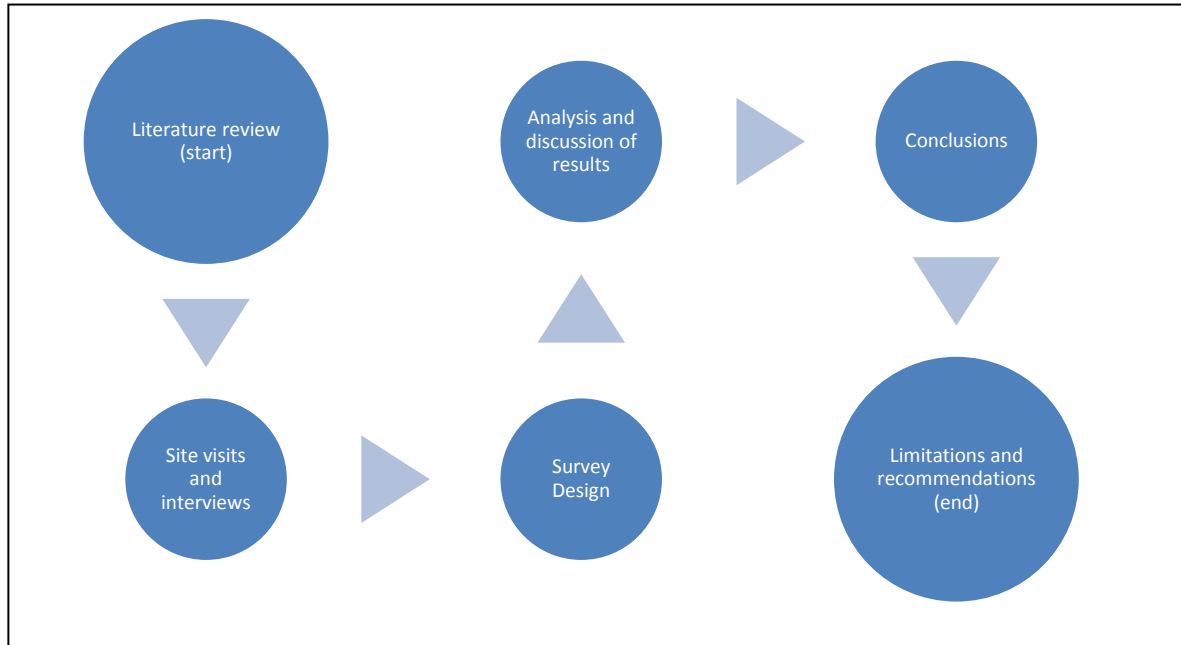


Figure 2: An overview of the methodology followed in the study

The literature study was first performed to obtain definitions of quality and quality in concrete construction. This was done by referring to journals, data bases and library books. The quality issues found in concrete and concrete construction were identified and addressed in the literature review. Quality management, quality control, quality assurance as well as total quality management will be discussed in the literature study. The total quality management tools and techniques available are used later to design the survey. Since the study is based on quality of concrete construction, it was a suitable choice to begin with these concepts of quality. The ingredients needed for concrete quality as well as the parameters (aspects) indirectly impacting the quality of concrete and their attributes are presented in chapter 3.2. The concepts are described in these sections in relation to quality of concrete construction procedures.

During the construction phase of a project there are certain parameters (aspects) which indirectly influence the overall quality of concrete. These aspects and their attributes were identified with the help of personal interviews and through literature. The root causes of these issues and their consequences were investigated through a literature study. One major consequence of poor quality, namely rework, is also discussed.

A risk based approach is used in analysing the results of a survey as well as in the design of the survey. In chapter 3.3, Risk, some concepts such as risk management is provided as background to this study. Quantitative and qualitative risk management is also briefly mentioned in relation to construction.

A definition of risk has been provided followed by a brief discussion of human attitude towards risk and risk management. In the construction industry, risk may influence cost, time and quality. Human attitude influences decision making (Table 2) therefore there is a risk aspect faced with every decision made during the process of achieving concrete quality. The risk section in chapter 3.3 provides background on risk management practices. Two risk based methods, namely prioritisation and cause and effect diagrams, were used respectively to rank the aspect or attribute having the highest risk and to link the source of a problem to its effect.

The purpose of research surveys may be to explore, describe or explain (Pinsonneault & Kraemer, 1991). The next section of the literature study discusses the kind of surveys and the purpose thereof. The qualitative nature of the survey was found to be best suited for an exploratory survey.

Finally, the literature study addresses the differences between quantitative and qualitative research.

To obtain a comprehension of the construction environment and to identify which parameters play a role in achieving concrete quality, construction sites were visited. Four construction sites were visited, each from a different construction company. Contractors were interviewed and a series of questions was asked at the construction site. The construction companies visited include Botes and Kennedy, Cobute, Concor (Roads and Earthworks) and Murray and Roberts Construction. In addition, observations on the construction sites were made and noted. These interviews and visits focused on identifying aspects which are needed for achieving quality. Expert opinion of the contractors was used as input to design a survey. As the study focused on concrete quality during construction, and not during the design phase, this approach was necessary to identify quality aspects.

The four sites were specifically chosen to represent one of each of the following projects:

- Precast construction;
- In-situ construction;
- A combination of precast and in-situ construction;
- Concrete repairs.

The interviews were an important part of the study as it formed the basis for the subsequent survey that was conducted across a broader spectrum of industry participants. There are many issues

related to the process of concrete construction which contractors need to manage on a daily basis. The practical knowledge of contractors was a good source for identifying relevant issues and to determine why and how they occur so that a suitable questionnaire can be designed. In this way, expert opinion is incorporated in the form of fact, opinion, judgement and interpretation making the questionnaire knowledge-based from a professional point of view. An in-depth summary of the interviews and observations is provided in chapter 5.

A list of questions was drawn up for the interviews and each contractor was asked identical questions. These interviews were recorded, with the approval of the respective contractor, and summarised so that it could be used to design the questionnaire.

The specific issues that were studied are related to the following:

- Aesthetics
- Durability
- Fitment and erection of precast elements

In chapter 5, Site visits, it has been concluded that the issues can be related to either of the components mentioned above.

Fitment and erection of the elements have been grouped together for the purpose of this study as this was seen as a single operation.

Aesthetics, durability and fitment and erection are considered components of quality. Each of the components mentioned above have specific parameters (aspects) to be investigated. These components were identified through the use of interviews and on site observations. Also, the attributes which influence the aspects were identified. The **aspects** were identified as: **labour, management, safety, subcontractors** and **site factors**. Each of the aspects has attributes which define them. Good management practices for instance are determined by the following attributes; how well the manager communicates, plans and coordinates a project.

Following the site visits and interviews with contractors, a survey questionnaire was designed and sent out to a broader spectrum of contractors. In doing so, expert opinion could be obtained from a contractor's perspective. As the study focuses on quality in the construction industry, all the questions in the questionnaire were formulated according to the topics addressed in the interviews.

The research survey was designed for the purpose of exploration. The results of the survey gathered basic information which was used to make the comparison. Information gathered from research

exploratory surveys could be used in descriptive or explanatory surveys for future studies. Qualitative techniques were used here as there was no theory or hypothesis which was tested.

The information received from the respondents was analysed accordingly so that a comparison between achieving quality through in-situ and through precast construction could be made. The manner in which this study is conducted follows a risk based approach. Prioritisation techniques and a cause and effect diagram were used to depict the similarities and differences. As this study followed a risk approach, the risk aspect was described in relation to the analysis of the results. The advantages and disadvantages of each construction method were then drawn from the outcome.

The purpose of prioritisation was to obtain an indication of the more important aspects of achieving quality whereas the cause and effect diagram was used to show how the aspects and attributes influence quality.

By using the respective qualitative methods to analyse the data, conclusions could be drawn to show when precast should be considered over in-situ construction and vice versa when considering achieving quality of construction.

3. Literature review

The literature review contains 4 sections of which 3 are presented in this chapter. Figure 3 below is a graphical representation of the literature review. The link between the 3 sections presented in this chapter will be shown at the end of the chapter. The section “Research surveys” was written in a separate chapter as the content therein pertains more to the survey questionnaire design.

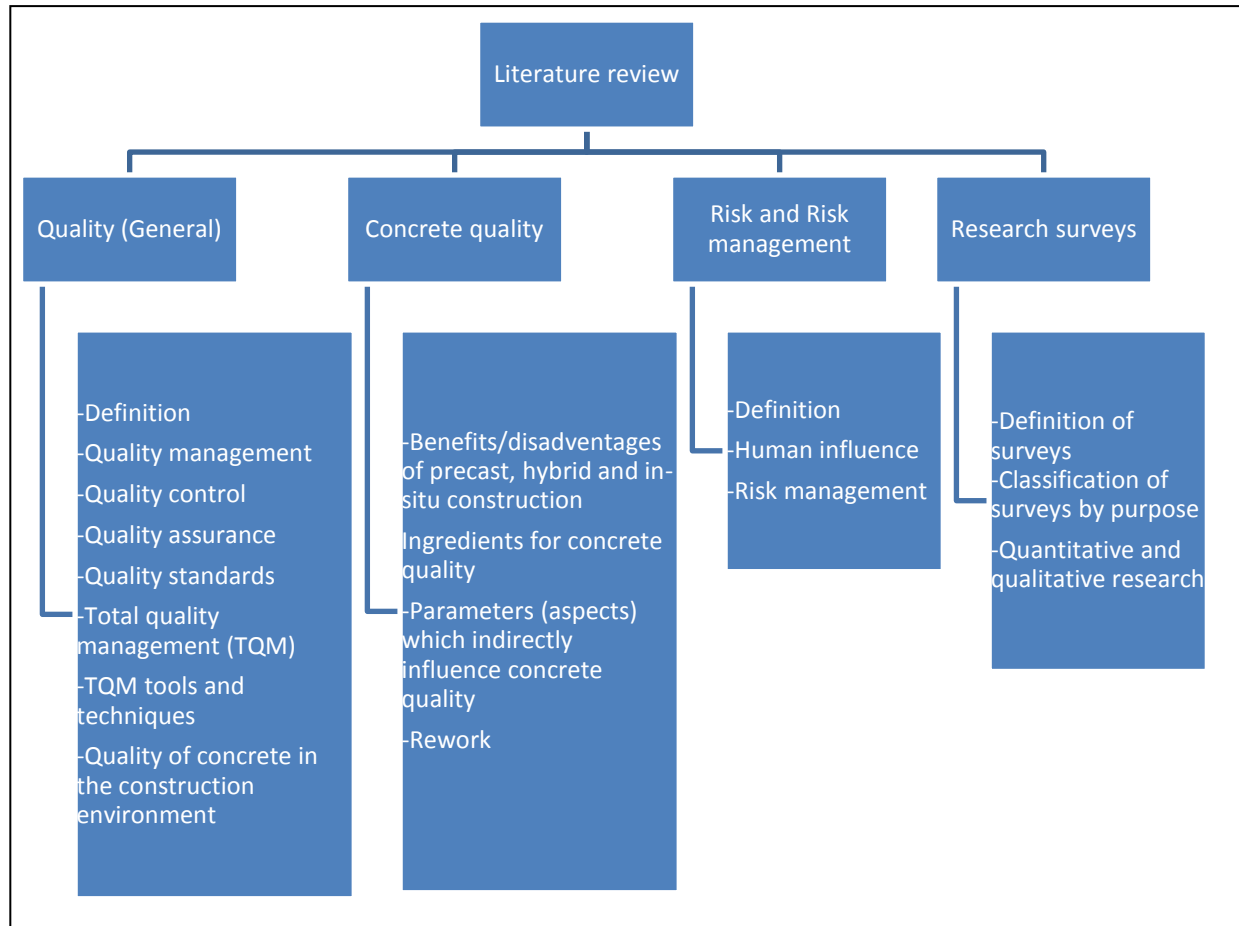


Figure 3: A graphical representation of the literature review

3.1. Quality

3.1.1. Introduction

During the process of concrete construction certain procedures take place to ensure that the company does not waste money due to unsatisfactory processes or at worst, have a law suit filed and end up with a tarnished reputation. It is essential that the quality of the structural elements comprising a building meet the specifications. Non-conformance to specifications could mean an unsatisfied customer or an impending construction disaster. As a form of control and to guarantee that none of the above mentioned occur, certain quality procedures are used. Quality, quality management, quality control, quality assurance and total quality management are a few of the

procedures that are exercised. These procedures are discussed in this chapter and below brief definitions for these concepts are provided.

Quality of an object is directly related to its prescribed set of traits (Harris, McCaffer, Edum-Fotwe, 2006: 12). The characteristics of each product are determined by its purpose and the environment in which it is constructed.

The term quality management is primarily concerned with all the activities that take place during a production process or service. Managers thus have to plan and act as such to implement their strategy (Harris, *et al*, 2006: 13).

One of the procedures in the quality management process is quality control. Ensuring that specifications are met as specified in the contract is done by inspection (Schexnayder, Mayo, 2004: 493).

Quality assurance on the other hand is a system that ensures a product or service will conform to the requirements from the time production starts up until completion. Unlike quality control, the purpose of quality assurance is not to detect defects but rather to prevent them occurring (Harris, *et al*, 2006: 13). Quality assurance is thus a management program employed by a company (Schexnayder, Mayo, 2004: 493).

The concept of total quality management refers to a process where a product satisfies the needs of a customer using both quality control and quality assurance as an aid. The product is developed by employees who strive to fulfil an ever growing need for improvement through training and learning. It is thus a system of constant improvement (Schexnayder, Mayo, 2004: 494). In addition the product conforms to all laws and regulations as stipulated by the government (Harris, *et al*, 2006: 13). This process has been addressed in this study. Furthermore, the tools and techniques which were used to develop the survey are discussed.

Various definitions and views on the above concepts are provided in this chapter with references to the construction industry. The concepts are discussed briefly in order to gain an understanding and will be used at a later stage in the study.

These processes guarantee a high standard of quality in the construction environment. Understanding quality and its processes are critical in order to produce sound products. When implemented suitably, these concepts can be adapted to the in-situ and precast activities such that products with a high level of quality can be produced.

The rest of this chapter proceeds as follows; firstly, quality is defined by providing various definitions. Then quality management is discussed followed by a discussion of quality control, quality assurance, total quality management, tools and techniques of total quality management. Quality management in the construction industry is discussed which is followed by cause and effect diagrams.

3.1.2. Defining Quality

The Oxford concise dictionary defines quality as:

“[mass noun] the standard of something as measured against other things of a similar kind; the degree of excellence of something” (Oxford English Dictionary, 2010).

Quality as defined by the business dictionary states:

“in manufacturing, a measure of excellence or state of being free from defects, deficiencies and significant variations. It is brought about by strict and consistent commitment to certain standards that achieve uniformity of a product in order to satisfy specific customer or user requirements” (Business Dictionary, 2013).

According to Mikkelsen, quality can be defined as:

“an user-orientated and an expression of the product’s usefulness, seen from the user’s point of view. Usefulness means meeting the user’s needs and the product’s reliability, safety, durability, etc.” (Mikkelsen, 1990: 138)

By meeting legal, functional and aesthetic requirements on a project, quality will be achieved. Thus it can also be defined in this manner. When specifications are met and the completed project is within specification, quality is guaranteed to be attained. In certain cases the definition of quality is approached from an alternate angle and aspects such as psychological effects on residents and fitting in with existing structures and landscape define quality. Aesthetic quality is a subjective aspect of quality and differs from project to project. It is thus in the hands of the designer to define aesthetic quality. (Arditi & Gunaydin, 1997: 235).

On the other hand one can compare quality by relating it to meeting requirements and conformance to project specifications. By applying this definition, the following is taken under consideration namely: the simplicity and ease with which technical aspects and drawings are understood, simplicity of operation and maintenance procedures as well as construction economics (Arditi & Gunaydin, 1997: 235-236). In construction, quality can be defined as “meeting or exceeding the needs of the customer” (Schexnayder, Mayo, 2004: 491).

Arditi and Gunaydin suggest that quality may be fact or perception. Quality with regards to goods and services are designed to meet 'quality in fact'. When dealing with quality that is dependent on the approval of a user, the product is designed to meet 'quality in perception'. In addition the quality of the product itself has to be accounted for. When the nature of work is related to construction, one has to account for the quality of the equipment, materials and technology used in the methods of construction. Quality of the process should also be accounted for but should be distinguished from product quality. Process quality relates to the system and way in which a project is managed to achieve a quality during design, construction, operation and maintenance (Arditi & Gunaydin, 1997: 236).

In the construction industry, defining quality is a bit more complex since there are many variables that contribute towards the definition. Firstly the responsibility for attaining quality lies between more than one party and secondly, the process is usually over a lengthy period of time (Rwelamila & Wiseman, 1995). Rwelamila suggests that quality can be defined as:

"the measure of the fitness of the building and its parts to fulfil the purpose defined in the brief or conformance to established requirements" (Rwelamila & Wiseman, 1995: 175).

Quality of a product can thus be defined as something that is fit for its intended purpose and meets the design specifications. The product should be safe and user friendly in its environment and should at least, be of use until the end of its design life.

In the bigger picture, the product is designed to fulfil the needs and requirements of the customer. According to Harris, McCaffer and Edum-Fotwe, "value for money" is the equivalence of exceptional quality (Harris, *et al*, 2006: 13).

3.1.3. Quality Management

During the production cycle of a product, many individuals contribute to the overall quality of the product. Involved in the process are the individuals who define quality and the individuals who plan quality. The consumer on the receiving end of the production line may experience quality completely different from the individuals in the production process. It is thus not a simple process to achieve an acceptable level of quality since the people involved in the production process do not know how the consumers on the other end will view the quality of the product (Mikkelsen, 1990: 139).

When defining the quality of a product, one cannot simply apply a universal definition to a specific product. Products differ from one another and are manufactured under different conditions. When defining quality, one should use multi-dimensional procedures rather than one-dimensional

procedures. Sousa and Voss (2002) believe that the quality of a product is related to the conditions under which the product is manufactured. There are eight different aspects of product quality: reliability, durability, aesthetics, serviceability, conformance, performance, perceived quality and features. Organisations should focus on the nature of their work and make use of these eight aspects to determine an appropriate output for the quality of their product (Sousa & Voss, 2002: 94).

During the process of manufacturing a product, the product follows a certain quality pathway and undergoes certain processes so that it can be of utmost quality. Figure 4 displays the quality pathway for a product.

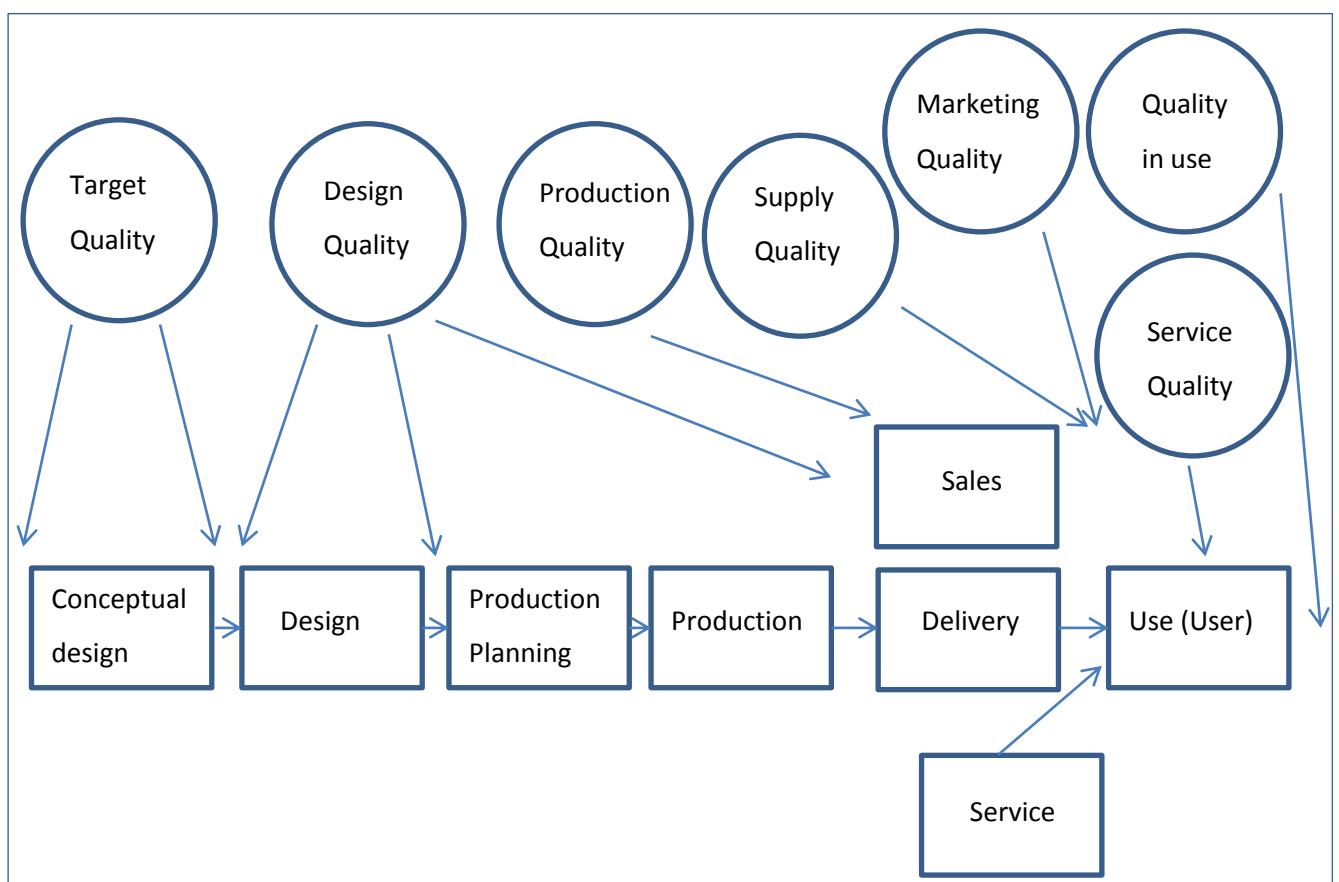


Figure 4: Quality pathway (Mikkelsen, 1990: 140)

The first phase to attaining quality of a product may be achieved when suitable procedures regarding planning, documentation, specifying, inspection and reviews are used. During the production or manufacturing phase of the project, the workers need to perform accordingly. Mikkelsen believes that by having the drive and motivation based on informed knowledge one can reach a target. This is the second phase to achieving product quality. Lastly, Mikkelsen states that quality control should be performed in both the planning and design phase (Mikkelsen, 1990: 140).

On a construction site it is the duty of the contractor to ensure that requirements are met and that they are according to specification. These requirements include; codes of practise, specifications and drawings. The contractor thus has the responsibility of ensuring that the implementation of the activities performed on site is within specifications. Quality management therefore enables the contractor to accomplish his task (Rwelamila & Wiseman, 1995: 175).

According to Rwelamila and Wiseman, quality management can be broken down into the following components: aim, method, result and mechanism. These four components comprise the quality management system. The components can be summarised as follows. (Rwelamila & Wiseman, 1995):

- Aim – to achieve quality such that specifications are met;
- Method – management of quality will make provision for improvements such that defects can be corrected;
- Result – by adapting quality assurance to the process, confirmation of quality will realise;
- Mechanism – improvement and quality assurance will be accomplished by quality control.

3.1.4. Quality Control

The primary goal for any contractor is to construct a product once and to its designed specification. Managers and labourers lacking experience make this target difficult to achieve and are thus a liability to project managers. Owners desire a high level of quality for the product thus fewer call backs and a reduced amount of rework implies higher quality. The Deming business philosophy contains 14 ideas on how quality can be enhanced. A few of his ideas relate to the construction industry. (Levy, 2012: 8):

- Every procedure has room for improvement;
- Training should be introduced on a project ;
- Set high standards and request no defects;
- Support education ;
- Encourage the workforce to demonstrate pride in their tasks.

The aim of quality control is to identify and eliminate all flaws. By using techniques such as statistical methods and inspection, quality control can be executed (Harris, *et al*, 2006: 8).

Quality control has five intentions(Harris, *et al*, 2006: 8):

- To ensure that specifications of the works are met;
- To minimise criticism from clients;
- Enhance durability of the product;
- Better the assurance of the client;
- Minimise the costs to produce the product.

Communication is an important part in the process of quality control. By having regular meetings, one can improve the quality process on a project by making it the number one priority (Levy, 2012: 8).

Quality control (QC) can be seen to be at the lowest level of the 'quality ladder'. Without quality control, quality achieved is as a result of fate and not by plan. Controls have been designed to identify defects and minimise the occurrence thereof. They also ensure that the process of manufacturing is inspected from start to finish. (Clarke, 1999: 52).

QC is a tool that is used in the process of Quality assurance (QA). When applied successfully, errors and changes can be reduced significantly and prevents disputes from occurring. The actions taking in the QC process include planning, checking and assessing (Arditi & Gunaydin, 1997: 236).

3.1.5. Quality Assurance

Quality assurance as defined by the International Organisation of Standardisation (ISO) 9000 (1994) states:

"All those planned and systematic actions necessary to provide adequate confidence that an entity will fulfil the requirements for quality" (Clarke, 1999: 52).

Assurance of quality determines the degree to which quality will be controlled and thus it guarantees quality as an end result by applying certain processes within the quality control procedure (Clarke, 1999: 52).

The process of quality assurance contains meeting specifications, training, guidelines and setting up the required policies and systems to achieve overall quality of a product. By applying the procedure of QA one can track defects and problem areas early in the project and prevent bigger failures from occurring later in the project (Arditi & Gunaydin, 1997: 236).

The objective of quality assurance is to prevent the occurrence of flaws rather than detecting them. The purpose of quality control as aforementioned is to detect defects. Quality assurance is achieved

by planning in an orderly fashion to obtain the requirements and in turn satisfy the customer. The principle behind assurance is achieving the required results the first time (Harris, *et al*, 2006: 10).

In order to design and execute an efficient quality assurance system, 4 phases of planning are required. Firstly understanding needs to be established, secondly, a manual to abide by needs to be created, thirdly, the system needs to be presented and, lastly, the system needs to be assessed (Harris, *et al*, 2006: 16).

3.1.6. Quality Standards

The international standards for quality are the ISO9000 group of standards. This group of standards allow corporations to design their own techniques. Thus, it can be seen to be a more versatile framework to achieve quality. Certain variables impact the quality of the product depending on the nature of the organisation. These variables include (Harris, *et al*, 2006: 14):

- Design;
- Work patterns;
- Management;
- Testing and control;
- Job title;
- Techniques;
- Training;
- Technology;
- Communication loops;
- Comprehension and skill of the employee;
- Production procedures;
- Work relationships.

Some of variables which impact the quality standards and which have been mentioned correspond to the variables which influence quality in concrete construction. This is evident in the site visits chapter. The information presented here will be used later to establish a connection between the results obtained from the survey and these variables which influence quality standards.

3.1.7. Total Quality Management

This section provides a concept of TQM and how it is used in industry. The tools and techniques of TQM are also addressed in this section and will be used to design the survey which will be sent out to various participants. The survey is discussed in more detail in the survey design chapter.

3.1.7.1. What is TQM

The TQM technique initially developed in Japan, began in the 1950's and during the 1980's and 1990's the approach was adopted by more corporations. This continually developing process originates from the advances made in quality control, quality assurance and inspection. The process was not developed by specific individuals but there were four major role players involved with the evolution of the TQM approach. These individuals were Philip B. Crosby, Joseph Juran, Edwards Deming and Kaoru Ishikawa. The process seeks to place emphasis on power of employment rather than status. Sullivan (2011) states that unlike statics, which may give an indication of the frequency of a problem or defect occurring, TQM seeks to minimise and eliminate problems and defects (Sullivan, 2011: 211).

Total quality management (TQM) has been incorporated into many companies during the last few years by applying the process of internal quality management. Internal quality management is management within the firm. The process seeks to break down barricades between organisations within the company and concentrate on the needs of the customer (Gould & Joyce, 2003: 69). This new process of managing quality has two objectives (Gould & Joyce, 2003: 71):

- Fulfilment of the customer's needs;
- A constant need for improvement.

The idea to satisfy the customer is beyond just "the needs of the consumer". This concept refers to the consultant, contractor and all employees. Each person that plays a role in the construction or manufacturing of a product contributes to the concept. Targets such as cooperation and innovation are achieved by discarding conventional means and instead an environment where profitability, trust and pride exist is the environment that is desired (Gould & Joyce, 2003: 71).

Constant need for improvement suggests that on every level of employment, from the labourer up to top management, the attitude of looking for a way to enhance a process is implemented. According to Gould and Joyce, TQM is a philosophy rather than a checklist or plan. When successful it will change the way in which employees think and the manner in which business is conducted (Gould & Joyce, 2003: 71).

Total quality management has been adopted in the construction environment and certain principles have been incorporated into certain companies. A few of these principles are mentioned below (Gould & Joyce, 2003: 71):

1. Specify the drive which is to improve the product;

2. Without hesitation apply the philosophy ;
3. Do not rely on quality control to attain quality, instead strive for perfection the first time round ;
4. Trust should be established between the subcontractors and suppliers;
5. Strive to better production and quality;
6. Incorporate training for employees within all levels of the organisation;
7. Train managers;
8. Motivate innovation and discourage fear;
9. Emphasis on team work rather than individual effort;
10. Strive for zero imperfections and reasonable production rates;
11. Management should be focused on leadership rather than on quotas;
12. Incorporate educational programs and programs for personal development.

It has been found that when TQM is applied, better results are achieved as there is unity in the organisation. Everyone works together as the target and attitude of the individuals in the team are the same. This leads to better production, improved quality of the product and thus fulfilment of the customer's needs (Gould & Joyce, 2003: 72).

A corporation practising good total quality management can be certain that their product or service will meet all the requirements, or will meet the needs of the customer and will deliver a product or service better than all competitors (Harris, *et al*, 2006: 7).

TQM cannot be achieved if quality control is applied on its own since the process ensures that defects be minimised. Similarly, quality assurance only ensures a flawless product but does not incorporate improvements or advances in the method of production.

It is the responsibility of the higher echelons of management to initiate the concept of TQM by emphasising the importance of it and their ambition to achieve it (Schexnayder, Mayo, 2004: 495). It is the responsibility of middle management to understand the principles underlining TQM, enlighten the relevant parties and show their commitment towards the concept. By encouraging the concept the positive results of its implementation should be acknowledged and remuneration should be given accordingly. This positive outlook towards TQM will ensure that the concept is spread throughout the company. TQM can thus be said to be based on pride and attitude rather than just procedure (Harris, *et al*, 2006: 20).

The mechanism used to achieve TQM is based on a chain of people involved in the process. Failure of one person to cooperate will break the chain since successful implementation relies on the competence of the previous person in the chain (Harris, *et al*, 2006: 20).

3.1.7.2. *TQM Tools and Techniques*

Tools and techniques have been developed to embrace the concept of TQM. A variety of these techniques are available for companies to use, such as brainstorming and statistical process. Certain steps can be followed to adopt the concept of TQM. Oakland's steps towards TQM are provided in Figure 5 below.



Figure 5: Oakland's steps to TQM (Harris, McCaffer, Edum-Fotwe, 2006: [21]).

There are a variety of tools and techniques that can be applied to a methodology in the process of attaining TQM. Combinations of these techniques have been used in this research to design the survey that was sent out to contractors in industry. Some of the techniques were also used to assist in obtaining and displaying information obtained from the surveys. Below is a list of a few techniques (Harris, *et al*, 2006: 21) that were used in the survey.

Matrix analysis

The Matrix analysis technique proved to be the most useful technique for designing the survey in this study. This two dimensional procedure allows the ranking of one aspect of quality against

another. In the case of this study, the aspects affecting quality were ranked against the components comprising quality. By applying this technique one can attain a group response using a set of criteria (Harris, *et al*, 2006: 22).

Paired comparisons

The aim of the survey was to prioritise the aspects affecting quality against the issues arising during the construction of the concrete elements. Paired comparisons enable one to do so by using a ranking system. By making use of this technique one can achieve a set of results that will explain the problem (Harris, *et al*, 2006: 22).

Ranking and rating

When an item is ranked it indicates preference in a list of possibilities. Aspects in the survey have been ranked from highest to lowest such that the aspect with the highest and lowest impacts can be underlined. This technique comes in handy when electing which problem to tackle first or in this case, which aspect has the biggest impact (Harris, *et al*, 2006: 22). The ranking system could aid a contractor when managing his risk on a construction project.

3.1.8. Cause and effect diagram

The information obtained from the respondents are presented as matrices (matrix 1 and matrix 2), in chapter 6, each matrix having an in-situ and precast section. By applying this technique, the information presented in these matrices can be combined such that the in-situ and precast information is represented separately. This technique can be seen in the results chapter.

A cause and effect diagram can be used to show the relationship between likely causes of a problem and the outcome. This diagram may be used in the following ways (Cause and Effect diagram, 2013):

- It can be used to point out the origin of problems;
- It could be used to connect the relationship between the origins and the outcome;
- Lastly it may be used to analyse problems so that remedial steps may be taken.

Cause and effect diagrams are a useful tool for organisation and structuring of events. The benefits of a cause and effect diagram increase the understanding of a process by expanding the knowledge on the topic (Cause and Effect diagram, 2013). In this study the cause and effect diagram is linked to quality management for a deeper understanding of the quality issues.

An example of a cause and effect diagram is depicted in the Figure 3.

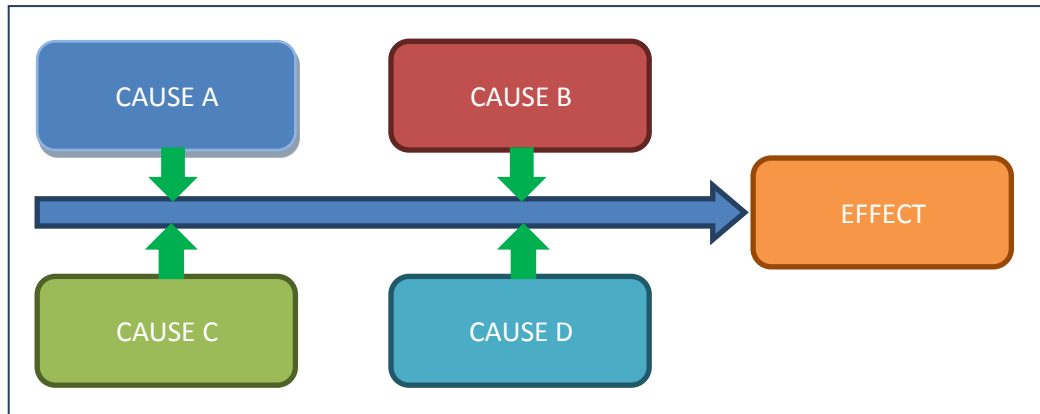


Figure 6: Example of cause and effect diagram (Cause and Effect diagram, 2013)

In Figure 6 the causes are the root of the problem. Causes A, B, C and D contribute to the overall effect of the problem and represent the main categories of the problem. Additional information can be added to the diagram above. Cause A may have other influences that affect it. This information may be displayed on the diagram by linking it up to the arrow leaving the box labelled “Cause A” (Cause and Effect diagram, 2013).

3.1.9. Quality of Concrete in the Construction Environment

By inspection, a contractor is able to determine whether or not a product complies with technical and specified requirements. These inspection tests are quality control procedures and provide the contractor with an idea of how good or poor the quality of the concrete is. On a construction site for example, quality control for concrete strength is performed by using statistical methods, thus samples are taken, tests are done and the results thereof shall determine whether the product conforms to requirements (Harris, *et al*, 2006: 7).

Due to the vast size of the construction projects, quality control becomes a complicated process. Sampling techniques by statistical methods are thus exploited to perform inspection (Harris, *et al*, 2006: 9). The two forms of quality control by statistical methods are the following:

- Acceptance sampling. This method is built on probability theory and enables work to continue provided the samples are within limits of the specification (Harris, *et al*, 2006: 9).
- Control charts. Expected and actual results are weighed against one another on a chart (Harris, *et al*, 2006: 9).

In the construction environment inspection is performed by either a quantifiable and objective approach or by simple observation. The objective approach is applied to road levels, tolerances, fitness for purpose and visual checks. This approach is inspected by using measuring devices or

equipment to verify that specifications have been met. Simple observation on the other hand requires experience to make a well-judged decision (Harris, *et al*, 2006: 9).

In order to abide by the instructions and requirements during the construction process: contract drawings and specifications are used. Unlike with a production line in a factory, there is no way of determining exactly when a process will be completed and when inspection will be done. The time variable between two tasks is not fixed due to the ever-changing conditions in the construction environment (Harris, *et al*, 2006: 9).

The inspection of the works is performed by foremen, contract engineers and resident engineers. Cube strength of concrete specimens, alignment and procedures are some of the quantifiable checks that are performed by these employees (Harris, McCaffer, Edum-Fotwe, 2006:|10|). The manner in which quality control is conducted presents a weakness, in that the standard set by the inspector is the bare minimum the contractor will strive to achieve. Rework is something contractors keep on the side as a form of insurance and this could at times become costly. Harris, McCaffer and Edum-Fotwe (2006) suggest that contractors should instead strive to achieve the best quality first time, understand the quality and not rely on an inspector to determine whether the standard of work is good enough (Harris, *et al*, 2006: 10).

International quality standards are defined by ISO (International organisation of standardisation) 9000 standards (Schexnayder, Mayo, 2004: 492). The organisation is systematic and is institutionalised with policies, procedures and records for managing quality.

On construction projects, three contracting parties namely; the consultant, client and contractor are involved in the construction process. The contractor is liable for the quality assurance procedure and has to execute certain procedures to establish a quality system that will ensure requirements are met. Once the tender has been awarded, the contractor has to formulate and submit a quality assurance plan. Once the site team has been selected, a project quality plan will be submitted. Selected suppliers and subcontractors are provided with the conditions for quality assurance and instructed accordingly. Detailed plans for quality are then received from the chosen subcontractor and are to be accepted before commencement of the works. Random inspections are done on site to ensure that the quality of the work is as prescribed in the documents. Controls and audits are held in addition to the project quality plan (PQP) and detailed quality plan (DQP). Subcontractors and suppliers are evaluated and lastly preparation for delivery commences. (Harris, *et al*, 2006: 18).

Quality control on site is achieved by either inspection or statistical methods. In the construction environment these inspections are objective. These inspections are executed by using measuring devices. The individual executing the inspection is either the foreman, contract engineer or the resident engineer.

Failure to meet the requirements will hold the contractor liable to correct his work. This results in rework and may double or triple the cost of the work (Schexnayder, Mayo, 2004: 496).

3.1.10. Overview

As noted in the chapter, there are many ways of defining quality. Quality of a product can be defined as being free from defects. Quality in the construction environment is a far more complicated definition since there are more variables when compared to a production line in a factory (Rwelamila & Wiseman, 1995). External factors often tend to influence the quality of a product. In construction it is found that there are usually many teams involved with the construction process (Pheng & Chaun, 2005:29). Ownership and responsibility from each team will be the success of another as they are dependent on one another.

As described in this chapter, quality of a product in construction can be defined when a unit or element is fit for its intended purpose, meets the requirements of the design specification and aesthetics. Thus the element or unit is user friendly, durable, safe, free from defects and significant variations.

Management should be viewed as a multi-dimensional procedure rather than as a one-dimensional procedure. Product quality depending on the nature of the product has eight aspects to which it could conform namely: reliability, durability, aesthetics, serviceability, conformance, performance, perceived quality and features. On a construction project it is the duty of the contractor to manage accordingly and ensure that work is implemented within the prescribed specifications.

Within the quality management structure the two quality aids are quality control and quality assurance. These procedures assist a manager to meet the requirements and can also be seen as a method of minimising risk that could negatively affect project cost and schedule. Quality control seeks to identify and eliminate flaws. The process also assures that specifications are met, it enhances durability, satisfies the client and minimises the costs of production. Quality assurance on the other hand is aimed at preventing defects rather than tracking them by tracking problem areas early in the project. Quality assurance guarantees quality as an end deliverable.

The concept of total quality management which originates from advances in quality control and assurance is aimed at customer satisfaction and continuous improvement. Provided that the concept

is practised at all employment levels it seeks to unite workers such that their attitudes and goals are alike. A similar attitude from all the team members will result in higher quality, improved production and satisfied customers.

Total quality management tools and techniques enable one to practise total quality management. Tools such as matrix analysis, paired comparisons and rating and ranking were used as available tools and techniques in the survey. The aspects were ranked against one another by using an appropriate ranking system. In this way the issues with the highest impact could be identified and be compared between the two scenarios.

In the construction industry quality is monitored by visual inspection or sampling techniques. Due to the large scale of construction, samples are taken with the aid of statistical methods. Quality control for concrete strength is monitored in this fashion to ensure that each batch conforms to the specified requirements. These controls are performed by contractors and when inspection relies on visual monitoring, expert judgement and experience is usually consulted.

The processes and activities performed during concrete construction are precise and need careful monitoring to prevent quality imperfections from occurring (Michaelides, 2012). These techniques for quality management are set in place to minimise or ultimately prevent these imperfections from occurring. According to Andrew Ibbetson (2012) it has been found that in the case of in-situ construction, there are more durability issues when compared to precast construction. By investigating what are the main causes influencing quality of concrete, these concepts of quality can be used to make recommendations on how the quality for in-situ and precast concrete may be improved.

3.1.11. Lessons learnt

This section of the literature study has been concluded and the important ideas have been summarised in point form as follows:

- In construction, quality of the product is the responsibility of more than one party;
- Many variables influence quality such as ; quality of the equipment used, quality of the materials and the technology used in the construction methods;
- Quality management is a multi-dimensional process;
- Quality control and quality assurance are processes available to improve the quality of a product;
- Training is important for obtaining the best results;

- TQM strives towards customer satisfaction and continuous improvement throughout the employee hierarchy;
- The success of TQM is dependent on the attitudes of the employees;
- TQM tools such as matrix analysis, paired comparisons and ranking and rating will be used later to design the survey;
- Cause and effect diagrams can be used to analyse problems so that steps can be taken and it can also be used to indicate the origin of a problem. This technique is also applied in chapter 6.4;
- Quality control on site is performed by inspection or by a quantifiable approach;
- Rework is considered to be a form of insurance which is readily available to the contractor;
- ISO 9000 is an important requirement for all construction works.
- The section identified the component aesthetics as part of the definition of construction quality.
- Similarly the compliance to the specification is seen through the durability of the construction of the product over the longer time, thereby the identification of durability part of the definition of construction quality.

3.2. Quality in the Construction Environment

Figure 7 below shows the content of this section on concrete quality.

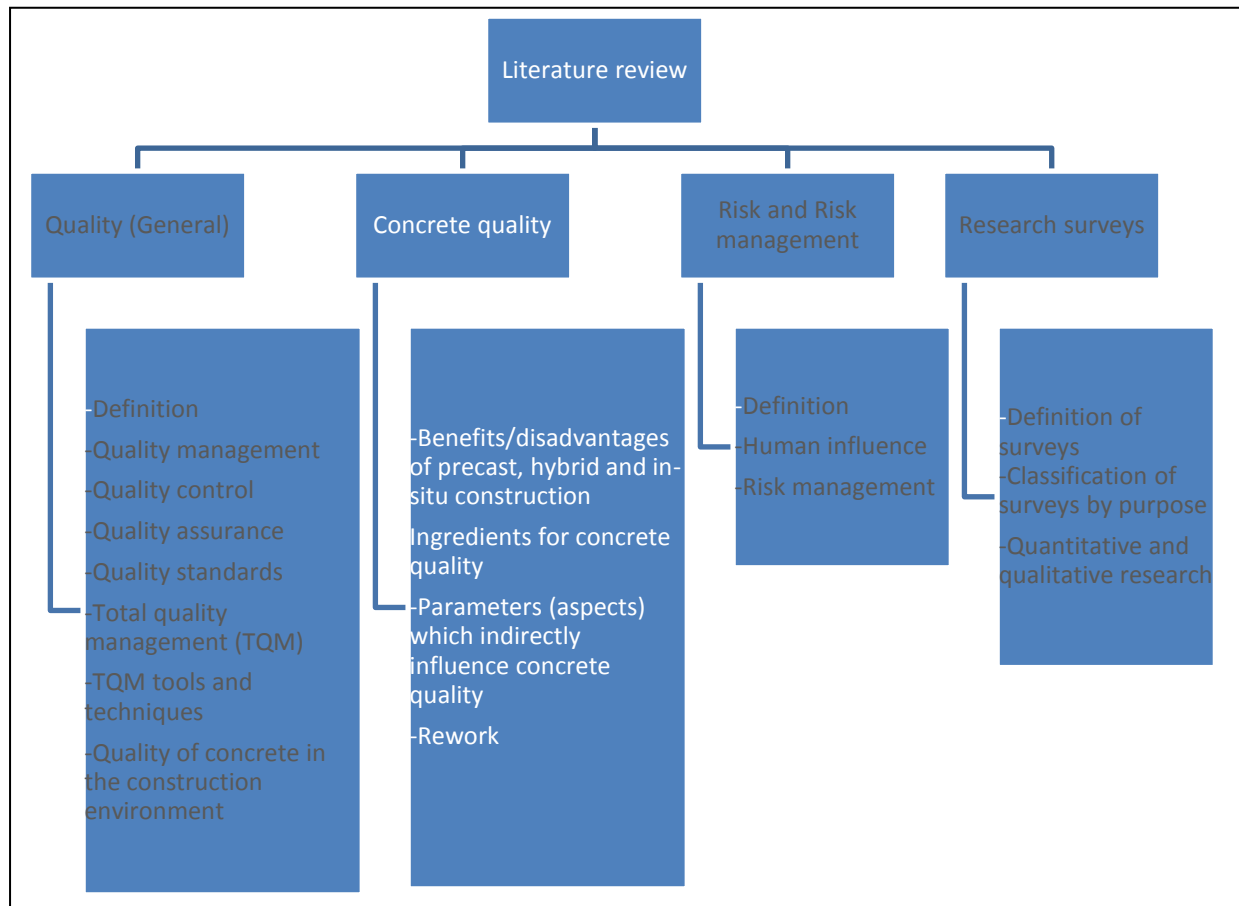


Figure 7: A graphical representation of literature review (Concrete quality)

Quality, with regard to concrete construction, is influenced by various parameters. During the interviews conducted on the construction sites, chapter 5 Site Visits, issues and parameters pertaining to concrete quality were discussed and in this chapter, chapter 3, overviews of the more frequently occurring issues and parameters are provided.

In the construction environment there are ingredients needed for concrete quality and which are directly related to the material. There are also parameters (aspects) which indirectly impact the quality of concrete. Examples of some of the ingredients which directly affect the quality of concrete are; concrete strength, concrete density, cover to reinforcement. On the other hand, examples of some of the parameters (aspects) which indirectly influence achieving quality of the concrete are; management, labour, safety and subcontractors.

One of the consequences of poor quality is rework. The root causes of rework are risk-related and in order to manage quality better it is much needed that these causes are known. In this chapter an overview of the categories and some of the causes of rework are provided.

In Chapter 5, site visits, these issues and parameters are discussed in further detail with relevance to the construction environment. The attributes and aspects discussed in this chapter will be used later to design the survey. An in depth discussion of the design of the survey is presented in Chapter 6.

3.2.1. Benefits and disadvantages of Precast and in-situ construction methods

Hybrid concrete construction

Hybrid concrete construction (HCC) makes use of both precast and in-situ construction methods. These construction methods are combined such that the benefits of each method is maximised. HCC methods have proven to be cost effective and faster than if either precast or in-situ methods are used. This is possible since a portion of the work is completed in a precast factory (Hybrid concrete construction, 2010).

Precast construction units are combined with cast-in place to obtain advantages of continuity (Avallone, Baumeister, Sadegh, 2006).

Some advantages of hybrid construction are reduced whole life costs. In addition, the construction process is quicker than the conventional precast and in-situ methods. It can be said to be safer as fewer labour is needed on site thus there is less congestion on site. (The Concrete Centre, 2014).

A disadvantage of this innovative construction method is innovation barriers and insufficient guidance. Another concern is lengthy distances to and from concrete batch-plants. (Glass & Baiche, 2001).

Benefits of precast construction

Precast concrete is a better choice when there are repetitive elements to be constructed. The elements may be erected quickly and the concrete colour is consistent and of high quality. Erection of precast elements needs less skilled labour and the process itself is accurate. Less labour is needed on site as the fabrication takes place in a factory where the conditions and working environment is controlled (Hybrid concrete construction, 2010). The precast construction method facilitates quality control and higher strength concrete (Merritt, Ricketts, 2001)

Where a client desires a high quality finish, precast construction is better suited. In tough environments, such as student homes, the precast option has proved to be a structure that is durable being more resistant to mechanical damage (Precast Concrete Structures, 2013).

Precast construction makes it possible to use computer controlled equipment for mixing, batching and casting. The conditions in which the elements are manufactured are predictable and is not affected by adverse weather conditions. The finish of the products is of high quality and the environments in which these elements are cast are safe. In the case where time is a constraint, the elements may be constructed throughout the night. When compared to in-situ, the erection of precast elements are quicker as weather does not influence the manufacturing thereof. The precast construction option assures better durability as the cover to reinforcement is consistent. This minimises the probability of corrosion of steel. (GPS Precast Concrete, 2013).

The procedures for precast are more flexible than the in-situ option as changes can easily be made right up until the concrete has been poured. As the conditions within the working environment are controlled, the precast option can assure that durability and strength requirements are met (Jack. 2013).

Disadvantages of precast construction

One of the disadvantages of precast construction is that many cities do not have an abundance of precast concrete subcontractors (Cudney, 1998).

Good planning is needed from an early stage and the nature of the structure needs to provide sufficient repetition to exploit the re-use of formwork. More crane time is needed for fitment of the elements (Advantages and disadvantages of precast concrete construction, 2011).

The design must compensate for handling during shipping. Stresses exerted on the element during transportation should be accounted for (Merritt, Rickett, 2001)

Benefits of in-situ construction

In certain areas, in-situ construction may be economical and it is in these areas where in-situ is combined with precast construction methods to maximise cost efficiency. In-situ construction is flexible and the process of construction shows continuity. The materials used for this method can be found within close proximity (Hybrid concrete construction, 2010).

Disadvantages of in-situ construction

It is more difficult to achieve concrete that is durable when in-situ construction methods are used (Cudney, 1998).

There are a few factors which may hinder the quality of in-situ construction. In particular the strength and durability of the concrete may be compromised by temperature instabilities and by

potential lack of quality control procedures. Last minute changes are rather difficult for the in-situ option when compared to the precast option. Strength tests conducted on site are the responsibility of the contractor and there is a general concern regarding concrete setting in the cement truck. It is also the responsibility of the contractor to wait and ensure that concrete has cured (Jack, 2013).

Unlike for precast construction, wall panels constructed using in-situ methods have a minimum requirement for the thickness. (Avallone, Baumeister, Sadegh, 2006).

3.2.2. Ingredients of concrete quality

The ingredients of concrete quality are directly related to the properties of the material. In the section these ingredients are discussed in relation to the role they play in achieving concrete quality.

3.2.2.1. *Quality control of concrete on the construction site*

Certain tests are performed on construction sites to ensure that concrete conforms to specifications. These are briefly mentioned in the following paragraphs. These specifications are provided in SANS1200G (SANS 1200G):

Slump test

This test is conducted in order to test the consistency of the concrete mixture. Samples are usually taken from each batch delivered to the construction site. Once the concrete has been compacted the slump test can be performed (Illston & Domone, 2001: 130).

Compressive strength test

Concrete cubes or cylinders are tested at seven or 28 days to verify concrete characteristic strength.

3.2.2.2. *Durability*

During the 1980's many countries reported that the maintenance and rehabilitation costs of concrete structures were remarkably high. Concrete may be managed such that the factors which influence the design life are minimised. By minimising the effect these factors have on durability of concrete, the product can be serviceable throughout its lifetime. (Addis & Davis, 1986: 369).

Durability of a material is its ability to remain functional for the desired lifetime of the structure it is part of. It may also be described as the result of the interaction between the structure and the internal environment and the interaction between the structure and the external environment (Addis, 2005). In the past concrete has proven to be a material which is highly durable but in past few decades this has not been the case. (Illston & Domone, 2001: 192).

If the requirements of durability are not met the effects may be; poor serviceability, a hazard to persons and property, expensive repair costs and poor aesthetics of concrete (Addis, 2005: 51).

For a structure to meet the requirements of durability, three parts have to be ensured namely (Addis, 2005: 51);

- Specifying
- Detailing
- Site practice

Specifying relates to the environmental conditions in which the structure will serve its design life. The engineer will determine the characteristics and properties of the concrete based on these conditions (Addis, 2005: 51). The part specifying refers to properties of the concrete such as strength, concrete cover to reinforcement, properties of the mix such as stone size, sand type and the manner in which the samples will be tested.

Detailing refers to specific characteristics of the reinforcement such as bar code, length and shape of bar. Detailing of reinforcement allows for easy placement and compaction of the concrete (Addis, 2005: 130).

Site practice, the third part of durability, is investigated in this study to obtain information on quality from a practical perspective.

Aspects of site practice as it relates to durability are discussed in the following paragraphs:

Consistence of the mixture

The method by which the concrete will be transported, placed and compacted will determine what the consistency of the mix should be. The slump is the parameter which is used for construction work (Addis, 2005: 16).

Reinforcement in concrete

Concrete as a material has a high compressive strength and a low tensile strength property. Steel is good tensile strength properties. It is therefore commonly found that concrete structures make use of reinforcing to make the structure more durable. Steel however may also be used to absorb compression in columns and beams. This property of steel allows for smaller element to be cast. A good property of steel is that it allows the concrete to freely expand and contract without cracking. (Ricketts, Loftin, Merritt, 2004).

The details of the reinforcement are provided by the engineer and shown on drawings and bending schedules. The information provided in these documents indicates location, bar reference, type of steel, length, dimension and shape of the bar (Addis, 2005: 130).

Quality issues associated with reinforced concrete include corrosion of the steel. Corrosion of steel may occur when there is inadequate concrete cover or poor workmanship (Angelucci, 2012).

Corrosion of the steel should not occur as the consequence thereof could result in reduced serviceability, reduced structural strength and poor aesthetics. Staining of concrete, cracking and spalling will be visible to the eye should the steel rust (Addis, 2005: 60).

Quality and durability of the reinforced concrete structure may be improved if emphasis is placed on the following (Addis, 2005: 130):

- Dimensions of the bar to ensure adequate concrete cover (cover blocks are used to ensure that the spacing between the steel and formwork is as specified)
- Bar dimensions effect tolerances and should thus be taken into account. Inadequate tolerances can result in insufficient cover and consequently bad durability.
- Dense reinforcement can compromise compaction and placing and should thus be avoided.

Cover to reinforcement

Experience with concrete construction has revealed that not only is the quality of concrete influenced by design and by specification of the material, but also by construction issues. Once the new concrete structure has been completed, the end quality potentially shows a high variability. In many cases, quality problems may be related to poor quality control and special problems during construction (Gjorv, 2011. P151).

The factor which impacts quality and long term performance of concrete is electrochemical corrosion of embedded steel and not disintegration of concrete itself (Gjorv, 2011. P152). Represented in Figure 8 is the schematic deterioration of a concrete structure due to steel corrosion.

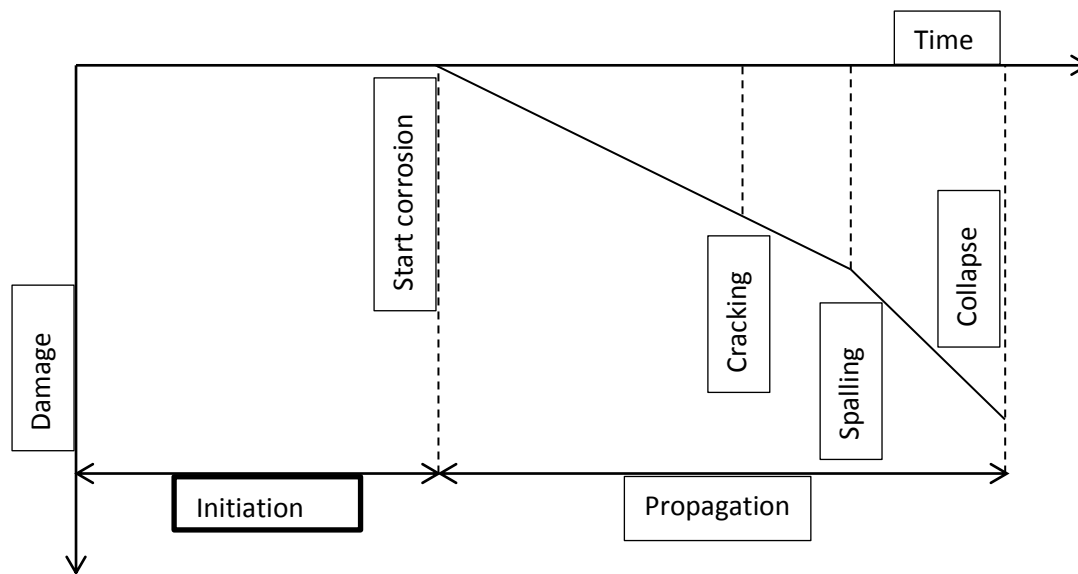


Figure 8: Deterioration of a concrete structure due to steel corrosion (Gjorv, 2011. P152).)

Concrete cover and the ability of the concrete to resist chloride penetration will determine the time it will take for the chloride to affect the steel reinforcement. Visual effects such as cracking and rust staining may also take some time before they appear on the surface of the concrete. By the time the visual effects are present, the process of corrosion would have already started (Gjorv, 2011. P153).

Once the process of corrosion starts, galvanic cell activities in the concrete structure develop. In the galvanic cell activities, the deterioration can be noted by pitted corrosion of the concrete in the anodic areas of the rebar system. In the cathode area, oxygen is collected. The real service life of the structure can be estimated however, once the process of corrosion begins, the time until the potential structural collapses cannot be accurately estimated. In the early stages of corrosion the only implications will be maintenance costs. If these maintenance measures are not acted upon, complex problems will arise at a later stage (Gjorv, 2011. P153).

In marine environments, chloride infiltration may have already taken place during the construction process. In this case, the chloride penetration should be measured before the structure is handed over to the client (Gjorv, 2011. P166).

An important parameter of durability is cover to reinforcement (Angelucci, 2012). Concrete cover can be defined as the distance from the face of reinforcement to the surface of the concrete. Reinforced concrete has a minimal cover to which it has to conform to. Minimal cover refers to the foundation on which durability and provision for fire is applied. The concrete cover is provided in SANS 1200G and should not be less than the diameter of the reinforcement (SANS 1200G), but is also a function of the specific environment, concrete class and expected service life. The actual cover

indicated on the drawings is known as the nominal cover and will be more than the minimal cover. This nominal cover varies according to construction conditions. (Ronne, 2006:2). Concrete cover is achieved by using the required cover blocks. The cover blocks are inserted between the formwork and reinforcement and are usually made of concrete, plastic or fibre cement. The cover depth can be found on the engineering drawings. Failure to meet cover to reinforcement requirements may result in corrosion of the steel. (Blackledge & Binns, 2002).

Curing

The purpose of curing concrete is to ensure that there is enough water available for hydration. If an excessive amount of moisture leaves the concrete once it has been placed, the concrete may crack as a result of plastic shrinkage. In addition to cracking the concrete may fail to achieve its required strength. Curing is thus a vital process of a concreting operation and should be dealt with accordingly (Illston & Domone, 2001: 138).

Surface zones are the areas which are affected by inadequate curing. Quality of the concrete cover determines the protection of the steel against the reinforcing (Blackledge & Binns, 2002).

Curing of concrete increases its resistance to abrasion. It ensures that the surface's permeability increases and is important for cover to reinforcement (Blackledge & Binns, 2002).

Curing of concrete may be achieved by; spraying water in regular intervals on the exposed surface, keeping the exposed surface out of sunlight and wind, covering the surface with hessian or polythene sheets or by using a curing membrane (Illston & Domone, 2001).

Formwork

With regard to durability, the formwork should produce acceptable concrete as specified by the number of formwork uses. Uneven absorption of water will result in a concrete finish with unsatisfactory quality (Addis, 2005: 133).

The joints between the formwork panels should be tight such that water loss is minimised as the appearance of the finished concrete could be affected (Blackledge & Binns, 2002).

Compaction

Compaction of concrete is achieved by vibrating the concrete so as to remove trapped air. The air inside of the concrete is as a result of mixing, transportation and placement (Blackledge & Binns, 2002). Inadequate compaction reduces the strength of the concrete and its durability as the voids

make the concrete more susceptible to chemical attack and corrosion of steel. Compaction may be accomplished by using either hand tampers or mechanical vibrators (Addis, 2005: 150).

Internal poker vibrators are commonly used to compact the concrete. The size of the poker is determined by the spacing between the reinforcing. External poker vibrators are used more frequently with precast construction and in certain cases where the concrete lies in confined spaces (Blackledge & Binns, 2002).

Concrete cracking

Cracking of concrete may take place before and after corrosion of the steel. Cracking of reinforced concrete before corrosion does not influence the load-carrying capacity but does have detrimental effects on the durability of the concrete. Cracks in the concrete make chloride attack on the steel easier resulting in corrosion of the steel (Alexander, *et al*, 2012: 28).

Bleeding

Bleeding can be described as the upward movement of water through the concrete towards the surface. Bleeding in turn increases the permeability of the concrete and takes place once the concrete has been placed. Permeability of the concrete determines how water and aggressive agents move into the concrete, thus it influences the protection of the reinforcement against corrosion (Addis & Davis, 1986: 378).

Bleeding is influenced by the mix proportion, grading of the sand, sand particle shape, amount of fines in aggregates, fines in the cement, admixtures, air content, temperature and the thickness of the concrete (Beall, 2001).

Excessive bleeding decreases durability by increasing the porosity, and weakening the interface bond to the reinforcement. By decreasing the water content, using well graded sand and air entrainment, bleeding can be reduced. (Beall, 2001).

Water/Cement ratio

The water/cement ratio of the mixture is defined as the weight of the water divided by the cement in the water. The strength of the concrete is determined by the water/cement ratio of the mixture. The water/cement ratio is inversely proportional to the strength of the mixture thus the lower the water/cement ratio, the stronger the concrete will be (City and Guilds 6290-001, 2002).

The parameter water/cement ratio impacts the durability of the concrete as the strength is determined by it. This parameter is design related and is determined by the clients' desire. The

water cement ration cannot be controlled by the project team unless the concrete used was from a batch plant established on site (Michaelides, 2012).

3.2.2.3. Tolerances in concrete construction

There are three groups of tolerances to which an element must abide. They are product tolerances, erection tolerances and interfacing tolerances respectively (Gutt, et al, 2010).

Tolerances for reinforcement, steel fixing, formwork and concrete cover are provided in documents such as SANS part CC1. The minimum cover for various exposure conditions is provided in SANS part CC1 (SANS 2001-CC1:2007).

Product tolerances

Product tolerances are the specific dimensions for each element. The variations on these tolerances should not compromise the variations of other elements (Gutt, et al, 2010).

Erection tolerances

Erection tolerances refer to those tolerances which are related to matching up of the elements. This comes into being once the precast elements have been erected (Gutt, et al, 2010).

Interfacing tolerances

Interfacing tolerances are related to building systems and other materials in the vicinity of the precast members. This may be of relevance before or after erection of the precast member (Gutt, et al, 2010).

Product tolerances would relate to precast and in-situ construction whereas only erection tolerances and interfacing tolerances are applicable to precast construction.

3.2.3. Parameters (aspects) indirectly influencing concrete quality during construction

Through the use of interviews with various contractors, it was found that certain aspects played a role in achieving concrete quality. These aspects are discussed briefly in this chapter and in the descriptions of the site visits in Chapter 5. In this section these concepts are discussed briefly to provide an understanding of what each aspect entails as they will be used in the questionnaire.

3.2.3.1. *Management*

A Project Manager is in overall charge of a project. He selects the equipment which will be needed, negotiates with subcontractors, submits progress reports to the company and is thus responsible for all communication on the project (Schexnayder, Mayo, 2004: 71)

A large part of quality management is also related to communication. This is one of the many requirements of management and is considered to be very important as communication is vital to conveying a message.

Conveying a message across to another individual is particular. A message can have many meanings ranging from being critical to being inspirational or may even be driven by disaster. Timing of the message is critical and the receiver of the message should be in the correct state of mind when the message is conveyed. Timing of a message can prevent a catastrophe from occurring. The content and selection of words is critical especially in a delicate situation. When criticism is brought across the message should be firm and straight to the point. Communication should thus be precise and timed correctly. Figure 9 represents the basic communication loop (Gould & Joyce, 2003: 80).

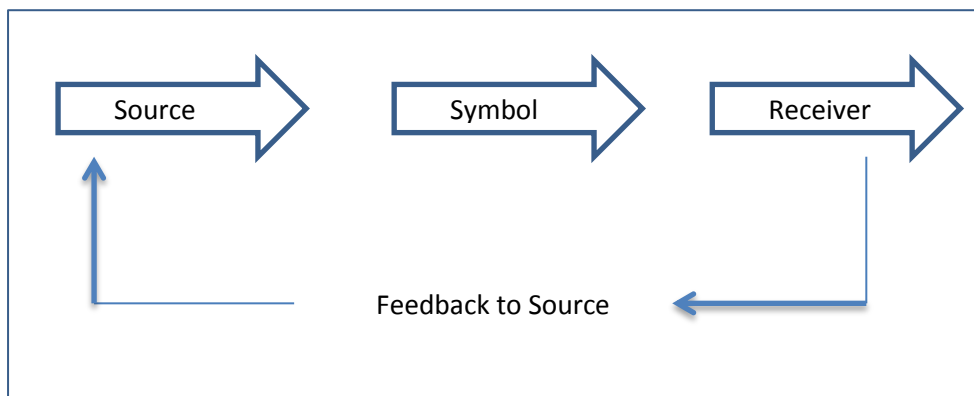


Figure 9 Basic communication loop (Gould & Joyce, 2003: 80)

It is important that a team or project leader not only communicates but stimulates the members in the team to communicate effectively. Figure 9 represents the basis of a communication channel. On a project the source is represented by the project or team leader; the symbols, oral or written statements, are the methods used to convey the message, and the receiver is represented by the individual receiving the message. The source should consider the receivers' characteristics in order to effectively communicate the intent of the message. Characteristics of the individual include education, background and expertise. The message also comes across successfully when it is conveyed in a private place from person to person rather than in a group (Gould & Joyce, 2003: 81).

When the project is doing well and things are running smoothly it does not imply that the team leader should sit back and watch. The role of the leader here is to ensure that the team does not become distracted but rather keep them motivated and focused (Gould & Joyce, 2003: 81).

3.2.3.2. Safety

Assessment of the job site for safety hazards is best identified by the project manager and project staff than by the company staff. The role of the Project Managers with regard to safety is to assist the project management staff where technical training or knowledge may lack (Schexnayder, Mayo, 2004: 511)

The construction industry is one of the most unsafe industries in comparison with others. It is the most risky and therefore extra measures have to be taken to prevent accidents. The positive attitudes of managers practicing safety is reflected onto his workers. Constructive attitudes of managers convey positive attitudes in the workforce. In order for the project manager to effectively manage the safety on site, he is required to have the following four basic skills. These are conceptual skills, human skills, technical skills and political skills (Zou & Sunindijo, 2012: 94), which are briefly discussed below.

1. Conceptual skill

Conceptual skills are characteristics that are needed in a manager as they allow him to visualise the entire project. The ability to adapt to change and the impact thereof is essential in a manager as the project environment is dynamic. Conceptual skill allows a manager to value good safety procedures and the positive outcome thereof (Zou & Sunindijo, 2012: 94).

2. Human skill

Human skills are important traits as safety procedures involve working with others. Understanding and emotional awareness are vital as they allow a manager to gauge other individuals' emotions and work accordingly. The administering of one's own emotions as a manager is significant to maintain a healthy and positive attitude (Zou & Sunindijo, 2012: 94).

3. Political skill

The first trait of political skill is the intelligence of a manager or social astuteness which permits a manager to assess and consider the feelings of others. The second trait is interpersonal ability which radiates superior or "role model" characteristics. Lastly, networking ability gives any manager an edge to conquering a successful organisation (Zou & Sunindijo, 2012: 95).

4. Technical skill

There are six requirements needed but for the purposes of this study, only the relevant requirements will be discussed. Scheduling is an important requirement as it determines when activities will start, end, and their duration. Quality management, the second requirement, incorporates conforming to project specifications and how to achieve the prescribed quality free of defects. Lastly, risk management is necessary as it seeks to identify, mitigate or manage potential project risks. The risks may be related either to time, cost, safety or quality (Zou & Sunindijo, 2012: 95).

Safety is an important process in the construction environment as it involves the lives of individuals concerned. All procedures are required to be safe, thus safety plays a role in the construction procedure and processes needed such that the quality of a product conforms to its requirements.

Technical skill is needed to conduct safe construction practices. One of the requirements of technical skill in particular is risk management. Understanding the scope of the project and being able to visualise it will positively impact the project managers' abilities to identify risk and manage it accordingly. Risk will be discussed in chapter 5 as the manner in which the study was conducted follows a risk approach.

3.2.3.3. *Labour*

Tasks on construction projects are conducted by a number of teams that have been formed within the organisation. Each team is responsible for his part on the project. With regards to concrete projects, the contractor usually has a "shutter team", a "steel fixing team" and a team to pour and vibrate the concrete. The teams are, however, susceptible to human influence, applied psychology and occupational health and safety. These factors define a team and could determine the difference between a well-oiled team and an incompetent team (Mitropoulos & Memarian, 2012: 1400).

Training is considered to be the most important strategy for an employee to gain knowledge and skills (Tabassi, Ramli, Baker, 2011: 214). Through training, self-awareness is developed and it is through self-awareness that employees grow. Training increases flexibility and adaptability (Tabassi, Ramli, Baker, 2011: 215). In developing countries such as Iran, due to lack of training and skilled workforces, companies were faced with many damages on their projects (Tabassi, Ramli, Baker, 2011: 217).

A team has two tasks: to focus on task work which revolves around technical issues and teamwork, which includes non-technical aspects. For a team to function successfully three requirements are needed. Firstly, cognitive team attributes are acquired, secondly, affective attributes need to be

considered. Lastly, behaviours and attributes have to be recognised (Mitropoulos & Memarian, 2012: 1401).

The first requirement, cognitive attributes, will enable the team to function by overcoming the knowledge barrier. Knowledge will enable an individual to comprehend tasks and the procedures involved; it will guide an individual to interpret the technology used, the duties, roles, skills and ability of the members within the team. For knowledge to enable supreme functioning, situational awareness should be utilised by the team. The information known should be distributed throughout the team as it will enhance the team's communication and coordination. Construction environments are dynamic and thus vulnerable to change. Workload could pile up on an individual, and thus adaptability of individuals within the team will enable the workload to be shifted. Adaptability is the third cognitive attribute. Through being able to anticipate and recognise changes, one can mitigate adverse risk by responding with a suitable solution (Mitropoulos & Memarian, 2012: 1401).

Affective attributes relate to the attitude of the individuals in the team and their eagerness to perform a task. Attributes of motivation include task commitment and interpersonal cohesion. Overall task commitment is a group effort but it starts with each individual in the group. Thus the failure of an individual to commit to the project will lower the group's probability of success. Interpersonal clashes have led to lower performance and unity.

3.2.3.4. Working Environment

Being able to build facilities is important for planning, designing and administration of any construction. In the construction industry it is important that knowledge and experience is learned and then extended and reviewed. This knowledge should be communicated so that the project objectives can be met. (Uddin, Hudson, Haas, 2013).

There are many factors that influence the success of a construction project. These factors in turn influence the project manager. Not much emphasis has been placed on these factors influencing the working environment. The specific factor that will be focused on for the purposes of this study is the project characteristic related factors (Pheng & Chaun, 2005: 25). These project characteristic related factors are described below.

Projects vary according to size, duration, complexity and type. These variables can be seen as project related variables. There are a few variables that may influence the characteristics of a project. These are project environment, relationship of team, complexity, size, materials and project duration (Pheng & Chaun, 2005: 28), which are briefly discussed below.

1. Project environment

Projects are subject to several factors based on the project environment. These factors can be broken up into intermediate and external factors. Internal factors are associated with suppliers, customers and contractors whereas external factors are associated with technology, economics and politics (Pheng & Chaun, 2005: 28).

2. Project size

Complexity and project size are directly proportional to one another. Increased project size requires complex systems and coordination. Delays in an area will create a ripple effect thus delaying other sections of the project (Pheng & Chaun, 2005: 29). Time constraints and the structural composition may also impact the scope of the project (Uddin, Hudson, Haas, 2013).

3. Teamwork

In situations where teams have been unsuccessful it was found that their failure was largely due to the failure of the team members to cooperate. The success of a team is thus largely related to cooperation and willingness to work together (Pheng & Chaun, 2005: 29).

4. Materials and suppliers

Materials and suppliers have an influence on the construction procedure. Productivity of labour and competency of the project is thus impacted by these factors. Tools used will impact the production rate and thus the success of the project (Pheng & Chaun, 2005: 29). The availability may also impact the project (Uddin, Hudson, Haas, 2013).

3.2.3.5. Subcontractors

The size of a construction project can be related to its complexity. Complex projects normally involve collaboration with subcontractors. Each subcontractor is responsible for a portion of the project (Wang & Liu, 2004: 110).

Management of the subcontractors by the main contractor is, in itself, complex in nature. The subcontractor is subjected to various factors which may influence his success rate. Factors such as labour, climate, malfunctioning of equipment, delay in delivery of materials and site factors may affect the work of a subcontractor. The primary contractor should be familiar with these factors and should be managed accordingly (Wang & Liu, 2004: 110).

3.2.4. Rework and the rework cycle

In the construction industry activities that have already been completed and do not conform to the specified requirements have to be redone. This is known as rework. The source of rework is commonly related to non-conformance, quality deviations and failure to conform to quality requirements (Zhang, et al, 2012: 1381).

Rework tracking and clause classification was conducted by Zhang (2012) to determine the origin of the category of rework. This was accomplished by using a supportive management program under the TQM structure. The results of this process were obtained by applying the management program to rework and can be found in Table 1.

Table 1: Causes of rework (Zhang, et al, 2012: 1381).

Rework root causes	Sub-causes
Process group	
Design and Engineering	<ul style="list-style-type: none"> • Drawing and specification inaccuracies or omissions • Insufficient documentation management • Scope and design changes • Lack of attention to detail
Instruction and inspection	<ul style="list-style-type: none"> • Poor communication • Poor decision making • Inadequate supervision
Schedule	<ul style="list-style-type: none"> • Shortcoming in field conditions predictions • Poor rescheduling of resources • Lack of development and application of practical application
Material and equipment supply	<ul style="list-style-type: none"> • Ill-timed delivery or misplacement • Imperfection in prefabricated element • Unsatisfactory condition of tools and equipment
Human performance group	
Knowledge	<ul style="list-style-type: none"> • Inadequate knowledge of the task at hand

Rework root causes	Sub-causes
Skill	<ul style="list-style-type: none"> • Lack of specialised skill • Shortages in personal training
Self-discipline	<ul style="list-style-type: none"> • Difficulty in understanding instructions or failure to abide by policies • No motivation

Table 1: Continued

Quality can be best assured when the supervisors have the proper attitude; firm, detached authority but should show willingness to help when help is required (Tuthill, 1986: 28). The manner by which work is supervised may minimise rework in the future.

3.2.5. Overview

The aspects and attributes which have been described in this chapter were mentioned by the contractors that were interviewed and were identified from the chapter Literature review – Quality issues in the construction environment. These aspects and attributes play a role in achieving overall concrete quality. The effect on quality may be a direct or indirect result of these aspects and attributes.

The aspect management is important as it is largely associated with communication. Ineffective communication could be disastrous for any construction project. Conveying a message includes transferring knowledge and giving instructions such as directing a vehicle into a driveway. Timing is crucial as is the manner in which the message is conveyed. A stimulating individual will be respected and acknowledged in the work environment. An educational background is thus important for the understanding of the requirements and specifications pertaining to quality. Management of a subcontractor, usually required on a complex project, is in itself challenging as the factors that influence the subcontractor also affect the main contractor.

Safety in the construction environment is significant as it involves the lives of the individuals on the construction site. Managing safety requires four skills: conceptual, human, political and technical skills. Visualisation of a project, ability to work with people, understanding and quality management will assure safe management practices.

On a construction site the labourers work in teams. The functioning of the team can be defined by human influences, psychological influences and occupational health and safety. Functioning of the team also relates to the cognitive attributes of the individual. The ability of the individual to grasp technical concepts and breach the knowledge barrier between himself and the contractor will

determine the success of the team. Affective attributes also affect team work as this is associated with attitudes of individual in the team, their commitment shown and interpersonal cohesion within the team.

Factors that may influence a project could be internally or externally related. An example of an internal factor is suppliers and an example of an external factor is technical requirements. Team work can impact the success of a project depending on their willingness to cooperate.

Failure to comply with quality requirements results in rework. The causes of rework are largely related to non-conformance, vast deviations and failure to meet specifications. The lack of attention to quality aspects, if not monitored adequately, may result in rework. Rework may be as a consequence of either faulty production processes or human nature. Human nature is associated with skill, knowledge and self-discipline whereas process is related to design and engineering, instruction and inspection, schedule and material and equipment supply.

Characteristics of good management practices are effective communication. Similarly it can be said that communication is one of the characteristics of good safety and labour practices. The impact of these aspects on quality is determined by the effect that their attributes have on them. Communication is one of the few attributes these aspects have in common. As aforementioned, the aspects of quality were defined as labour, management, site factors, safety and subcontractors and the attributes are the characteristics of the respective aspects. Communication is an attribute of safety and labour. The literature used in this chapter indicates how these attributes may influence the respective aspects and in time affect quality. The root causes of rework have a similar nature as the attributes which influence the aspects. It can be deduced that failure to communicate, insufficient knowledge, lack of skill or coordination negatively impacts the aspects of quality which in turn may result in rework.

Achieving quality in concrete construction goes beyond testing procedures such as slump tests and compression tests. Specification and requirements are needed including a method which will allow the required level of quality to be achieved. Training and good supervision is required as well as communication and understanding the problem. (Tuthill, 1986: 24).

3.2.6. Lessons learnt

The lessons learnt, which are presented below, represent the key points of the Chapter. These points were deduced from the conclusions.

- The quality aspects: management, the working environment, safety, labour and subcontractors influence the quality of the product during the construction process;

- Emotions of individuals and the ability to work with people play a role in achieving quality with regard to safety;
- Motivation of a labourer determines his eagerness to perform and thus, the success of the project team will be determined by the attitudes of the individuals in the team. Cooperation thus also plays a role in achieving quality;
- The subcontractor is subjected to various factors such as delays, malfunctioning of equipment, climate, labour, and many other factors;
- The causes of rework may be related to either process or human traits.

3.3. Risk

Figure 10 below shows the content of the risk chapter.

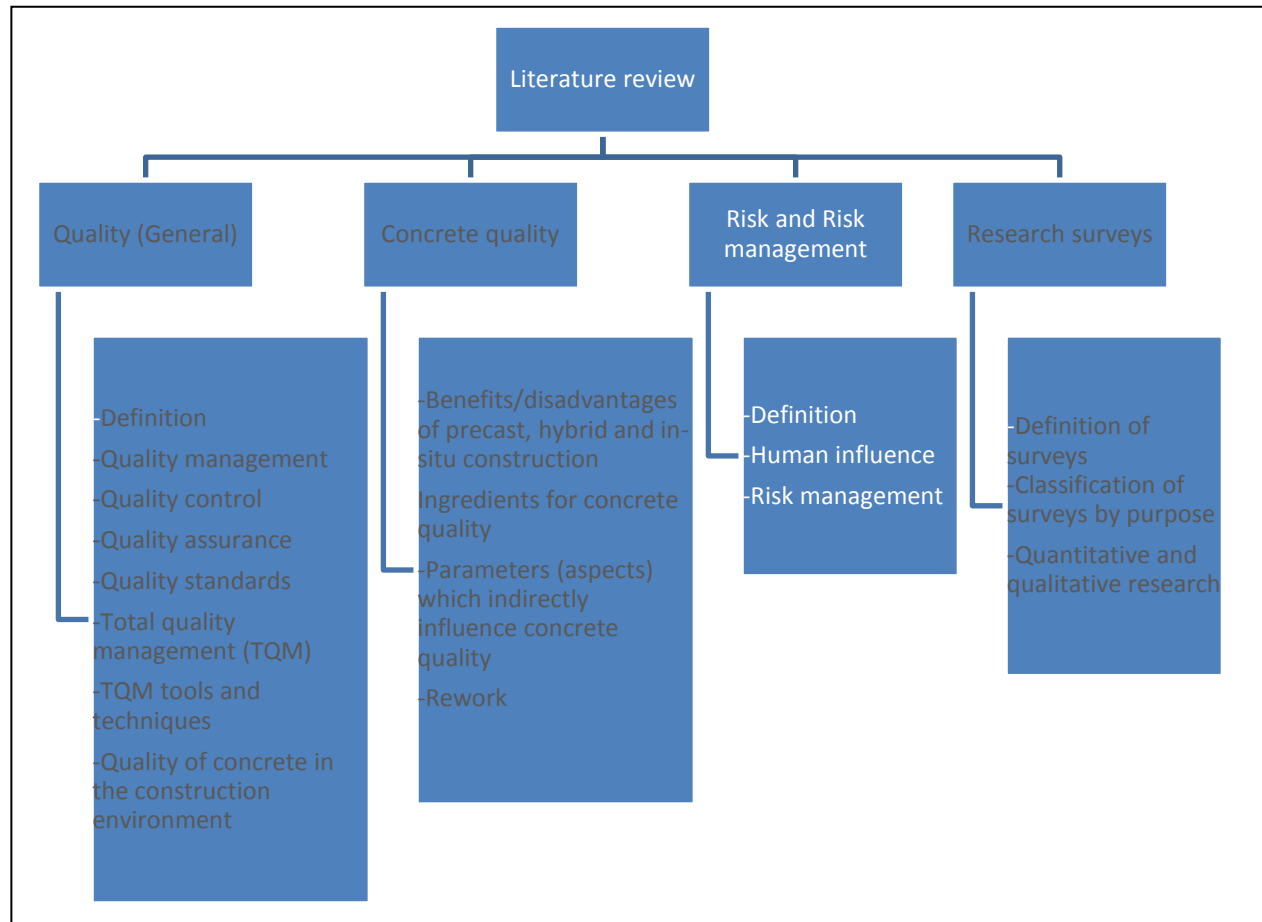


Figure 10: A graphical representation of the literature review (Risk)

In the construction industry it is found that risk management is not very efficient and is primarily due to absence of knowledge. In this environment it is found that risk is usually handled by the use of contingencies or time (Serpella, Ferrada, Howard, Rubio, 2014 :654).

Management of risk involves the perceptions of individuals and their ability to make decisions to treat the risk, therefore the perception of risk can be influenced by human attitude. General risk management processes include; risk planning; risk identification; assessment of the risk by either qualitative or quantitative techniques; risk analysis and risk responses (Serpella, *et al*, 2014: 655). During the planning phase of a project certain procedures are discussed to assure quality throughout the construction phase.

In this chapter a definition of risk is provided followed by a brief discussion of the impact of human attitude towards risk, and risk management. In the construction industry, risk may influence cost, scope, time and quality. (The content of the risk chapter is used to demonstrate the correlation

between risk management concepts and procedures in the construction industry, and construction quality), hence the grounds on which the information is gathered and synthesised. This information is used later in the study as a basis for the survey design as well as the analysis of the results.

3.3.1. Definition of Risk

Whenever there is an amount of uncertainty related to an outcome, there is a potential risk. The uncertainties may be related to time constraints, budget or conformance to quality specifications. Risk can be described as a product of probability of occurrence and impact. Risk may be high probability low impact or high probability low impact. Low probability high impact risk includes construction or structural collapses whereas high probability low impact risk may be associated with concrete volume of the foundations. In general there are many risks on a construction project. There is a probability that a flood could occur, a fire may break out, variations in cost prices, labour incompetence's or non-conformance from labour. These are all uncertainties and there is no way of knowing whether or not they will occur. These uncertainties should be accounted for and it is important that the client, contractor and engineer be aware of them (Barnes, 1983: 24).

3.3.2. Human Attitude towards Risk

Risk may be treated in three different ways. The way in which the risk is managed characterises the individual. There are three kinds of individuals according to risk: the risk adverse individual, the individual who welcomes risk and the risk-neutral individual. The risk adverse individual will pay some premium to account for the risk, the individual who welcomes risk can be seen as a gambler and the risk-neutral person is in between the two previously mentioned (Barnes, 1983: 25).

These individuals basically need to make decisions based on risk. The decision making process is subjective since each individual perceives risk differently. Numerous factors determine how the risk is distinguished namely: educational background, culture and personal beliefs. The risk attitude of each individual is associated with their personalities as well as the political, economic and management environment (Wang & Yuan, 2010: 210).

The decision making process is determined by a number of factors. The factors that influence the decision making process was obtained by the use of a questionnaire (Wang & Yuan, 2010: 210). The questionnaire was sent out to 300 participants. The factors were ranked according to the contractor's perspective and are shown in Table 2.

Table 2: Factors influencing decision making (Wang, Yuan, 2010: 214)

Factors	Ranking
Effects of making a decision	1
Engineering experience	2
Completeness of project information	3
Sensitivity to external information	4
Decision inspiration	5
Professional knowledge	6
Educational background	7
Scope of knowledge	8
Boldness	9
Judgement ability	10
Company's economic strength	11
Social experience	12
Values	13
Interest in the engineering	14
Desire for decision objectives	15
External economic environment	16

Clients as well as contractors will suffer from these risks. Contractors are however more vulnerable since these decisions impact their own benefits as well. It is during the conceptual stage of the projects where the most uncertainties exist (Wang & Yuan, 2010: 216).

From table 2 above there are many factors which influence a decision however the factor which will be emphasised on later in this chapter is the factor “Professional knowledge”.

3.3.3. Risk management

In the construction industry, associated risk impacts the project cost, schedule and quality.

A solution to manage risk is not simply to pass the risk over to a different owner. Managing risk means to lower the impact of the potential threat on the project. Risk may be treated by using a combination of the following: risk transfer, risk retention, mitigation or prevention (Kartam^a & Kartam^b, 2000: 328).

Risk mitigation occurs in the early stages of the project. This procedure is accomplished by identifying the potential sources of risk and treating them accordingly (Kartam^a & Kartam^b, 2000: 328). A few risk reduction strategies that may be used are alternate construction methods, a redesign of the project, performing extra site investigations or alternating the contract strategy (Akintoye & MacLeod, 1997: 34).

Decision making is an important part of the risk management process during the construction phase of the project. Optimal decision making is influenced by good communication. Communication therefore has the ability to improve risk management. A decision may be good or bad and thus it can be said that risk management is essentially decision making. (Tang, *et al*, 2007: 945).

A questionnaire was designed by Tang (Tang, *et al*, 2007) and handed out to a number of respondents in the construction industry in China. These respondents played different roles in the construction industry. These roles included clients, designers, contractors, management and site supervisors. The questionnaire contained construction risks and the participants were asked to rank these risks accordingly. According to Choudhry and Iqbal, the most common technique used to identify a risk is by consulting experts. The next favourable technique is using industry information followed by checklists, risk review meetings and lastly, brainstorming (Choudhry & Iqbal, 2013: 45). The construction risks these participants were asked to rank were quality of the work, safety, inadequate planning, incompetence of the subcontractor, bad coordination, site access and logistics. These were a few of the construction risks these respondents were asked to rank most of which may have an influence on achieving quality. (Tang, *et al*, 2007: 946).

There are three techniques which can be used to analyse risk during a construction project. It may be done qualitatively, quantitatively or semi-quantitatively. A questionnaire was designed by Choudhry (Choudhry & Iqbal, 2013) and sent out to a number of respondents. The respondents were asked to rank the technique according to the frequency usage. The results of this analysis showed that qualitative methods were used more frequent. Most organisations do not have reliable data and expertise on the matter, quantitative risk analysis is seldom used on construction projects. (Choudhry & Iqbal, 2013: 45).

According to Tang (Tang, *et al*, 2007: 950), in the Chinese construction industry, qualitative techniques obtained higher rankings than quantitative techniques suggesting that qualitative techniques are used more frequent than quantitative techniques (Tang, *et al*, 2007: 950).

According to Jerling (Jerling, 2009), in the South African construction industry, during the early stages of the project qualitative techniques are used to gather information and grasp potential problems of the project (Jerling, 2009: 28).

Quantitative methods may be used however; they do not incorporate problems encountered, remedial measures and lessons learnt from previous projects. Risk management systems should enable the user to capture this information when managing a new project. This will allow new projects to continually incorporate knowledge into the risk management system. The knowledge which is referred to relates to fact, procedure, concepts, interpretation, ideas, observation and judgement (Serpella, *et al*, 2014: 657).

As aforementioned, the critical risk constraints on a construction project are scope, time, cost and quality. The factor “knowledge” can thus relate to either one of the risk constraints. For the purpose of this study, the factor “knowledge” shall relate purely to quality of concrete during construction.

One approach which is used in quality management to analyse processes is the cause and effect diagram. The approach has four main steps: detect the problems, identify associated factors, identify potential causes and analyse the cause and effect. A cause and effect analysis may be used to address risk management. (Hekmatpanah, 2011: 537).

3.3.4. Discussion

Uncertainty about an event presents hesitation and doubt. When it is uncertain whether an event such as a strike or flood will occur, there is a risk. The risk may have a low impact and high probability or a high impact and a low probability. No matter what the impact may be, risk should be accounted for and, preferably, it should be treated.

The construction risks which the respondents in the Chinese construction industry were asked to rank are similar to the aspects and their attributes which influence quality of concrete on a construction site. These aspects (Labour, management, etc) and their attributes (factors) were identified in the literature as well as through interviews which were held during the site visits (chapter 7). It can thus be deduced that the aspects and attributes can also be viewed as construction risks which were identified. These risks which were identified were ranked in the survey as part of this study by participants in the South African construction industry. The rating and ranking is explained further in chapter 8, Questionnaire and Results.

The manner in which these rankings are analysed in this study is by using qualitative techniques as this method was used more frequent in the construction industry (Choudhry & Iqbal, 2013: 45).

The cause and effect diagram is an approach which can be used to manage risk on a construction project. Hekmatpanah showed that the cause and effect diagram could be used to manage risk as the relationship between a defect and its cause can be portrayed from the diagram (Hekmatpanah, 2011: 537). This was used as an alternative way to interpret the results. Individuals who welcome risk in the construction industry are the contractors. There are many risks associated with the construction environment. Decisions need to be made to manage these risks. There are critical factors which may influence these decisions. The top five critical factors are in order of rank: are the effects of making a decision, engineering experience, the completeness of project information, sensitivity to external information and decision inspiration.

3.3.5. Lessons learnt

- Uncertainty of an event occurring is considered a risk;
- Factors such as educational background, culture and personal belief influence how risk is perceived, thus risk is subjective to human decisions;
- Qualitative methods to manage risk, especially in the construction environment, can prove to be more effective;
- Decisions are taken when risk is managed. These decisions are influenced by factors such as, the effects of the decision, engineering experience, decision inspiration and educational background, to name but a few;
- Continually incorporating new knowledge into risk management systems can lower the risk on a construction project by minimising the effect of the risk constraints namely scope, time, cost and quality;
- Risk may be treated by transferring the risk, reducing the risk, mitigating the risk or preventing the risk from occurring;
- Cause and effect diagrams can be used as risk tools to determine the origin of a problem.
- Construction risk identified in previous studies may have an influence on achieving construction quality.
- Quality is a construction risk and therefore management of quality should be from a risk approach.
- Methods which are used in the industry are mostly from a qualitative basis.

3.4. Chapter overview

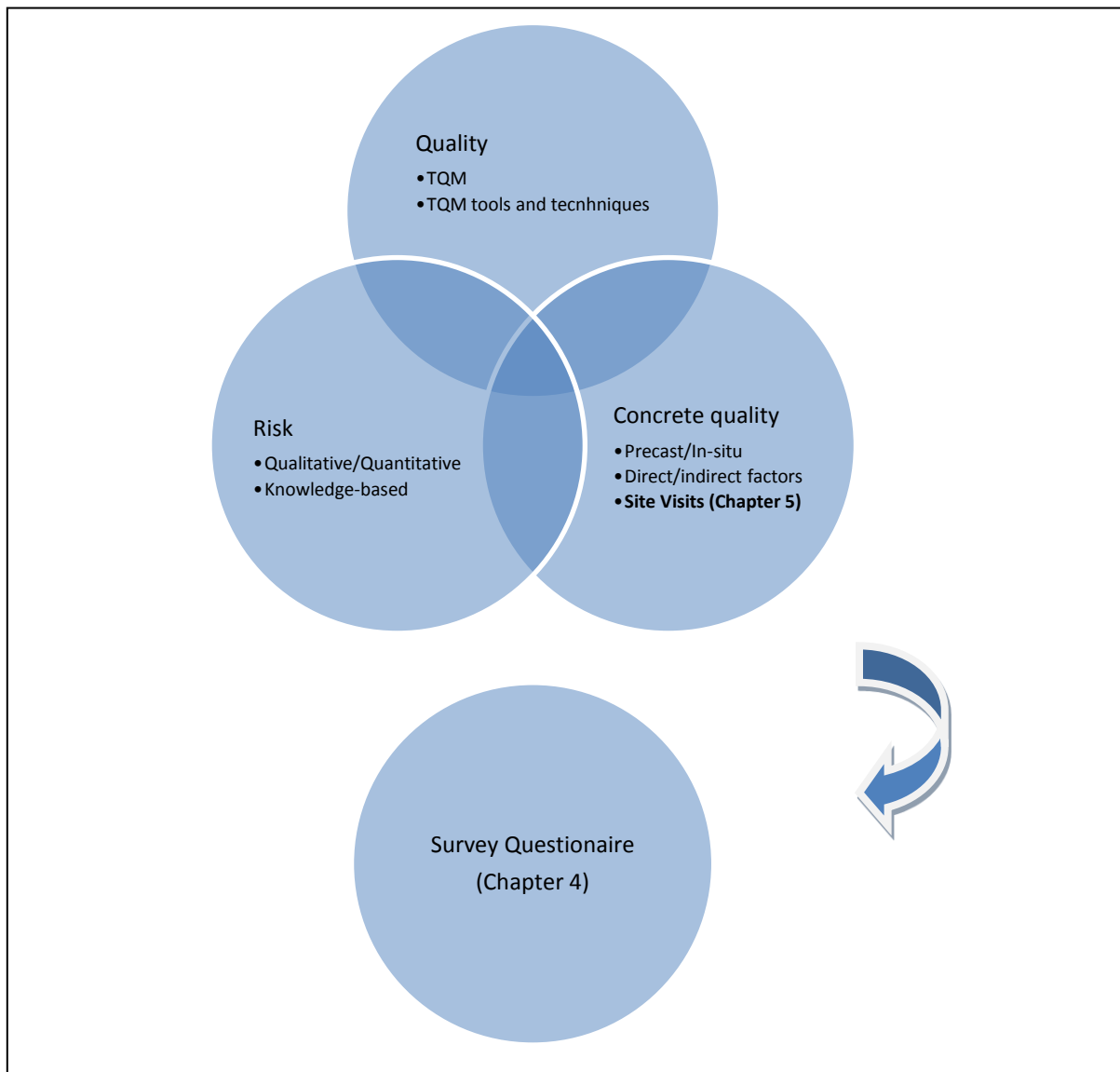


Figure 11: Correlation between risk and quality

The diagram in Figure 11 above shows the correlation between risk and quality.

Quality and total quality management was discussed in the chapter 3.1. Some of the tools and techniques mentioned there were used to design the survey which was sent to various participants in industry. The quality addressed is specifically related to concrete during the construction phase. Chapter 3.2 went on to discuss concepts and procedures in relation to concrete. Quality of concrete was identified to be defined by durability and aesthetics. In chapter 5 (Site visits) it will go on to show that the third part tolerances also form part of the definition of quality. As risk management is essentially decision making, on a day to day basis there are many decisions which need to be made on a construction site. The decisions related to quality are influenced by experience, knowledge, motivation, values, to name a few. The factors influencing rework which is a consequence of bad

quality are poor decision making, lack of attention to detail, inadequate knowledge, lack of skill, to name a few. These factors that influence quality are thus risk-related.

Current risk management systems make use of either qualitative or quantitative techniques. It is evident that qualitative techniques are preferred over quantitative techniques. In chapter 4 these techniques are discussed further with reference to survey data. The three concepts namely; quality, risk and management of concrete quality were used concurrently in the design of the survey which is discussed in further detail in chapter 6.

4. Research surveys

Figure 12 below shows the content of the chapter Research surveys.

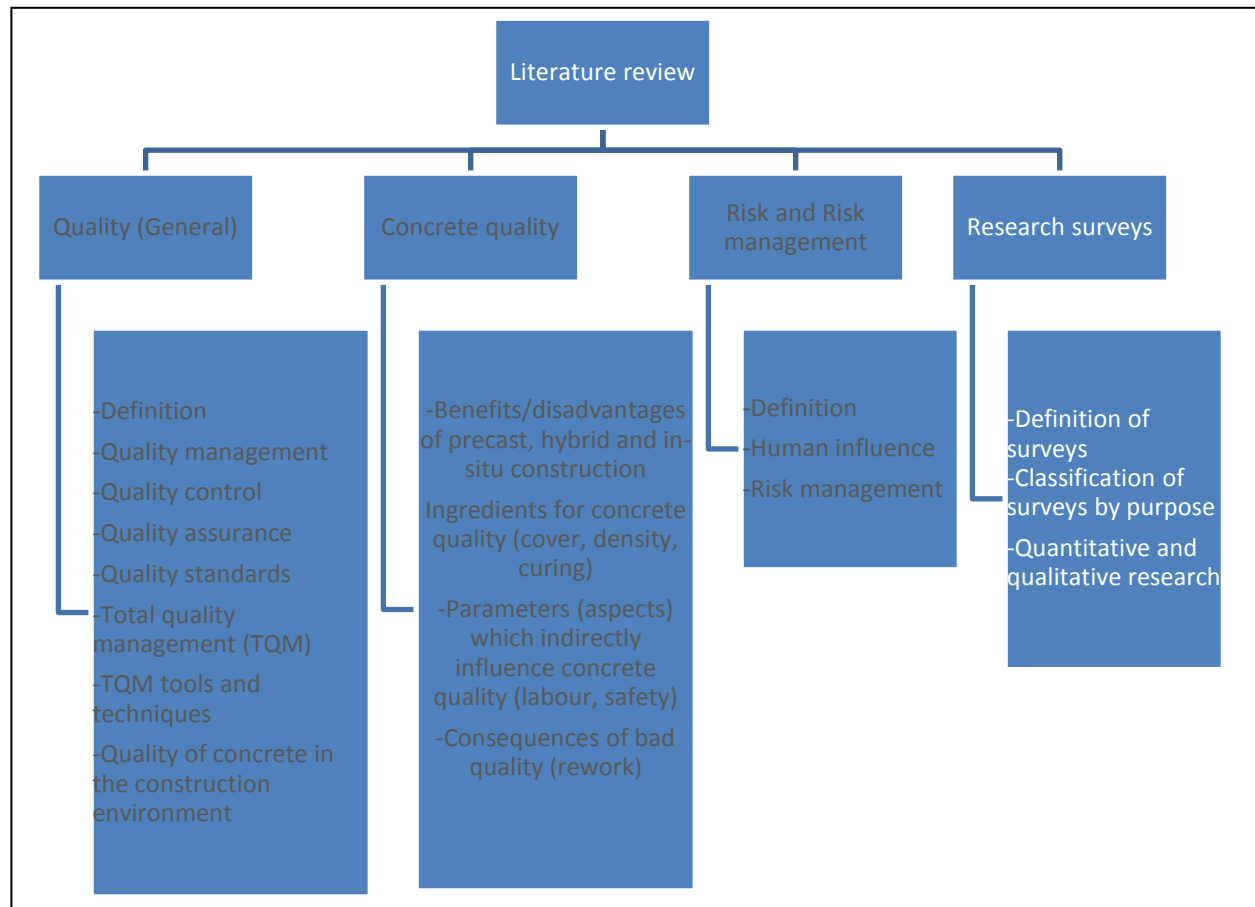


Figure 12: A graphical representation of the literature review (Research surveys)

4.1. A definition of survey

Surveys are designed in order to obtain behaviours, actions or opinions from a group of individuals known as a population (Pinsonneault & Kraemer, 1991). A survey was used in this study to obtain information from the contactors and engineers in the construction industry. In this section three types of research surveys are described. The intentions of these surveys, classification thereof and problems that may arise when using these kinds of surveys are discussed.

Research for a qualitative study is obtained from interviews, field observations and a literature study. The objective was to determine which aspects and attributes influence quality during the construction phase of the project. Many variables were thus identified and studied making the quantitative approach less suitable. When an analysis is conducted by means of a qualitative approach, the results reflect a deeper meaning (Pinsonneault & Kraemer, 1991).

4.2. A brief description of research surveys

The surveys which are designed for the intent of research have three distinct features. Firstly, the data obtained is described by using qualitative methods. The findings are generated either by making use of relationships that exist between the variables or by projecting findings descriptively of a demarcated population. The subjects who respond to the survey are individuals, groups, organisations or communities (Pinsonneault & Kraemer, 1991).

Secondly, the data obtained from the population is mainly gathered by making use of organised and pre-set questions (Pinsonneault & Kraemer, 1991).

Lastly, the information collected is only obtained from a fraction of the population, namely the sample. In most cases the sample size is large enough such that statistical analysis may be conducted (Pinsonneault & Kraemer, 1991).

4.3. Purpose of study by classification

Research surveys may be applied for the purpose of exploration, description or explanation. A survey for the purpose of exploration may be used to focus on establishing which concepts should be measured and how to best measure them. The survey used for exploratory purposes is thus best put to use when various viewpoints from individuals are obtained such that a more structured survey can be designed (Pinsonneault & Kraemer, 1991).

A survey used for the purpose of descriptive research may be used to determine which events, situations, opinions or attitudes come about in a distinct population. The main purpose of survey research is to describe a certain distribution or to make comparisons between two distributions (Pinsonneault & Kraemer, 1991).

A survey can also be used for the purpose of explanation, tests concepts and relations. This kind of survey is concerned with the relationships that exist between variables. The element of cause and effect comes into being as not only the relationships between the variables exist, but also the positive or negative effects which these variables have on each other. The principle question with surveys of explanation is: "Does the hypothesized causal relationship exist, and does it exist for the reasons speculated?" (Pinsonneault & Kraemer, 1991). In Table 3 below, the characteristics of the three surveys are listed.

Table 3: Dimensions of research survey study by purpose (Pinsonneault & Kraemer, 1991)

Element/Dimension	Exploration	Description	Explanation
Research design			
Survey type	Cross-sectional	Cross-sectional	Cross-sectional and longitudinal
Mix of research methods	Multiple methods	Not necessary	Multiple methods
Units of analysis	Clearly defined	Clearly defined & appropriate for the questions/hypotheses	Clearly defined & appropriate for the research hypotheses
Respondents	Representative of the unit of analysis	Representative of the unit of analysis	Representative of the unit of analysis
Research hypothesis	Not necessary	Questions or hypotheses clearly stated	Hypotheses clearly stated
Design for data analysis	Not necessary	Inclusion of antecedent variables and time order of data	Inclusion of antecedent variables and time order of data
Sampling procedures			
Representativeness of sample frame	Approximation	Explicit, logical argument; reasonable choice among alternatives	Explicit, logical argument; reasonable choice among alternatives
Representativeness of the sample	Not a criterion	Systematic, purposive, random selection	Systematic, purposive, random selection
Sample size	Sufficient to include the range of the phenomena of interest	Sufficient to represent the population of interest & perform statistical tests	Sufficient to test Categories in theoretical framework with statistical power

Table 3: Continued

Data collection			
Element/Dimension	Exploration	Description	Explanation
Pre-test of questionnaires	With subsample of sample	With subsample of sample	With subsample of sample
Response rate	No minimum	60-70% of targeted population	60-70% of targeted population
Mix of data collection methods	Multiple methods	Not necessary	Multiple methods

4.4. Problems faced with survey research

4.4.1. Mixture of data collection methods

Fewer than 7 per cent of studies use a combination of one or more research methods to collect data. Thus a limited viewpoint is obtained limiting the possibility for acquiring an understanding. A mixture of research methods is essential for exploration and explanation studies. A combination of field work and case studies will enable the researcher to gain a deeper understanding of the research topic (Pinsonneault & Kraemer, 1991).

4.4.2. Sample representation

Greater than 50% of descriptive studies have no methodical sampling procedure. This is a result of researchers not taking into account the limitations of the studies and the bias it may have on the results (Pinsonneault & Kraemer, 1991).

4.4.3. Response rates

Low response rates are a common problem however, they are not very important for the purpose of exploratory surveys since the findings are not intended to be generalised. Unlike the case where more than one third of explanatory surveys have a response rate of 51 per cent, only one fifth of exploratory surveys are above 51 per cent (Pinsonneault & Kraemer, 1991). Descriptive and exploratory surveys are usually either of poor or adequate quality whereas explanatory surveys have proven to be of better quality (Pinsonneault & Kraemer, 1991).

4.5. Quantitative and qualitative research

In this section a definition of a quantitative analysis is provided. The purpose is to demonstrate that the nature of the research in this study does not comply with quantitative characteristics. The

section also discusses why quantitative methods are used and when it is not suitable to use them. Lastly a table is provided discussing the differences between qualitative and quantitative methods.

4.6. What is quantitative analysis?

Quantitative analysis can be described as a phenomena whereby numerical data is gathered and the results thereof are described by using mathematical methods such as statistics (Sakamolson, 2013).

Data may be analysed by using either quantitative or qualitative methods. Unlike with quantitative methods, qualitative methods may not always be analysed by using statistical methods as the data is not always represented in a numerical format (Sakamolson, 2013).

In order to make use of quantitative analysis, it is important to utilise the correct methods of analysis but it is more important that the data collection procedures allow for a quantitative analysis (Sakamolson, 2013).

Quantitative research, as mentioned previously, is based on numerical data such that statistical methods can be used to analyse the data whereas for qualitative research, a range of techniques such as research, interviews and case studies are used. The view of a quantitative researcher can be described as being a realist whereas that of a qualitative researcher can be seen as subjective (Sakamolson, 2013).

4.7. Why use a quantitative analysis?

When there is a large amount of qualitative data available to a researcher it may be useful to use quantitative methods to extract important results. Quantitative analysis may also be useful when the qualitative data is collected in some structured way. An example of this may be where information has been obtained through discussion and other approaches (Abeyasekera, 2013).

4.8. Choice between qualitative and quantitative research

The following considerations are useful to decide between qualitative and quantitative research (Sakamolson, 2013):

1. Quantitative methods are too shallow for an in-depth investigation of a problem;
2. Quantitative methods are normally used to test hypotheses and theories;
3. When the areas on which attention is to be emphasised are complex, a qualitative study, such as case studies, would render better results than a quantitative study. A quantitative study is limited by the number of variables it can address;
4. Quantitative studies are better suited for looking into cause and effect whereas qualitative studies look at the meaning (depth) of particular events.

From the list it is evident that qualitative research is suitable for the explorative nature of this research. The following table provides information concerning the difference between qualitative and quantitative research methods.

Table 4: Quantitative research versus qualitative research (Xavier University, 2012)

Criteria	Qualitative Research	Quantitative Research
Purpose	To understand and interpret social interactions.	To test hypotheses, look at cause and effect, and make predictions.
Group Studied	Smaller and not randomly selected.	Larger and randomly selected.
Variables	Study of the whole, not variables.	Specific variables studied
Type of Data Collected	Words, images, or objects.	Numbers and statistics.
Form of Data Collected	Qualitative data such as open-ended responses, interviews, participant observations, field notes, and reflections.	Quantitative data based on precise measurements using structured and validated data-collection instruments.
Type of Data Analysis	Identify patterns, features, themes.	Identify statistical relationships.
Objectivity and Subjectivity	Subjectivity is expected.	Objectivity is critical.

Criteria	Qualitative Research	Quantitative Research
Role of Researcher	Researcher and their biases may be known to participants in the study, and participant characteristics may be known to the researcher.	Researcher and their biases are not known to participants in the study, and participant characteristics are deliberately hidden from the researcher (double blind studies).
Results	Particular or specialized findings that is less generalizable.	Generalizable findings that can be applied to other populations.

Scientific Method	Exploratory or bottom-up: the researcher generates a new hypothesis and theory from the data collected.	Confirmatory or top-down: the researcher tests the hypothesis and theory with the data.
View of Human Behaviour	Dynamic, situational, social, and personal.	Regular and predictable.
Most Common Research Objectives	Explore, discover, and construct.	Describe, explain, and predict.
Focus	Wide-angle lens; examines the breadth and depth of phenomena.	Narrow-angle lens; tests a specific hypotheses.
Nature of Observation	Study behaviour in a natural environment.	Study behaviour under controlled conditions; isolate causal effects.
Nature of Reality	Multiple realities; subjective.	Single reality; objective.
Final Report	Narrative report with contextual description and direct quotations from research participants.	Statistical report with correlations, comparisons of means, and statistical significance of findings

4.9. Why was qualitative methods more suitable for this study

The sample size selected in this research was small and was not selected randomly. The manner by which information was gathered was through the use of interviews, observation during the site visits and field notes. The aim of analysing the data was to identify patterns rather than produce statistical relationships. The scientific method followed throughout this study was exploratory and the behaviour was dynamic. The research was conducted in the natural environment with the objective of exploring and discovering.

A qualitative approach was thus more suitable since the criteria of qualitative research have been met (Table 4).

4.10. Conclusion

Descriptive surveys may be used to indicate where additional studies are needed. Exploratory surveys on the other hand are of lower quality but could be used effectively as independent research efforts or as basic information for an explanatory or descriptive study. Initial concepts may be tested

by using exploratory surveys to become familiar with a topic. The range of responses which occur in the survey can be best viewed when using exploratory surveys.

The type of survey chosen for this study was an exploratory survey. The criteria of the sampling procedure for an exploration survey best suites this study. The criteria states that there is no minimum response rate and the sample size is sufficient to include the events of interest.

For this study there was no hypothesis or theory to be tested. The data was collected by means of field work, interviews and reflections. The type of analyses used: cause and effect diagrams and prioritisation were used to identify patterns and themes. The behaviour of the participants considered as a part of this research could be considered to be dynamic and situational. The nature of the observation during the site visits were conducted in a natural environment rather than under controlled conditions. As the objective of the approach used in this study was to perform a qualitative analysis, qualitative tools were used in the study. The tools used include interviews, site visits and the analysis of the survey questionnaire.

5. Site Visits

5.1. Introduction

The purpose of the site visits was to obtain information on quality in different construction environments. Information regarding the quality of concrete was obtained by visiting a precast, in-situ and a construction site where both precast and in-situ construction is used. A company specialising in repair work was also considered to obtain information regarding quality of structures which have already been built.

The construction sites that were visited were owned by companies namely: Cobute, a company specialising in precast concrete construction for multi-storey buildings, Murray and Roberts (Buildings and Concor Roads and Earthworks divisions) and Botes & Kennedy, a company specialising in repair work and general construction work.

Figure 13 below displays the content which can be found in the Site visits chapter

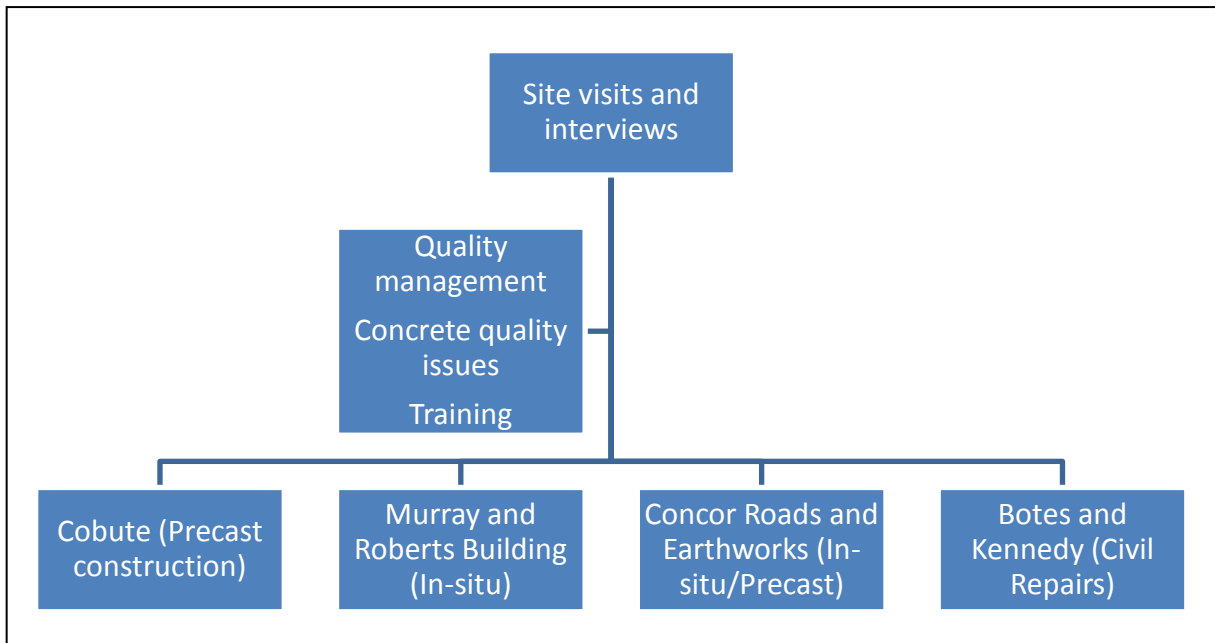


Figure 13: A graphical representation of chapter 5 Site visits

This chapter provides an overview of each of the companies visited. It addresses quality components such as durability, aesthetics, fitness for purpose, general quality and the quality systems used by the respective companies, installation of precast elements as well as staff training. Due to the wide range of concrete structures in the building and construction industry, only structural elements were considered. Structural elements namely; beams, columns, slabs and staircases were considered for the purposes of the study. The chapter concludes with a synthesis made of quality related issues identified for both precast and in-situ concrete construction.

The information obtained during these visits was used as a basis to design a matrix in which the quality between precast and in-situ concrete construction could be compared.

A series of questions were asked at each construction site. These questions can be found in Appendix A of at the back of the document. The interviewee was asked to elaborate accordingly on each of these questions.

5.2. Cobute (Precast construction)

5.2.1. Company Background

The information provided in the following paragraphs was obtained through a personal interview with the managing director of Cobute (Angelucci, 2012). Cobute, which is an acronym for Concrete Building Technology, was founded in South Africa in 1994. The company's head office is located in Killarney just outside of Cape Town's Central Business District (CBD). This precast company specialises in lightweight structural elements for multi-storey buildings. The precast concrete

shutters are manufactured and become part of the final product and thus their method of construction can be seen as an innovative solution to the building industry.

The structural elements which Cobute manufactures include slabs, beams, columns and staircases and are supported by load bearing walls.

5.2.2. Cobute's Precast System

Cobute manufactures a range of precast elements which are light and easy to handle. These include the following:

- Ribs and panels
- Permanent concrete shutters for reinforced concrete edge ribs
- Permanent concrete shutter for reinforced concrete beams
- Permanent concrete shutters for reinforced concrete columns
- Permanent concrete shutters for reinforced concrete staircases.

The elements mentioned above are all permanent shutters and thus they are designed as a part of the final element.

Decking system

Cobute supplies a decking system consisting of precast lattice ribs interlock with precast panels, polystyrene blocks and an in-situ topping with wire mesh. The system requires no skilled labourers for the installation. It uses up to twenty per cent less concrete, thus it is lighter than the conventional concrete decks. A deck designed by Cobute using the polystyrene blocks is shown in Figure 14.



Figure 14: Layout of the decking system with polystyrene blocks

Beams, columns and staircases

In the African market, the construction of beams, columns and slabs has been proven to be somewhat troublesome for building contractors. These problems arise as a result of the carpenter's lack of knowledge, theft on the construction site, the high costs of the shutter boards and timber, and misinterpretation of the design (Angelucci, 2012).

Beams

As with the decking system, the Cobute beam element has been designed to be light and easy to handle during the erection phase of a project. The beam manufactured by Cobute is comprised of two L-shaped members. The members are tied together before the concrete is poured.

Columns

A thin square concrete pipe at a height of 3m is used as a precast shutter for a column. The column can be handled by four labourers. Once the column is lifted into place it is plumbed, the reinforcement is inserted inside the concrete pipe and is fixed to the starter bars at the base. Once this phase has been completed the column is ready for casting of the concrete.

Staircases

The staircases manufactured at Cobute are a combination of the precast slab used in the decking system and the precast shutter used for the beams. The shutters for the beams are used as left and right girders. See Figure 15 below.



Figure 15: Precast staircase

5.2.3. Cobute's Precast Yard

All building components are manufactured at the precast yard situated in Killarney. The production line comprises of a number of stations. At each station an individual is responsible for the task to be performed at the station. The stations are set out as follows:

- Station 1 - The steel is cut into the required size;
- Station 2 - The steel is bent to form a reinforcement lattice;
- Station 3 - The top and bottom steel of the element is welded to the lattice;
- Station 4 – The moulds are set out as required by the drawings and the reinforced lattice is placed in position. Once the dimensions of the mould have been checked according to plan, the concrete is poured into the mould and then left to cure;
- Station 5 – The plant has a concrete mixer on site and the mixture is measured as required by the mix design. The concrete mix is designed using polypropylene fibres which help resist fire and also play a role in the manner in which the concrete reaches its required target strength of 25MPa. The polystyrene fibres are delivered in soluble paper bags which dissolve in the mixture thus limiting measurement errors. The completed elements are transported by a forklift from the batch plant to the production plant.

5.2.4. Installation of the precast members

The building components manufactured by Cobute can be delivered to site and can be installed without the aid of any lifting equipment. The components have been designed for the installation of the elements by manual labour. Once all the elements have been installed and the engineer has done the necessary inspection, the concrete (25 Mpa) can be cast. After 15 days of casting, subject to approval by the engineer, the props supporting the structure may be removed. This can only occur if the structure is self-supporting.

Not much time is needed for the installation of the components. In joint ventures Cobute is often held up by subcontractors due to delays such as weather or misinterpretation of the design (Angelucci, 2012).

5.2.5. Quality of the precast components

The elements manufactured are relatively thin thus vibration is effective and efficient. Honeycombing and exposed steel is seldom an issue and because no shutters are used, no wood is left behind when the element is stripped from the mould. Defects as a result of used shutters do not concern Cobute since no carpenters are needed.

Concrete cubes are made with every sample of concrete and these are tested in a laboratory. The rib and block system used in the slab is manufactured by using a machine. The machine drives at a constant speed over a platform constructed by Cobute and evenly places the ribs one by one on the platform. A sprinkler system, shown in Figure 16, has been installed along the side of the platform for the curing of the rib and blocks.



Figure 16: Concrete platform with sprinkler system

There is however instances where the machine produces partially formed ribs but this does not occur often.

5.2.6. Training

When Cobute first located to South Africa their method of construction and innovation had to be conveyed to the work force. Training was provided to unskilled labourers by the founders of the company. The majority of the firm's labour force was found in the nearby township known as Dunoon situated across the road from the precast yard.

Today, the labour trained at the time the company was founded, can provide the necessary training to newly unskilled employees. The company has plans to expand their business in Namibia and Saudi Arabia. They plan on using their employees to train the new recruits in those countries.

This can be seen as motivation for unskilled labour as it promotes growth opportunities for the individuals in the working environment.

5.2.7. Conclusion

The construction industry in South Africa was analysed by Cobute and a solution suited for the environment was adapted with three points in mind:

- The elements were manufactured to be as light as possible;
- Erection of the elements required no machinery or cranes ;
- elements were of such a nature that no carpentry attention was needed for installation.

The nature of the construction procedure provided job opportunities since it was designed for the unskilled working class. Training was provided by the owner and today the labourers can provide basic training to new trainees.

Beam, slab and column components are constructed individually and at different stations. The systematic approach applied by Cobute enables product control and quality assurance at each station. Checklists and quality control plans are provided and followed thoroughly at each station. Concrete mixtures are measured precisely using a cement mixer with measuring devices for the water, sand and stone. Fibres included in the mixture are ordered in soluble bags thus eliminating the time used to measure these delicate particles.

The precast system used by Cobute is based on a rib and block system. The precast elements that are manufactured include ribs and panels and permanent concrete shutters for beams, columns and staircases.

The elements manufactured by Cobute provide the basic framework and structure for the building. The permanent shutters are thin. Thus when pouring concrete, vibration can be done with ease and efficiently. The mere fact that no wooden shutters are required implies no wood can be left behind and there is generally minimal rework on the structure.

5.2.8. Lessons learnt

Certain attributes of **labour** may influence the effect that labour has on achieving quality in concrete construction. The aspect of labour may be influenced by:

- Level of skill and experience may determine their ability to understand the scope of the works;
- Training can improve the abilities of labourers;
- Casual labour presents an unskilled group of individuals and therefore they may fail to understand the importance of meeting the requirements of quality;

- Human attitude of an individual influences the level of competency in which a task is carried out thus overall quality will be impacted by it.

Similarly the aspect of **plant and equipment** used in the construction process may impact the quality of the concrete. These attributes of plant and equipment are:

- Choice of Formwork system;
- The quality of the shutter boards and the number of uses.

There are certain attributes which may impact the component **durability** of the concrete. Although identified in the literature review, these attributes are confirmed to be:

- Bleeding;
- Cover to reinforcing;
- Steel spacing;
- Mix design;
- Moisture content (aggregates).

5.3. Murray and Roberts (Building Division - Portside)

5.3.1. Company background

One of the leading construction companies in South Africa is Murray and Roberts Construction. The company engages in many spheres of construction such as infrastructure, building, energy, mining, power and industrial. The infrastructure division of Murray and Roberts can further be broken down into the following divisions: Marine, Roads and Earthworks and Railways (Murray & Roberts, 2013).

Murray and Roberts have been part of a number of trademark construction projects. In South Africa they were involved with the construction of the Gautrain rapid rail link in Johannesburg, the Cape Town Stadium as well as the Medupi Power Station. In the Middle East they were involved with the construction of the Khalifa burj al Arab and at project completion, it was the tallest building in the world (Murray & Roberts, 2013).

5.3.2. Portside Construction Site

Portside, constructed by Murray and Roberts, was soon to be a new addition to the skyline in Cape Town's city centre. At project completion the summit of building was 139m making it the tallest building in Cape Town. The method chosen for the construction of the building was by in-situ construction. The building was located in the heart of Cape Town's CBD.

The position and location of the building was one of the main reasons the precast method was not chosen (Michaelides, 2012). For a precast system, a precast yard would be needed in order to manufacture the structural elements. The CBD has limited space, thus a precast yard would have to be located somewhere outside of the city centre. With vast amounts of traffic entering and leaving the city centre on a daily basis, it would take some time for these vehicles to travel in and out of the city. In addition it would also be time consuming for these abnormal vehicles to manoeuvre around the construction site. The structural elements are erected and fitted into place using a crane. Many hours of crane time will be wasted due to transportation logistics, thus the precast method was proven to be a costly option (Michaelides, 2012).

5.3.3. Batch Plant

Logistics for the portside construction site was proven to be a large problem due to high traffic volumes in the CBD. The decision to use ready-mix was also considered a problem since the closest concrete plant is located just outside of the city centre. The use of ready-mix would have had a great influence on the quality of the finished concrete since long travel time compromises the consistency of the concrete mixture (Michaelides, 2012).

The system used to pour concrete on the Portside construction site consisted of a pipe network running underneath the street from the batch plant to the construction site (Michaelides, 2012). The batch plant is situated opposite the construction site.

The concrete mixed in the batch plant is pumped, as needed, in a system of pipe networks beneath the street to where it is needed on the construction site. The system is easy to adjust and can be extended as the structure increases in height. The network of pipes was inserted by jacking through underneath the road and inserting them. The concrete was designed to flow through the pipe network with ease. The size of the stone used was also small in diameter in order to accommodate bends in the network. Additives to either retard or speed up setting of the concrete were also used in the mix to aid the ease with which the concrete is pumped (Michaelides, 2012).

The system used to pour the concrete was the first of its kind. At the beginning of the project there were a few problems as the team working at the batch plant were new to the technology. Concrete often got stuck in the line due to problems with the mix design. The moisture of the materials going into the mix also played a role in the flow ability of the concrete mix. This was discovered after by trial and error. Rubber balls, subjected to high water pressure, were used to clean out the pipe network once the concrete has been poured. Hardened concrete in the line caused delays of up to one day in the beginning stages of the project (Michaelides, 2012).

The concrete used for the structure was as follows (Michaelides, 2012):

- 40 Mega Pascal (Mpa) concrete was used for the floors
- 30 Mpa concrete was used for the decks
- 60 Mpa concrete was used for the columns

The batch plant can easily be adjusted for the specific concrete mixture needed. The batch plant manager knows how much concrete is in the line thus he is able to minimise wastage. The system is capable of pumping 30m³ of concrete per hour where as six cubic concrete buckets can take up to 20 to 30 minutes to deliver (Michaelides, 2012).

5.3.4. Quality of the concrete

Quality of concrete was not compromised by height. The quality of the concrete was consistent regardless of height. The concrete mix could easily be adjusted if excessive bleeding was experienced or if the concrete was too dry. Quality issues such as honeycombing was found in certain areas of the structural elements. This was primarily as a result of insufficient vibration of the concrete. This is usually found in areas where the reinforcement is dense (Lagrange, 2012). Another cause of honeycombing was due to late pouring as a result of other delays, inadequate supervision and poor monitoring during the pouring process. Excessive bleeding and grout loss were also a few of the quality issues found in the structural elements. Grout loss was found where columns were not sealed properly. In certain sections of the structural elements exposed aggregate was evident and was as a result of grout loss (Michaelides, 2012).

The staircases, also cast using the in-situ method, have uneven finishes that need patching after the pour. This is due to timber that is used to prevent the shutters from kicking during the pour. The concrete used to cast the staircases is taken to the floor where the staircase is to be cast by a crane and then wheel barrows are used to transport the concrete from the concrete bucket to the staircase mould. The concrete is provided by ready mix trucks. Concrete often dries out due to long travel distances and it results in honeycombing (Lagrange, 2012). The last concrete truck usually required remixing of the concrete due to standing time (Swanepoel, 2012).

Where shutters cannot close gaps due to an irregular shape of the structural element, cheap wooden timber is used to close these gaps. The area covered by these cheap shutters usually need repair work and often these shutters break and stick to the concrete (Lagrange, 2012).

5.3.5. Training

Skilled labourers are needed to operate the batch plant. However, the pipe system used to pour concrete was new technology and new to the company. The team working at the batch plant did not receive any training. They learnt to fix problems together in the beginning stages of the project (Michaelides, 2012).

Labourers do not regard quality as a deliverable and do not understand where to vibrate and why vibrating of concrete is needed. Skill plays an important role in achieving quality and is not generally a trait of an unskilled labourer. (Swanepoel, 2012).

5.3.6. Quality Control

The work is routine thus lessons can be learnt and used in the tasks to come. Toolbox talks are held on a daily basis. These sessions are used to discuss and brief the labourers on issues such as quality, safety and task progress. Any important information is normally discussed during these sessions. These toolbox talks have the overall intention of keeping the labourers motivated. Daily routines are often changed to keep morale high. An example of a change in routine may be casting six columns instead of seven per day (Michaelides, 2012).

Engineers do regular checks to make sure that the specifications are according to plan. The specifications used were according to SANS 1200G (Swanepoel, 2012). External consultants often do regular checks in addition to the engineers and certain tasks are signed off by the relevant party. The day before concrete is poured; a laser survey is conducted to ensure that all levels are correct (Michaelides, 2012). On the day that the concrete is poured, a blower is used to remove dust that may have accumulated the previous evening and excess steel pieces used by the steel fixers are removed by using magnets (Lagrange, 2012).

The columns, at times, are lower than the deck and usually create problems with the finishing. Columns are therefore often cast about 20mm higher than specified to prevent dirt from accumulating above it (Lagrange, 2012). See Figure 17.



Figure 17: Concrete column cast 20mm higher

Material checks are also conducted by the relevant party. Tests such as sieve analysis and grading are conducted in the lab to ensure that the materials are as specified and of adequate quality (Michaelides, 2012).

During the pouring process of the concrete, labourers are used to vibrate the concrete with pokers. When the area in which the labourer is vibrating has dense steel, a thinner poker is usually used in order to vibrate between the dense reinforcing (Lagrange, 2012).

A “repair” team is set in place to fix all the visible defects once the shutters have been stripped. Grout loss, uneven surfaces and honeycombing are repaired by this team (Lagrange, 2012). Subcontractors used on site are usually cheap and need to take ownership of the quality of their work. This often poses as a problem due to lack of ownership by the contractor (Robyn, 2012)

At certain times of the day, the concrete was affected by the weather. To compensate for this, a winter and a summer concrete mix were designed to prevent the concrete from altering its characteristics. The heat dried the concrete out in summer and in winter cold air had an effect on setting of the concrete (Swanepoel, 2012).

5.3.7. Conclusion

The Portside building constructed by Murray and Robert’s building division will be the tallest building in Cape Town’s CDB. The entire building was constructed by using in-situ construction methods as logistics posed a potential problem. With high traffic volumes moving into and out of the CBD, congestion posed a potential problem for concrete and delivery trucks going to the construction site.

Since crane time is very expensive, the majority of this expense had been eliminated by the choice of in-situ construction.

A batch plant was chosen instead of ready-mix concrete. The high volume of concrete that would be used on the building made the choice suitable and since ready-mix trucks would have to travel in high traffic volumes they would eliminate losing time waiting for them. Potential problems with the concrete mixture due to a change in consistency of the mix would also be eradicated by using the batch plant. The batch plant was located across the street from the construction site and a network of pipes underneath the road was installed to pump concrete from the batch plant to the construction site. The concrete mixture could easily be adjusted by the batch plant engineer and wastage was eliminated by knowing exactly how much concrete there was in the pipe network.

The quality of concrete seemed to be consistent regardless of height. Honeycombing was, however, found in certain structural elements and was due to dense reinforcement, inadequate supervision during pouring of the concrete and poor vibration. Late pouring as a result of other delays also resulted in honeycombing. Excessive bleeding and grout loss were found where columns had not been sealed properly. Concrete used to cast staircases often dried out due to travel time and resulted in honeycombing in certain areas. It is often found that when subcontractors are employed, they do not take ownership of their work.

The team operating the batch plant trained with the engineer and through trial and error they learnt to fix the mistakes that were made along the way. The labourers working with concrete generally do not understand the importance of quality as a deliverable and this is very common among the unskilled labourers.

The nature of the work on site was routine and quality control could be enforced from the lessons that were learnt. Toolbox talks were held on a regular basis to keep the workforce motivated. By changing the daily plan and creating a change in the work environment, the interest levels and attitude of the labourers could be kept high. Material checks and sieve analysis were taken on a regular basis to ensure the quality of the materials was at an acceptable level. Repair teams were used to control the quality of work that was performed and fix any defects in the elements.

5.3.8. Lessons learnt

High traffic volumes in the CDB and limited space may play a role in achieving concrete quality. Thus the aspect **access** is influenced by the following attributes:

- As the building increases in height, a combination of effects such as; lengthy travel times of the concrete truck and limited crane usage, may influence the quality of the concrete;

- A confined working space, such as working on an incline, may limit the ability to achieve adequate concrete quality;
- Locations such as CDB's create logistical problems;
- Distance to the closest supplier.

Management decisions dictate quality. The attributes which may influence these aspects are:

- Communication from top to lower management throughout the construction period is vital in the process of achieving quality;
- Construction method/technique.

Certain attributes of **labour** may influence quality in concrete construction. The aspect labour may thus be influenced by:

- A labourer may be sent on a course to specialise in erecting formwork or steel fixing. Training of this nature may improve procedures and thus minimise quality defects of concrete;
- The level of skill of a labourer may influence his ability to understand and grasp the construction technique;
- Human attitude of an individual could compromise the spirit within a team and effect workmanship;
- Non-conformance will lead to poor quality.

Subcontractors are utilised to carry some of the construction risk on a project. They thus also influence the quality of the overall product. The attributes, which have been identified, are:

- Interpretation of the scope of work may determine whether the requirements of quality are met;
- Level of skill and experience of the subcontractor may influence the quality of the work

There are certain attributes which may impact the component **durability** of the concrete. These attributes have been identified by the contractors who were interviewed. As found from the literature study, but confirmed by this visit, these attributes are:

- Consistency of the mix;
- Mix design;
- Moisture content (aggregates);
- Bleeding;

- Grout loss;
- Steel spacing;
- Compaction.

Similarly, there are certain attributes which may impact the component **aesthetics** of the concrete. These attributes have been identified by the contractors who were interviewed. These attributes are:

- Grout loss
- Consistency of the mix
- Kicking of formwork.

5.4. Concor (Murray and Roberts) Roads and Earthworks

5.4.1. Company background

Concor, a construction company in South Africa, is made up of three divisions namely: Concor Open Mining, Concor Civils and Concor Roads and Earthworks. The company has been involved in large construction projects in many parts of South Africa. Projects include parts of Koega Harbour in Port Elizabeth, the Huguenote Tunnel just outside Cape Town and the Sundays River Bridge in Colchester. Concor has found itself working not just in South Africa, but in many parts of Southern Africa. The Roads and Earthworks division concentrate on the construction of roads, earthworks, bridges, dams, mining and infrastructure planning of townships (Murray and Roberts, 2013). For years Concor has operated as a sole proprietor but have lately have with Murray and Roberts Construction.

5.4.2. The Sunday River Bridge project

Colchester, located outside Port Elizabeth in South Africa, is positioned alongside the Sundays River. The National Route 2, one of the interstate highways in South Africa, passes over the Sundays River. The existing bridge is single carriage and on a daily basis many vehicles pass through the little town of Colchester.

The Sundays River project entailed the construction of a new road and the construction of a new bridge over the Sunday River. The National Route 2 would thus be altered by having two dual carriage ways, one going westbound and the other eastbound (Nortjie, 2012). A new 15km road was constructed and the existing road rehabilitated. For the purposes of this thesis, only the construction of the bridge will be considered.

The bridge was constructed by using a combination of precast and in-situ construction methods. The beams and parapets were constructed by using precast methods and the piles, piers, cross beams

and deck by using in-situ methods. The bridge consisted of six spans, each having six 33m beams across the span. At completion each beam would weigh 66 ton (Nortjie, 2013). See Figure 18.



Figure 18: Bridge span with 6 beams

The piles used to anchor the bridge were raked piles. A subcontracting company was hired for the construction of the piles. The constructed piles can be seen in Figure 19. The piles went up to a depth of 42m. In the beginning certain piles failed and had to be redone. The foundation of the pier was then constructed followed by the piers themselves. Once all the piers had been constructed, the beams, constructed in the precast yard, were transported to the bridge and placed. Once this was done cross beams were constructed followed by the construction of the concrete deck.



Figure 19: Raked piles within the base of the pier

5.4.3. The Precast yard in Colchester

A precast yard was established in Colchester to construct the parapets, end caps and beams for the bridge. Since there were many elements to be constructed, the structural elements could be mass produced thus the precast option was considered to be most viable (Nortjie, 2012).

Foundations for the construction of the beam elements were constructed during the establishment phase on the contract. The foundations were designed to hold the total weight of the beam and were constructed according to the dimensions of the beam (Anderson, 2012). Steel fixers used markers to mark the foundation on which the beam would be cast according to the engineers' design. The steelworkers would start by constructing a basic framework for the rebar so that the steel could support itself. Once they had the framework, top, middle and bottom steel would be inserted into the framework until all the steel had been placed. See Figure 20.



Figure 20: Rebar framework above foundation

Once the rebar was in place, a shutter team, led by a shutter hand, prepared the beam for the pour. Before the shutters were fixed in place, grout tape was placed at the interface of the base and the formwork. This prevented seepage and grout loss when the concrete was poured. The shutters were used repeatedly on all the beams (Anderson, 2012). Before closing the formwork, two steel ducts were inserted in between the rebar from end to end to accommodate the prestressed steel.

5.4.4. Concrete quality

5.4.4.1. Concrete quality in the precast yard

Whilst working on the construction site, in the precast yard, the following observations were made.

The concrete cover was maintained at the base of the beam by using specified cover blocks. Shutter boards that were used to build the mould for the beam were reused numerous times. Mishandling of these shutters by labourers and the crane operator had effects on the aesthetics of the concrete finish. The condition of the rebar, at times, did not allow for the specified steel spacing due to the bars not being straight.

5.4.4.2. Concrete quality at the bridge

Whilst working on the construction site, in the precast yard, the following observations were made.

The piers had been constructed using in-situ construction methods while the beams were constructed using precast construction methods. During the erection of the beams, the specified tolerance was 40mm on either side of the bearing. Due to the varying tolerances of the bearings varying, at times it was not possible to achieve this 40mm cover. Thus due to one tolerance being out of its range, there were noticeable effects on the interfacing elements of the structure.

The concrete planks which were used between the adjacent beams had to be redesigned as they could not handle the weight of the concrete.

During the erection of the beam, the crane operator played an important role. The experience of the crane operator contributed to the success of erecting the beams. Briefings were held prior to erection of the elements where risks were identified for the safety of all employers involved in the erection process.

5.4.5. Training

Certain labourers were sent on a training program where they learned about technical aspects and the importance of performing procedures correctly. These were usually the skilled labourers the managers wished to improve. All employers are sent for a basic induction where the importance of safety was emphasised (Anderson, 2012).

All graduated engineers are sent to Johannesburg for training before they are assigned to a construction site. During this training program the graduate engineers are taught how to mix concrete, fix steel and build shutters for formwork upon many other things.

Experienced employees transfer their knowledge across to new employees and over time the employee gains knowledge due to experience. Some engineers have also been sent to the construction management program held at Stellenbosch University to improve their management skills (Construction management program, 2013). This program is however only available for contractors who have been in the industry for a few years.

5.4.6. Quality Control

5.4.6.1. Quality control in the precast yard

The workforce in the precast yard is divided into either the steel team or the shutter team (Anderson, 2012). Each team has a leader that assigns tasks to the individuals in the team. The team leader is known as the contract hand and has enough skill to delegate tasks and take responsibility. These contract hands have a good understanding of what needs to be done. They work off the engineers' plan and thus they need a thorough understanding of what is being conveyed in the plan. The foreman will regularly check up on the teams and make sure that all is according to plan (Anderson, 2012).

On the day before a beam is poured, the contractor calls in the consulting engineer on site, also known as the Representative Engineer (RE), to do a final check. During this pre-check, cover blocks are checked to see whether the correct cover will be achieved, steel spacing is checked. In addition the RE checks whether all the steel is in place. Once he has been given the go-ahead, the final shutters are erected and the beam is ready to be poured.

While the concrete is being poured, the shutter hand walks around the base of the beam to make sure that there is no seepage of concrete. The steel fixers and shutter team usually combine and thus work together to pour and vibrate the concrete. Once the concrete has been poured, it is left to set and the following day, the shutters on one side are stripped.

A repair team make sure that the finish is smooth and that no pieces of the shutter board have been left behind on the concrete. The curing process also starts the day following the pour to prevent cracking of the concrete (Anderson, 2012).

5.4.6.2. Quality control at the bridge (In-situ construction)

In between the beams of the bridge, precast concrete planks have been placed and act as permanent concrete shutters. Once the beams between a span have been placed and the cross beams have been constructed, these concrete planks are packed. Steel fixers then fix the steel. Before the steel fixers start working, a few labourers use a cylindrical shaped sponge to seal the gaps in between the planks. See Figure 21 below.



Figure 21: Concrete plank with sponge sealing the joint

Once the sponge is in place, cement is used to further seal the joint so that when the deck is poured, no concrete seeps through. When all the steel has been fixed and the deck is ready to be poured, labourers walk around on the deck and collect all pieces of excess wire lying around by using magnets. Prior to the pour, a compressor is used to blow away all the dust that may have settled beneath the steel. The compressor also collects excess wire that a labourer failed to see while collecting the wire.

Once the contractor gives the go-ahead for the concrete to be poured, the RE is notified and performs his pre-inspection checks. This usually takes place the day before concrete is poured. On the day the concrete is poured, the RE will do one final check and if approved, the concrete may be poured. With each batch of concrete that arrives on site, samples are taken where strength and durability tests are done.

5.4.7. Conclusion

The new addition of the Sunday River Bridge situated in Colchester consisted of six spans each with 6 33 meter beams weighing 66 ton each. The bulk of the bridge was constructed by using in-situ construction methods and all the beams were constructed using the precast construction method. Parapets and end caps for the pier were also constructed using precast construction methods.

Basic training and the importance of following procedures correctly are demonstrated to labourers and at each construction site safety induction is conducted by an assigned safety officer. Graduate engineers are subject to training where they learn how to erect scaffolding, fix steel and many other

things. This usually takes place before they are assigned to a construction site. Within the management division, certain employees are sent on various courses to improve their professional development and management skills.

Quality control is the responsibility of the shutter hand whether it is fixing rebar or erection of the formwork. Final checks are performed by the foreman followed by the representative engineer from the consulting firm. Repair teams are put in place to eliminate any defects that may have resulted during the process of pouring, vibration or removal of the formwork. Curing is performed by a designated labourer to ensure that concrete remains wet. The foreman regularly monitors this process and keeps the designated labourer.

Quality aspects and their attributes have been noted and it was found that quality of the concrete either did not conform or conformed due to the items described in the lessons learnt, section 5.4.8.

5.4.8. Lessons learnt

Management decisions dictate quality. The attributes which may influence these aspects are:

- Where both precast and in-situ construction methods are used, coordination is vital as precast elements need to match up and fit between or on the in-situ constructed elements;
- Planning is important especially where both in-situ and precast construction methods are utilised. It is important that access be taken into account during the planning phase;
- Changes in scope of the work sometime occur. Rescheduling is then needed and it is important that management deal with this change accordingly as it may impact concrete quality.

Certain attributes of **labour** may influence the effect that labour has on achieving quality in concrete construction. The aspect labour may be influenced by:

- Level of skill of an individual may determine the level of quality of the finished product;
- Understanding of the technical requirements may be achieved through the use of training.

Similarly the aspect **plant and equipment** used in the construction process may impact the quality of the concrete. These attributes of plant and equipment are:

- The operator controlling the ,Machinery (cranes) determines whether precast elements can be placed free of damage. Elements which are damaged in the process are subjected to rework.

- Quality and the number of times the shutter boards may be used will determine the quality of the finish.

The aspect **safety**, especially when it involves working at height and using cranes, is dangerous to the employees involved in the process and may compromise quality of the product. The attributes have been noted during the site visits and are as follows:

- Experience of crane operator comes into being when conditions are unpredictable and precast elements are to be placed. Unsafe operations may result in damage to the constructed elements;
- Risk identification is the process whereby potential risk which may influence quality of the concrete elements should be identified;
- During toolbox talks, safety procedures are discussed and in addition, all areas which are problematic is discussed between management and the workforce;
- Pre-task planning can aid identification of safety risk. Practicing safe acts may promote precision work.

There are certain attributes which may impact the component **durability** of the concrete. This attribute have been identified by the contractors who were interviewed. This attribute is:

- Steel spacing.

Similarly, there are certain attributes which may impact the component **fitness for purpose** of the concrete. These attributes have been identified by the contractors who were interviewed. These attributes are:

- Product tolerances are related to the dimensions of the element;
- Erection tolerances involves fitment of the element into the designated area;
- Interfacing tolerances refers to the elements which surround the individual element.

5.5. Botes and Kennedy

The interview conducted at Botes and Kennedy was focused on the experience on concrete quality by companies specialising in repair work on precast and in-situ constructed buildings or bridges. In this section general issues and their root causes are discussed (Botes and Kennedy, 2013).

The structure followed here differs from the three previous construction sites since the purpose of the interview conducted at Botes and Kennedy was to obtain information regarding repair work in

order to identify the type and nature of quality problems that arise during construction, and which needs repair at a later stage.

5.5.1. Company background

The head office of Botes and Kennedy is situated in Bellville, Cape Town. Botes and Kennedy specialise in a diverse group of construction services and have provided civil engineering services for the past 32 years. These services include mining, infrastructure, underground construction, industrial and commercial development, residential development, water retaining structures, Bridges, Dams as well as specialised repair work (Botes and Kennedy, 2013).

They are comprised of three different companies namely Northern Cape and Namibia, Africa and Special Projects and Botes and Kennedy Plant. The Africa and Special Projects division is primarily involved with concrete repairs, alternative energy, bridges and mines. Botes and Kennedy Plant is not directly related to the civil services performed but can be seen as an independent company. Plant can be supplied to the company for construction purposes or plant may be hired out to other construction companies (Botes and Kennedy, 2013).

5.5.2. Concrete quality

Forty years ago when concrete structures were constructed, durability of the concrete was not the most important requirement. Engineers were not aware of the potential problems in concrete of at the time and procedures such as compaction, vibration and curing were often neglected. Contractors in the construction industry had not seen these factors as potential risks (Ibbetson, 2013).

Typical problems that affected finishing of concrete were found where shutters that were reused were not cleaned properly. In certain places it was found that concrete decks had no cover. It is often found that steel spacing in the structural elements are incorrect. Inadequate or no cover resulted in corrosion of steel and spalling of the concrete. Corrosion is a common repair problem. Eighty per cent of corrosion problems due to workmanship and twenty per cent are due to design (Ibbetson, 2013).

Botes and Kennedy found that the repair work on structures was located on similar areas of the structure. Geographically, the majority of these structures are situated between 20 and 30km from the coast. In South Africa most of the repair work is found on the weather facing side, the North-West face. The weather facing side receives the wind, rain and harsh sun. The sheltered side seldom needs any repair work. In cases where repair work was done on buildings, it was common to find repair work in areas around window frames and around lintels. Sometimes areas inside buildings

needed repair work where condensation of moisture occurred. These problems usually occurred in bathrooms and a coating was usually applied to protect the damage in these areas. Most of the rework is done on structures that were constructed using the in-situ method of construction (Ibbetson, 2013).

On construction projects where Botes & Kennedy themselves were the contractor, they found that formwork related problems such as kicking of shutters were the most common problem related to concrete quality. Failures in cube strength tests also occurred from time to time. In one project it was found that a concrete column was in the incorrect position (Ibbetson, 2013).

5.5.3. Training

A labourer needs to obtain a training certificate as a basic requirement. A certificate is obtained by attending an internal training school. Labourers with experience are also used to train new labourers (Ibbetson, 2013).

5.5.4. Quality Control

In certain cases spalled concrete is repaired with the aid of phenolphthalein. Affected areas turn purple once phenolphthalein is applied to the affected area. This procedure is, however, seldom used on buildings during the repair process. Buildings have maintenance work done on them five years after they have been constructed. Usually only the affected areas are repaired and areas with potential but not visible damage will be repaired at a later stage. In cases where spalling of concrete has occurred, only the exposed steel will be replaced, the steel further inside would also have started corroding but will only be replaced at a later stage (Ibbetson, 2013).

Rework is limited by access. It becomes a costly process should scaffolding be used to repair damages to high rise buildings. Instead, rope access is used to repair the damages to the building (Ibbetson, 2013).

Quality assurance check lists are used to assure that common errors affecting quality do not occur during the construction process. Positioning and spacing of steel is accompanied by check lists. Quality control and quality audits are performed by the quality officer. Internal Audits are also conducted by the quality officer (Ibbetson, 2013).

5.5.5. Conclusion

Botes and Kennedy are involved in a wide range of projects including infrastructure, energy, mining and specialised repair works in concrete construction.

When construction in concrete started in South Africa, the importance of compaction procedures, vibration and curing of concrete was not a primary concern. Durability problems realised a few years later and the root of these problems were mainly as a result of poor vibration, compaction and curing. Aesthetics were also bad due to these unsatisfactory processes. Reused shutters not cleaned properly were another cause of bad aesthetics. Inadequate concrete cover resulted in corrosion of rebar and eventually this led to spalling of concrete. In general it was found that the majority of the repair work was on the weather side of the buildings and within a range of 20 to 30 kilometres from the coast. In cases where specialised repair work was performed it had been found that majority of the structures were constructed by using in-situ construction methods.

All labourers required a training certificate in order to perform work. These training certificates are obtained by attending a training school.

Rework on buildings was limited by height and access. In the rework process only visibly affected areas are repaired. With regard to the works performed by Botes and Kennedy, quality control and quality assurance is performed by a quality control officer with the aid of internal audits.

5.5.6. Lessons learnt

The aspect **plant and equipment** used in the construction process may impact the quality of the concrete. These attributes of plant and equipment are:

- Quality of the shutter boards;
- Condition of the Crane (Machinery);
- Manufacturer of the formwork.

Certain attributes of **labour** may influence the effect that labour has on achieving quality in concrete construction. The aspect labour may be influenced by:

- Training may increase the labourers understanding of quality and the importance of procedures;
- Level of skill of the labourers may affect the level of quality of the product;
- Motivation or drive of an individual may encourage the individual to strive for perfection.

Certain attributes of **access** may impact the quality of concrete during the construction phase. The aspect access may be influenced by:

- Working at height could subject workers to dangerous conditions especially when the space is confined;

- Location determines what the concrete mix and cover will be. Areas close to the sea and on the weather side of the building were found to have more repair work on them;
- A confined working space may influence the ability to adequately vibrate the concrete.

There are certain attributes which may impact the component **durability** of the concrete. These attributes have been identified by the contractors who were interviewed, and confirm the results from the literature review. These attributes are:

- Compaction;
- Concrete cover;
- Cube strength;
- Steel spacing.

Similarly, there are certain attributes which may impact the component **aesthetics** of the concrete namely:

- Kicking of the formwork;
- Shutter quality;
- Type of shutter;
- Shutter company.

5.6. Chapter overview and lessons learnt

The technology used by Cobute reduces the risk of durability issues namely cover to reinforcement, steel spacing, and mix design. The thin elements assure proper vibration of the concrete. Also, since quality control and quality assurance is incorporated into every procedure in the manufacturing process, defects may be detected and reduced. The light elements imply that no crane is needed for the erection of the elements thus there are fewer risks or influences on the element's fit for purpose. Since the elements manufactured serve as permanent shutter, no wooden shutters are needed thus aesthetic issues are immediately minimised. This technology has been proven to minimise rework. Cobute technology thrives on unskilled labour which is usually seen as a cause for concern when the conventional methods for precast are applied.

The system Cobute employs does not put strain on management. Management does not require that their attention be needed in every area. Drawing revisions and rescheduling can be easily adapted in the precast environment as there are fewer variables playing a role in the procedure.

Precast construction, in the case of the Sundays River Bridge, was considered since there were many identical elements (beam elements) which were to be constructed. Precast construction allows

quality control and quality assurance to be integrated since it follows a systematic procedure. Another advantage here is that lessons can be learnt from the first few elements and potential issues could be eliminated.

The Portside construction site in Cape Town made use of a batch plant rather than ready-mix concrete. Due to dense congestion in the CBD, access was an issue. A decision to use ready-mix concrete would imply long travel time of the concrete which may compromise the consistency of the mix. Limited space for construction due to location was also seen as an issue during the pre-planning phase of the project. Murray and Roberts thus selected to cast the structure using in-situ construction methods due to these factors.

When subcontractors are utilised they sometimes lack ownership of their work. Unskilled labourers do not understand the task and do not normally regard quality as an objective. Failure to communicate and understand a task may compromise quality, among many other factors.

Toolbox talks are held on a regular basis to practise safety procedure, explain difficult concepts and they generally keep the up to date regarding project information. These talks may stimulate the workforce.

It is sometimes found that the quality of the concrete after the pour is not of an acceptable standard. When this occurs, a 'repair team' will come along and fix these defects.

Labour, in the case of the batch plant, trained together with the foreman and engineers to operate the system. In other cases labourers are sent on a general training course. This, however, does not happen when they start working but rather occurs once the employee shows promise and dedication or can be seen as a potential asset for the company. Casual labour on a project can thus have a big impact for achieving overall quality.

The majority of durability issues are related to poor compaction, vibration and curing of the concrete. Poor quality control by supervisors has led to bad aesthetics i.e., reused shutters are not cleaned properly. Kicking of shutters has also proved to be a frequent problem. On the Portside construction site it was found that moisture content of the aggregates used to mix the concrete affected the mixture of the concrete.

The construction industry differs vastly from the manufacturing industry. The problems found with implementation of the total quality management procedures have been identified and are as a result of: Commitment by top management, training of skilled and unskilled labourers, the use of subcontractors, supervision, tenders and culture. (Joubert, *et al*, 2005: 31).

In the South African industry the priorities of management lean more towards cost and time. Quality targets are often not communicated to them and thus the labourer's attitude toward quality is not as it could be. Workers are not trained as their contracts are not fixed and therefore contractors to invest in them. In certain cases contractors do not have the time to invest in training. (Joubert, *et al*, 2005: 31).

The primary goal of a subcontractor is to use cheap labour, finish the task as quickly as possible so that he can receive his remuneration. This sort of attitude does not make room for good quality practices. The tenders are usually awarded to the lowest bidder. This may limit the potential level of quality. (Joubert, *et al*, 2005: 31).

Supervision during construction is not performed on regular intervals and therefore defects cannot be identified in the early stage of the project. Workers sometimes feel that quality is beyond their scope of knowledge and is a task for top management (Joubert, *et al*, 2005: 32).

The overview above has made it possible for the following deductions to be extracted.

- Quality in the construction environment can be confirmed as durability, fitness for purpose and aesthetics.
- Durability can be broken down further into a number of attributes. Similarly fitness for purpose and aesthetics could be broken down further into their respective attributes. This can be seen in Table 5 in the next chapter (Questionnaire and Results).
- These specific issues pertaining to quality are affected by various factors. These factors may or may not be controllable and the contractor should be made well aware of them. Factors namely; Access, Labour, Management, Subcontractors and Safety play a role in the occurrence or severity of the quality issues mentioned above.
- Access, labour, management, subcontractors, site factors and safety are influenced by attributes. These attributes have been concluded from the site visits and literature study and can found in Table 6 in the following chapter (Questionnaire and Results).

The descriptive summary in Figure 22 shows how these aspects and components together may influence quality of concrete.

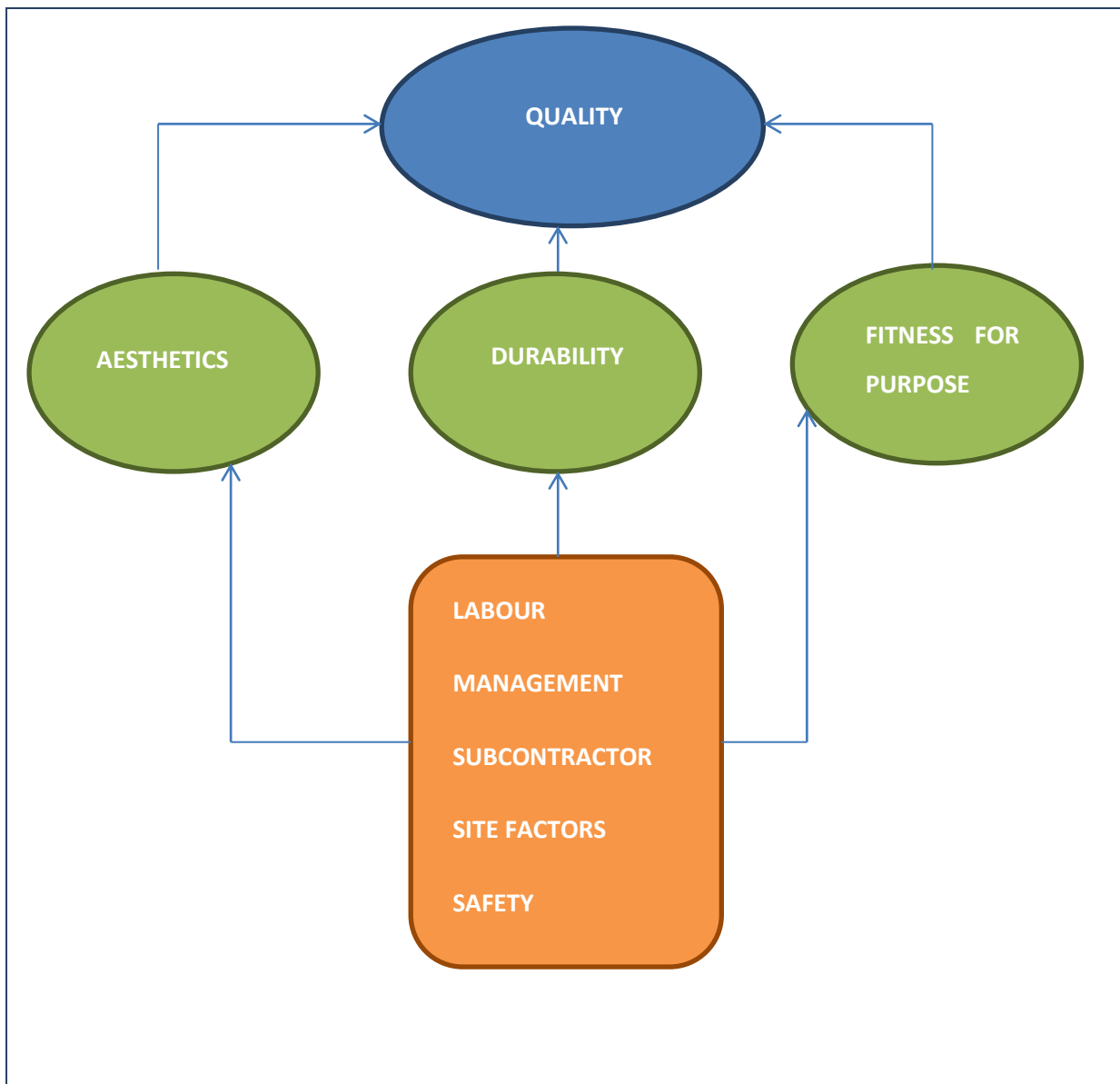


Figure 22: Components of quality and quality aspects relating to overall quality in concrete

6. Questionnaire and Results

6.1. Questionnaire design

6.1.1. Introduction

“In the South African construction industry it is found that concrete structural elements are constructed more frequently by using cast in-situ methods rather than precast construction methods” (Angelucci, 2012). Precast construction may be faster but it requires careful planning and coordination for the success of the project. It is important that the entire project team commit to the pre-cast option before the operation commences. In this way the project team can eliminate possible changes that could occur during the project operation. In the South African construction industry it has been found that contractors do not favour precast construction methods. They prefer in-situ methods instead. (Jurgens, 2008: 25). The use of precast construction in South Africa is thus not all that extensive and the contractors who have worked with both in-situ and precast construction methods are limited as in-situ is still predominantly used (Angelucci, 2012).

The nature of the research survey conducted in this study was exploratory. This survey therefore seeks to obtain information regarding the quality of precast and in-situ construction in South Africa. The results of the survey are thus informative and can be used as a basis for future studies.

The analysis of the survey results do not lead to a statistical result as the sample size of the survey is too limited to be presented as a statistical result. The results are therefore analysed by using a qualitative approach rather than a quantitative approach.

The questions used in the survey were developed following the interviews during the site visits. During these interviews information was obtained on quality procedures and quality issues encountered and exercised during the construction process.

Once the survey had been designed, it was sent to various contractors, clients and contract managers. The survey participants were all CMP delegates from 2007, 2008, 2009, 2010, 2011 and 2012. The CMP is a middle management programme presented annually in Stellenbosch to between 40 and 50 industry participants involved in infrastructure development. Between 70 and 80% of participants are representatives from construction companies, whilst the remainder are from client organisations.

The purpose of the survey was to obtain expert information from contractors associated with the concrete construction environment. The average age of these participants were 35-40 and their

experience in the construction industry was approximately 15 years. Information obtained in the survey pertained to the components comprising quality of concrete and the aspects which influence these components. The survey was structured so that a comparison could be made between the quality of precast and in-situ concrete construction.

This comparative research survey was designed by using a combination of total quality management tools namely, matrix analysis, paired comparison and a rating and ranking system. By using these in conjunction with one another, a survey was designed and sent out in the form of an Excel spreadsheet to a number of relevant contractors, clients and contract managers.

The definition of quality of concrete can be described as an element meeting the specified requirements for durability, being fit for its intended purpose and aesthetic requirements as specified by the client. These three components cover all the areas to which an element must comply and thus can be seen as the components comprising overall quality (as executed on site).

Site visits revealed that there are a number of factors (aspects) that influence these quality components. These dynamic aspects have been defined (through site visits) and were identified as site factors, management, labour, subcontractors and safety. Each of these aspects contributes to the overall quality of the element and thus need to be taken into account for a thorough comparison.

The cause and effect diagrams and a rating and ranking system were used to analyse the results individually. The rating and ranking systems make use of a weighting system which was used to highlight the most significant aspects and or attributes of quality. These rankings represent the opinion of respondents and were thus subjective. The cause and effect diagrams were used to draw a relationship between the aspects and attributes of the components of quality. To recap, aspects refer to labour, management, site factors and subcontractors whereas attributes refer to the characteristics of the aspects. Level of skill, human attitude and non-conformance are examples of the attributes of labour (see also Table 5).

A comparison was made between the results of each method for the precast and in-situ construction option.

6.1.2. Design of the survey

The aim of the survey was to obtain expert information so that a comparison between the quality aspects of precast and in-situ concrete could be made. Once again the nature of the survey was exploratory. Therefore the results and conclusions drawn were used for informative purposes. The information obtained from these surveys could also assist the decision making process which enable

project teams to choose between precast and in-situ concrete construction methodologies. The questionnaire had the aim of allowing a qualitative comparison between the aspects which influence concrete quality.

During the site visits described in Chapter 5, various contractors were interviewed and one of the key questions asked was the identification of quality issues within their working environment. This generated a list of possibilities. The origin of these issues was also discussed in the interview and has been noted in Chapter 5: Site Visits.

Once the site visits had been concluded, the information obtained from the various participants was grouped into components under the headings of durability, aesthetic and fitness for purpose issues. The ability to achieve concrete quality was then defined with reference to the construction environment from the perspective of a contractor. The components and their attributes were grouped and are shown in Table 5.

Table 5: Quality components and their attributes

DURABILITY
1. Cover to reinforcement
2. Steel spacing
3. Compaction
4. Cube Strength
5. Cracking of concrete
6. Moisture content of aggregates
7. Bleeding
8. Mix design
9. Consistency of the mix
10. Grout loss
FITNESS FOR PURPOSE
1. Product tolerances
2. Erection tolerances
3. Interfacing tolerances
AESTHETICS
1. Grout loss
2. Kicking of formwork/bulging
3. Consistency of mix

The attributes influencing the components of quality are dynamic since the construction environment is always changing. A number of these attributes have been discussed during the site visits and as with the components comprising quality; these attributes have been grouped accordingly.

Apart from the attributes of the components which determine quality, there are also quality aspects which may influence quality of the concrete. The primary categories for these aspects influencing quality have been described as management, labour, subcontractors, safety and site factors. Site factors can be divided into access and plant and equipment. Each aspect has attributes which may influence it. The aspects and their attributes are listed in Table 6.

Therefore there are attributes which influence the components of quality. There are also attributes which influence the aspects of quality. The quality aspects influence the components of quality which in turn determine the overall quality of the concrete. The attributes of the components may also indirectly be influenced by the quality aspects. This will be described later in the discussion of results. This relationship is depicted in Figure 23.

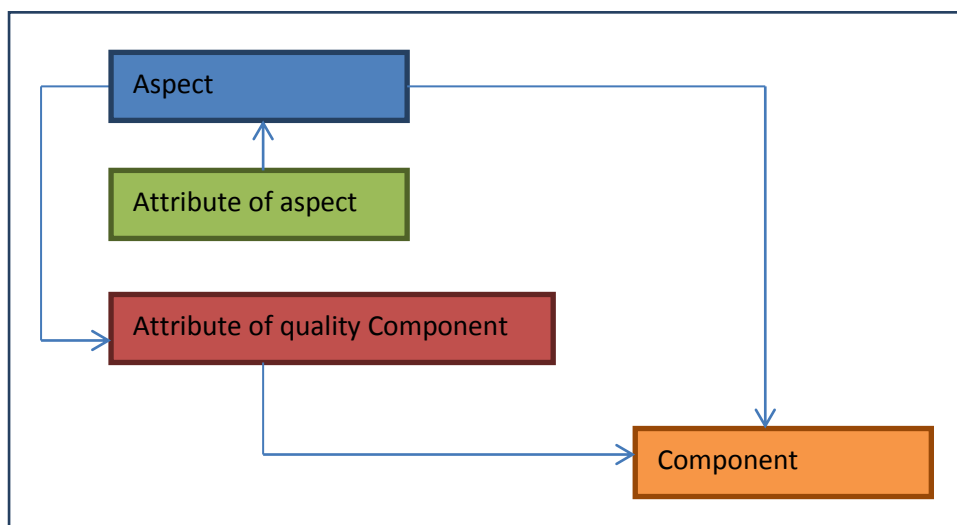


Figure 23: The relationship between quality components, quality aspects and the respective attributes

Table 6: Attributes influencing quality aspects

ACCESS
Increasing/Working height
Working space
Location (Urban/Semi-urban/Rural)
Distance to/ from supplier
LABOUR
Training
Level of skill
Amount of casual labour
Non-conformance
Motivation/human attitude
MANAGEMENT
Drawing revisions
Coordination
Communication
Precision planning
Construction method/ Technique
Rescheduling
SUBCONTRACTORS
Interpretation (Communication)
Construction method/technique
Level of skill
Knowledge of operation
Collaborative experience
SAFETY
Experience of crane operator
Toolbox talks
Pre-task planning
Risk identification
PLANT AND EQUIPMENT
Machinery (Cranes)
Shutter boards
PLANT AND EQUIPMENT

Formwork system

Tables 5 and 6 above provide an overview of the general attributes which play a role in achieving concrete quality for both in-situ and precast construction techniques. Table 5 displays information from experts and highlights the important problem areas that affect concrete quality. Similarly, Table 6 focuses on the attributes influencing quality aspects from the perspective of the interviewed contractors.

Information provided in the Tables above has been applied to total quality management tools in order to design the survey. Matrix analysis was the primary tool used as it permitted the components to be compared against the quality aspects. The paired comparison, another tool of total quality management, was used in sync with the Matrix analysis to make prioritisation possible. Prioritisation was conducted by applying an appropriate ranking and rating system.

Two matrices were designed to be used in the questionnaire. This was done to enable an inverse evaluation to verify results. Table 8, presented later on in this chapter, further explains how this was accomplished. These matrices were designed as follows:

Matrix 1

In the first matrix, the quality components and their attributes were compared to the quality aspects by ranking them accordingly.

Matrix 2

In the second matrix, the quality aspects and their attributes were compared to the quality components by ranking them accordingly.

A ranking and rating system was used in both matrices to rank the aspects against components. The lowest number in the ranking system was used to represent the aspect having the highest impact on the component and the highest number represented the lowest impact.

Matrix 1

In the first matrix the aspects of labour, management, subcontractors, site factors and safety had to be ranked by the participant for the impact it had on the quality components. It was done in such a way that the aspect having the highest impact and the aspect with lowest impact could be stressed. Table 7 is an example to show how the ranking system worked.

Table 7: Example of the ranking system used in the survey

Example	Labour	Management	Subcontractors	Site Factors	Safety
Concrete cover	5	2	1	4	3
Notes on Example:	Labour has the least influence on concrete cover		Subcontractors has the biggest influence on concrete cover		

The example in Table 7 illustrates that subcontractors are considered to have the greatest influence on concrete cover and labour the lowest influence. Each attribute of the quality components in the survey was ranked by an individual contractor according to their experience. The information is thus based on events that have occurred in the construction environment and will be relevant for the comparison.

The first matrix which was designed is illustrated in Table 8. This matrix would give an indication as to which quality aspects had the greatest influence on quality components which restrict overall concrete quality.

Assumptions

- Throughout the study it will be assumed that for the precast solution, the subcontractor constructs the concrete elements
- The labour for the precast solution pertains to the subcontractor and not to the primary manager.

Table 8: Matrix 1: The influence of quality aspects on quality components

Quality components	Quality Aspects				
Durability	Labour	Management	Subcontractors	Site factors	Safety
Cover to reinforcement					
Steel Spacing					
Compaction					
Cube Strength					
Cracking of concrete					
Moisture content (Aggregates)					
Bleeding					
Mix Design					
Consistency of mix					
Grout loss					
Fitness for purpose					
Product tolerances					
Erection tolerances	N/A for in-situ	N/A for in-situ	N/A for in-situ	N/A for in-situ	N/A for in-situ
Interfacing tolerances	N/A for in-situ	N/A for in-situ	N/A for in-situ	N/A for in-situ	N/A for in-situ
Aesthetics					
Grout loss					
Kicking of formwork/bulging					
Consistency of mix					

Participants were asked to complete two versions of this matrix; one for in-situ construction and one for precast construction. Two scenarios, namely in-situ and precast, were considered in order to effectively compare the quality between the two methods. Erection and interfacing tolerances were not considered for the in-situ scenario since the method does not require any placement of elements previously constructed.

Matrix 2

A second matrix was designed and can be considered as an inverse of the first matrix. The horizontal and vertical axes have been switched such that emphasis can be placed on the attributes related to the quality aspects rather than the quality components. For example, the matrix emphasises the impact of working space, as an attribute of access, on the components of quality. This example is illustrated in Table 9.

Table 9: Example of ranking system used in the second matrix

Example	Durability	Fitness for purpose	Aesthetics
Working Space	1	3	2
<u>Notes on example:</u>	Working space has a high impact on durability	Working space has the least influence on Fitness for purpose	

The example provided in Table 9 suggests that working space has a higher impact on durability than on fitness for purpose. Thus durability poses a greater threat and therefore there is a greater risk that durability may be compromised as a result of available working space. Fitness for purpose on the other hand is not a cause of great concern. The second matrix is shown in Table 10 below.

Table 10: Matrix 2: Influence of quality aspects on quality components

Quality Aspects	Components		
Access	Durability	Fitness for purpose	Aesthetics
Increasing/Working height			
Working Space			
Location (Urban/Semi-Urban/Rural)			
Distance to/from supplier			
Labour			
Training			
Level of Skill			
Amount of casual labour			
Non conformance			
Motivation/human attitude			
Management			
Drawing revisions			
Coordination			
Communication			
Precision Planning			
Rework			
Construction Method/technique			
Rescheduling			
Subcontractors			
Interpretation (Communication)			
Construction Technique/method			
Level of Skill			
Knowledge of operation			
Collaborative experience			
Safety			
Experience of Crane Operator			
Toolbox talks			
Pre-task planning			
Risk identification			

Table 10: Continued

Plant and Equipment			
Machinery (Cranes)			
Shutter boards			
Formwork system			

Each matrix was presented to the interviewers for both in-situ and precast construction options. In this way, four matrices had to be completed. Two of the sheets were related to in-situ and the other two sheets were related to precast.

In the following sections, the results from the survey are discussed. At first, the analysis of matrix 1 is discussed followed by a discussion of the analysis of matrix 2.

6.2. Discussion of results

The matrices had been designed using Microsoft Excel and the surveys were sent out as an attachment in the form of an email. The survey was comprised of five Excel sheets with the first sheet of the questionnaire requiring personal information such as the respondent's position in the firm, their experience, expressed in number of years, and the number of projects they have been involved in. These findings were used to get background information on the participating respondents and not to determine the outcome of the results. Fifty-three participants were invited to take part in the survey. Twenty-three respondents filled in the survey. From the twenty-three respondents, thirteen were Contracts Managers, seven were Directors, two were Site Agents and one was a Client.

Exploratory surveys have been proven to have a low response rate (Section 6.4.3). Since the results of the survey will be analysed qualitatively, statistical methods will not be used to represent the responses as a statistic.

The participants who were considered were employees from leading construction companies in the country. Some participants were from consulting companies such as Aurecon. However, all participants were required to respond from the perspective of a contractor. Many of the participants have worked on more than 10 construction projects and were thus relatively experienced. The participants invited to take part in the survey were employed at construction firms including Murray and Roberts, Wilson Bailey Holmes-Ovcon (WBHO), Stefanutti Stocks, Haw and Inglis, Basil Read, Grinaker LTA, Aurecon, Afristruct, Exeo Construction, King Civil Engineering Contractors, Ubume Construction and Civil, and Cobute.

Although twenty-three participants responded to the survey, four of them only responded to the in-situ section as the respondents were not familiar with the precast construction method. Thus in total, nineteen respondents comprehensively responded to the invitation. This constitutes a 36% response rate.

The purpose of the survey was to obtain expert information from individuals working in the specific field of concrete construction so that a comparison between in-situ and precast concrete construction could be made. The information should be seen as input obtained from specialists, and is a simplified form of personal interviews. The data was analysed using the qualitative techniques of ranking and rating, and cause and effect diagrams.

The results received from the surveys were analysed using three methods. The first method considered only the number 1 priorities whereas the second method was used to verify the results of the first method, taking into account all the priorities (priority 1 – 5). The third method was used to combine Matrix 1 and Matrix 2 by using a cause and effect analysis. Figure 24 below represents the methods used to analyse the results.

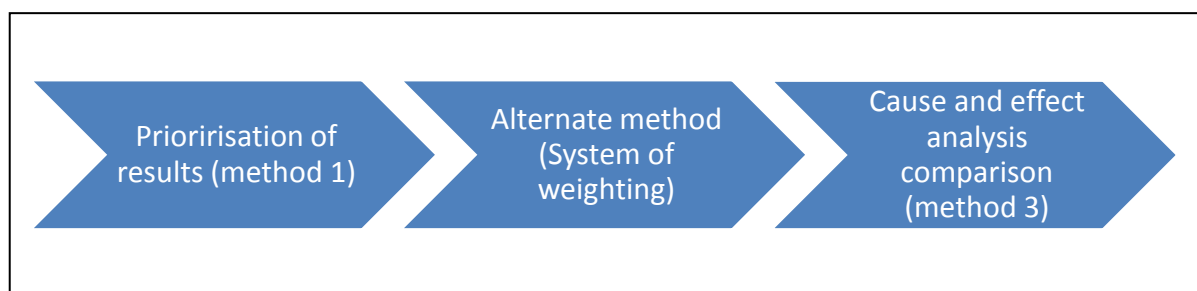


Figure 24: Methods used to analyse the results

Once all the questionnaires had been received, the results were tallied. Table 11 and Table 12 below represent the tallied up data for the aspects with the highest impact on the quality components. The aspects are shown in the columns, and the quality components (durability, fitness for purpose and aesthetics) in the highlighted rows, each with sub sections. In the next section the results obtained from the survey were analysed by using a weighting system. This method was used to justify the results obtained in this section. The data in Table 11 represents the tallied up responses for in-situ and Table 12 for precast.

6.2.1. Analysing matrix 1 for in-situ and precast solution

Table 11: In-situ results from Matrix 1

Durability	Labour	Management	Subcontractors	Site factors	Safety
Cover to reinforcement	6	8	5		
Steel Spacing	8	5	6		
Compaction	13	4	1	1	
Cube Strength	7	6	4	2	
Cracking of concrete	3	7	2	7	
Moisture content (Aggregates)	2	6	5	6	
Bleeding	4	6	3	6	
Mix Design	1	15	2	1	
Consistency of mix	4	7	6	2	
Grout loss	9	8	1	1	
Fitness for purpose					
Product tolerances		14	4	1	
Erection tolerances					
Interfacing tolerances					
	Labour	Management	Subcontractors	Site factors	Safety
Aesthetics					
Grout loss	7	9	2	1	
Kicking of formwork/bulging	4	10	3	1	1
Consistency of mix		13	4	2	

Tables 11 and 12 represent the in-situ and precast options respectively. It shows the number of respondents who chose this aspect as the one with the highest impact on the respective quality component. Each number thus represents the sum of all first choices of respondents. These decisions are subjective and vary from person to person. The areas highlighted in red in Table 11 and Table 12 show the most influential aspect affecting the respective quality component.

The attributes of the respective components of quality have an equal weighting when considering the importance of ranking. Based on this assumption, the impact of the aspects on the components can be ranked and compared. Consequently, in this manner the aspects with the biggest influence can be identified and compared between the precast and in-situ solutions.

The aim of the survey was to obtain information on the aspects with the most influence on the respective quality components. The areas not highlighted also represent expert opinion and cannot be discarded. However, for the purposes of this study, only the highlighted areas will be considered

since they represent the sum of the highest impact (number 1's) from this survey. This was the method chosen to obtain the results which were used to compare the precast to the in-situ solution. An alternate method was used to determine the results so that the approach used to determine the results in first method could be justified. The alternate method is described further in section 6.2.2

Table 12: Precast results from matrix 1

Durability	Labour	Management	Subcontractors	Site factors	Safety
Cover to reinforcement	7	5	7		
Steel Spacing	7	5	7		
Compaction	11	2	5	1	
Cube Strength	5	7	6	1	
Cracking of concrete	2	7	5	5	
Moisture content (Aggregates)	1	7	5	6	
Bleeding	3	6	5	5	
Mix Design	1	14	4		
Consistency of mix	5	7	7		
Grout loss	9	4	5	1	
Fitness for purpose					
Product tolerances	5	10	4		
Erection tolerances	5	7	6	1	
Interfacing tolerances	4	10	4	1	
Aesthetics					
Grout loss	11	4	4		
Kicking of formwork/bulging	8	5	5		1
Consistency of mix	5	8	6		

In Table 12 considering aesthetics, it can be said that labour and management each have “red blocks” indicating that they have a higher priority than site factors and safety. The “red blocks” portray the aspect having the highest impact on the respective quality component attribute. The attribute “grout loss” shows there were 11 respondents who felt it was primarily influenced by labour, 4 respondents chose management and 4 chose subcontractors. Thus grout loss is more likely to be influenced by labour as opposed to management or subcontractors.

In order to quantitatively evaluate the results of the survey, a scale of comparison was chosen. This approach is described in the following paragraphs. To distinguish which aspect i.e. labour,

management or subcontractors has a higher priority on the components of quality, a new scale was chosen so that two-thirds or more need to be highlighted in red in order to be first priority.

First priority

Considering aesthetics in Table 12, in the column labelled “labour” there are 2 “red blocks” which indicate that the respective attributes namely, grout loss and kicking of formwork, may most likely be influenced by labour. Of the three attributes of aesthetics, two fall under labour. Two-thirds of the attributes are influenced by labour. Thus, labour may be considered to be a first priority for aesthetics when the precast solution is applied.

Second priority

Considering aesthetics in Table 12, in the column labelled “management” there is only one attribute under management which has a bigger impact. Thus less than two-thirds of the attributes are influenced by management. Therefore management can be considered a second priority.

Low priority

The column labelled “safety” in Table 12 has no “red blocks” thus safety is not a high cause for concern for aesthetics. Safety can be considered a low priority.

The purpose of the “red blocks” was merely to place emphasis on the individual attributes of the quality components. These “red blocks” show which aspect is most likely to influence the respective attribute of the quality component. Application of Table 13 prioritises the aspects which are most likely to have the biggest influence on the respective quality component by using the “red blocks”.

Table 13: Scale representing priorities

First priority ($\geq 2/3$ of “red blocks”)	●
Second priority ($< 2/3$ of “red blocks”)	◊
Low priority (no “red blocks”)	–

Table 14 and Table 15 below show a summary of the results obtained from the first 2 sheets of the survey. The scale in Table 13 has been applied to Table 11 and Table 12 respectively. The scale used to display the results shows the priority of aspects with respect to the components of quality and in doing so prioritises the aspects.

The tables used to display the results can be analysed by using a horizontal or vertical analysis (with reference to the columns or rows of the matrix). Both analyses have been considered in this study. In the analysis the impact of quality aspects are considered on the quality components (refer to table 14). The quality aspects are labour, management, subcontractors, site factors and safety. The quality components are durability, fitness for purpose and aesthetics. Considering Table 14 below, a horizontal analysis is applied by looking at the rows one at a time. The impacts of the aspects on the components are emphasised.

Management is a first priority and influences durability, fitness for purpose and aesthetics.

A vertical analysis on the other hand, by analysing the columns one at a time also considering Table 14 below, describes which quality components: durability, fitness for purpose and aesthetics have a higher priority than the other. From this it can be seen that durability has one first priority as do fitness for purpose and aesthetics, but two more second priorities than fitness for purpose and aesthetics. Thus, durability has a higher priority than fitness for purpose or aesthetics for in-situ construction. The quality component with more “●” dots will have preference over those with few “●” dots. The number of “●” dots will determine which component has the higher priority. If the components have the same number of “●” dots or no red dots, then the “◊” symbol, representing second priority, will determine the component having the highest priority.

Table 14: Summary of In-situ results presented in Table 11

	Durability	Fitness for purpose	Aesthetics
Labour	◊	–	–
Management	●	●	●
Subcontractors	–	–	–
Site Factors	◊	–	–
Safety	–	–	–

In-situ horizontal analysis (line by line analysis)

By analysing at the lines one at a time, a horizontal approach of the summary represented in Table 14 above shows that for in-situ construction management is a first priority in achieving a product that is durable, fit for its intended purpose and aesthetically acceptable. Labour and site factors are a second priority in achieving durability. The areas of most concern are the highlighted areas in Table 11 and Table 12. According to the respondents, safety does not play a role in achieving overall

product quality. Labour, subcontractors, site factors and safety do not have a high impact on aesthetic requirements and fitness for purpose and thus create a lesser cause for concern. These aspects are low priorities. According to the scale (Table 13) used in the summary, “low priority”, does not lower the importance of the factors, it only prioritises them.

In-situ vertical analysis (column by column analysis)

By studying Table 12 column for column, a vertical analysis shows that for the in-situ solution, durability has a higher priority in determining the perception of quality than fitness for purpose and aesthetics. Fitness for purpose and aesthetics have a similar, perceived effect on the overall quality of the concrete. As found by the line by line analysis, durability, aesthetics and fitness for purpose are influenced by management, but the column by column analysis shows durability to have a higher priority than aesthetics and fitness for purpose. It thus shows that management is the aspect which has the biggest impact on quality for in-situ construction, whilst the component which determines quality the most is durability. Fitness for purpose and aesthetics are equally of low priority, thus it can be said that they are equally weighted according to their priority.

Table 15: Summary of Precast results from presented in Table 12

	Durability	Fitness for purpose	Aesthetics
Labour	◊	–	●
Management	●	●	◊
Subcontractors	◊	◊	◊
Site Factors	–	–	–
Safety	–	–	–

Precast – horizontal analysis (line by line)

Table 15 above represents a summary of the results presented in Table 12 for the precast results. A line by line analysis shows that there are three areas in which the aspects may have a major impact on the quality components. Management is a first priority in achieving a durable concrete. Management is also a first priority where fitness for purpose is concerned. Labour also has a high impact on aesthetics for the precast solution, thus it is a first priority. Assuming that prefabrication is undertaken by an independent subcontractor, the labour he utilises will have a major impact on the aesthetics of the product. Once the product is completed it will be the responsibility of the primary contractor to install the elements. Thus, management plays a major role in fitness for purpose.

Subcontractors are responsible for the durability of the concrete since they manufacture the elements for delivery during the construction phase. Labour may also influence the durability of the concrete but as stated before, the labour refers to that of the subcontractor. Management is also an area of concern when it comes to aesthetic requirements. The subcontractor himself will be liable for ensuring that the dimensions of elements are as prescribed. Therefore, the subcontractor needs to ensure that the product tolerances are according to specification. A subcontractor's labour may also influence the aesthetic quality of the product.

Labour has very little influence on fitness for purpose for the precast solution. Safety and site factors pose a low threat to the quality of the precast solution as conditions in a precast yard are more manageable.

Precast – vertical analysis (column by column)

Considering a column by column analysis on Table 15, it is evident that durability and aesthetics have a higher priority than fitness for purpose as these components of quality have more second priorities than fitness for purpose. There is one “●” dot under each quality component but only one “◇” dot beneath fitness for purpose. Durability and aesthetics have two “◇” dots. Durability and aesthetics have a similar impact on the overall quality of the product. Fitness for purpose however has a higher relative priority when a precast solution is selected in comparison to the in-situ solution.

Lessons learnt

In-situ construction

As can be seen in Table 14:

- More than one aspect has an impact on durability (column by column analysis);
- The aspect management influences all three components namely; durability, fitness for purpose and aesthetics (line by line analysis);
- A horizontal analysis (line by line analysis) shows that subcontractors and safety is a low priority for durability, fitness for purpose and aesthetics and thus have a lower impact on overall quality.

Precast construction

As can be seen in Table 15:

- The components durability and aesthetics are an issue for precast construction;
- The aspect management influences durability and fitness for purpose;
- The aspect labour influences aesthetics;
- A horizontal (line by line) analysis shows that site factors and safety are a low priority for durability, fitness for purpose and aesthetics and thus have a lower impact on the overall quality.

6.2.2. Analysing matrix 2 for the in-situ and precast solution

Table 16: In-situ results from Matrix 2

Quality Aspects	Components		
Access	Durability	Fitness for purpose	Aesthetics
Increasing/Working height	10	3	6
Working Space	13	1	5
Location (Urban/Semi-Urban/Rural)	11	3	5
Distance to/from supplier	13	3	3
Labour			
Training	10	2	7
Level of Skill	7	0	12
Amount of casual labour	9	3	7
Non conformance	10	3	6
Motivation/human attitude	9	1	9
Management			
Drawing revisions	2	8	9
Coordination	4	7	8
Communication	6	7	6
Precision Planning	3	8	8
Construction Method/technique	7	5	7
Rescheduling	4	6	9
Subcontractors			
Interpretation (Communication)	8	5	6
Construction Technique/method	9	5	5
Level of Skill	4	3	12
Knowledge of operation	6	4	9
Collaborative experience	5	4	10
Safety			
Experience of Crane Operator	5	3	11
Toolbox talks	6	6	7
Pre-task planning	5	6	8
Risk identification	5	8	6
Plant and Equipment			
Machinery (Cranes)	5	7	7
Shutter boards	4	1	14
Formwork system	4	3	12

Table 16 and Table 17 represent the data obtained from the last two sheets of the survey. The axes are the inverse of Matrix 1 as described earlier in this chapter. In this matrix, specific information regarding quality aspects was used to describe the aspects in greater detail.

As with the first Matrix, the areas highlighted in red show the factors with a higher priority. Both matrices, namely Table 16 and Table 17, were analysed in the same fashion as Matrix 1. The numbers in the table show the number of respondents who chose this aspect as the one with the highest impact on the respective quality component. Thus each number represents a respondent's first choice.

Table 17: Precast results from Matrix 2

Quality Aspects	Components		
Access	Durability	Fitness for purpose	Aesthetics
Increasing/Working height	5	5	9
Working Space	9	5	5
Location (Urban/Semi-Urban/Rural)	9	6	4
Distance to/from supplier	10	5	4
Labour			
Training	8	1	10
Level of Skill	3		16
Amount of casual labour	7	3	9
Non conformance	8	3	8
Motivation/human attitude	6	1	12
Management			
Drawing revisions	4	9	6
Coordination	4	8	7
Communication	6	7	6
Precision Planning	2	9	8
Construction Method/technique	2	6	11
Rescheduling	5	8	6
Subcontractors			
Interpretation (Communication)	7	4	8
Construction Technique/method	6	3	10
Level of Skill	5	1	13
Knowledge of operation	5	3	11
Collaborative experience	4	3	12
Safety			
Experience of Crane Operator	5	5	9
Toolbox talks	8	6	5
Pre-task planning	6	5	8
Risk identification	4	9	6
Plant and Equipment			
Machinery (Cranes)	6	9	4
Shutter boards	6	2	11
Formwork system	6	3	10

Table 18: Summary of in-situ results presented in Table 15

	Durability	Fitness for purpose	Aesthetics
Access	●	–	–
Labour	●	–	◇
Management	◇	◇	●
Subcontractors	◇	–	●
Safety	–	–	●
Plant and Equipment	–	◇	●

The components of Table 16 and Table 17 have been analysed according to their priorities by using the ranking system shown in Table 13. According to Table 13, a “●” dot represents first priority, a “◇” symbol represents second priority and a “–” symbol represents low priority.

In-situ – horizontal analysis (line by line)

From the summary of the in-situ results presented in Table 18 above, access and labour are first priority regarding durability. A horizontal analysis of the table (line by line) depicts these first priorities. Management, subcontractors, safety and plant and equipment are equally important for the aesthetics of the product for the in-situ scenario. In Table 18 above, the aforementioned quality aspects are first priorities regarding aesthetics. Access and labour are less important regarding aesthetics.

According to the respondents, second priorities, namely management and subcontractors, are important with regards to durability. Management and plant and equipment may influence fitness for purpose, whilst labour, also a second priority, could affect the appearance of the product.

Fitness for purpose is, however, not influenced by access and labour for the in-situ scenario. Aesthetics are also not influenced by access. Safety, and plant and equipment do not present as a threat towards the durability of the concrete. Subcontractors and safety seems to be a low cause for concern with regards to fitness for purpose.

In-situ – vertical analysis (column by column)

A vertical analysis of Table 18 illustrates that aesthetics have a higher priority than durability and fitness for purpose. As aforementioned, a vertical analysis emphasises the quality component with the highest priority. Durability is the next priority since there are areas of concern which require

more attention than for aesthetics. Fitness for purpose on the other hand does not require as much attention but should still be monitored with equal importance.

Table 19: Summary of precast results presented in Table 17

	Durability	Fitness for purpose	Aesthetics
Access	●	–	◇
Labour	◇	–	●
Management	–	●	◇
Subcontractors	–	–	●
Safety	◇	◇	◇
Plant and Equipment	–	◇	●

Table 19 provides a summary of the precast part of Matrix 2. The table used the approach of the coloured dots with priorities defined in Table 13.

Precast – horizontal analysis (line by line)

A horizontal approach (line by line), of the summary of the precast results displayed in Table 19 shows that access is first priority in achieving concrete that is durable. Management on the other hand may strongly influence the fitness of the products. Labour, subcontractors and plant and equipment are first priority for the aesthetics of the product.

Considering the precast solution, labour and safety may partially compromise durability. Similarly, safety and plant and equipment may impact the product's ability to fit. Access, management and safety are a cause for concern and could have an effect on the aesthetics of the concrete.

Management, subcontractors and plant and equipment do not appear to be a primary cause for concern regarding the durability of the concrete since they have been marked with the “–” symbol. Similarly, access, labour and subcontractors do not have a high impact on the dimensional tolerances of the element. As stated previously, the areas marked in “–” are low priority. This does not necessarily mean they are less important, it just illustrates their priorities.

Precast – vertical analysis (column by column)

A vertical analysis of Table 19 suggests that aesthetics has a higher priority than durability and fitness for purpose. Considering Table 19, it can be seen that aesthetics has 3 “●” dots compared to one dot for durability and fitness for purpose. Thus, aesthetics is a higher priority. Durability, when

compared to the in-situ solution has a lower priority since there are fewer “●” areas but unlike the in-situ solution, the precast solution has a higher priority for fitness for purpose.

Lessons learnt

In-situ construction

According to Table 18:

- The components durability and aesthetics are more important than fitness for purpose for in-situ construction.
- Aesthetics is influenced by more aspects than durability
- The quality aspects management, subcontractors, safety and plant and equipment influence aesthetics.
- The quality aspects access and labour influence durability.
- A vertical (column by column) analysis shows that fitness for purpose is a lower priority for in-situ than durability and aesthetics.

Precast construction

According to Table 19:

- The components aesthetics, durability and fitness for purpose influence precast construction.
- Aesthetics plays a bigger role as there are more quality aspects which influence it.
- The quality aspects labour, subcontractors and plant and equipment influence aesthetics.
- Quality components durability and aesthetics impact quality of the concrete equally.
- The aspect access influences durability and the aspect management influences fitness for purpose.
- A column by column analysis indicates that fitness for purpose is a higher priority for precast than the in-situ solution.

6.3. Alternative result evaluation

Under the previous section, the results obtained from the respondents were tallied by taking into account the number 1 rankings only. Only first priorities were considered. Since the rankings (1 – 5) had different weightings they could not be combined by adding various rankings together. An alternative approach was used and is described here, so that the combined effect of the rankings could be analysed. In order to perform the sensitivity analyses, the rankings (1 – 5) were given a different weighting. The weightings were as follows:



Ranking	Weighting
1	10
2	8
3	6
4	4
5	2

Figure 25: Weighting used in alternate result evaluation

For the alternative approach, in each of the nineteen surveys that were received, the rankings were converted as shown in Figure 25. The rankings in each matrix were converted by using the weighting described in Figure 25. The respective matrices were added together and divided by 19 (the total number of surveys). The new matrix obtained represents the combined effect of rankings (1- 5). The highest numbers represent the highest priority. As in Tables 11, 12, 16 and 17, the “red blocks” are now represented by the highest values. The values in Tables 20, 22, 24 and 26 have been rounded off to the nearest whole number. **Even though there are rows with equal values, the “red block” represents the attribute with the higher impact.** Before the value in the “red block” was rounded to the nearest decimal, the respective block had the higher value. Thus, only this higher value will be taken into account. A sensitivity analysis was not used as it would produce a similar result to the first approach. This is because the difference in the weighting between (ranking 1 and ranking 2) becomes larger, thus the alternative approach was considered as a means to verify the results.

The in-situ part of Matrix 1 is represented in the Table 20 below. This table verifies the prioritising used from Table 11. The results from the alternative approach indicate minor differences in comparison to the initial approach. These differences can be accounted for as the prioritisation

method only considers first priorities. Only “number 1’s” are taken into account, whereas, the sensitivity analysis combines 1’s, 2’s, 3’s, 4’s and 5’s respectively.

In Table 11 steel spacing is influenced by labour, whereas in Table 20, steel spacing is influenced by management. These differences may result due to management possibly having more 2’s than labour thus giving management a higher overall average. Since the alternative approach makes use of averages, the attribute having a bigger total will have the highest impact on the respective aspect.

The results obtained using the alternative approach can now be verified by application of the prioritisation scale used in Table 13.

6.3.1. Verification of Matrix 1

Verification of matrix 1 – in-situ construction

Table 20: Verification of matrix 1 – in-situ construction

Durability	Labour	Management	Subcontractors	Site factors	Safety
Cover to reinforcement	8	8	7	5	3
Steel Spacing	7	8	7	5	3
Compaction	9	7	4	6	4
Cube Strength	7	8	6	6	3
Cracking of concrete	7	7	5	7	3
Moisture content (Aggregates)	6	8	6	7	3
Bleeding	7	8	5	7	3
Mix Design	5	10	6	6	3
Consistency of mix	7	8	6	6	3
Grout loss	9	8	5	5	3
Fitness for purpose					
Product tolerances	6	10	6	6	2
Erection tolerances	N/A	N/A	N/A	N/A	N/A
Interfacing tolerances	N/A	N/A	N/A	N/A	N/A
Aesthetics					
Grout loss	8	8	6	6	2
Kicking of formwork/bulging	7	8	6	5	3
Consistency of mix	7	9	6	6	2

A similar approach, prioritising the aspects described in Table 13, was used to present the results which were obtained by using the alternative approach. The data was analysed by using a horizontal (line by line) and vertical (column by column) approach.

Table 21: Summary of in-situ results represented in Table 20

	Durability	Fitness for purpose	Aesthetics
Labour	◇	–	◇
Management	●	●	●
Subcontractors	–	–	–
Site Factors	◇	–	–
Safety	–	–	–

Horizontal (line by line) analysis

Labour is considered to be a low priority in the original analysis but is considered to be a second priority when the alternative approach is applied. This is as a result of the attributes with rankings between 2 and 5 which have now been included.

Vertical (column by column) analysis

The results obtained from the alternative approach indicate that durability is a high priority for in-situ construction. The same result was obtained using the prioritisation approach.

Table 22: Verification of matrix 1 – precast construction

Durability	Labour	Management	Subcontractors	Site factors	Safety
Cover to reinforcement	8	8	6	5	3
Steel Spacing	7	8	6	5	3
Compaction	9	7	5	6	3
Cube Strength	7	9	5	6	3
Cracking of concrete	7	8	5	7	3
Moisture content (Aggregates)	6	9	5	7	3
Bleeding	7	8	5	7	3
Mix Design	6	10	5	6	3
Consistency of mix	8	9	6	5	3
Grout loss	8	8	5	5	3
Fitness for purpose	0	0	0	0	0
Product tolerances	7	9	5	5	3
Erection tolerances	6	8	5	4	3
Interfacing tolerances	6	8	5	5	3
Aesthetics	0	0	0	0	0
Grout loss	9	8	5	5	3
Kicking of formwork/bulging	8	8	6	5	3

Table 22: Continued

Aesthetics					
	Labour	Management	Subcontractors	Site factors	Safety
Consistency of mix	7	9	6	5	3

Table 23: Summary of Precast results from presented in Table 22

	Durability	Fitness for purpose	Aesthetics
Labour	◇	–	◇
Management	●	●	●
Subcontractors	–	–	–
Site Factors	–	–	–
Safety	–	–	–

Horizontal (line by line) analysis

When Table 23 is compared to Table 15 (summary of precast results), which considered the sum of first priorities only, there seems to be more differences with the precast solution than the in-situ solution. Considering aesthetics, management is a first priority instead of labour; labour is considered to be a second priority. For both of the methods used, management is a first priority for durability as well as fitness for purpose.

Subcontractors are a low cause for concern rather than a second priority for durability, aesthetics and fitness for purpose when compared to the results obtained from Table 15.

Vertical (column by column) analysis

A column by column analysis shows that durability and aesthetics is still a higher priority for the precast solution. This is also the case for Table 15.

Lessons learnt*In-situ construction*

According to Table 21:

- A line by line analysis shows that management is a high priority for durability, fitness for purpose and aesthetics;
- A column by column analysis shows that durability is a high priority for in-situ construction

- A horizontal (line by line analysis) shows that safety is a low priority for durability, fitness for purpose and aesthetics;
- A vertical (column by column) analysis shows that fitness for purpose has a lower priority for the in-situ solution than aesthetics and durability.

Precast construction

According to Table 23:

- A line by line analysis shows that management is a high priority for durability, fitness for purpose and aesthetics;
- A column by column analysis shows aesthetics and durability are a higher priority for the precast solution than fitness for purpose. Aesthetics and durability have the same amount of “_” and “◇” symbols and “●” dots;
- A line by line analysis indicates that subcontractors, site factors and safety are a low priority for durability, fitness for purpose and aesthetics.
- According to the analysis, in this case it can be seen that the precast and in-situ analyses display similar results

6.3.2. Verification of Matrix 2

Table 24: Verification of matrix 2 – in-situ construction

Access	Durability	Fitness for purpose	Aesthetics
Increasing/Working height	9	8	8
Working Space	9	7	8
Location (Urban/Semi-Urban/Rural)	9	7	8
Distance to/from supplier	9	8	7
Labour			
Training	9	7	8
Level of Skill	9	7	9
Amount of casual labour	9	7	8
Non conformance	9	7	8
Motivation/human attitude	8	7	9
Management			
Drawing revisions	7	9	9
Coordination	7	8	9
Communication	8	8	8
Precision Planning	7	8	9
Construction Method/technique	8	7	8
Rescheduling	8	8	8
Subcontractors			
Interpretation (Communication)	8	7	8
Construction Technique/method	8	7	8
Level of Skill	8	7	9
Knowledge of operation	8	7	9
Collaborative experience	8	8	9
Safety			
Experience of Crane Operator	8	8	8
Toolbox talks	8	8	8
Pre-task planning	8	8	9
Risk identification	8	8	8
Plant and Equipment			
Machinery (Cranes)	8	8	8
Shutter boards	8	7	9
Formwork system	8	7	9

Again, a similar approach, prioritising the aspects, described in Table 13, was used to present the results which were obtained by using the alternative approach. The approach was analysed by using a horizontal (line by line) and vertical (column by column) approach.

Table 25: Summary of in-situ results presented in Table 24

	Durability	Fitness for purpose	Aesthetics
Access	●	—	—
Labour	●	—	◇
Management	◇	◇	●
Subcontractors	◇	—	●
Safety	—	◇	●
Plant and Equipment	—	◇	●

Horizontal (line by line) analysis

When Table 25 is compared to Table 17 (summary of the precast results) which concerned the sum of first priorities only, there is only one difference once Table 13 has been applied to the results. Safety is considered to be a second priority and not a low priority whereas the results from the alternative method consider safety to be a second priority for fitness for purpose.

Vertical (column by column) analysis

Aesthetics is still regarded as the priority which is most likely to influence the in-situ solution. Fitness for purpose has a slightly higher priority and in addition, there is one second priority. (Safety for fitness for purpose as described above in the line by line) only. This however does not change the fact that aesthetics is the higher priority for in-situ.

Table 26: Verification of matrix 2 – precast construction

Access	Durability	Fitness for purpose	Aesthetics
Increasing/Working height	8	7	9
Working Space	9	7	8
Location (Urban/Semi-Urban/Rural)	8	8	8
Distance to/from supplier	8	8	8
Labour			
Training	9	7	8
Level of Skill	8	7	9
Amount of casual labour	8	7	8
Non conformance	9	7	8
Motivation/human attitude	8	7	9
Management			
Drawing revisions	8	8	8
Coordination	8	8	8
Communication	8	8	8
Precision Planning	7	8	9
Construction Method/technique	7	7	8
Rescheduling	8	8	8
Subcontractors			
Interpretation (Communication)	8	8	8
Construction Technique/method	8	7	9
Level of Skill	8	7	9
Knowledge of operation	8	8	9
Collaborative experience	8	8	9
Safety			
Experience of Crane Operator	8	8	8
Toolbox talks	8	8	8
Pre-task planning	8	8	9
Risk identification	7	8	8
Plant and Equipment			
Machinery (Cranes)	8	9	8
Shutter boards	8	7	9
Formwork system	8	7	9

Table 27: Summary of in-situ results presented in Table 24

	Durability	Fitness for purpose	Aesthetics
Access	●	—	◇
Labour	◇	—	◇
Management	◇	●	◇
Subcontractors	—	—	●
Safety	—	◇	●
Plant and Equipment	—	◇	●

Horizontal (line by line) analysis

In comparison with Table 19 (Summary of precast results) which concerned the sum of first priorities, there are five notable differences when Table 13 is applied to the results in Table 26.

Management is considered to be a second priority rather than a low priority and safety is considered to be a low priority rather than a second priority for durability. Considering fitness for purpose, management is considered to be a second priority rather than a first priority. For aesthetics, labour is a second priority and not a first and safety is a first priority not a second priority.

Vertical (column by column) analysis

Even though the line by line analysis shows five differences between the two methods for the precast solution, a column by column analysis between the two methods show a similar outcome. The number of “—” and “◇” symbols and “●” dots in the columns is the same as in Table 19 (Method of using first priorities). The analysis shows that aesthetics has a higher priority for precast construction than durability and fitness for purpose.

Lessons learnt*In-situ construction*

According to Table 25:

- A line by line analysis shows, access and labour are a high priority for durability;
- A line by line analysis also shows that management, subcontractors, safety and plant and equipment are a high priority for aesthetics;

- Considering in-situ construction as a whole, a column by column analysis in the table shows that aesthetics has a higher priority than fitness for purpose or durability.

Precast construction

According to Table 27:

- A line by line analysis shows access is a high priority for durability and management is a high priority for fitness for purpose;
- A line by line analysis also shows subcontractors, safety and plant and equipment are a high priority for aesthetics;
- A column by column analysis shows aesthetics is a high priority for precast construction;
- A column by column analysis shows durability and fitness for purpose is a lower priority for precast construction. Fitness for purpose and durability has the same amount of “_” and “◇” symbols and “●” dots.

Conclusion

The results obtained from the alternative method were used to support the results obtained from the first method. Here, the sum of the first priorities was used to show how and where the quality aspects impacted the components of quality. The alternative method was used to verify the results discussed in the previous chapter. This was achieved by using a sensitivity analysis.

The results achieved from the second method (sensitivity analysis) display similar results to the results obtained by adding the first priorities. This was shown by applying Table 13 to the Matrices (Matrix 1 and Matrix 2 each for in-situ and precast). There were minor differences between the analyses of the 2 methods, however, the differences will be accounted for in the conclusion of the study.

6.4. Comparison between in-situ and precast using cause and effect diagrams

In this section the two approaches used in the survey (Matrix 1 and Matrix 2) are combined so that the overall outcome can be synthesised. The information in the survey was used to compare the precast and in-situ construction methods. This was achieved by using two matrices. The first matrix compared the quality components namely; durability, fitness for purpose, aesthetics and their respective attributes, between in-situ and precast. The attributes of durability, aesthetics or fitness for purpose influence the respective components, but are also in turn influenced by the quality aspects of labour, management, subcontractors, site factors and safety. The second matrix compared the quality aspects of labour, management, subcontractors, site factors, safety and their respective attributes, between in-situ and precast. The attributes influence the aspects which in turn impact the quality components of durability, fitness for purpose and aesthetics. The relationship between the matrices is shown in Figure 26.

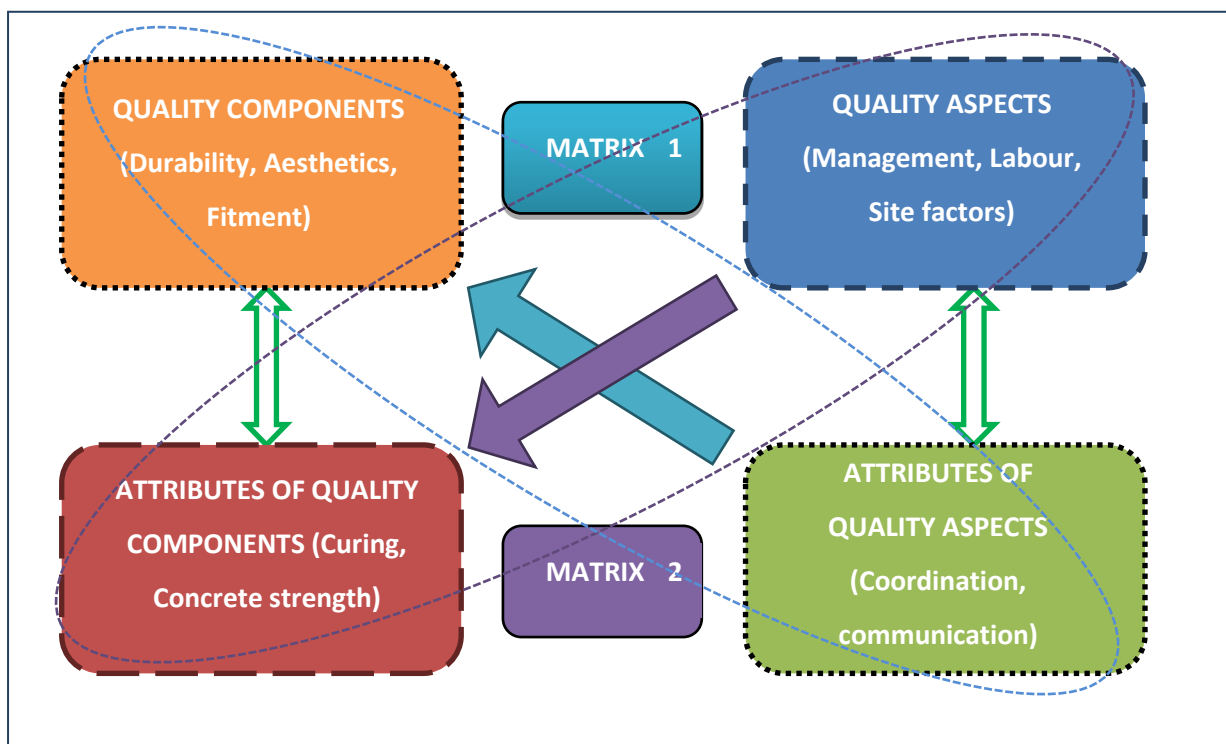
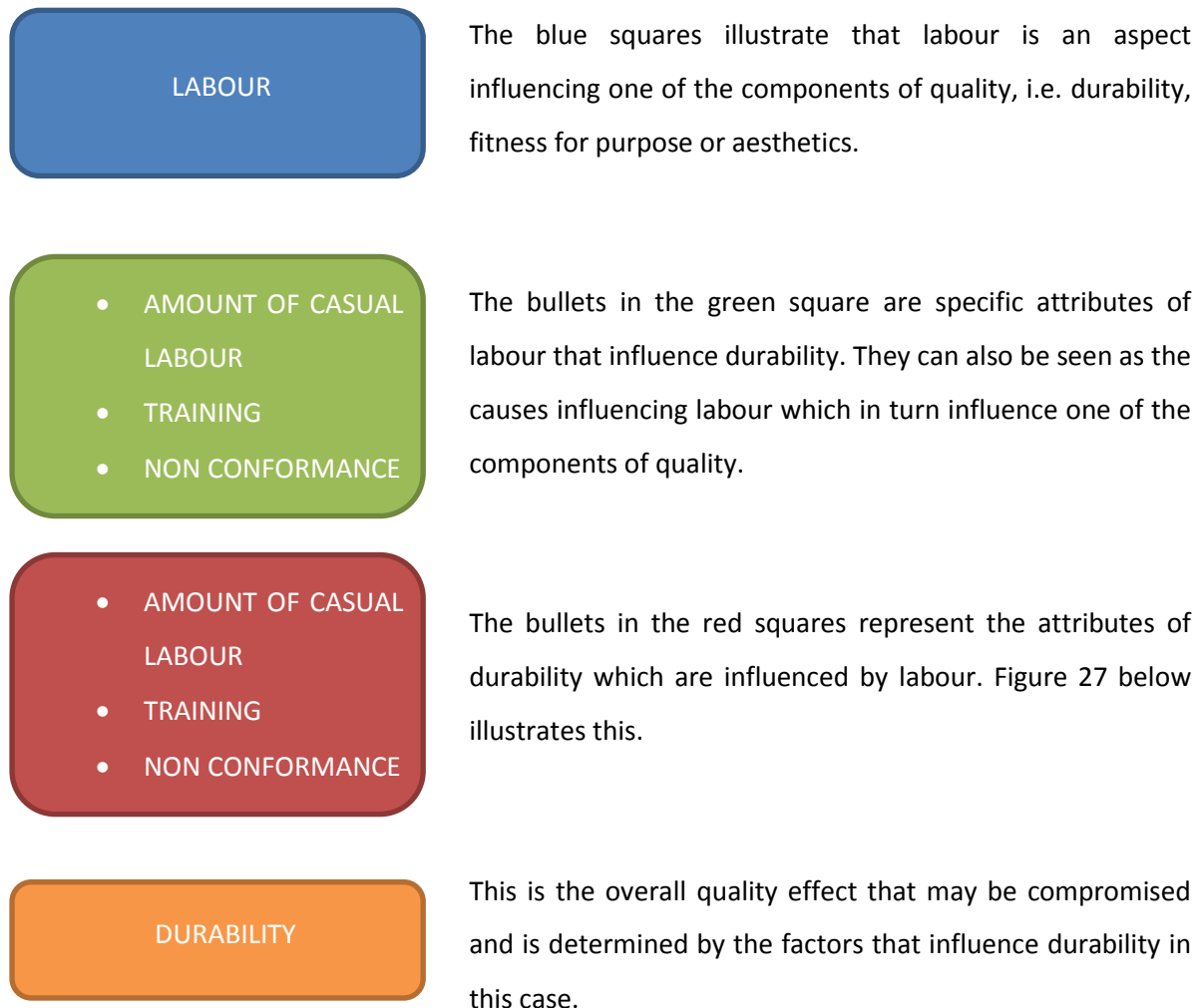


Figure 26: Relationship between components of quality and quality aspects

The diagrams below represent the combined effect of the Matrices used in the questionnaire. In other words the two sheets used for each of the in-situ and precast survey have been combined such that the information obtained could be displayed in one figure. This was made possible through the utilisation of cause and effect diagrams. Durability, fitness for purpose and aesthetics have been defined as the three components comprising overall quality in concrete construction. The attributes

influencing these components have thus been used to describe how each component may be affected.

Different colour codes have been used to describe the cause and effect diagram. These are described below. The example of Figure 27 is used to describe the notation that is used further on:



The layouts of the cause and effect diagrams were constructed from the feedback from the respondents. The diagrams will be used to compare the precast and in-situ options by considering all the factors which influence overall quality. The approach using the cause and effect diagram will become clear when the component durability is described using section 9.4.1.1

6.4.1. Cause and effect analysis

The cause and effect analysis for the quality effects of durability, aesthetics and fitness for purpose are now presented for each of the precast and in-situ methods in the following paragraphs. The diagrams in Figures 27, 28 and 29 represent the relationships which describe how the aspect and respective attributes influence the components. These figures represent the impact of both, the in-situ and precast solutions.

The cause and effect diagrams which follow can be interpreted as follows:

- The attributes and aspects in “white” font represent the in-situ scenario;
- The attributes and aspects in “black” font represent the precast scenario;
- The attributes and aspects in “white” font and which are underlined are relevant to both the in-situ and precast scenario.

6.4.1.1. Durability

Durability for the in-situ solution

The description which follows refers to the diagram in Figure 27. The quality aspects (blue blocks) which influence durability are management, labour, access, subcontractors, site factors and safety for in-situ construction.

The attributes of durability (red squares) are related to either management, labour or site factors. Concrete cover, cube strength, moisture content, bleeding, grout loss, consistency of the mix and mix design are the attributes of durability which management may impact. This relationship also reveals that management may impact durability.

Steel spacing, compaction and grout loss are influenced by labour. Cracking of the concrete, moisture content of the aggregates and bleeding are associated with site factors. The conditions on site are thus determined by the outcome of this specific effect.

The attributes (green blocks) of the quality aspects are related to management, labour, access or subcontractors. The attributes, amount of casual labour, training, non-conformance and human attitude influence labour. This in turn may be a contributing factor as to why steel spacing and compaction is unsatisfactory and why excessive grout loss takes place. Therefore the attributes of labour may impact durability.

Working space, working height, location, and distance to the closest supplier are the attributes which impact access. As the height of the building increases, the durability may be compromised. Working space, when working in a confined area, may also compromise durability.

The construction method, interpretation and communication are the attributes which influence subcontractors. Misinterpretations could compromise durability and a lack of communication or miscommunication may play an important role in achieving concrete that is durable.

Durability for the precast solution

The description which follows also refers to the diagram in Figure 27. The cause and effect diagram shows that management, labour, access, subcontractors and safety are the quality aspects (blue blocks) that influence durability. It can be noted that site factors do not play a role in achieving durability for the precast solution.

The attributes influencing durability (red blocks) are a result of management, labour and subcontractors. The precast solution assumes that construction of the prefabricated elements is carried out by an independent subcontractor. Moisture content, bleeding, consistency of the mix, mix design, cube strength and cracking of concrete is associated with management and steel spacing; compaction, concrete cover and grout loss are associated with labour. Concrete cover, steel spacing and consistency of the mix are related to the subcontractor. From Figure 27, it can be noted that management and labour have an equal amount of responsibility. For the precast solution however, it is noted that some of the responsibility lies with the subcontractor. Site factors do not play a role in durability for the precast solution since the construction activities take place in a controlled environment.

The attributes (green blocks) of the quality aspects are related to labour, access and safety. Working space, location and distance to supplier may all impact access. Failure of labourers to conform may compromise durability. Working height does not influence the durability of the precast solution but may impact that of the in-situ solution.

Comparison between in-situ and precast durability

By referring to Figure 27, a comparison can be made between the in-situ and precast information. Firstly, site factors barely play a role in achieving durability for the precast solution. Secondly, it can be seen from Figure 27 that the focus of durability control shifts slightly from the site manager to the subcontractor, and even to the labour, which will be the labour of the subcontractor. Lastly, with reference to the aspects (blue blocks) which influence durability, the principle difference between in-situ and precast is the effect of labour. Training and casual labour may indirectly influence durability for the in-situ solution. Local labour forms an integral part of the agreements in a construction contract but also presents a potential problem for meeting specification since casual labour is usually unskilled. Without training, unskilled labourers do not have an understanding of quality concepts and don't think of it as a deliverable. Thus, labour plays a bigger role for in-situ construction than for precast construction.

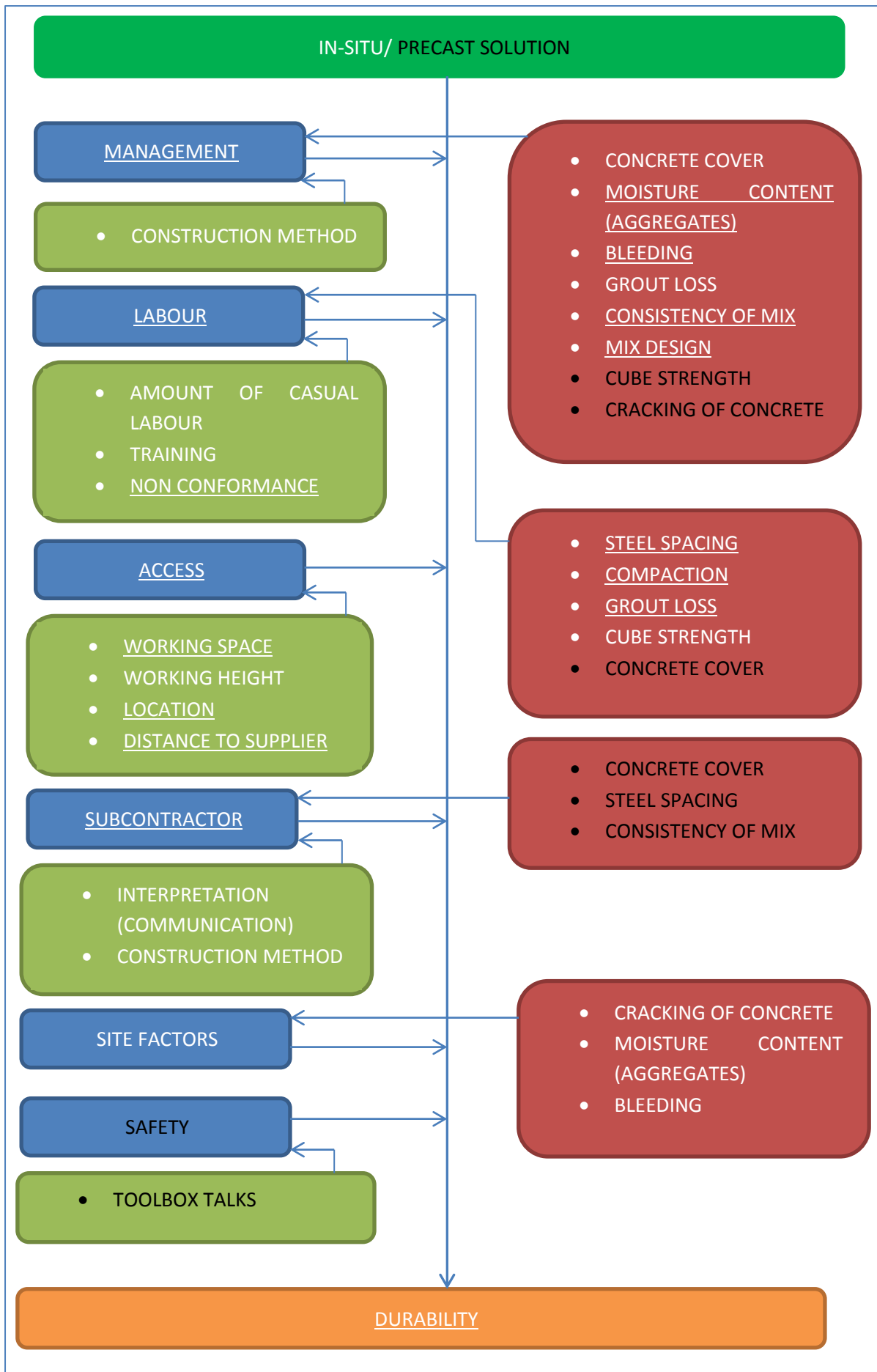


Figure 27: Cause and effect diagram – durability of in-situ versus precast

6.4.1.2. Aesthetics

Aesthetics for the in-situ solution

The description which follows refers to Figure 28. The in-situ solution shows that management, labour, subcontractor, safety and plant and equipment (blue blocks) are all the aspects that may impact aesthetics.

The survey shows (green blocks) that drawing revisions, coordination, construction method, rescheduling and precision planning influence management, which in turn impacts aesthetics. Coordination is needed in any activity where two or more individuals determine the outcome.

Motivation and level of skill are the attributes that may impact labour. Willingness to act has proven to have a large impact on the outcome.

A subcontractor chosen to construct a part of the project may influence aesthetics in the following way: his knowledge of the operation, collaborative experience and level of skill. These factors may influence his ability to produce a product with sound aesthetics.

Plant and equipment play an important role in final product. The formwork system and shutter boards will determine the final shape of the element. Sub-standard equipment will have an effect on aesthetics.

Safety plays a bigger role in achieving a product that is free of aesthetic defects. Experience of the crane operator, risk identification, toolbox talks and pre-task planning may influence safety.

The attribute of aesthetics namely grout loss, kicking of formwork and consistency of the mix may be influenced by management. When either of these attributes is unacceptable, rework is needed in order to remove the visible defects.

Aesthetics for the precast solution

For the purposes of this discussion refer to Figure 28. Management, labour, subcontractors, plant and equipment, safety and access are the aspects (blue blocks) that may influence aesthetics for the precast solution. Access does not impact aesthetics for the in-situ solution but does, however, play a role in the precast solution.

The construction method, precision planning and communication are the attributes which influence management. This could ultimately influence the aesthetics of the element.

Similarly, motivation and level of skill influence labour. These attributes describe how well or badly the labour force will perform.

Knowledge of operation, collaborative experience, level of skill, construction technique and the ability to interpret instructions may impact the subcontractor.

The formwork system and shutter boards play a major part in the aesthetics of the product. The quality of the equipment will determine what the human eye will see. Apart from environmental conditions, the experience of the crane operator will govern the way in which the elements will be placed. Mistakes are sometimes made and the consequences thereof may result in rework or construction of a new element.

Experience of the crane operator and toolbox talks may impact safety. Pre-task planning of the operation, by incorporating safety procedures, could prevent accidents from occurring. Accidents not only injure the work force but may also result in damage to the structural element. Working at a height may compromise aesthetics. As the building increases in height, weather conditions may sometimes make erecting and placing problematic.

The attributes of aesthetics (red blocks) are consistency of the mix, grout loss and kicking of the formwork. Consistency of the mix may be as a result of poor management and grout loss and kicking of formwork may be due to the incompetency of the labourers.

Comparison between in-situ and precast aesthetics

By referring to Figure 28 it can be seen that, unlike with the case for the in-situ solution, the attributes impacting aesthetics are influenced by both management and labour. The in-situ solution holds management accountable for these attributes. In addition, there are a few attributes which influence management for the in-situ solution which do not apply to the precast solution. However, there are more attributes which influence the subcontractor and thus his ability to produce a

product that is aesthetically sound. With reference to the attributes which influence aesthetics, the principle difference between precast and in-situ quality is the effect of labour and management. Labour plays a bigger role in aesthetics for precast than for in-situ construction. Considering the precast solution, the labour referred to belongs to the subcontractor and not the main contractor. Management is more involved during in-situ construction, whereas, in the case of precast construction, labour has more responsibility delegated to them.

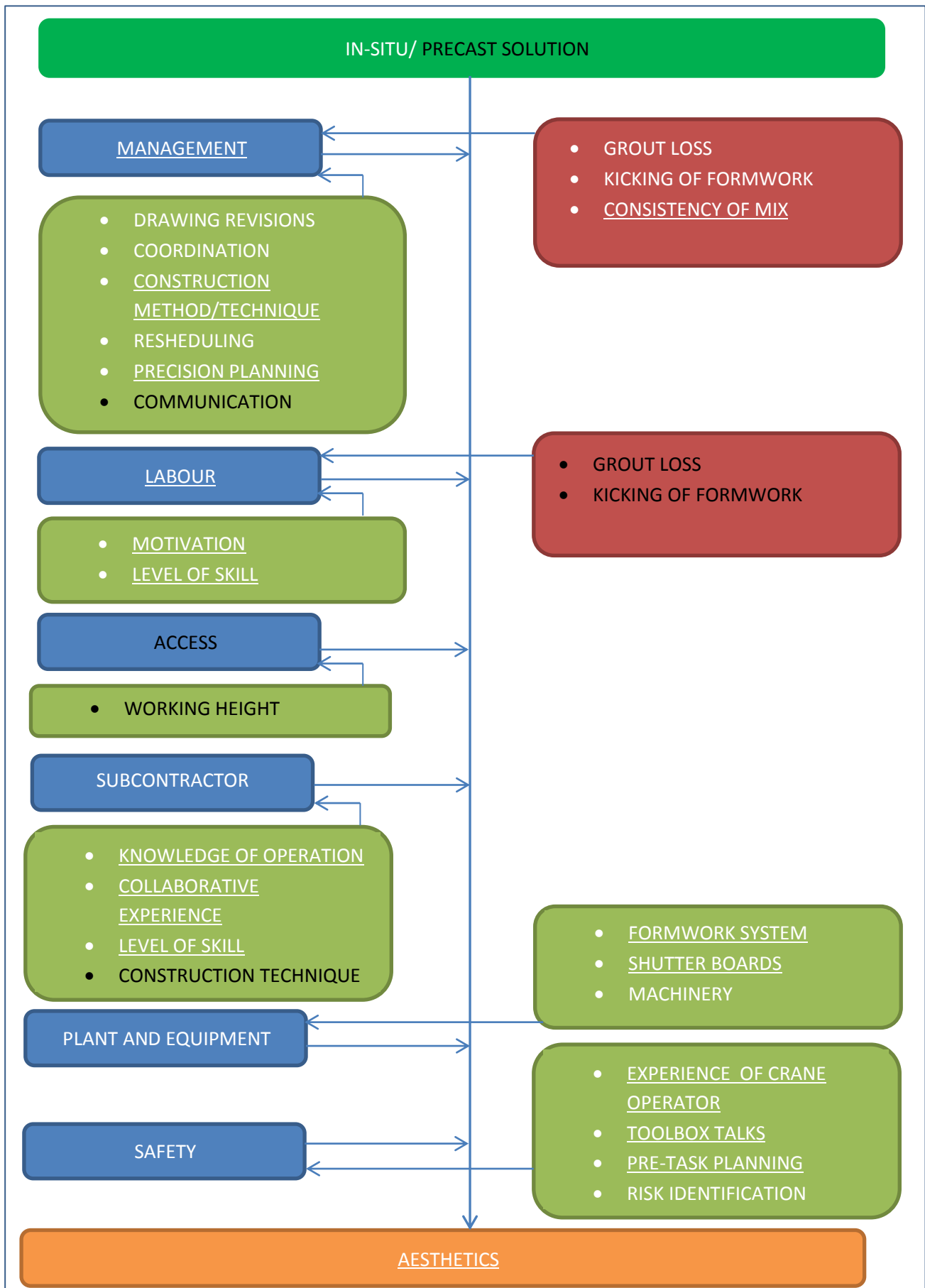


Figure 28: In-situ versus precast aesthetics

Fitness for purpose

Fitness for purpose for the in-situ solution

The discussion that follows refers to Figure 29. This figure reflects that there are not many attributes which influence fitness for purpose. Since in-situ construction is only associated with product tolerances and not erection and interfacing tolerances, in-situ does not really present great risk for this component.

Management and plant and equipment (blue blocks) are the aspects that may influence fitness for purpose. Product tolerances are associated with management.

Furthermore, the attributes of management (green blocks) that play a role are communication and precision planning. These attributes may also be seen as the tools which could be used to improve the accuracy of the product tolerances. Machinery such as cranes may also impact this component of quality.

Fitness for purpose for the precast solution

The discussion that follows also refers to Figure 29. When compared to the in-situ solution, the precast solution has an extra quality aspect (blue block) namely safety, which also impacts fitness for purpose. There are more risks related to erection of the elements since a crane is required to complete the operation. This involves more safety procedures and thus presents more risks.

The discussion to follow refers to Figure 29. Product tolerances, erection and interfacing tolerances are the attributes of fitness for purpose (red blocks) and are influenced by management.

The attributes of management (green blocks) that play a role are more significant in precast than for in-situ. Coordination is an important factor as this incorporates fitment of the elements. In most cases a combination of precast and in-situ is used. An example of this is demonstrated in chapter 5, Site Visits precast beams were erected onto in-situ piers. Drawing revisions and rescheduling may also influence fitness for purpose.

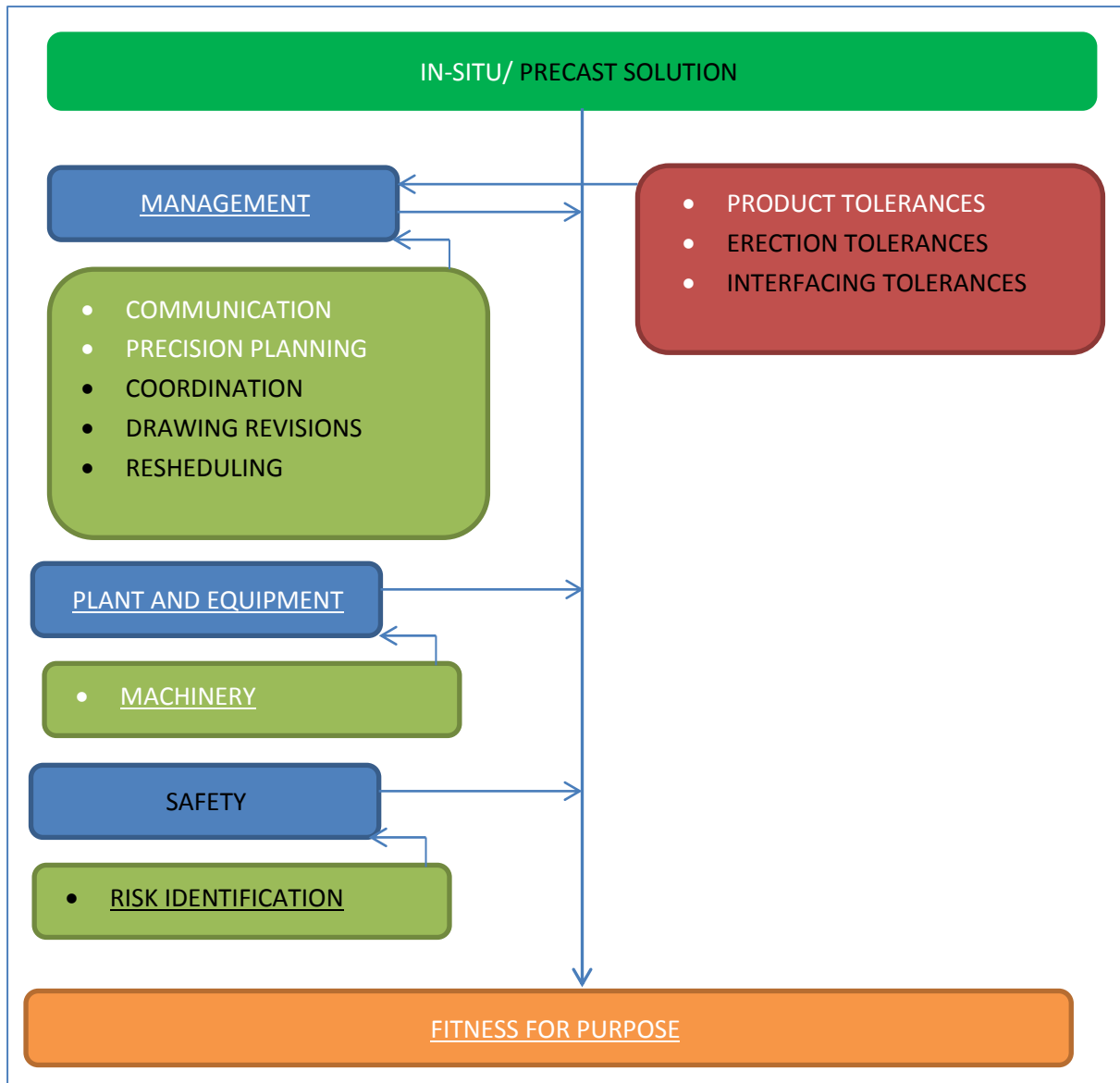


Figure 29: In-situ versus precast fitness for purpose

6.5. Chapter conclusion

The results obtained in the survey were analysed by using priorities (Table 13) and the cause and effect diagrams.

Lessons learnt

Durability

- In-situ and precast concrete construction are influenced by the aspects management, labour, access and safety;
- Precast construction is not influenced by site factors;

- Considering the attributes of durability (red blocks), responsibility of the risk is transferred between management, labour and subcontractors, whereas for in-situ, the risk lies between only management and labour.

Aesthetics

- The aspects management, labour, subcontractors, plant and equipment and safety play a role in achieving quality for the precast and in-situ solutions;
- However, access only plays a role for the precast solution;
- Considering the attributes of aesthetics (red blocks), responsibility of the risk is transferred between management and labour whereas for in-situ, the risk lies with management.

Fitness for purpose

- The attributes erecting and interfacing tolerances only apply to the precast solution;
- Safety does not play a role in achieving fitness for purpose for the in-situ solution.

Figure 26, 27 and 28 show a summarised comparison between precast and in-situ quality for each aspect of durability, aesthetics and fitness for purpose. The lessons drawn from the priority tables (Tables 14, 15, 18 and 19) and the lessons learnt from the cause and effect diagrams have been combined so that the important components, aspects and their respective attributes can be used to present the comparisons.

It can be deducted from the priority tables that durability is an issue for in-situ construction and aesthetics is an important issue for precast construction. However, aesthetics is also an issue for in-situ construction.

Table 28: In-situ versus precast durability summary

	In- situ		Precast	
Quality aspects	Attributes of aspect	Attributes of durability	Attributes of aspect	Attributes of durability
Management	-Construction method	-Concrete cover -Moisture content (aggregates) -Bleeding -Excessive grout loss -Consistency of mix -Mix design		-Cracking of concrete -Moisture content (aggregates) -Bleeding -Cube strength -Consistency of mix -Mix design
Labour	-Amount of casual labour -Training -Non conformance -Human attitude	-Steel spacing -Compaction -Grout loss -Cube strength	-Non-conformance	-Steel spacing -Compaction -Grout loss -Concrete cover
Access	-Working space -Working height -Location -Distance to supplier		-Working space -Location -Distance to supplier	

Table 28 shows that labour plays a bigger role in achieving durable concrete for in-situ construction. There are more attributes that labour has to account for when compared to the precast solution. The amount of casual labour, lack of training and human attitude could be a disadvantage to the project team with regard to durability. This is, however, not the case for the precast solution.

Height influences precast construction however it does not influence in-situ.

For both in-situ and precast construction, management plays a similar role for durability. Considering the precast solution, the labour utilised belongs to the subcontractor. Thus, labour is not the responsibility of management but that of the subcontractor. The precast solution thus allows the risk

of the main contractor to be transferred. In the case of labour by subcontractor, the precast approach allows more room for training, mentorship and control.

Table 29: In-situ versus precast aesthetics summary

	In- situ		Precast	
Quality aspects	Attributes of aspect	Attributes of durability	Attributes of aspect	Attributes of durability
Management	-Drawing revisions -Coordination -Construction method/technique -Rescheduling -Precision planning	-Grout loss -Kicking of formwork -Consistency of mixture	-Construction method/technique -Precision planning -communication	-Consistency of mixture
Labour	-Motivation -Level of skill		-Motivation -Level of skill	-Grout loss -Kicking of formwork
Subcontractor	-Knowledge of operation -Collaborative experience -Level of skill		-Knowledge of operation -Collaborative experience -Level of skill -Construction technique -Interpretation	
Safety	-Experience of crane operator -Toolbox talks -Pre-task planning -Risk identification		-Experience of crane operator -Toolbox talks -Pre-task planning	
Plant and equipment	-Formwork system -Shutter boards -Machinery		-Formwork system -Shutter boards	

Table 29 shows that the subcontractor takes on a big role where aesthetics is concerned. Management on the other hand plays a larger role where the in-situ scenario is concerned. On a precast construction site, where high rise structures are constructed, there are more risks where safety is concerned. Safety could be a potential threat to achieving an aesthetically sound product. Risk identification and experience of the crane operator are important factors, should the aforementioned scenario be realised.

Table 30: In-situ versus precast fit for purpose summary

	In- situ		Precast	
Quality aspects	Attributes of aspect	Attributes of durability	Attributes of aspect	Attributes of durability
Management	-Communication -Precision planning	-Product tolerances	-Coordination -Drawing revisions -Rescheduling	-Product tolerances -Interfacing tolerances -Erection tolerances

Management plays a bigger role in the fitment of the element for the precast scenario. This is evident in Table 30. As aforementioned, interfacing and erection tolerances do not pertain to the in-situ solution thus there is less risk concerning the fitment of elements for the in-situ solution.

As a potential guideline, tables 28, 29 and 30 may be used to assist a contractor in managing quality when deciding to choose between either, the in-situ or precast option. Figure 30 represents an interpretation of these tables where the pros and cons of in-situ and precast concrete construction are compared with regard to labour, management and subcontractors.

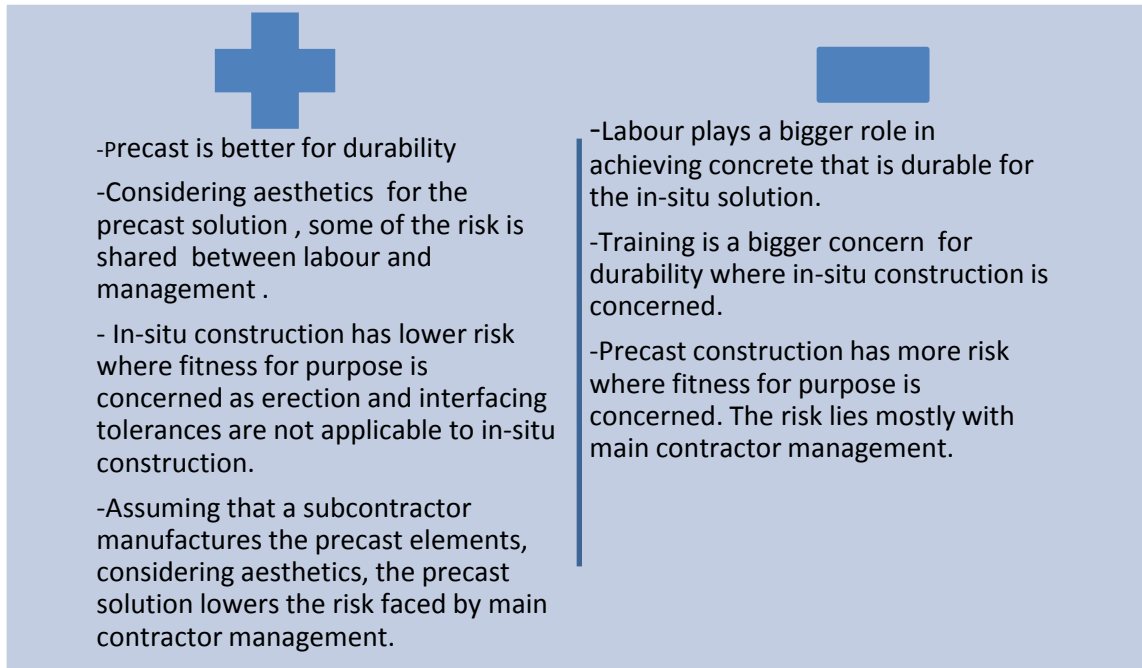


Figure 30: Advantages and disadvantages for the in-situ and precast solution considering labour, management and subcontractors

7. Conclusion

7.1. Summary of research findings

Quality in the construction environment is complex as the industry is dynamic in nature. There are many factors which may influence the quality of a product. Quality of a product in construction can be defined when a unit or element is fit for its intended purpose, meets the requirements of the design specification, and aesthetics. Thus, it needs to be user friendly, durable, safe, free from defects and free from significant variations.

Quality management should be addressed as a multi-dimensional concept rather than a one-dimensional concept as there are many factors involved. Quality control and quality assurance are quality management tools which can be used to ensure the pristine quality of the product. This brings one to the concept of total quality management. The concept strives towards customer satisfaction. This is accomplished by seeking unity within the organisation. TQM unites attitudes and goals of employees and will be beneficial to the procedure.

Communication is an important attribute of management. The manner in which it is done and the timing thereof are essential to the purpose of the message. Educational background is necessary to understand the content. Conceptual, human, political and technical skill is required to practice safety procedures on the construction site. Teamwork is influenced by occupational health and safety, human influence and psychological factors.

Subcontractors are influenced by certain factors which may be internal or external, as are the main contractors. The management of subcontractors is thus complex as the factors influencing them will also impact the main contractor.

When there are deviations or the nature of the work is not according to specification, additional work or reworks are done to repair or remove the quality imperfections. Rework may be as a consequence of either processes or human nature. Human nature is associated with skill, knowledge and self-discipline whereas process is related to design and engineering, instruction and inspection, schedule and material and equipment supply.

The aspects influencing quality were identified as labour, management, subcontractors, site factors and safety. The attributes impact the relevant aspects. The consequences of these impacts may also result in rework or even a worst case scenario: failure of the structure.

These attributes influencing the quality of the concrete may be seen as uncertain events. These events are likely to occur but there is no definitive likelihood or probability that suggests they will occur. Many decisions are made on the construction site and these decisions themselves carry a certain amount of risk.

The risk is subjective and management thereof is thus largely related to the individual. The educational background, culture and personal belief affect the risk and this varies for each individual. The risk is thus also associated with the personality of the individual.

Thus in the construction environment, these factors would play a role in achieving quality. These factors described in the literature can be integrated with the quality components, quality aspects and their respective attributes. Total quality management can be incorporated in the process of achieving quality and in doing so improve quality in the construction environment.

7.2. Conclusions

In the light of this study, the deductions drawn from these conclusions portray basic information and represent how the professionals who participated in the survey feel about achieving quality of concrete construction in South Africa. The explorative nature of this study seeks to convey a message for informative purposes rather than to present a statistical picture of how a sample within a population perceives concrete quality. The qualitative techniques which were used best provide answers to the objectives of this study.

It was found that the precast solution is better for durability than the in-situ solution. There are fewer attributes influencing durability for the precast option. The conditions in the precast environment are more controlled which is one of the reasons why better durability could be achieved. Site factors do not influence durability for precast solution but do play a role for the in-situ solution. Considering that the same attributes that influence durability for in-situ, also apply to durability for precast, it would be prudent for a main contractor to review the quality management of subcontractors.

There are many aspects and attributes which influence aesthetics for both precast and in-situ. However, access plays a role in aesthetics for precast and not for in-situ. The specific attribute is working height. Even though precast has one more aspect influencing it, the aspects which account for the aesthetics in precast are labour as well as subcontractors. The responsibilities are thus divided between the two implying that more attention can be placed on these individual attributes. In-situ on the other hand places all the responsibility for aesthetics with management.

Management plays an important role in fitness for purpose for the precast solution. Erection and interfacing tolerances come into being when the precast solution is considered, however the in-situ solution is less concerned with these tolerances. Communication is an important part of the management process, the manner in which the message is conveyed, timing of the message as well as the contractors' ability to stimulate his team will play a role in the success of erection and interfacing tolerances.

Management plays a bigger role in the overall quality of in-situ than it does with precast. In the precast environment, subcontractors and labour take on some of the responsibility that management deals with in the in-situ environment. Thus it lowers the risk of management and allows management to focus their attention where needed.

During the construction process, teams comprised of labour, engineers, project managers and the subcontractor will need to make decisions. These decisions have consequences and are influenced by the educational background, knowledge and inspiration of each individual. There is thus an element of risk brought forward with each decision since a decision by these individuals can have an impact on the overall quality.

Each aspect of quality has an element related to people skill and knowledge. Management and communication go hand in hand. The manner in which information is brought across will influence how the receiver responds to the message. Knowledge barriers will determine the interpretation of the message. In order to practice safety, conceptual, human, political and technical skill is required. Again the element of human skill arises which involves working with people, self-discipline and knowledge. Labour includes team work. Team work is influenced by human stimulus, psychological factors and occupational health and safety.

The characteristics of these attributes are mostly concerned with people skills and knowledge or educational background. The aspects of quality and its attributes carry an amount of risk. Risk is subjective but is also managed according to the educational background and personal beliefs.

Total quality management has two primary objectives which are to satisfy the customer and to achieve continuous improvement. The quality of the concrete for the in-situ construction method is largely based on the ability of management to monitor and make decisions. This requires an amount of knowledge and people skills. By satisfying the customer, a contractor will strive to produce pristine quality and in doing so will guide the employees to have the same goal in mind. As TQM strives for continuous improvement, knowledge will continually be incorporated into the work environment and can be beneficial in maintaining a high level of quality in the in-situ environment.

By applying this concept in the precast environment, the standard of quality can be higher as management plays a smaller role in achieving overall quality. This, however, transfers the responsibility to the subcontractor where the same principles apply. However, total quality management may be more achievable in a controlled environment.

8. Research questions

In this section the research questions which were to be investigated are answered.

1. What are the factors that play a role in achieving quality?

The components which impact quality were identified as:

1. Durability;
2. Fitness for purpose;
3. Aesthetics.

The aspects which influence these components were identified as:

- Management, relates to the manner in which a project is coordinated, planned and the way in which the manager communicates;
- Training and level of skill of labour may influence the level of quality of the concrete achieved on a construction project;
- Site factors such as access and equipment govern logistical issues that may or may not arise on a construction project;
- A subcontractor, when utilised, has his own team and therefore the level of skill of his labour force becomes the risk. Interpretation of the scope of the works and the subcontractors ability determines the level of quality;
- Practicing safety procedures will lead to safe acts and therefore could promote work of higher quality.

2. How do these factors differ in the precast and in-situ environments?

The manner in which these factors differ between the precast and in-situ environment as can be seen in Table 22, 23 and 24 are summarised as follows:

Advantages:

- Precast is better for achieving durability
- Considering aesthetics for the precast solution, some of the risk is shared between labour and management ;
- In-situ construction has lower risk where fitness for purpose is concerned as erection and interfacing tolerances are not applicable to in-situ construction;
- Assuming that a subcontractor manufactures the precast elements, considering aesthetics, the precast solution lowers the risk faced by main contractor management.

Disadvantages:

- Labour plays a bigger role in achieving concrete that is durable for the in-situ solution;
- Training is a bigger concern for durability where in-situ construction is concerned;
- Precast construction has more risk where fitness for purpose is concerned. The risk lies mostly with the main contractor management.

3. What are the risk implications of these quality issues?

The risk implications of these issues found in quality construction are:

Lack of fit, poor durability (insufficient cover, inadequate steel spacing), poor aesthetics (uneven finishes due to quality of shutters or formwork system) which all leads to rework. Poor quality implies more time would be needed to fix the defects and in construction, more time implies more costs.

These are the risks that need to be considered in terms of the specific project conditions which would include labour, management, subcontractors, safety and site factors.

4. What role does labour play in achieving quality in the South African construction environment?

With regard to in-situ construction, labour plays an important role in achieving durability. Training and level of skill play a big part in the capabilities of the labourers. Human attitudes as well as non-conformance are also attributes which influence the labourer. These attributes also play a role when precast construction methods are used. However, labour plays a bigger role in the aesthetics of the product. In the case of precast, labour can potentially be better controlled.

The choice of method may thus be determined by the labour available for a specific project, being either trained or local (unskilled) labour.

5. What should the project team ask themselves when considering the decision to construct using either precast or in-situ for a specific part of a project as far as quality is concerned?

There are many factors which need to be taken into account before construction can commence.

The factors relating to quality of concrete construction are:

- Which components of quality, namely durability, aesthetics or fitness for purpose, are more likely to compromise overall quality?
- What is the nature of the construction site as far as accessibility is concerned?
- What level of skill do the available labourers have?
- How much casual labour will be utilised?
- Does the construction procedure involve repetitive procedures?
- How many phases does the project have? Could a subcontractor be utilised to minimise the risk of the main contractor?

9. Limitations and recommendations for further study

9.1. Scope of investigation and assumptions

During the study certain assumptions were made thus limiting the scope of the study. These limitations and recommendations for future studies are mentioned below:

- The study only considers the construction environment and the execution of the works. It is not design related, neither does it address the specification of concrete nor does it concern the tests which are carried out to ensure durability requirements;
- The subcontractors construct the elements during precast construction;
- In the case of prefabrication, a major portion of the work is completed in the precast yard. A comparison was not made between the individual processes which take place during precast and in-situ construction;
- There is no absolute scale for quality management. Results are therefore only comparable at a qualitative level.

9.2. Recommendations for further study

Now that the aspects and attributes influencing quality have been identified, it would be useful to quantify the risks associated with these aspects by using statistics. The risk will be represented by a probability multiplied by a value consequence. The consequence could be expressed either as a monetary value or time implication.

The quality of concrete from a designer's perspective could be investigated and compared to the contractor's perspective. In doing so, the similarities and the differences between the contractor and consultants' views can be obtained. The differences could be used to describe the design related issues.

A comparison between the quality of precast and in-situ construction can be conducted by only taking into account the processes of each method.

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11. Appendix A - Interview questions

With regard to concrete quality

1. What are the quality issues which commonly occur during the construction process?
2. How do these issues impact the overall project?
3. Who are the parties responsible for these imperfections?
4. What are the quality control procedures followed by the company?
5. What are the external factors which influence quality of the concrete?
6. What role does labour play in achieving quality?
7. How does training play a role in the process?
8. Are there any training opportunities available and if so, what are they?

12. Appendix B - Survey Data

See cd attached at the back of the document.