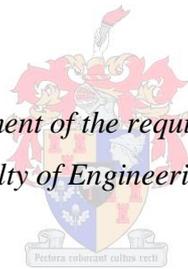


The Role of Knowledge Management in Improving Constructability

by
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*Thesis presented in fulfilment of the requirements for the degree of
Master of Science in the Faculty of Engineering at Stellenbosch University*



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Declaration

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Abstract

Constructability issues cause dire repercussions in the industry and often pose as overwhelming threats to the successful delivery of projects. Constructability issues mainly arise from a design, which does not sufficiently embody the knowledge and expertise of the construction phase. Subsequently this creates a variety of negative secondary effects during project execution, which eventually manifest as time-, budget- and quality-risks to the project. The research thesis explores the status quo of constructability issues in South Africa, with specific reference to the relationship between construction and design.

It is well known that close collaboration between consultants and contractors has the potential to lead to more effective construction processes, improved construction safety and to cost effective structural solutions. Not all contract forms allow sufficient collaboration between these parties at the time of conceptual design, nor at the detailed design stage. For this reason it is imperative that a designer has sufficient experience and knowledge of construction processes to produce suitably constructible designs.

In principle, constructability issues can be regarded as the result of poor coherence, and thus poor communication, between construction and design. The problem therefore lies in the transfer of knowledge between project participants, which can be described as poor knowledge management, in particular, of constructability knowledge.

This research aims to address the topic of constructability and to demonstrate how structural knowledge management between contractors and designers can lead to improved construction processes. The concept of constructability is defined, through the identification of technical traits to explicitly describe constructability, concurrently with input from industry expertise and professional experience in the field. Knowledge management principles are also studied in detail and the status quo of current knowledge management initiatives in the industry is investigated. The investigations are done through a series of questionnaire surveys, personal interviews and correspondences.

The principle conclusions from the study are that designers do not always understand what constitutes a constructible design. Furthermore, although constructability knowledge is found to exist in complex tacit forms, some explicit guiding principles can indeed be formulated to aid designers. In addition, considering the unique characteristics of each project, these guiding principles should be supported by proposed knowledge management initiatives to facilitate structured forums of knowledge sharing between different parties to develop and transfer constructability knowledge. This will assist to accelerate the learning process towards becoming an accomplished designer, and empower the capacity of both designers and contractors to manage constructability problems.

Opsomming

Boubaarheidsprobleme veroorsaak ernstige gevolge in die bedryf en hou dikwels oorweldigende bedreigings in vir die suksesvolle lewering van projekte. Boubaarheidsprobleme ontstaan hoofsaaklik as gevolg van 'n ontwerp wat nie genoeg kennis van die konstruksiefase behels nie. Gevolglik, word 'n verskeidenheid van negatiewe sekondêre effekte geskep tydens die projek uitvoering, wat risikos uiteindelik veroorsaak in aspekte van tyd, geld en kwaliteit. Hierdie navorsing ondersoek die status quo van boubaarheidsprobleme in Suid Afrika, met spesifieke verwysing na die verhouding tussen konstruksie en ontwerp.

Dit is bekend dat geskikte samewerking tussen konsultante en kontrakteurs kan lei tot meer effektiewe bouprosesse, verbeterde bouveiligheid en goedkoper strukturele oplossings. Kontraktuele ooreenkomste laat nie altyd toe vir behoorlike samewerking tussen die partye gedurende ontwerp stadiums nie. Om hierdie rede, is dit noodsaaklik dat 'n ontwerper voldoende ervaring en kennis van die konstruksie prosesse bevat, om behoorlike boubare ontwerpe te kan produseer.

In beginsel, kan boubaarheidsprobleme beskou word as 'n gevolg van swak kommunikasie tussen konstruksie en ontwerp. Die probleem lê dus in die oordrag van kennis tussen projek deelnemers, wat ook beskryf kan word as swak kennis-bestuur, in die geval, van boubaarheidskennis.

Hierdie navorsing beoog om die onderwerp van boubaarheid aan te spreek en te demonstree hoe strukturele kennis-bestuur tussen die kontrakteurs en ontwerpers tot verbeterde konstruksie prosesse kan lei. Die konsep van boubaarheid word gedefinieer, deur die identifisering van tegniese eienskappe wat boubaarheid eksplisiet kan beskryf, gelyktydig met die insette van industrie kundigheid en professionele ondervinding. Kennis-bestuur beginsels word ook in diepte bestudeer en die status quo van die huidige kennis-bestuur inisiatiewe in die bedryf word ondersoek. Die ondersoek word gedoen deur middel van vraelys opnames, persoonlike onderhoude en korrespondensies.

Die algemene gevolgtrekkings uit die studie is dat ontwerpers nie altyd die implikasies van 'n boubare ontwerp verstaan nie. Verder, alhoewel boubaarheidskennis bestaan in komplekse vorms in die gedagtes van konstruksie personeel, eksplisiete riglyne kan wel geformuleer word om die ontwerp proses te steun. Aangesien projekte uniek is, moet hierdie riglyne ondersteun word deur die voorgestelde kennis-bestuur inisiatiewe, om oop platforms van kennis oordrag te fasiliteer tussen verskillende partye. Dit sal help om die leer proses te versnel en sal die kapasiteit van beide ontwerpers en kontrakteurs bemagtig, sodat hulle boubaarheidsprobleme beter te kan hanteer.

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All said, I sincerely hope that the thesis has created some value, not only on the level of academia, but also on that of industry. I hope this research poses as a starting point for many more to come, producing feasible, and desperately needed, solutions to our industry.

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Glossary of Abbreviations

AEC	Architect, engineer and contractor
ASCE	America Society of Civil Engineering
BAC	Building Construction Authority
BAM	Buildability Assessment Model
BDAS	Buildable Design Appraisal System
CAS	Construction Appraisal System
CEM	Construction Engineering and Management
CII	Construction Industry Institute
CM	Construction management
CPM	Critical Path Methods
CRP	Constructability review process
HVAC	Heating, ventilation and air conditioning
IT	Information technology
KM	Knowledge Management
LLP	Lessons learnt programmes
LSI	Labour saving index
VE	Value engineering

Chapter 1 Introduction

The research is ultimately geared towards understanding the broad problem related to constructability and the how Knowledge Management (KM) principles can be applied in tools or as initiatives implemented in the project environment to improve constructability in the industry at large. This constitutes investigations to define constructability more explicitly and identify traits of constructability knowledge that can be readily managed through KM approaches. Before more detail is given on the commencement of this research, a fundamental starting point needs to be defined as a context for the research within the field of Construction Engineering and Management (CEM).

This opening chapter aims to set the basis for this research and present the Construction Engineering and Management (CEM) perspective, in which the relevance of the research is clearly demonstrated. This chapter gives a background of the construction industry project environment and sheds light on some of the related problems, resulting from fragmentation of project personnel, processes and knowledge. This leads up to the formulation of the research problem statement at the end of the chapter, followed by the summary overview of the thesis document as a whole.

1.1 Brief History of CEM

Construction engineering and management (CEM) emerged as a field of graduate engineering education during the 1950s in the United States. Five decades since then, CEM matured as a respected field of graduate engineering education within civil engineering departments, and sometimes within architecture or building technology departments. During the early stages of CEM, there were two prevalent elements in the vision for CEM as a graduate academic discipline (Levitt, 2007):

First and foremost, a vision was for CEM to develop into a legitimate “profession” comparable to other legitimate and respected “engineering professions”. In the mid 1950s, there were virtually no graduate degrees in CEM, and no form of professional registration was available for “construction engineers” anywhere.

Secondly, it was also desired for CEM to establish its own respected community of researchers. The early CEM researchers began to harness the physics, chemistry, management science, and computer science (a discipline that had not yet been created, and to which civil engineers made seminal contributions in their development of databases) as the underlying science to help them analyse and optimize work processes and organisations for design and construction.

Over the following 50 years of CEM research development, the pioneering vision of early researchers and educators has largely been realized. CEM can now be viewed as a “real profession” in civil and environmental engineering communities. CEM practitioners and academics are regularly elected to leadership positions in civil engineering societies. CEM research is now viewed as bona fide “engineering science” by engineering faculty and university administrators and CEM has many first rate journals, conferences and societies (Levitt, 2007).

Construction Engineering and Management CEM research over the past 50 years has focused on extending and applying management and computer science approaches to minimize cost during the implementation phase of construction projects. Three emerging trends can be identified:

- 1) More integrated delivery of design, planning, construction, and operation of buildings and infrastructure requires us to broaden the focus of construction engineering and management research across the entire facility lifecycle
- 2) Rapid globalization of the construction industry requires new governance structures for projects that can bridge across the gap in values, beliefs, norms, work practices and laws between participants from different countries
- 3) Heightened global awareness of, and demand for, enhanced sustainability requires new approaches, methods, and tools to incorporate sustainability issues in the early phases of the facility development process.

Still, if one regards the 50 years of CEM research, the striking trend is that it has primarily focused on one phase in the lifecycle of facilities – the construction phase – without much consideration of what comes before or what comes after it in the lifecycle. This may not be too surprising, given that the field is called “construction engineering and management”, but constructors do not operate in isolation in creating the built environment. Along with this focus on a single phase has been a focus on the production cost efficiency of this part of the process, again in isolation, leading CEM researchers and the industry seem to measure success almost exclusively in terms of reduction of first cost for facilities. The result has been a set of valuable insights about how to build facilities that have lower capital cost, but which may perform poorly in terms of lifecycle economic metrics – not to mention environmental and social equity metrics (triple bottom line). It is evident, looking at the first five decades of CEM development, researchers need to broaden and deepen the frame of analysis (Levitt, 2007).

1.2 ASCE's Broad New Vision for Civil Engineering

In June 2006 The ASCE Task Committee produced a report entitled "The Vision for Civil Engineering in 2025" (ASCE, 2009). The task force developed a broad vision statement in the professional and society by the year 2025, where future civil engineers will function as master builders, who will serve as planners, designers, constructors and operators. Vision 2025 also envisages future civil engineers as project leaders leading "multidisciplinary, collaborative teams consisting of a well-defined hierarchy of professional and paraprofessionals". This may offer a fundamental guideline to direct the research of CEM in the near future, especially in the context of civil engineers, in terms of the professionalization of CEM personnel in South Africa, or other applicable countries.

1.3 Characteristics of AEC Industry

Two notable characteristics of the AEC (architect, engineer, contractor) industry are its fragmented organisational structure and one-off methods of project design and construction (Shen & Jensen, 2011). Fragmentation is reflected in the fact that the project participants – architects, engineers, and contractors – are often organised in an ad hoc manner and that they often come from different geographic locations and different companies. Each participant is responsible for completing his or her own speciality. The one-off characteristic is reflected in the fact that no two construction projects are exactly the same. Continuous improvement and refinement of the end product are difficult, unlike in the auto industry, where mass production provides opportunities for continuous improvement of the production processes and coordination among participants along the supply chain. The fragmentation and one-off nature of the AEC industry create significant challenges for coordination of overall project activities (Shen & Jensen, 2011).

Despite technology advances, the AEC business structure has changed little over the last 40 years. (Shen & Jensen, 2011). Typical project delivery systems are design-bid-build or design-build. Most traditional consulting engineering firms have a clearly define scope of work in particular specialities, such as structural design; heating, ventilation and air conditioning (HVAC) design; or civil system design. Some consulting firms also provide construction-related services such as construction management (CM), value engineering, or design-build. Most traditional construction companies also provide a different array of typical services, such as general contracting, subcontracting, construction management and risk management. Some construction companies provide design-build, which often includes consulting (design) services.

The typical services provided by construction and consulting (design) engineering firms and their overlap are illustrated in figure 1-1.

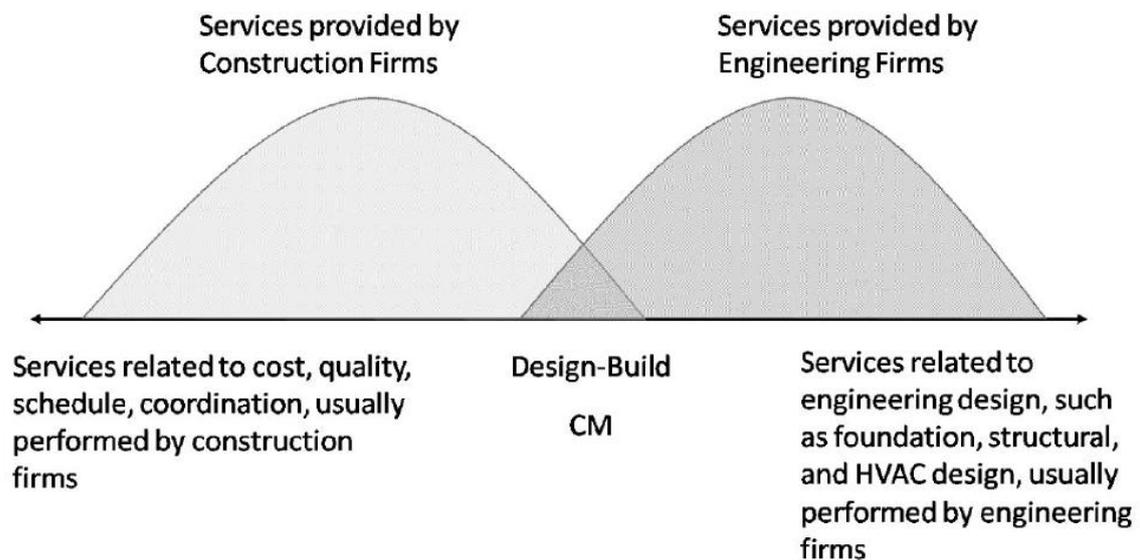


Figure 1-1 Typical services provided by construction firms and engineering firms

Most of the overlap occurs on heavy civil and infrastructure projects such as highways, bridges power plants, dams, and water treatment systems (Shen & Jensen, 2011). Here the challenge is the dominant concern during the design and construction process; there is less subcontracting compared to a typical building project. In commercial and residential building, the separation of design and construction services is more common (Shen & Jensen, 2011).

There is evidently a lack of integration in the industry, especially between construction and design, or more specifically, in the integration of construction knowledge and expertise during the design phase. In principle, this can be seen as a fundamental cause of many problems in subsequent phases of the project progression, often leading to disputes between project participants with deep financial implications. The design stage thus is a significant starting point to attaining the ultimate goal of a comprehensively integrated lifecycle approach in project decision making.

1.4 Fragmentation of the industry

The construction industry is highly fragmented as compared to other industries. This may have caused significant low productivity, cost and time overruns, conflicts and disputes, resulting in claims and time consuming litigation (Latham, 1994). The fragmentation problem is further compounded by the fact that the construction process typically involves several disciplines collaborating for relatively short periods in the design and construction of a facility (Anumba, 2000).

Another facet of the fragmentation problem is the fact that construction projects, whether they are buildings, bridges, dams or offshore structures, usually involve many stages, starting from the establishment of the client's requirements through to design, construction, utilization and eventual

disposal of the facility. These stages of the project's life cycle and the associated activities and tasks are often undertaken as discrete processes, with only limited integration of data/information, participants, tools and procedures (Anumba, 2000).

Some of the consequences of the fragmentation problem include (Amor & Anumba, 1999):

- Inadequate capture, structuring, prioritization and implementation of client needs
- The fragmentation of design, fabrication and construction data, with data generated at one project not being readily used downstream
- Lack of integration, coordination and collaboration between the various functional disciplines involved in the lifecycle aspects of the project
- Lack of true lifecycle analysis of projects (including costing, maintenance etc)
- Poor communication of design intent and rationale, which leads to unwarranted design changes, unnecessary liability claims increase in design time and cost, and inadequate pre- and post-design specifications

1.5 Research problem statement

A completely integrated lifecycle approach is difficult to achieve in the construction industry, due to the fragmented nature of construction projects on so many levels. Different people, from different disciplines (often from diverse social/national backgrounds), work on different projects at different times. Even within the same project, there may be segregation between project participants to the extent that one party may be completely oblivious to another. This is more so the case within large complex projects.

Comprehensive integration amidst all project processes is an ambitious goal. It is perhaps better described as a fundamental principle, consisting of numerous objectives. Fragmentation may well occur on a "space-time" level between project participants, but these relationships can indeed be managed to transcend the geographical and time limitations, thus achieving integration on a knowledge- or intelligence level. Integration thus implies successfully creating an active knowledge flow between all parties of the project through all phases. These endeavours already have taken shape in so many forms through the use of modern technology and communication platforms; however, much fragmentation evidently still exists.

Due to the fragmented nature of project procedures and the implicit barriers to integration, many problems arise (described previously in section 1.4) such as: the inadequate capture of clients' needs;

data and knowledge generated at one project not being used elsewhere, lack of collaboration between various functional disciplines; lack of lifecycle approach; poor communication of design intent and rationale (Amor & Anumba, 1999). These problems eventually lead to substantial wastage during the execution of the project in the form of constructability issues. These constructability issues arise, because of misalignment of interests and the subjective interpretation of available knowledge between functional parties during preceding phases – i.e. planning stages before construction.

Constructability issues cause dire repercussions in the industry and often pose as overwhelming threats to the successful delivery of projects. Explicitly stated, constructability issues can arise from a “poor” design. “Poor” in this case implies a design, which does not sufficiently embody the knowledge and expertise of the construction phase, subsequently creating a variety of negative secondary effects mentioned in the previous paragraph. Constructability can be simplified to: “the extent to which the design of a building facilitates ease of construction” (CIRIA, 1983), or more descriptively “the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives” (CII, 1986)

Considering the nature of the problems linked to fragmentation and the lack of integration, constructability issues can be seen as a result of poor coherence between construction and design, and thus, broadly expressed, poor communication. The deduction can be made that fragmentation problems are attributed to the ineffective creation, capture and transfer of knowledge between project participants, hence poor knowledge management (KM).

Different parties involved in a project naturally have different facets of interests and thus perceive knowledge differently in terms of degree of relevance and importance. The discrepancy leads to different perceptions between design and construction, specifically when it comes to the constructability or “buildability” of designs. Many clients are unwilling to dedicate extra effort in improving constructability, thinking that construction problems should be solved by the contractors in any case (Griffith & Sidwell, 1995). Furthermore, many designers lack the motivation to consider constructability seriously in their designs, thinking that construction is a transient process, which is lesser of the more permanent functional and aesthetic priorities (Wong et al., 2004).

On the other hand, without suitable incentives, contractors are unwilling to contribute their construction expertise prior to the award of contracts (Ma et al., 2001) and even if they were willing to, there is neither any standard procedure to facilitate this nor is there concrete organised knowledge to distribute. Worse still, there is presumably a lack of partnering spirit between some designers and constructors (O'Connor & Miller, 1994), resulting in a conflicting “them-and-us” attitude. This could lead to design problems well spotted in tender or contract documents in anticipation of claim opportunities, which defeats the sole purpose of the project – to work together in synergy and succeed as a team.

Knowledge management (KM) is defined as the process of creating, acquiring, capturing, sharing and using knowledge to enhance organisational learning and performance (Scarborough et al., 1999). KM thus deals with the process of capturing and organising knowledge within an organisation, which allows the meaningful accessibility of this information. This enables the relevant information to be delivered or acknowledged by the right person/subordinate within the organisation, at the right time. Thus, KM governs knowledge flow from the organisational knowledge pool to each and every employee, as well as the information interaction between different employees. A sound management of knowledge-flow within an organisation enables the clear and systematic identification of problems and the subsequent efforts to mitigate or avoid them in future – in this case, constructability problems. Organisations would be able manage the knowledge streams to ensure that knowledge is extracted, stored and shared so that the relevant personnel is able to receive this knowledge when it is most needed.

1.6 Thesis overview

The thesis presents the comprehensive response to the problem statement discussed above and the ensuing investigations. The study consists of different components, which can be structured into the 13 Chapters of the research paper. The brief objectives and contents of each of these chapters are discussed.

Chapter 2 Research scope, aim and objectives

The scope of research activities and extent of investigation are extrapolated from the research problem statement. The nature of the research problem is better described and the objectives are inferred and explicitly stated. In the end, a research plan of development is presented as a flow chart of progressive research activities.

Chapter 3 Research Methodology

Different research methodologies are discussed in detail, covering different principles and classifications of research. The approaches and techniques chosen for this particular research are presented and their relevance motivated. Primary techniques chosen are questionnaires, expert correspondences, personal interviews and case studies.

Chapters 4 and 5 Literature study

The literature study is a review of all aspects concerning constructability and knowledge management concepts and related principles. Here the research context will be expanded, the details of which also contribute to the formulation of further refined research questions to be used in the research methodology. The complete literature study is divided into 2 chapters, for constructability related literature and knowledge management related literature respectively. This is done to present the literature in a more logical manner, covering principles from both fields. However, the contents of the

two chapters should not be regarded mutually exclusive; they bear an inherent relationship to each other relevant to this research.

Chapter 6 Synthesis of literature study

The relationship between constructability and knowledge management is discussed in more detail. This chapter describes some results and deduction from both literature study chapters. The synthesis highlighted here evokes further principle questions, which are used as material basis for the formulation of the questionnaires, correspondences, interviews and case study.

Chapters 7, 8 and 9 Questionnaires

These 3 chapters constitute most of the data acquisition and analysis for this research. Two questionnaires were distributed, which were based on the synthesis of the literature studies with relevance to the research problem of improving constructability through knowledge management principles. Phase-1 questionnaire is shorter and covered in chapter 7, while the Phase-2 questionnaire contained substantially more premise for discussion and thus covered over 2 chapters (chapters 8 and 9)

Chapter 10 Constructability cases/issues in practice

This chapter presents the analysis of specific constructability issues or cases in the context of real projects. This can be regarded as a large-scale case study, of small cases on the particular issues of constructability in practice. The results and deductions are used to validate the findings of the questionnaires from previous chapters.

Chapter 11 Tubular Track case study

A comprehensive case study is carried out on the company Tubular Track (Pty) Ltd. Tubular Track has a very integrated design and construction philosophy, which follows an inherent evolutionary process. Together with sound quality system handling and knowledge management, constructability problems are addressed intrinsically over time as modifications implemented into their project. The case study aims to conceptualize the numerous Tubular Track processes and extract lessons and principles that can be applied in the industry at large to improve constructability.

Chapter 12 Comprehensive review and discussion

All the findings from the research investigations are summarized and combined to formulate a final discussion. The relationship between the results of the different investigations is elaborated. The chapter also discusses the reasoning leading up to the possible recommendations arising from this research.

Chapter 13 Final conclusion and recommendation

The concise conclusions and recommendations are given. A finale is drawn concerning the role that knowledge management can play in improving constructability in the construction industry.

Recommendations are given, which form part of a broad solution strategy to address constructability problems and industry fragmentation.

The following chapter proposes a response approach to the problem statement mentioned in this chapter. Furthermore, the scope and limitations of the research is defined, and explicit research objectives are formulated, leading to the establishment of the research plan of development.

Chapter 2 Thesis Scope, Aim and Objectives

This chapter clarifies the comprehensive plan of this research. The solution approach, as a response to the problem statement is presented, followed by a discussion of the scope and limitations of this research. The research aim is formalized, and explicit objectives can be established to be fulfilled in this research. The research objectives indicates the process by which this research aims to define constructability and related problems, as well as the approach knowledge management can employed to address these problems. From the objectives of the research, the plan of progression is outlined, describing the activities undertaken to address each of the objectives set out. It is shown that there is a pertinent need for addressing constructability problems, and knowledge management is in principle a holistic approach to doing so.

2.1 Response to problem statement

To condense the research problem discussed in Chapter 1, the broad issue at hand is AEC (architect, engineer, contractor) industry fragmentation, in other words, the incoherent nature of project participants. This issue is embodied by the poor relationship (and thus poor communication) between mainly the consultant (designer) and the contractor, leading to numerous constructability problems in subsequent phases of the project. This is more specifically attributed to the fact that the design procedures do not necessarily integrate constructability expertise. From this, it can be deduced that the primary reason for poor constructability is the lack of sufficient knowledge streams between the design and construction aspects of the project. Knowledge management addresses this problem. The effective capturing and arrangement of construction expertise downstream can be channelled back to the design phase to allow construction-integrated design. The designer may then reciprocate this by passing on design expertise/knowledge back to the contractor to initiate and maintain a cyclic negotiation process, which will eventually lead to better, more holistic designs from project to project. Achieving a holistic design is not an affair exclusive to the design phase, as it actually requires the integrated knowledge of all subsequent phases during the design. The design phase inherently defines the project constitution and thus has a direct influence the operations that need to be carried out during project execution. It is therefore apparent that many of the impending risks downstream can be traced back to some design decision.

As a response to the problem statement, this research explores the status quo of constructability issues in South Africa, with specific reference to the relationship between construction and design. The constructability problems would be identified and an attempt will be made to somehow classify them, with the intention of giving constructability a more explicit definition. Factors that contribute to the principles of constructability – implications of good and bad constructability – will be explored in detail in this research. Through deeper understanding of constructability, an explicit problem model of constructability issues can be established, thus identifying the root of constructability problems. This validates the role of knowledge management principles in improving constructability problems on a

practical industrial level. Clear modelling of constructability problems allows the sensible application of knowledge management (KM) initiatives to improve the project processes.

In particular, lessons learnt programmes – a knowledge management as well as a constructability improvement initiative – will be investigated in detail. These lessons learnt programme identify, analyse and implement the lessons learnt in projects progressively with time. In principle, it builds up a virtual knowledge pool within the organisation, while encouraging collaborative work between different project parties. The research aims to investigate the basis, on which lessons learnt programmes are employed in the industry. This can be a pertinent starting point for knowledge management principles to be adopted among construction organisations.

More details on the development of both constructability and knowledge management related research are presented in the literature study chapters (Chapters 4 and 5).

2.2 Research scope and limitations

The scope of the research adheres to the context of a dual-level problem. On the one, hand the research investigates the specific technical (constructability) knowledge to share and the extent of sharing, while the other explores the perceptions and attitudes of knowledge sharing. The outcomes of the two levels of investigations will be jointly reviewed to arrive at a more realistic set of conclusions and recommendations to promote project integration through knowledge sharing.

The research constitutes a great deal of qualitative investigations, where the input of industry personnel on a variety of different perceptions is required. Therefore the scope is substantially influenced by the availability of acquirable data, information or knowledge. The scope is set to ensure that the optimal response can be obtained from questionnaire enquiries, expert correspondences and personal interview.

The scope of the study is influenced by many aspects of the research environment and academic context, which subjects the research to some limitations. The scope and some limitations are discussed in the paragraphs below:

- 1) There is almost no local academic literature with regards to constructability and knowledge management. It is chosen to base the investigation primarily on (but not limited to) the building industry, as most civil engineering organisations would have had experience in building projects.
- 2) An important justification for the focus on the building industry is that the commercial and residential building industry is characterized by more separation between design and construction services (Shen & Jensen, 2011) and subcontracting is more common in building

than other industries. This gives probable cause for more potential fragmentation, between construction and design knowledge in building.

- 3) A case study is employed at the end of the research to validate and explore the research deductions on a practical implementation level. The case study is done on a rail based company (Tubular Track Pty Ltd). Although it operates in a considerably different field than building, Tubular Track's integrated design procedures hold many lessons that can be conceptualized to be used in the building industry. The extension of the case study context beyond the building industry, and the comparison that ensues, also enables the understanding of research problems on a more scientific and conceptual level, as opposed to a symptomatic industrial level, which is often limited to the nature of specific construction fields. This enables the formulation of generic theories and recommendations not limited to say rail or buildings.
- 4) Theoretical investigations and literature study is done on all sources, however, industry knowledge extraction is done only within the local South African industry. It was impractical to acquire input from foreign organisations. However, most of the local organisations that participated in the research operate internationally and carry out engineering activities in foreign countries.
- 5) The investigations on knowledge sharing are limited to those of companies, and do not consider factors associated with cross-cultural, cross-national or globalization issues of construction projects. The scope of the research includes the knowledge integration within the same project, between different projects and within design and construction disciplines in the building industry.

2.3 Research aim and objectives

The broad research aim is to investigate the potential role of knowledge management in promoting integration in the AEC (architect, engineer, contractor) industry by improving the assimilation of construction knowledge to all project stages, but particularly to the design. Due to the limited available literature in South African, much of the research consists of studies to understand the status quo of the various practices and perceptions regarding constructability and knowledge management activities locally. The research verifies the local findings by comparison with other international studies and approaches – both theoretical and industrial. In addition to the specific focus on constructability issues and knowledge management initiatives, the research output will also contribute to better understanding and clearer definition of the generic problem of AEC industry fragmentation at large. This research aims to achieve the following explicit objectives:

1. Explore the literature for existing research done over the last few decades regarding both constructability and knowledge management. The associated principles, concepts and approaches embedded within each field will be explored in detail, along with the understanding of the relationships between these fields.
2. Investigate the contents and completeness of company project archives. Furthermore, determine the extent of the available intelligence in these archives to be able to derive sensible constructability lessons and knowledge.
3. Investigate the trends and best-practices in the South African industry relating to the perceptions of constructability from consulting (design) and contractor (construction) perspectives.
4. Generate an explicit definition for the traits and implications of "good" vs. "bad" constructability within the South African building construction context.
5. Explore the trends, perceptions and best-practices in the industry regarding the nature of knowledge sharing as well as knowledge management initiatives in South Africa, in particular lessons learnt programmes.
6. From all of the above, a strategic conclusion with recommendations will be given on how knowledge management principles can improve constructability issues in the construction industry.

Taking into consideration all the explicit objectives, the ultimate aim of the research is to promote the principles of integrated design, where consultants recognise the significance of the construction phase, and where contractors have the motivation to share their construction expertise during the design phase. This can be brought about by implementing better knowledge management in the form of lessons learnt initiatives or other knowledge sharing mechanisms, which will improve cross disciplinary communication during projects and subsequently improve the constructability of designs.

A plan of development can now be drawn up to in order to fulfil these objectives over the research period. The plan of development is presented in the following section.

2.4 Research plan of development

The comprehensive research plan of development can be organised into the many activities in chronological progression, described in the paragraphs below. The diagram of the plan of development flow-chart can be found at the end of this chapter (figure 2-1).

1. Preliminary literature review

The preliminary literature study consists of the first gathering of academic documents and study as to gain a broad view of the nature of Construction Engineering and Management (CEM) research and different research methods for different types of problems.

2. Identify the provisional knowledge gap and research problems

From the preliminary literature review some problems and concepts were identified to generate a problem statement and to map a provisional scope of the research. The outcome of this was used to draw up a Phase-1 questionnaire,

3. Phase-1 questionnaire

Sample group was identified and questionnaires were developed and distributed. The responses were analysed. This contributed as an added endeavour to better understand and narrow down the problem statement, which contributed to the further refinement of specific research questions.

4. In-depth literature review

Major concepts in knowledge management and constructability research were explored in detail. The relevant existing research done in similar fields was studied, major themes and important principles were identified and the relationships between them explored.

5. Refine problem statement and research objectives

From the conclusions of the Phase-1 questionnaire, as well as the in-depth literature study, a clear understanding of the different concepts was reached; problem statements and knowledge gaps relevant to the research can thus be refined and more clearly identified.

6. Phase-2 questionnaire

From knowledge acquired in all the previous activities, the Phase-2 questionnaire was developed, which addresses the crux of the research problem identified. The sample groups of respondents were identified and questionnaire is distributed.

7. Receive Phase-2 questionnaire results and analyse

Detailed analysis is done and a conclusions were reached, which was compared with the findings of the Phase-1 questionnaire. An in-depth analysis was done on a variety of real constructability issues/cases in the practical context.

8. Tubular Track Case study

A study was done on Tubular Track's integrated design procedure. The procedures and systems employed at Tubular Track that allow their evolutionary development to occur were conceptualized and documented. The lessons and principles learnt from Tubular Track,

together with analysis results of both questionnaires, are used to formulate a comprehensive conclusion of the research and demonstrate a potential solution to the problem statement

Figure 2-1 below shows the 8 research activities discussed above as part of the plan of development, in a flow-chart format.

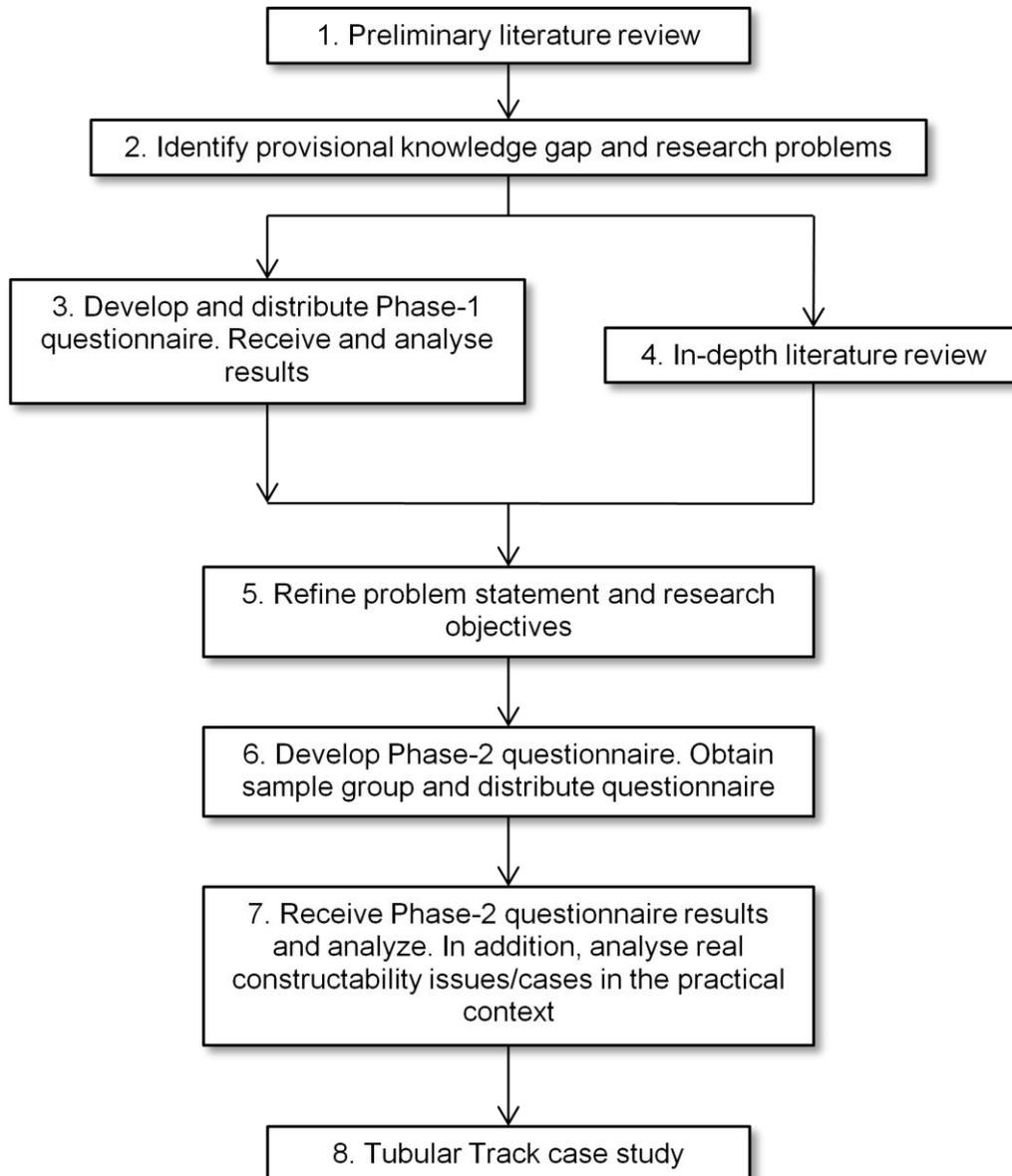


Figure 2-1 Summary flow-chart of research plan of development

In the following chapter, the methodology used to fulfil the objectives stated in this chapter is discussed. The motivation behind the choices of research techniques chosen are also elaborated in detail. The literature study chapters commence after the methodology chapter.

Chapter 3 Research Methodology

3.1 Introduction

In a typical civil engineering field, scientific principles are modelled in a laboratory and the behaviour and mechanics of physical phenomenon are explored, thus extracting knowledge through an experimentation setup. In the field of Construction Engineering and Management (CEM) more often than not, there is no laboratory. The role of the lab is replaced by the construction industry, where large pools of knowledge exist and interact with other pools of knowledge in a complex fashion. Most of this knowledge is non-explicit and non-codified, in other words, much expertise lingers in the minds of professionals and are often transferred through word of mouth or mentorship, thus social human interaction. The methodologies employed in this research are geared towards the extraction of such knowledge from the “minds” of the industry. This extracted knowledge will be sensibly managed to enable academic/scientific analysis and subsequent conclusion.

In this section the research methodology is discussed in full. Some classifications and principles of research are covered, leading up to the description of different research techniques and their conditions; and finally the research techniques chosen for this specific research are presented.

3.2 Research principle and classification

3.2.1 Pure and applied research

CEM research work is difficult to classify as it occurs within a continuum between two extremes, one being “pure research” and the other “applied research”. Pure research involves the discovery of scientific theories, laws of nature and philosophies, while applied research is directed towards the end users and practical applications, often relating to the implementation of certain tools and modules. Academics are encouraged to focus on pure research while industrialists focus on applied research. Applied research would be of little value without the contribution of pure research and vice versa. The challenge lies in the hands of the researcher, who must overcome the uncertainty by combining the pure and applied research principles simultaneously, initially with broad perspective and progressively narrowed down until finally the problem and the feasibility of possible solutions thereof, can be assured. This is the principle that was followed in this research, thus the depiction of the research as a continuum within the spectrum of pure to applied research.

3.2.2 Principle of Triangulation

Triangulation is the method of using two or more research methodologies, such as qualitative and quantitative approaches together (Fellows & Liu, 2003) or a combination of different research

techniques (discussed in the following sections). The objective is to gain a multi-dimensional view of the subject through synergy between the respective approaches.

In construction management research, the worlds of natural sciences and that of social sciences intersect (Love, Holt & Li, 2002). It was found that both hard scientific data and perceptions of participants contribute to research matter. This creates difficulties for researchers in the Construction Engineering and Management (CEM) field. The element of uncertainty, which is largely absent from natural sciences or quantitative research, is introduced in CEM research. Triangulated approaches, which comprise a blend of different methods, are suggested as a favourable solution.

3.3 CEM Research Techniques

Defining the appropriate research methodology/technique to be implemented deals with four key issues (Yin, 1984); what questions to study, what data is relevant; what data to collect, and how to analyse the results. In addressing these questions it is necessary to explore the advantages and disadvantages of the five commonly utilised research techniques (Yin, 1984) – Questionnaire, Case Study, History, Archival Analysis, Experiment – and a sixth, Modelling, suggested by Steele (1999). Technique selection depends upon three conditions: the type of research question; the control of the investigator over behavioural events; the focus on contemporary phenomenon (Steele, 1999). Table 3-1 shows the different techniques along with the different conditions linked to each technique.

Table 3-1 Research techniques and conditions

Technique	Form of research question	Requires control over behavioural events	Focuses on contemporary events
Survey/ Questionnaire	Who, what, why, where, how many, how much	No	Yes
Case Study	How, why	No	Yes
Modelling	Who, what, how many, how much	No	Yes/No
History	How, why	No	No
Archival Analysis	Who, what, why, where, how many, how much	No	Yes/No
Experiment	How, why	Yes	Yes

Despite the literature review, which is typically done by default in research, a number of other techniques should be employed. In this study the richness of contemporary data is extremely important to help understand the complexity of the research problem. Therefore, techniques that are able to collect data on many facets of an issue are vital. Modelling is considered inappropriate, as it is not able to capture the “why” or “where” questions. Also archival analysis is difficult as the contents

and availability of industry archive information is still unknown. It partially forms the objective of this research to explore the nature of industry project archives; however, through questionnaires, not through analysis of the archival data itself. As it is not necessary to control behavioural events, experiments were not required. However, the case study approach is considered appropriate as it allows an empirical enquiry to investigate contemporary phenomena within real life criteria and can act as an additional filter of validation with regards to the research argument.

In addition to the techniques provided above, the personal interview is also identified as an important technique and can form part of the case study in acquiring in-depth knowledge through a dynamic interaction with field personnel and experts.

Therefore in this research, the following investigation techniques are appropriate and thus employed:

- 1) Literature review
- 2) Questionnaire
- 3) Personal interview (forms part of Case study)
- 4) Case study

In the sub-sections below, each technique is discussed – first generically and then with specific reference to this research.

3.3.1 Literature review

The overwhelming advantage of this method is the lack of “social obstacles”. Often the research methods require the extraction of knowledge from individuals (such as interviews and questionnaires), which is often impeded by the respondents’ willingness to participate; and/or their availability. The literature review forms part of the methodology in this research. However, no data is collected from the literature review and no qualitative or quantitative analyses are done on the outcome of the literature review.

The literature study only serves to establish the fundamentals of the concepts explored in the research. The relevant existing research done in similar fields are studied, major themes and important concepts are identified and the relationships between them are derived. This partially enabled the formulation of the problem statement and thus contributes to narrowing down the methodologies feasible for actual data collection. Furthermore, the deductions and synthesis from the literature study guides the compilation of the questionnaire and the handling of the case study. More detail on this is discussed under Chapter 6 (Synthesis of Literature Study).

3.3.2 Questionnaire

The questionnaire is by far the most widely used research method, because it can be very specifically designed to focus on a certain purpose in different circumstances. However, this powerful attribute is in itself the greatest challenge of employing questionnaires, as the standard of a questionnaire is implicitly erratic and its effectiveness and accuracy depend heavily on the diligence of the researcher, to draw up a clear and concise questionnaire that is free of bias and ambiguity.

It is decided for the questionnaire to be used as the primary research technique for data collection. It is chosen as the preferred technique due to the nature of this research, which requires the extraction of a wide variety of data and knowledge from personnel in the industry, along with the imposed limited time and budget. The research objective requires the acquisition of data from a wide range of respondents and thus was not practical for personal interviews to be organized with each respondent.

The research objectives also prompt the use of the questionnaire. Constructability is viewed differently by different people representing a number of different backgrounds, all of which from part of the project team. The Knowledge Management initiatives are also subjected to contrasting perspectives by different personnel, in terms of their explicit definitions and implementation. Thus, qualitative research methods are considered ideally suited to study this concept as it enables the extraction of perceptions among industry personnel. Quantitative methods do play a role in this research and are considered valuable in the processing of qualitative data obtained in the research process. The qualitative part captures the perceptions regarding constructability and knowledge management initiatives on the different facets and the quantitative analysis allows for the sensible interpretation of the data acquired.

The questionnaire allows the following to be achieved:

- Assured anonymity for the respondents
- Distribution to a diverse selection of geographically separate respondents
- Rapid distribution and collection of data
- Small amount of time required for respondents' involvement – quick completion
- The inclusion of open-ended and closed questions
- Consistent qualitative response without potential influence by interviewer

The following issues pose as challenges of the questionnaire:

- In-depth preparation was required to ensure non-ambiguity of questions
- Phrasing of questions was scrutinized to achieve highest conciseness and clarity
- Detailed investigation of design and formatting of questionnaire to ensure simplicity
- Ensuring a satisfactory response rate as to allow sensible results

- Consideration of different distribution platforms and their respective advantages and disadvantages

Two different questionnaires (Phase-1 and Phase- 2 Questionnaires) are compiled for this research, distributed successively to two different groups of respondents. The Phase-1 Questionnaire is shorter and its results are partially used to guide the direction of the longer Phase-2 Questionnaire. Details of the contents of both questionnaires are covered in subsequent chapters on the questionnaires (Chapters 7, 8, 9 and 10).

3.3.3 Personal interview

The interview allows a dynamic exchange of knowledge between researcher and respondent, in person or over the telephone. Growing recently are through VOIP (voice over internet protocol) technologies over the internet. However, interviews are mostly done in person and carried out by two researchers, as it is difficult for a single researcher to comprehensively document the interview while posing questions. Multiple researchers can also reduce bias during the interview. Usually personal interviews are conducted with or after a questionnaire session, where the respondents' answers can be explained in more detail.

In this research, personal interviews with questionnaire respondents are unpractical and thus not employed. The personal interview is only carried out in conjunction with the case study, where the respective project participants are engaged in discussion regarding the case study in question.

3.3.4 Case study

Numerous case studies have been found in past Construction Engineering Management (CEM) research, which employ both quantitative and qualitative methods. In some cases personal observation or participation by the researcher was fulfilled, other cases were based on information from interviews with project participants or through the collection of documents in the archives or records of data captured during the case study project. The personal interview is the primary technique to acquire the knowledge for the case study.

The case study is done on the company Tubular Track (Pty) Ltd, who designs and manufactures rail in a pre-cast, longitudinally supported ladder-track configuration. This company was chosen due to its integrated design philosophy, where the project processes – design, manufacturing and installation – are done in-house and form a continuous improvement cycle. Tubular Track's integrated design process incorporates constructability expertise into the design phase as a continuous development. This holds potential lessons to be learnt and applied in the traditional, more fragmented, construction industry to improve constructability. Details of the case study are given under the chapter dedicated to the case study later in the thesis (Chapter 11).

Chapter 4 Constructability Literature Study

4.1 Introduction and overview

This chapter is a literature review of all aspects concerning constructability relevant to the research question. Currently, the definitions and implications of constructability are sporadic and subject to different interpretations amongst the fragmented industry. All concepts relating to constructability knowledge, expertise and problems is reviewed. The construction environment and design management process also holds a great deal of insight to constructability issues and is also looked at in some detail in the literature review.

The literature review starts, in a broader perspective, with the construction and design environment, concepts relating to design management and the associated problems. A review of the terms “constructability” and “buildability” is done and a comparison is drawn up with short discussion on how this research specifically handles the two terms. Some principles of constructability is identified as a first step to defining constructability explicitly, and previous measures to improve constructability is covered – including the so-called constructability initiatives, and design and construction codes. In the end, special attention is given to the discussion of Singapore’s Codes of Practice on Buildability – presenting a codified form of constructability which enables the calculation of buildability and constructability scores.

The literature review is set out so that the concepts of constructability and buildability, stemming from the late 1980s and 1990s, are discussed first. Then the review moves progressively to younger concepts and more recent research results of the 2000s and 2010s.

4.2 The Construction Design Environment

In order to fully understand the definitions and implications of constructability issues, it is important to gain a perspective of the environment, in which design and construction knowledge interacts with each other. This interaction can be simply described as the design management process, whereby knowledge and expertise from subsequent phases of the project can be captured, organised and channelled back to design stage to be implicitly integrated into the design. This ensures the highest benefit and the prevention of specific problems during subsequent phases of the project. Likewise, however, the knowledge that is overlooked from the start become disadvantages built into the design and will thus manifest problematically during later stages on metrics of time, quality and cost.

The construction design process is a specialised and highly demanding form of problem solving (Pressman, 1993; Lawson, 1997). It is there that the stakeholders’ needs and requirements are conceptualized into a physical model of procedures drawings and technical specifications (Freire & Alarcon, 2000). It is a dynamic and complex multidisciplinary process, involving many parties and

performed in a series of iterative steps to conceive, describe and justify increasingly detailed solutions to meet stakeholder needs (Sterman, 1992; Ogunlana et al., 1999; Cockshaw, 2001), defining up to 70% of the final product cost (Kochan, 1991) and adding value by delivering functionality, quality, enhanced services, reduced whole life cost, construction time and defects as well as delivering wider social and environmental benefits. (Treasury Task Force, 2000; Prescott, 1999).

There are several defining features of the design management process that have been noted (Frankenberger & Badke-Schaub, 1998; Austin et al., 1996; Ballard, 2000; Kalay et al., 1998; Kvan, 2000; Lawson, 1997; Reinertsen, 1997; Ulrich & Eppinger, 1999; Austin et al., 1993; Eppinger, 1991; Koskela, 1997; Newton, 1995; Formoso et al., 1998; Mohsini, 1984; Mohsini & Davidson, 1992; Love et al., 2000) that interact and make it difficult to manage. Primarily, the process is iterative and poorly defined which can be attributed to two key factors. It requires the production of incomplete outputs to develop understanding of both design problems and alternative solutions. Furthermore, this is undertaken by a diverse team (e.g. Architects, Clients, Contractors, Mechanical, Civil, Structural, Electrical, Environmental and Process engineers, Quantity Surveyors, Estimators and Planners) representing different disciplines, educational backgrounds and goals. As a result, the process is an enormous negotiation agreement, often compromised under uncertainty and time-pressure, thus affecting progress and budget. Furthermore, if progress does falter then it can be difficult to get back on programme, as individual design tasks cannot be accelerated by introduction of additional resources. This is compounded by the difficulty in determining progress of a process with the potential for iteration and yielding only negotiated solutions with no absolute answers.

Poor design process performance has a significant effect on the performance of subsequent activities and the finished product. The cause of the majority of construction delays and defects can be traced back to poor design process performance (Josephson, 1996; BEDC, 1987), with poor information alone creating problems more significant than those attributed to poor workmanship and site management. This can be attributed to the difficulty in controlling the nature of the design process (Baldwin et al., 1999). Therefore the complexity and uncertainty of the construction design process requires the application of significant management effort (Newton, 1995; Gray & Hughes, 2001) for project success.

4.3 Design management

Design management is an emergent professional discipline, which separates the management function of a project's design phase from the design function. It is becoming increasingly important in modern construction projects (Gray & Hughes, 2001). It is closely aligned to project management and must provide a fully co-ordinated design, on time, meeting all stakeholder needs. This is done through co-ordinating, controlling and monitoring design activities while interfacing with other project and external parties. It is a task typically carried out by a design manager or a team of managers depending on a project's size and complexity. However, Gray and Hughes (2001) suggest that while

there needs to be a single point of responsibility to control the production of construction information they also believe design management is the responsibility of the whole project team.

4.4 Problems with current design management practices

Considerable advances have been made in design management, but there are still few examples of total success (Gary & Hughes, 2001). Current practice is characterized by poor communication, lack of adequate documentation, deficient or missing input information, poor information management unbalanced resource allocation, lack of coordination between disciplines and erratic decision making (Austin et al., 1994; Cornick, 1991; Hammond et al., 2000; Koskela, 1997; Lafford et al., 1998). This can be partly attributed to the complex nature of the design process. However, many current approaches are inappropriate for managing the design process. For example, the design process is typically unstructured, which leads to insufficient understanding of the design process between parties (Karhu & Lahdenpera, 1999) and is a barrier to people working effectively together (Taylor, 1993).

Some key problems can be identified from literature: design planning, integration of design and construction, information management, design changes. The nature of each key problem and their implications towards the construction design process is discussed in the following sections.

4.4.1 Design planning

An effective and workable design programme is essential to improve coordination between disciplines and exert managerial control over the design process (Austin et al., 1994). Yet it is usually programmed to achieve the required timing of information released to contractors, followed by the preceding procurement activities and finally the release to design (Austin et al., 1998). There is now increased recognition that construction efficiency and costs are heavily dependent on the quality of the design solution and information (Austin et al., 1998) and therefore the quality of the design programme. Yet little effort is given to planning the design in detail in the belief that it is not possible for such a creative and iterative process (Cole, 1993) a situation perpetuated by a lack of understanding of design information flow dependency and availability of suitable techniques (Austin et al., 1996).

Poor understanding of information flow and dependency exists because each discipline does not understand how their work contributes to the whole building design process, causing a fragmented approach to planning. Therefore the identification and co-ordination of cross disciplinary information, essential for a fully integrated design is left to the expertise of the design planner and project manager (Baldwin et al., 1994) who lack a full understanding of the processes of design (Hedges et al., 1993). This results in a poor quality design programme with implications for the coordination of design principles and general process control.

4.4.2 Integration of design and construction

A construction project involves a large group of people with different skills, knowledge and interests working together for a short period and then separating upon completion of the project. This creates problems in organising both the design and construction processes, due to the large number of interfaces and communication difficulties (Kagioglou et al., 1998). However, integration during the design phase is crucial to project success. It prevents problems in subsequent phases, it is necessary for the development of suitable design solutions (Mitropoulos & Tatum, 2000) and ultimately to achieve client satisfaction (Ferguson & Teicholz, 1992). Thereafter, while it is clear that the integration of design and construction is vital to project success – it is also a fundamental weakness in the industry (Egan, 1998).

The distinct background, culture learning style and goals of each category of construction professional is likely to cause adversarial positions (Powell & Newland, 1994; Kalay et al., 1998) with competition based on values associated with each party's speciality (Ballard, 1999). Yet this is exacerbated by each discipline focussing on its own processes with little energy on the development of the whole project process (Karhu & Lahdenpera, 1999). This has led to a growing misunderstanding of the role of each profession (Alshawi & Underwood, 1996). Amongst the most significant problems that result are: lack of value for money for clients; increased design time and cost; sub-optimal solutions; lack of true project life cycle analysis; late design changes and litigation. Therefore, design and construction is a key improvement issue if the industry is to deliver advances (Latham, 1994; Egan, 1998)

4.4.3 Information management

The principal design activity of any project is the processing of information (Baldwin et al., 1994; Heath et al., 1994), yet in the construction industry this is poorly performed (Latham, 1994; Kagioglou et al., 1998). Current management of design information is predominantly through schedules (Ballard, 1999) programmed to achieve the required timings of information release to the contractors (Austin et al., 1998). Yet it does not consider the internal logic of the design process – such poor planning practice is a factor in poor information management (Formoso et al., 1998). As a result, the timing of information transfer is not properly controlled; designers do not have the right information at the right time and are overloaded with unnecessary information (Huovila, 1997). This creates the risk of failure of design tasks, deficient analysis and wrong decisions with potential for waste in the process due to rework (Huovila et al., 1997; BRE, 1995; O'Brien, 1997; Frankenberger & Badke-Schaub, 1998). Furthermore, the erratic delivery of information and unpredictable completion of prerequisite work can quickly result in the abandonment of design planning (Koskela et al., 1997), therefore perpetuating a cycle likely to create further difficulties. As such information management is another issue vital to project success where the industry performs poorly. In this research the same phenomenon (described here as information management problems) is encompassed within the field of Knowledge Management, which will be discussed in detail in the following chapter.

4.4.4 Design Changes

Design changes are a significant problem in the construction industry. They have large administration costs (Machowski & Dale, 1995), account for 40-50% of a designers total work hours (Koskela, 1992) and even in well-managed projects can cost between 5 and 15% of total construction cost (Morris et al., 1999; CIDA, 1994; Burati et al., 1992). Love et al. (2000) highlight that such costs could even be higher as they do not represent the latent and indirect costs and disruption caused by schedule delays, litigation costs and other intangible aspects such as constructability (Kagioglou et al., 1998). However, evidence suggests that even for successful, well-managed projects carried out by industry leaders, around two-thirds of design changes by cost are avoidable (Morris et al., 1999). There is a significant potential for improvement.

Controlling change is a great challenge, because traditional design management techniques cannot predict the effects of change on the design programme. As such, it is difficult to determine all the possible change paths and to select which one of them is the best to follow (Mokhtar et al., 2000). Thus if current tools cannot determine the full impact of design changes and human judgement is unable to account for the myriad interactions that jointly determine its outcome (Richardson, 1991; Sterman, 1992) then many design changes are being made without full exposure to all potential impacts. Such an inability to predict the impact of changes must be considered a barrier to effectively controlling design changes.

4.5 Constructability and Buildability

The problems mentioned above with current design management practices indicate that there is a poor grasp of constructability itself, not to mention the sharing of constructability knowledge. Some of these problems can manifest as the causes of poor constructability. Concurrently, poor management of constructability knowledge is a great barrier to good design management. Now, the questions to be asked here is: What exactly does constructability mean and what does constructability knowledge entail? Can one conceptualise constructability and partially or comprehensively quantify constructability issues? This section covers some literature on existing constructability and buildability concepts.

Constructability (or buildability), because of its abstract nature, requires tacit understanding before improvements can be realised. Decades have elapsed since problems arising from the separation of design and construction came into light in the 1960s. Notwithstanding numerous studies which have looked at the subject from different perspectives and with different approaches, the problems associated with constructability have not diminished (Egan, 1998; CIRC, 2001). In the following sections, the related concepts and principles of constructability and buildability in existing literature will be reviewed.

The terms buildability and constructability had been defined in many cases by various researchers in literature. Without too much detail on all the specific definitions formulated by all the different researchers and organisations over the years, the following sections sum up the essence of these two terms – buildability and constructability – the origins, similarities and differences in definition and implication and the relationship between them. Subsequently, an explicit statement is given regarding the nature of the term “constructability” adopted in this research.

4.5.1 Buildability

The term “buildability” was invented after a number of studies in the UK on the detrimental effects brought about by the fragmentation of design and construction in the 1960s and 1970s (Emmerson, 1962; EDC, 1967; Banwell, 1964; NEDO, 1975). Subsequently, further studies on buildability in the UK were carried out by Gray (1984), Griffith (1984), Adams (1989) and, Ferguson (1989). However, after so many years, there was still little emphasis placed on buildability of designs.

The three common definitions of buildability have shown differences from one another. These definitions refer to buildability as “the extent to which the design of a building facilitates ease of construction, subject to the overall requirement for the completed building (CIRIA, 1983); “The ability to construct a building efficiently, economically and to agreed quality levels from its constituent materials, components and sub-assemblies” (Ferguson, 1989); and “the extent to which decisions made during the whole building procurement process, in response to factors influencing the project and other project goals, ultimately facilitate the ease of construction and the quality of the completed project” (McGeorge et al., 1992).

In Asia, the Singapore Government has put legislation in place to require minimum buildability scores of designs before approvals of building plans as of 2001. The buildability scores are calculated based on the Buildable Design Appraisal System (BDAS), which was devised to measure buildability performance of designs in Singapore. The “3S” principles of Standardisation, Simplicity and Single Integrated Elements form the cornerstones of the BDAS. These represent the considerations that designers should take in developing designs, including determination of the most appropriate building systems to be used (BCA, 2011). More will be elaborated in subsequent chapters of the literature review regarding Singapore’s Buildable Design Appraisal System.

4.5.2 Constructability

In the 1980s, the term “constructability” evolved in the USA. The proponents of this concept believe that constructability, which embraces both design and management functions, is more comprehensive in facilitating construction operations and solving problems on site. In particular, the Construction Industry Institute (CII) was instrumental in providing guidelines for implementing constructability at

various project stages (CII, 1986; 1987a, b; 1993). Almost at the same time, Australian researchers were also aware of similar problems being caused by the lack of integrated design and construction.

Through studies on constructability, Hon et al. (1988), McGeorge et al. (1992) and CII Australia (1996) strived to encourage contractors' involvement in design and efficient communication, thus boosting the quality of project management during the whole process, with specific emphasis on ease of construction and achieve better project performance. CII Australia had also published the Constructability Principles File in 1992, consisting of a system which involves the whole project team (including contractors) from the very beginning of the project for improving constructability, and the Constructability Manual in 1996, providing guidelines for implementing the constructability system.

Dissimilarities are also exhibited between the two common used definitions for constructability: "the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives" (CII, 1986), and "the integration of construction knowledge in the project delivery process and balancing the various project and environmental constraints to achieve project goal and building performance at an optimal level" (CII Australia, 1996).

4.5.3 Comparison between constructability and buildability

Despite the slight disparities in definition of buildability and constructability within themselves, there is a distinguishing factor between buildability and constructability. Regarding the stages of implementation, buildability focuses itself at the design stage. On the contrary, the term constructability encompasses all project stages and thus overcomes the perceived narrowness of the scope of "buildability". Although some constructability improvement measures do take place at particular stages of a project, it is commonly recognised that constructability is concerned with the whole process of project development to facilitate construction efficiency and achieve project goals. Constructability therefore implies the integration of the contractors' knowledge, not only from a physical or technical perspective, but also the non-technical, into the design and planning stages. These non-technical issues are often difficult to quantify and include managerial, financial, legal or even psychological concerns during the project as a whole.

The definition adopted in this research is the one by CII (1986), that constructability is "the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives". This point of view will enable exploitation of the greatest potential of the construction knowledge owned by contractors; this knowledge goes beyond technical and engineering issues to include also management issues and even legal issues. It is seen that the scope of buildability is embedded within constructability; and according to the scope of this research, constructability is a more pertinent term to describe the problem at hand.

Please note that in this research, as described above, buildability forms part of the scope of constructability, thus the references to buildability essentially is the same as constructability. Buildability should not be confused to being another concept altogether. Constructability and buildability are often used interchangeably in literature. However, constructability has a more comprehensive definition and will be used primarily term in this research, except in cases where previously coined terms already contain “buildability” – such as “Singapore’s Code of Practice on Buildability” or “Buildability Assessment Model” etc.

4.6 Principles of Constructability

The purpose of constructability is to ensure that the impact of the design and details on construction are recognized and taken into consideration at the earlier stages of conceptual planning. This will minimize any inconvenience or problems that will be experienced at later stages of construction, thus reaping the maximum benefits from constructability in terms of time, cost and quality. With this in mind, predictability will be raised and competitiveness of the industry will be improved. The basic constructability principles as defined by O’Connor and Miller (1994), Ferguson (1989), Adams (1989), Tatum (1987), O’Connor (1985), Griffith and Sidwell (1995), Gray (1984) and others are summarized below:

(1) Efficiency and economical building production. To ensure efficient and economical production of a building, a logical organization of the sequence of assembly is essential. To achieve this efficiency and economy, the building organization must ensure continuity of work by having good management of labour, machinery and materials delivery (O’Connor, 1985)

(2) Simplicity. The designers must strive to produce the simplest possible details compatible with the overall requirements for the building. This is especially important for the building’s group of elements. This would open the way to efficient, defect-free work, which will satisfactorily perform its end function (Ferguson, 1989; Bishop, 1985).

(3) Tolerance level. The building assembly design should recognize the tolerances, which are normally attainable under site conditions. Different materials and components used on site have different composition and thus require different jointing methods. Therefore, a practical level of tolerance for the materials and components should be adopted. Special attention should be given to interfaces where jointing of materials are difficult (Ferguson, 1989).

(4) Repetition and standardization. The building elements should be designed in such a way that they encourage appropriate repetition and standardization so as to reduce the time for construction. The use of readily available and standard items should be encouraged to reduce costs and the increased risk of errors involved in the construction of customized items (Adams, 1989; Ferguson, 1989).

(5) Participation and communication. Project team members with the relevant knowledge should be encouraged to participate at all level of project construction. This will allow the construction programme to be well discussed and documented. Early project planning should be done so as to avoid interferences between design and construction. Clear project information should be planned and coordinated to suit the construction process and to facilitate the best possible communication and understanding on site (Fischer & Tatum, 1997).

(6) Proper scheduling. Proper scheduling allows smooth construction progress. A more systematic way of construction can be achieved with a good schedule. Moreover, the construction sequence should be practical to allow for a continuous flow of work. The sequence should assist the coordination of trades and minimize delays. If the project involves a series of buildings to be built, similar sequence of operations for all building construction should be employed (Gugel & Russell, 1994).

(7) Avoid damage by subsequent works. The design should enable works to be carried out in a workman-like manner without the risk of damage to adjacent finished elements and with minimum requirements for special protection. This would also reduce the need for return visits by the various trades to repair the damage. Moreover, the works should be completed with as few return visits as possible, thus reducing the project completion period (O'Connor & Tucker, 1986).

(8) Innovation. Any innovative ideas that can improve the buildability of a project should be encouraged. The contractor should also try to bring in new machinery or even methods of working or construction that will improve productivity. However, the contractor would need to consider the level of skills available in the local industry before bringing in new ideas (Tatum, 1987).

Lam and Wong (2011) reviewed the Buildability Assessment Model (BAM), proposed for measuring buildability of designs and establishing benchmarks for the construction industry in Hong Kong. The BAM identifies nine “buildability factors” and appraisal is based on how well the designs embrace these nine factors as expressed by a large pool of experienced practitioners having hands-on construction expertise. The nine “buildability factors” are as follows:

1. Allowing economic use of contractors resources
2. Enabling design requirements to be easily visualised and co-ordinated by site staff
3. Enabling contractor to develop and adopt alternative construction details
4. Enabling contractors to overcome restrictive site conditions
5. Enabling standardisation and repetition
6. Enabling freedom of choice between prefabricated and onsite works
7. Enabling simplification of construction details in case of non-repetitive elements
8. Minimising the impact due to adverse weather by enabling a more flexible construction programme

9. Allowing design to achieve safe construction sequence on site

These nine buildability factors are specifically geared towards the buildability appraisal of the design, while the buildability principles cover activities of subsequent phases as well. The nine buildability factors should thus be embedded within the buildability principles. Furthermore, the nine buildability factors offer more specific conditions and perhaps contribute more to a consistent definition of buildability or constructability of design – i.e. good vs. bad constructability. This research looks at the perception of these “buildability factors” as “criteria for buildable design” within South African consultants and contractors.

4.7 Constructability problems

The prevalent procurement methods of building construction projects, such as design-bid-build, hinder the application of constructability concepts. This is problematic mainly during early project phases, in which constructability application is particularly desirable (Pocock et al., 2006; Song et al., 2009). Traditionally, therefore, either first steps of design and planning take place without any constructability input (Fisher & Tatum, 1997), or, at best, the flexibility of changing the design by further constructability input from the contractor, after major decisions have already been taken, is limited (Soibelman et al., 2003).

Egan (1998) claims that too much time is spent in construction on site trying to make design work in practice. He adds that this is indicative of a fundamental condition in the industry – the separation of design from the rest of the project. This is mainly because the traditional procurement method of design-bid-build remains rooted within the industry (Arditi et al., 2002; Song et al., 2009; Kent & Becerik-Gerber, 2010).

Several studies have dealt throughout the years with the issue of designers being unfamiliar with construction knowledge. Fisher and Tatum (1997) claimed that designers often did not consider the impact of construction constraints and that the fragmentation of design and construction hindered effective information exchange. Touran (1988) stated that “A lack of communication between designer and builder frequently results in designs that are unnecessarily difficult and expensive to build.” Jergeas and Van der Put (2001) described the gap between the potential and realized benefits of applying constructability. Gambatese et al., (2007) described the barriers to addressing constructability as the lack of construction experience in the design team and the absence of tools to assist designers in addressing constructability. Song et al. (2009) stated that failure of design professionals to consider how a contractor will implement the design can result in scheduling problems, delays, and disputes during the construction process.

It is thus evident that there is a lack of practical knowledge on the part of designers and fragmentation of the construction process as a factor that hinders the implementation of constructability knowledge

during design. Another great barrier is that there is no comprehensive explicit definition for constructability knowledge, highlighting its tacit nature, and thus makes knowledge sharing difficult. In other words, it is in many cases uncertain what exactly needs to be shared with the designer.

This research looks at the extent that constructability can be explicitly defined and thus measured or quantified. Along with this, approaches of knowledge management and sharing are explored to allow implementation of constructability knowledge during design.

4.8 Measures to improve constructability

The key question to be asked is, to what extent is design capable of implementing constructability knowledge during the project preliminary phases, often in the case when the contractor has not been nominated yet?

The great benefits of utilizing constructability input already at the early stages of a project, where in most cases the general contractor has not yet been nominated, have been recognized by many (CII, 1986; Jergeas & Van der Put, 2001; Pulaski & Horman, 2005; Song et al., 2009). Mechanisms for constructability knowledge transfer have been studied in an attempt to plot the course of action needed to improve constructability in projects. Radtke & Russell (1993) argued that owners have to be provided with a formal constructability process and defined a range of “approaches to implement constructability.” Fisher & Tatum (1997) suggested expert system technology to integrate design and construction during early project phases. Fisher et al. (2000), who coined the term “constructability tools” within a constructability review process (CRP), defined 27 such tools and suggested their sequence of implementation. According to them, a successful CRP must identify when, where, and how each tool might be integrated into the review process.

The state of practice regarding constructability implementation has drawn some attention in recent years. Arditi et al. (2002) stated that a little over half of design firms indicated that they have a formalized philosophy about constructability in their organization. Among other conclusions, he found that faulty working drawings and incomplete specifications were the major constraints working against the constructability of design, and that deficiency of design was one of the major challenges facing the construction industry. Dunston et al. (2005) reported that the implementation of CRP had been rather slow due, in part, to lack of clarity regarding related costs and benefits and a perception that CRPs are resource intensive. Pocock et al. (2006) described constructability tools that were used in practice; although a wide variety of constructability techniques were implemented, many areas of constructability practice could still be improved.

4.8.1 Constructability initiatives

The means for constructability knowledge transfer have been defined using different terms in the literature. Radtke and Russell (1993) dealt with “approaches to implementation of constructability.” Fisher et al. (2000) used the term “constructability tools” and defined them as mechanisms that are used to perform a function; in that context tools include documents, procedures, persons, entities, or software programs. Pocock et al. (2006) discussed “mechanisms” that are used to address constructability. Arditi et al. (2002) also used the term “constructability tools”.

These tools, approaches, mechanisms used to implement constructability essentially fulfil the same function: to encourage and improve integration of construction knowledge, and thus can be seen generally as “constructability initiatives”. One can see the benefit of constructability initiatives as a way of preventing constructability problems from becoming constructability failures. The following are the main constructability initiatives identified in the literature. The initiatives were sorted and are grouped by families that are characterized by different approaches or ways of implementations:

(1) Formal corporate policy statements: statements that elaborate on the intention of the organization in implementing constructability.

(2) Checklists covering corporate procedures, lessons-learned, technical issues, etc. Checklists are specified to ensure a comprehensive performance of tasks without overlooking vital issues. Among the constructability methods they list, Pocock et al. (2006) counted checklists aimed to avoid common construction errors as well as the International Organization for Standardization (ISO) certified quality system.

(3) Organizational measures: these are administrative measures taken by the organization in order to establish management teams that are bound to be dedicated to implementing constructability. Fisher (2007) described the team building process, constructability team, constructability champion, and constructability engineering role.

(4) Contractual measures: measures taken within prevalent procurement methods or innovative procurement methods, such as design-build, partnering or the Integrated Project Delivery (IPD) method, through which all parties involved (owners, general contractors, sub contractors, etc.) share risk and reward (Kent & Becerik-Gerber, 2010).

(5) System modelling and analysis methods: procedures and methods used to perform or analyze actions related to the project. Typical such methods are Value Engineering (VE), which focuses on function/performance; cost-benefit analysis within the VE process; and the use of the Critical Path Method (CPM) to define and schedule formal constructability review process steps (Fisher et al., 2000; Dunston et al., 2005; Fisher, 2007).

(6) Reviews: a review is a step of a quality assurance method performed during design and construction. Radtke and Russell (1993) described constructability design reviews at set percentages of design completion using formal design checklists. Peer reviews are popular within design firms (Arditi et al., 2002; Pocock et al., 2006).

(7) Advanced technology methods: these methods take the advantage of the remarkable progress in project modelling in recent years. They include Building Information Modelling (BIM) (Eastman et al., 2008), multimedia, virtual reality, geographic information systems, databases, analytical-simulation tools such as artificial intelligence, decision support systems, and expert systems. Sacks et al. (2010) described the interaction of BIM and lean construction as two approaches effecting fundamental change in the construction industry.

Many of these initiatives imply the implementation of knowledge management principles. Checklists; some contractual and organisational measures; system modelling; reviews; advanced technology methods, all to some extent use knowledge management approaches, and essentially facilitate the creation and sharing of relevant knowledge (in there different forms) with the relevant project participant to allow them to make informed strategic decisions. Knowledge management literature is covered in the following chapter in detail.

4.8.2 Design and construction codes

Another approach to mitigating or preventing constructability problems is through the implementation of universal guidelines, standards or codes. In principle, these design or construction codes should encompass inherent knowledge from subsequent phases of the project after design, thus integrating constructability knowledge into a standardised set of codified material. Furthermore codes should also hold specific practical specifications for the execution of the works in the form of a “constructability code”. Theoretically, the implementation of functional codes into the design-construction environment will improve all the activities associated with the process of design management (as defined in this research), the technical design itself and the integration of constructability knowledge into the beginning stages of the project. Therefore it improves the constructability of designs comprehensively.

The challenge here lies in the explicability of constructability expertise – in other words, is it possible to explicitly represent constructability knowledge in a codified format and to what extent? This literature reviews current endeavours towards the codification of construction expertise in mainstream codes. This would give an indication of the methodology employed in the codification and the constraints associated therewith.

In the following sections the Eurocode, ISO and Singapore’s Buildability and Constructability Appraisal Systems are discussed in detail.

4.9 Eurocode and ISO

It is recognised that the Eurocodes are becoming de facto international standards for structural design. The construction requirements included in the Eurocodes are actually the assumptions, which designers are required to make about the standards of construction and site management and which they also expect to be carried out on the project they are designing. The following sections cover the nature of the Eurocodes, its assumptions and mechanisms, which are available for converting norms into effective specified requirements for the construction contractor and/or the contractor's designer to comply with.

It is widely recognised that the Eurocodes “form a coherent package of codes that are technically the most up-to-date and internally consistent codes in the world. They are rigorous and yet flexible, allowing their adoption not only within Europe but also internationally” (Greenly, 2008) It is likely that most countries with design codes based on UK or other European standards will adopt the Eurocodes fairly quickly after their Europe wide implementation in March 2010, including India. China may also adopt the Eurocodes in the longer term. Even where they are not formally adopted, there is often likely to be a de facto adoption through the acceptance of Eurocode based structural designs for use on major construction projects.

The Eurocodes, like all design codes, are based on assumptions regarding site workmanship and supervision. The basic assumptions are (i) “execution is carried out by personnel having the appropriate skill and experience” and (ii) “adequate supervision and quality control is provided during the execution of the work”. (Biennial report of Standing Committee on Structural Safety, 2008)

The key word here is “appropriate” and “adequate”, which are perhaps difficult to quantify and measure. It partly relies on professional integrity and judgement of the designer and/or contractor, which in itself can be highly subjective and variable due to the fragmented nature of the industry. There may be contrasting perceptions pertaining to, for example, what is constructible and what is not.

EN 1990 of the Eurocode addresses these assumptions by providing the designer with tools for the management of “structural reliability for construction works”. For concrete structures, EN 1993 goes further by demanding compliance with requirements for execution and workmanship given in ISO 22966. ISO 22966 itself incorporates comprehensive guidance for the designer/specifier, to manage the project specification with a view to ensuring that the underlying design assumptions will be complied with. Unfortunately for the designer, the current tendency towards design-and-construct type contracts makes it even more difficult to manage these assumptions as the tender documents have to be finalised before the design is complete.

Curtis (2010) argued that the construction assumptions of the design Eurocodes – and particularly the construction requirements of ISO 22966 – must be converted into practical, effective and contractually

enforceable “specified requirements” for each relevant construction process. These requirements must be incorporated in the project specification – and the design drawings and details must be consistent with the specified requirements. It was further argued that sets of model “specified requirements”, built around the framework provided by ISO 22966 for each set of interlocking construction processes, must be developed and made available to owners and their designers so that the underlying assumptions of the Eurocodes will actually be fulfilled during the planning and execution of on-site and off-site construction works. Curtis (2010) proposed that the mandatory control and verification requirements must be specified in the tender documents – and enforced during construction. He expressed that stated assumptions concerning standards of workmanship and supervision as stated in the relevant design codes is neither realistic nor fair to potential contractors.

It can be seen with Curtis’ analysis of the capabilities of the Eurocodes and ISO in constructability that they are inadequate in ensuring standardized, measureable and enforceable set of specifications for construction integrated design. The Eurocodes appear to be broad and specific construction processes are set out more as guidelines or checklists, rather than a methodology of quantifying specific design and construction specifications.

4.10 Singapore’s Code of Practice on Buildability

The legislation on Buildability was introduced by the Singaporean Building and Construction Authority (BCA) in 2001 under the Building Control Act to promote buildable design through greater adoption of prefabricated, modular and standardised building components. Under the legislation, building designs are required to comply with a minimum buildable design score. Various editions of the Code of Practice on Buildable Design had been published by BCA, to reflect the revisions made to the buildable design requirements through the years and to accelerate the pace of adoption of labour-efficient designs (BCA, 2011).

While the Singaporean industry has gained more experience with buildable designs, more could be done to enhance buildability and further reduce labour usage (BCA, 2011). Good buildable designs will have to be complemented by the adoption of labour-efficient technologies and methods to improve productivity at the construction stage. To achieve this, Singapore’s Buildability framework has been strengthened to require designers to deliver more buildable designs upstream, and builders to adopt more labour-saving construction methods/technologies downstream. Builders will have to comply with a new minimum “Constructability Score” downstream, which encourages the use of construction technologies, methods and processes that reduce the industry’s reliance on foreign workers.

To reflect the development of Buildability concept beyond design, Singapore’s “Code of Practice on Buildable Design” has been renamed as “Code of Practice on Buildability”. This Code sets out the requirements of minimum Buildable Design Score, minimum Constructability Score and their

submission procedures. It also sets out the method of determining the Buildable Design Score and the Constructability Score (BCA, 2011).

The Code sets out the requirements of minimum Buildable Design Score and minimum Constructability Score for buildings. It also sets out the method for computing the scores. In the context of the Code of Buildability (BCA, 2011), the definitions of the following terms are applicable:

Buildability

The extent to which the design of a building facilitates ease of construction as well as the extent to which the adoption of construction techniques and processes affects the productivity level of building works.

Buildable Design Score

The score for buildable design computed in accordance with Buildable Design Appraisal System (BDAS) as set out in the Code of Practice.

Constructability Score

The score for constructability computed in accordance with the Constructability Appraisal System (CAS) as set out in the Code of Practice.

Minimum Buildable Design Score or Constructability Score

The lowest Buildable Design Score or Constructability Score allowed under a particular category of development stipulated in the Code of Practice.

Labour saving index (LSI)

A value given to a particular building system which reflects the relative difference in site labour productivity associated with the various structural and wall systems. In certain instances, the LSI could be further lowered to discourage the use of labour intensive elements or components. A LSI is also given for the use of prefabricated reinforcement/cages in case in-situ components.

The Code of Practice on Buildability acts as a guide to using the two appraisal system documents – namely the Buildable Design Appraisal System (BDAS) and the Constructability Appraisal System (CAS) – to compute the respective Buildable Design Scores and Constructability Scores. In the following sections, Singapore’s Buildable Design Appraisal System (BDAS) and the more recently published Constructability Appraisal System (CAS) will be explained. Note that Singapore’s BCA seems to have separated buildability and constructability as two separate concepts in the two appraisal systems. However, this is actually not true and it is important not to confuse “Buildability” with the “Buildable Design Score”. Singapore’s Buildability concept, as seen in the definition given above, aligns well with the definition of constructability adopted in this research. The terms “buildability” and “constructability” can thus still be used interchangeably. The Buildable Design Score

and Constructability Score is different in terms of their scoring components and the project phases at which the scores should be computed. More detail is given in the following sections.

4.10.1 Buildable Design Appraisal System

The BDAS is basically a means to measure the potential impact of the building design on the usage of site labour by each specific contractor. The principle the Buildable Design Appraisal System is based on the premise of saving labour. The appraisal system results in a Buildable Design Score.

A building design can be divided up and categorised into numerous components where the scoring is computed. The characteristics of the design of each component partly bring about the proposed construction methods associated, which have an implication on the labour intensiveness during the building of the design. The approach adopted by the Buildable Design Appraisal System to compute the Buildable Design Score is based on the principle that labour efficiency is equated to constructability/buildability. Therefore, the less labour-intensive methods are employed by the design details, the more constructible/buildable the design is assumed to be, and thus the higher is the Buildable Design Score. Designs with higher Buildable Design Scores will result in more efficient labour usage in construction and thus have higher site labour productivity.

The BDAS is based upon three main principles (the “3S principles”) of Standardisation, Simplicity and Single integrated elements to achieve a buildable design. The designer s required to first consider the typical external factors such as soil condition, access and storage on site, availability of resources, skills and technology, sequence of operations etc. to determine the most appropriate building system to be used and then appraise the detailed design by applying the 3S principles. The 3S principles are explained in more detail below.

Standardisation refers to the repetition of grids, sizes of components and connection details. A repeated grid layout, for example, will facilitate faster construction whether formwork or precast components are used. Similarly, columns or external cladding of repeated sizes will reduce the number of mould changes whether on-site or in the factory.

Simplicity means uncomplicated building construction systems and installation details. A flat plate system, for example, eases formwork construction as well as reinforcement work considerably. Use of precast components reduces many trade operations on site and should improve site productivity provided the standardization principles are observed.

Single integrated elements are those that combine related components together into a single element that may be prefabricated in the factory and installed on site. Precast concrete external walls, curtain walls or prefabricated toilets are good examples of technologies that fall under this principle.

4.10.2 Buildable Design Score

The associated regulations affect new building works as well as additions and alteration works. With this, a proposed project needs to achieve a minimum Buildable Design score before its building plans can be approved by authorities for construction.

The minimum Buildable Design Score is different depending on the specific type of building and the gross floor area of the building design. The specific categories and types of buildings are listed comprehensively in the BDAS. The BDAS looks at the design and computes the extent which the 3S principles are found. It covers the structural system and other major components such as the external and internal walls, door and windows.

Each component of the system is assigned a labour saving index, which essentially determines the different Buildable Design Scores for each system and thus a reflection of the labour efficiency for each system. The LSI is represented as a fraction of 1 – thus a component having a LSI of 1 means it is 100% buildable. The more buildable the system, the more points are awarded. The points are then totalled to give the Buildable Design score of the design. The labour saving indices are determined thorough in-depth industry research and are thus subject to change in future revisions of the BDAS depending on the state of the industry. The different systems, their respective components as well as the labour saving indices of each are tabulated in tables to be found in Appendix A.

There Buildable Design Score of a project is made up of three parts, which forms the three main areas of scoring:

1. Structural system (Refer to Table 1 in Appendix A-1 for details)

This area of the BDAS examines the different types of structural systems that designers would use. This is effectively further divided into 4 systems in the BDAS. The maximum score for this system is 50 points. The 4 systems are as follows:

- Precast concrete system
- Structural steel system
- Cast in situ system
- Roof system

2. Wall system (Refer to Table 2 in Appendix A-2 for detail)

This area holds a maximum of 40 points. The wall system may be one or a combination of the following:

- Curtain wall
- Precast concrete wall/Panel

- Precast concrete formwork
- Precision block wall
- Traditional brick/RC and plaster wall
- Cast in situ wall
- Cast in situ wall with prefabricated reinforcements
- Brick wall

3. Other Buildable Design Features (Refer to Table 3 in Appendix A-3 for details)

This section examines the design of the building at a detailed level. Basic design characteristics, namely standardization of columns, beams windows and doors, structural grids and usage of precast components are considered. The use of these buildable design features will be awarded with points directly. In addition, bonus points would be given for the use of single integrated elements. The maximum Buildable Design Score for this section amounts to 10 points.

The maximum Buildable Design Score is 100 points. For example, the Buildable Design score for the structural system is determined by taking the fraction of the structure's total volume to be constructed by each method or system, multiplying by the relevant index, summing the result and multiplying by 50. A similar calculation is performed for the wall system only that the sum is multiplied by 40. Finally the Other Features score, up to a maximum of 10, is added in. The total of the Structural, Wall and Other Feature scores should not exceed 100.

The Building Construction Authority's objective in promoting buildability in Singapore seems to have been achieved over the years though the Buildable Design Appraisal System. The average Buildable Design Scores for various categories of building work between 1997 and 2005 have increased constantly, indicating an improvement in buildability in the Singaporean industry.

4.10.3 Constructability Appraisal System (CAS)

The Constructability Appraisal System (CAS) is similar to the Buildable Appraisal System (BDAS) in principle. It was developed as a means to quantify factors during a certain phase of the project affecting the overall constructability of the project, and uses a scoring approach under different categories. However, CAS aims specifically to measure the potential impact of downstream construction methods and technologies on the productivity on site, while BDAS looked exclusively at the constructability of the design systems alone. As the BDAS, the CAS results in a Constructability Score of the building works; a high Constructability Score would indicate a project with more labour efficient construction methods and technologies, and therefore improve labour productivity. While the BDAS focuses on the use of buildable designs during the upstream design process, the CAS seeks to encourage the use of downstream labour efficient processes and construction technologies, to bring

about greater ease in construction. Same as the BDAS, the minimum allowable Constructability Score is dependent on the type of building development and the gross floor area of the building.

4.10.4 Constructability Score

CAS is a performance based system with flexible characteristics that allow builders to adopt the most cost-effective solution to meet the constructability requirement. The constructability of building works is assessed in the areas of structural works, architectural, mechanical, electrical and plumbing (AMEP) works as well as site practices. Unlike the BDAS, the labour saving index is not used for computing the Constructability Score; rather, the CAS has absolute points assigned for each different method or technology used in specific circumstances. The following is a brief summary of the three parts where the Constructability Score is calculated, as well as the maximum points and rationale for each area of scoring. Only the crux of the CAS is given below, please refer to Appendix B for the exact number of points for each one of the methods and technologies under each of the three areas.

1. Structural System

This part has a maximum of 60 points (Table 1 of Appendix B-1). The points are awarded for various methods and technologies adopted during the construction of structural works. The Constructability Appraisal System accepts that structural works require the greatest manpower usage for building projects and any improvement here takes direct effect – hence the higher point for this area. The structural system is further divided into the following categories:

- External Access System (max 15 points)
- Formwork System (max 30 points)
- Structural Innovative Methods, Systems, Processes, Plant & Equipment (max 15 points)

2. Architectural, Mechanical, Electrical & Plumbing (AMEP) System

This part has a maximum of 50 points. Points are awarded for the methods and technologies adopted during the construction of AMEP works, details of which can be found in Table 2 of Appendix B-2.

3. Good Industry Practices

This part has a maximum of 10 points and the points are awarded for on-site processes to improve productivity. The details can be found in Table 3 of Appendix B-3.

The total Constructability Score is the summation of the scores computed from the three areas and as can be seen the maximum point is 120.

4.10.5 Summary of constructability literature review

The literature study sets out to explore existing and related research on constructability and/or buildability. Constructability of the design can be greatly dependant on the design management process, whereby constructability knowledge from subsequent phases of the project can be channelled back – in a formal or informal fashion – to be integrated into the design specifications. This makes obvious sense in theory, but reality holds many barriers to effective design management and thus obstacles in achieving good constructability, as described in the literature review. The design-construction environment, for one, makes it very difficult to share constructability knowledge. The variety of problems related to design management is discussed in detail, all of which have a close relationship with the fragmentation of the industry and concepts of constructability.

There are many ways to define constructability. This research adopted the definition by the Construction Industry Institute:

“Constructability is the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives”

In sight of the literature and definitions on buildability, it is mainly related to the design phase, while constructability covers many more project phases. This research accepts that the scope of buildability is embedded within constructability and can in many cases be used interchangeably. “Constructability” has a more comprehensive definition and will be used as the primary term in this research, except the cases where previously coined terms already contain “buildability” – such as “Singapore’s Code of Practice on Buildability” or “Buildability Assessment Model”. To define constructability further, existing principles of constructability are reviewed. Furthermore, the so-called “buildability factors” are discussed. These “buildability factors” make the design buildable and can thus be regarded as the criteria for sound, constructible design.

In addition to design management problems, specific constructability problems are also reviewed, all of which centres around the lack of communication of constructability knowledge between builder and designer manifesting in a variety of problems at a later stage of execution.

Efforts have been made to improve constructability through the use of constructability tools, approaches and mechanism (as termed in various research literatures), which this research will collectively name “constructability initiatives”. As seen in the literature review, constructability initiatives essentially facilitate the creation and flow of constructability knowledge in different levels of organisation, and are closely related to knowledge management principles and initiatives.

Design and construction codes are the most explicit way to define concepts and thus another significant avenue for improving constructability. However, concepts in constructability often maintain

a highly abstract nature and difficult to express in quantifiable terms. Existing explication of constructability knowledge as codes – Eurocode; ISO; Singapore’s Buildable Design Appraisal System (BDAS) and Constructability Appraisal System (CAS) – are discussed in the literature review.

The Eurocode and ISO offer guidelines to the execution process and specifications. These guidelines are more specific than mere principles, but are still relatively broad (perhaps similar to the “buildability factors” of the Buildability Assessment Model (BAM) and thus difficult to enforce systematically, often relying on the integrity and judgement of the personnel to make the assumptions required by the guidelines. The BDAS and CAS are only applicable in the building industry, but they are the most explicit form of constructability knowledge set out in a code. The codes enable the degree of constructability to be quantified and measured, thus making the issues of constructability enforceable.

It can be concluded that the Eurocode and ISO are able to cover a wider range of circumstances and if professionally adopted by the personnel, can pose great improvement to constructability. However, the Eurocode and ISO are not specific enough to allow the explicit definition of good, as opposed poor, constructability. The BDAS and CAS on the other hand are very specific, and an enormous amount of work has been done to quantify the constructability of myriad categories of components of buildings – based on analytical as well as empirical research. The BDAS and CAS is subjected to numerous constraints, such as the limited scope in only buildings designs, and many limited to the nature of the Singaporean industry. Even though the same principle may be used to compile such codes elsewhere another country, the conditions for the calculation of the scores will need to be determined from first principles and may be completely different to that represented in the Singaporean codes. Any prospective adopter of the BDAS or CAS needs to undergo extensive research in its local environment, understands the numerous constraints associated with the DBAS and CAS system and make the necessary adjustments accordingly.

The next chapter forms the second part of the literature review. Knowledge Management (KM) research literature is discussed in detail, as well as the relevance of KM initiatives in the context of the industry, with specific reference to constructability knowledge.

Chapter 5 Knowledge Management Literature Study

5.1 Introduction

In the context of the escalating importance of knowledge resources the primary function of the company is often assumed to be: to create the conditions, in which individuals can integrate specialist knowledge in order to produce goods and services of increasingly higher value. From a resource and capability perspective, sustainable competitive advantage comes through continuously developing existing resources and capabilities and creating new resources and capabilities in response to changing market conditions. Implicit is the belief that knowledge can be stored, measured and moved around the enterprise, but knowledge is a social construct that emerges through interaction and cannot be readily managed in the way of physical assets. "Like culture, knowledge exists only in a highly abstract form within organisations. It may be represented by certain physical artefacts, and it may be affected by managerial action. However, its fundamental nature can change over time, through a process of interaction between the many and various individuals within the organisation" (Empson, 1999).

The view that knowledge is a valuable organisational resource has become widely recognised and accepted in the business community. As a consequence, within the last few decades, there has been an increasing interest in the tacit dimension of knowledge, within the experiences of individuals, which is perhaps hardest to manage as it cannot be formally communicated and is often embedded within human beings. Nevertheless, tacit knowledge has become more relevant to sustaining business performance than traditional physical capital and considered as a very crucial factor affecting an organisation's ability to remain competitive (Grant, 1996; Spender, 1996; Eisenhardt & Santos, 2000).

This trend is very applicable to the construction environment. The construction industry is considerably more fragmented than many other industries with a much greater concentration of small professional organisations (Carty, 1995; Halpin & Woodhead, 1998). The services offered by these professional organisations are characterised by being highly tacit-knowledge-intensive in nature (Lowendahl, 2000), with a wide range of professionals involved, working as an inter-disciplinary team in delivering the construction products and services. In addition, the concept of the knowledge worker (Green et al., 2004) has long been acclaimed within the construction industry, which is considered to be one of the most labour intensive sectors of the economy compared to other industries.

The concept of constructability and related problems as described in the previous chapter highlight the tacit nature of constructability knowledge. Constructability knowledge largely forms part of the experiences and expertise embedded within the minds of personnel in construction. Constructability knowledge is difficult to standardize due to the diverse perceptions of constructability itself amongst different divisions and subdivisions of the industry.

To promote integration in construction project processes essentially implies the integration of knowledge from subsequent project phases – as constructability is defined: “the optimum use of construction knowledge and experience in planning, design, procurement, and field operations to achieve overall project objectives”. Therefore, the sound management of knowledge resources is key to improving constructability overall. However, knowledge, being an abstract and often inconsistent social construct, requires special management approaches. Paired with the highly tacit nature of constructability knowledge, it cannot be managed and taught in the same manner as the standardised or codified form of knowledge (in databases, books, guides or codes), with which consulting and construction firms are most familiar.

This chapter is a review of relevant literature pertaining to the conceptualisation of knowledge, and the field Knowledge Management (KM). Different concepts associated with knowledge are defined and explored. The importance of tacit vs. explicit knowledge, models of knowledge creation and sharing is discussed in this chapter. The literature review covers general organisational knowledge resources, but also specifically as constructability knowledge to promote project integration. In this study, specific emphasis will be placed on the implementation of lessons learnt programmes, which in itself is a form of KM initiative commonly used in the construction project environment, and also identified as a “constructability initiative” in the previous chapter. The knowledge-theory concepts covered in this chapter are typically from older research, while the newer citations mainly cover the Knowledge Management concepts and its relevance to the construction industry.

5.2 Definition of Knowledge Management

Different authors have presented different definitions of Knowledge Management (KM). Davenport and Prusak (1998) suggests that KM is the process of capturing, distributing and effectively utilising knowledge. This is closely reflected by the definition given by Scarbrough et al. (1999), who describe KM as the process of creating, acquiring, capturing, sharing and using knowledge to enhance organisational learning and performance. Robinson et al. (2005) define KM as a method of exploiting, or transforming knowledge as an asset for organisational use to facilitate continuous improvement.

Knowledge Management (KM) approaches are described by numerous different terms. Clarke and Rollo (2001) describe the different approaches adopted by various companies as “KM initiatives”, which incorporate the shared characteristic of a company’s commitment to developing the production and flow of knowledge, and the dissemination and use of knowledge to create economic value. A KM “initiative” denotes a holistic approach to managing knowledge. This may be different from the term “system”, which is often used in KM literature to describe IT-orientated approaches to KM. “KM initiative” is therefore the term utilised to describe an organisation’s approach to managing its knowledge that includes both human (soft or tacit) and system (hard or explicit) components. Numerous KM initiatives have been identified in literature, using soft as well as hard approaches to implement and promote KM.

Egbu (2004) stated that Knowledge Management (KM) is very difficult to define precisely due to a lack of general consensus in KM literature. A generic definition for KM can be proposed and used in this research:

“The process associated with the creation of new knowledge, the sharing and transfer of new and existing knowledge, the capture, storage, exploitation and measurement of the impact of knowledge, in such a way that it benefits the unit of adoption, which can be the organisation.”

The different definitions of KM in the literature result from the various perspectives and context that are specific to the authors (Carrillo, 2004; Egbu, 2004). Within construction, KM can be difficult to define precisely as there is not a general consensus on a single unified meaning of the concept (Egbu, 2004). However, Egbu (2004) explains that knowledge is an important resource for construction organisations due to its ability to provide market leverage and contributions to organisational innovations and project success. The idea of knowledge as a competitive resource within project-orientated industries is a concept shared by numerous authors (Egbu, 2004; Egbu & Botteril, 2001; Nonaka & Takeuchi, 1995; Oltra, 2005).

5.3 Conceptualisation of knowledge

As philosophers have debated since the earliest civilizations, knowledge is a complex and elusive concept. Advances in knowledge define the achievements of the ancient Greek, Roman, Egyptian and Chinese civilisations. The transforming impact of the industrial revolution was typified by the application of new knowledge in technology.

As defined by Gianetto and Wheeler (2000), knowledge involves beliefs and values, creativity, judgement, skills and expertise, theories, rules, relationships, opinions, concepts, and previous experiences. It is more than data or information. Wiig (1993) agreed that knowledge is different from information, which consists of facts and data that are organised to describe a particular situation or condition. He believed that knowledge is accumulated and integrated and held over longer periods to be available to be applied to handle specific situations and problems. It is subsequently applied to interpret the available information about a particular situation and to decide how to manage it. This is further supported by Turban and Frenzel (1992), who defined knowledge as information that has been organised and analyzed to make it understandable and applicable to problem solving or decision making.

In the era of knowledge-based economies, it remains easier to understand knowledge in terms of what it is not, by distinguishing data, information and knowledge. There are many different definitions of each term summarising a wide literature, combined with a working definition provided by Standards Australia (2001) in the knowledge management framework.

Data

Data are sets of discrete objective facts presented without judgement or context. Data become information when they are categorised analysed, summarised and placed in context, becoming intelligible to the recipient. Data relate to the actual bits and characters in an information system or in the other physical manifestations of communication such as sound and temperature. Examples of data in construction industry are simply numerical representations of a certain unit – e.g. 5m (length), 20MPa (pressure/stress), 500N (force), 40m² (area) etc.

Information

Information is data endowed with relevance and purpose. Information develops into knowledge when it is used to make comparisons, assess consequences, establish connections and engage in dialogue. Information is data in context that can be used for decision making. Data are usually arranged to provide meaning to the observer. Information is the sensible classification of data, e.g. depths of beams, thicknesses of slabs, volume of earth material, axial load of columns etc. in specific circumstances of construction and design.

Knowledge

Knowledge can be seen as information that comes with insight, framed experience, intuition, judgement, and values. In some sense knowledge represents truth and therefore offers a reliable basis for action. Knowledge is the body of understanding and skills that is mentally constructed by people. Knowledge is increased through interaction with information (typically from other people), and can be closely associated with lessons learnt. Examples of knowledge (or lessons) could be: steel structure are more susceptible to wind loads than concrete structures; cable-stayed bridges are more susceptible to dynamic forces; in situ concrete systems are preferable over precast (or vice versa) etc. Knowledge requires some synthesis and analysis of data or information and is a result of intelligent reasoning.

Wisdom

Wisdom could be described as the best use of knowledge. Knowledge processes can always be improved but wisdom is necessary to determine which processes to focus on in order to achieve organisational objectives. As data and information are processed and interpreted, and become invested with meaning through analytical thought processes, they increase in utility and value.

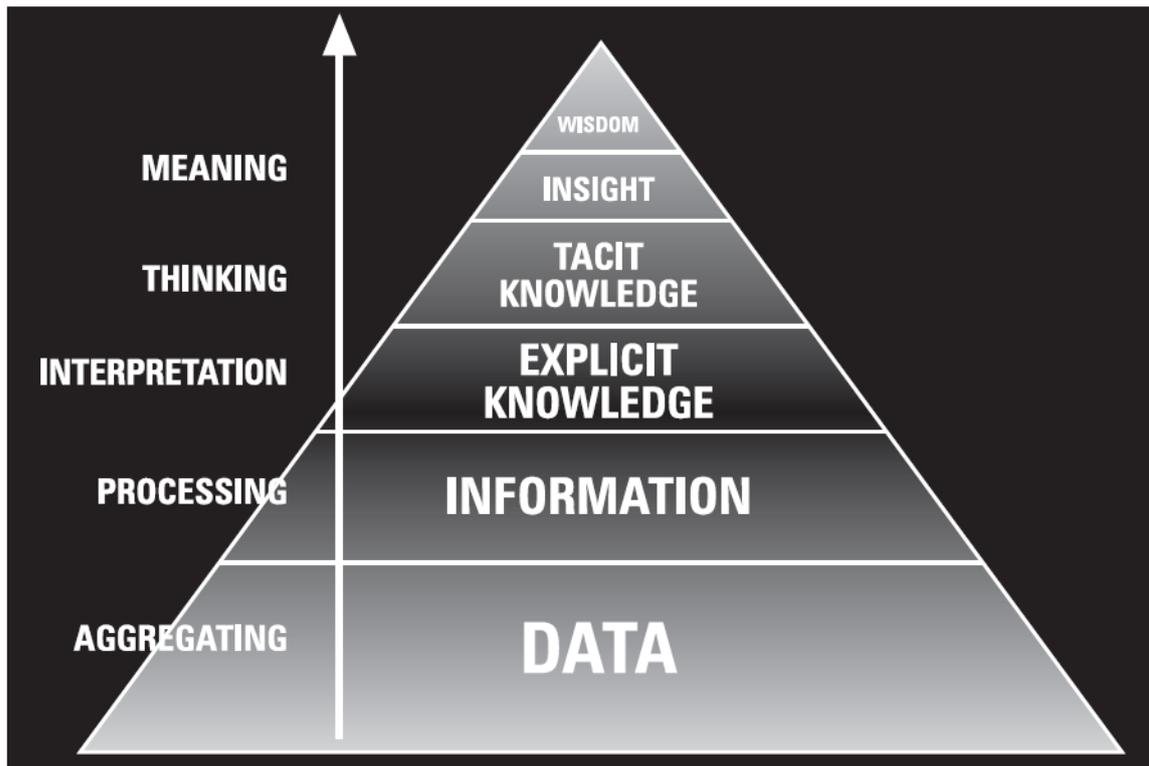


Figure 5-1 Knowledge/Intelligence hierarchy

Figure 5-1 shows the intelligence hierarchy as increasing levels of intelligence in graphical form. This model indicates that each tier (component of intelligence) can be derived from the tier below it, and that the development of intelligence must proceed upwards to take sensible effect in understanding. Davenport and Prusak (1998) offer a working definition of knowledge, which expresses the characteristics that make knowledge valuable, and the qualities – often the same ones – that make knowledge difficult to manage:

Knowledge is a fluid mix of framed experiences, values, contextual information, and the expert insight that provides a framework for evaluating and incorporating new experiences and information. It originates and is applied in the minds of knowers. In organisations, it often becomes embedded not only in documents or repositories, but also in organisational routines, processes, practices and norms (Davenport & Prusak, 1998)

5.4 Tacit and Explicit knowledge

Despite various definitions and classifications of knowledge, work by Polanyi (1958), Nonaka and Takeuchi (1995) divided knowledge into tacit and explicit. Although knowledge could be classified into personal, shared and public; practical and theoretical; hard and soft; internal and external; foreground and background, the classification of tacit and explicit knowledge remains the most common and

practical. Tacit knowledge represents knowledge based on the experience of individuals, expressed in human actions in the form of evaluation, attitudes, points of view, commitments and motivation (Nonaka et al., 2000). Since tacit knowledge is linked to the individual, it is very difficult, or even impossible, to articulate. Explicit knowledge, in contrast, is codified knowledge inherent in non-human storehouses including organisational manuals, documents and databases. Yet, it is difficult to find two entirely separated dichotomies of tacit and explicit knowledge, instead knowledge can fall within the spectrum of tacit knowledge to explicit knowledge.

As Herrgard (2000) and Empson (1999, 2001) contended, organisations' knowledge resources can be described as an iceberg. The structured, explicit knowledge is the visible top of the iceberg, which is easy to find and recognise and therefore also easier to share. Beneath the surface, invisible and hard to express, is a momentous part of the iceberg. This hidden part applies to tacit knowledge resources in the organisations. Tacit knowledge is the unarticulated knowledge that resides in human beings, which is obtained by internal individual processes like experience, reflection, internalisation or individual talents (Herrgard, 2000). Therefore it cannot be managed and taught in the same manner as explicit knowledge.

Constructability problems, as discussed in the previous chapter, highlight the tacit nature of constructability knowledge. The knowledge and constraints in subsequent construction phases of the project are not effectively taken into consideration during earlier stages, because there are no standardised guidelines available for constructability, as there are explicit design codes for the designer. With reference to the constructability initiatives from the previous chapter, it is evident that these methods of handling constructability problems are geared towards the fact that a substantial part of constructability expertise is embedded within the experience, and thus the minds, of the individuals.

Researchers have argued that the diffusion of tacit knowledge is more difficult than sharing explicit knowledge (e.g. Nonaka & Konno 1998; Leonard & Sensiper, 1998). An organisation's core competency is more than the explicit knowledge of "know-what"; it requires the more tacit "know-how" to put "know-what" into practice (Brown & Duguid, 1998). Brockmann and Anthony (1998) note that the efficiency of making decisions, serving customers, or producing products, and accuracy of task performance are improved by the use of tacit knowledge.

Usually explicit knowledge is collected in written format. Thus, organisations collect and synthesize tacit knowledge to make it standardized and widely allocable for employees, e.g., cost data, document templates. Firms believe that explicit knowledge can reduce costs and deliver a standard and acceptable solution to multiple clients. On the other hand, tacit knowledge is usually collected from employees' brains. Since explicit knowledge is usually in written form, employees generally know how to find it. They usually "connect" explicit knowledge with filing cabinets libraries, databases, training

sessions, E-mail messages, newsletters etc. However, tacit knowledge is rather difficult to connect as it tends to be distributed across multiple individuals' minds.

The management and sharing of tacit knowledge poses pertinent relevance to constructability knowledge, given its tacit nature. However, there is in existence also explicit forms of constructability knowledge. Good examples of existing explicit constructability knowledge can be seen as Singapore's Buildable Design Appraisal System and Constructability Appraisal System, where specific components of constructability of buildings are classified and quantified. Knowledge management of constructability knowledge – both as tacit and explicit formats – is explored in this research.

5.5 Knowledge Flow “SECI” model

Nonaka and Takeuchi (1995) in their influential book “The Knowledge Creating Company” examines the process of the translation of tacit (subjective) knowledge into explicit (objective) knowledge, which can be codified. A model of knowledge flow is based on the exchange of tacit knowledge within a community of practice. The transfer to other communities requires its explication, and subsequently the knowledge is internalised and made tacit again through application.

As an illustration of the knowledge flow model within the construction context, tacit constructability knowledge is created amongst constructability personnel and assumes the form of constructability expertise within the minds of these individuals. This expertise is then extracted from these individuals, analysed and explicated into a codified format, eventually set out in guidelines, databases, standards etc. The transfer of the codified knowledge can occur easily between one community and another, say construction and design. The community on the receiving end would need to internalise the received explicit knowledge, interpret it, understand it and eventually apply the knowledge in the functions it fulfils – e.g. carrying out design or planning processes using constructability knowledge.

Nonaka and Takeuchi (1995) identified four inter-related processes, by which knowledge flows around the organisation and transmutes into different forms – tacit to explicit and vice versa. The processes are: socialisation, externalization, combination, and internalisation. They are sometimes termed the “SECI” model. Figure 5-2 is a diagram to represent the steps in the SECI model, the knowledge flow/translation (between tacit and explicit) and the activity representing each step of the SECI model.

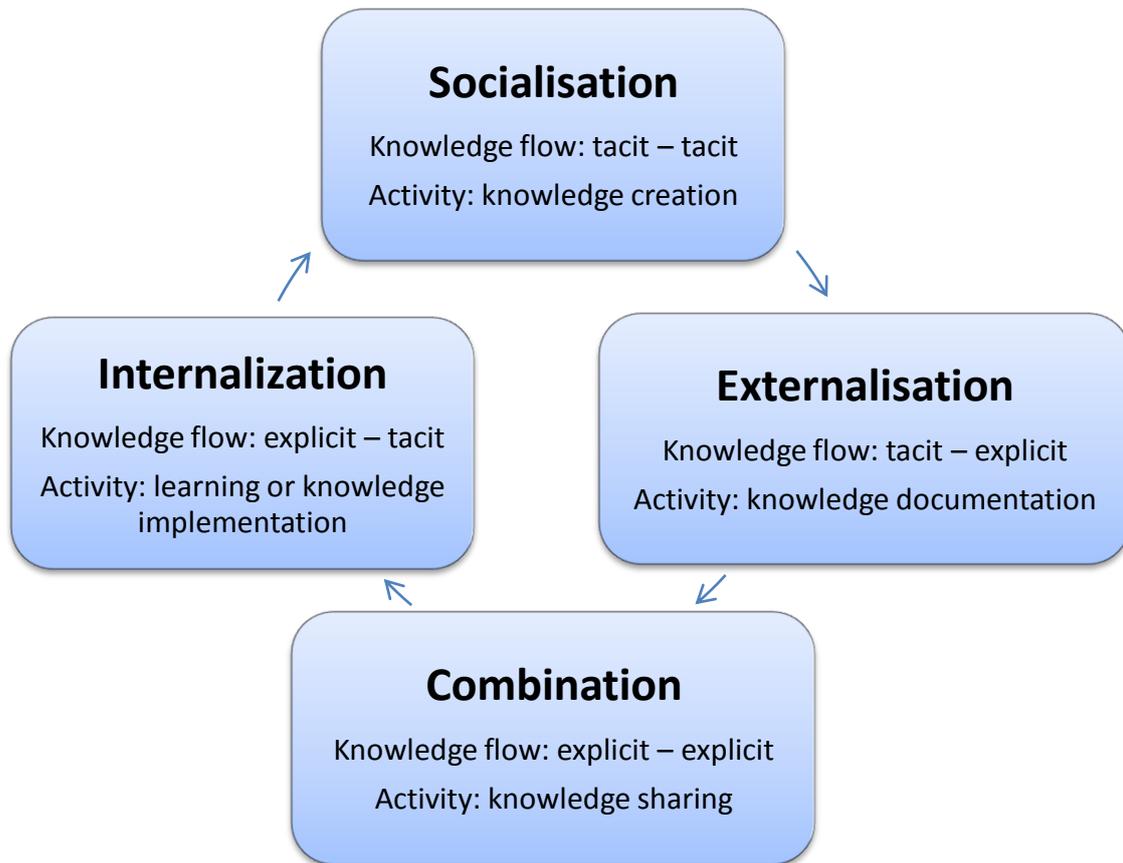


Figure 5-2 The SECI model

A brief discussion of each of the four SECI model steps is elaborated in the following paragraphs:

Socialisation

Socialisation is a process of sharing experiences and creating tacit knowledge such as shared mental models and technical skills. The key to acquiring tacit knowledge is experience. “Without some form of shared experience, it is extremely difficult for one person to project her or himself onto another individual’s thinking process”. (Nonaka & Takeuchi, 1995). In a construction project, socialisation creates the experiences and knowledge gained on site or other subsequent project phases, which exists as technical skills in the minds of the personnel.

Externalisation

Externalisation is a process of articulating tacit knowledge into explicit concepts. “It is a quintessential knowledge-creation process in that tacit knowledge becomes explicit, taking the shape of stories, metaphors, analogies, concepts, hypotheses, or models. When we attempt to conceptualise an image, we express its essence mostly in language – writing is an act of converting tacit knowledge into articulable knowledge. The externalisation mode of

knowledge is typically seen in the process of concept creation and is triggered by dialogue or collective reflection” (Nonaka & Takeuchi, 1995). In the construction environment, the experiences of constructability issues and problems are captured, analysed and documented.

Combination

Combination is a process of categorising and integrating explicit knowledge. Individuals exchange and combine knowledge through media including documents, meetings, telephone and computer networks. Reconfiguration of existing information through combining and categorising can lead to new knowledge. Through combination, systematic knowledge is created and the documented knowledge is collectively regarded and understood. In industry this process constitutes all the activities of sharing codified knowledge – e.g. distribution of guidelines or standards.

Internalisation

Internalisation is the process of embodying explicit knowledge back into tacit knowledge. It is closely related to “learning by doing”. When experiences through socialisation, externalisation into individual’s tacit knowledge base in the form of shared mental models or technical know-how, they become valuable assets” (Nonaka & Takeuchi, 1995). Internalisation deals with the application and implementation of the explicit organisational knowledge. For the construction industry, this constitutes the learning and understating of legislations, rules or standards. This involves the implementation of organisational guidelines into the design process in order to respond to the constructability issues experienced and previously documented.

Together these processes of knowledge creation and transmission produce a knowledge-creating spiral in organisations. Organisational knowledge creation is a continuous and dynamic interaction between tacit and explicit knowledge (Nonaka & Takeuchi, 1995). The kind of knowledge created by each mode of knowledge conversion is different. Socialization yields the so-called sympathetic knowledge, such as shared mental models or technical skills. Externalisation outputs conceptual knowledge. Combination gives rise to systematic knowledge such as a new prototype or component technology. Internalisation produces operational knowledge, for example about project management, new construction or design processes.

Evidently, this knowledge creation and flow model requires the successful translation of knowledge between tacit and explicit forms. Theoretically, constructability knowledge should be created, explicated, transferred and then internalised to take effect. However, as seen in the previous chapter (on constructability) constructability knowledge is not easily codified due to its inconsistent nature. There are an enormous number of variables, which constructability issues are dependent upon, making the establishment of specific guidelines very difficult. However, as Singapore’s Buildable Design Appraisal System and Constructability Appraisal System have shown, codification is possible to an extent, given a large number of very specific constraints or circumstances.

This research explores how the SECI model can be used as a basis for constructability knowledge flow, thus the potential for constructability to be systematically explicated in the South African construction industry. The detailed understanding and conceptualisation of constructability is key in making the explication of constructability knowledge possible and subsequently enable effective dissemination of the knowledge between different communities of disciplines.

5.6 Construction Knowledge Model

Within construction, the type of knowledge varies enormously, yet gains increase concern on tacit knowledge as a labour intensive industry as previously discussed. Specially, engineers, architects and other professionals within the construction industry are not in a position to “cut and paste” best practice (Kamara et al., 2003) from the past due to the unique and the complex nature of the construction projects. They have to draw on the past to find solutions for the future. Tacit knowledge evolves from these shared practices and experiences, which needs to be managed for the project and the organisational success. According to Wetherill et al. (2002), knowledge in the construction domain can be classified into three categories, which further highlights the emphasis placed on knowledge workers and tacit knowledge. The three categories of construction knowledge are represented as follows:

Domain knowledge

The information available to all companies and is partly stored in electronic databases

Organisational knowledge

Company specific and intellectual capital of the firm, which also comprises knowledge about the personal skills, project experiences of the employees

Project Knowledge

This includes both project records and the recorded and unrecorded, memory of processes, problems and solutions

Wetherill et al.'s (2002) classification reflects the organisational hierarchy and when one moves from domain knowledge to project knowledge the concentration on knowledge too moves from explicit to tacit nature, which highlights the knowledge worker concept in construction. By taking a different stance Stahle (1999) suggests organisations into three-dimensional system, i.e. mechanistic, organic and dynamic nature, depending on the different challenges presented for management of knowledge. Mechanistic part deals more with explicit knowledge whilst, organic nature helps the organisation to work flexibly with a people-centred orientation and involves the management of tacit knowledge. The dynamic nature facilitates continuous improvement and innovation – the constant translation between tacit and explicit knowledge. Stahle's suggestion indicates both the management and the creation of

the knowledge. In a similar sense, Moodley et al. (2001) contends that the tacit knowledge is developed through the individual or project teams, while the explicit knowledge is created through process, procedures and other routines that can be codified.

Despite the type of knowledge to be managed in construction, review of current literature reveals numerous definitions and techniques of knowledge management (KM) due to wide range of interests, perspectives and issues represented by different authors. These fall mainly into the IT perspective (explicit knowledge) where authors focus on IT tools to deliver KM solutions, the human resources (tacit knowledge) perspective that relies on the people aspect to provide KM solutions and the integrated perspective, which acknowledges that both the IT and HR perspectives complement each other (Scarbrough et al., 1999; Tiwana, 2000). Nevertheless, KM is defined as “process of creating, acquiring, capturing, sharing and using knowledge, wherever it resides, to enhance learning and performance in organisations” (Scarbrough et al., 1999), which emphasise both perspectives.

This more recent model of knowledge in construction aligns well with the components of the intelligence hierarchy, as well as processes of the SECI model. However, this model covers mainly the first two steps of the SECI model – socialisation and explication – where constructability knowledge is created through experience as “Project Knowledge” an subsequently explicated to form “Organisational Knowledge” and codified even further to become “Domain Knowledge”, which is almost general to the industry.

5.7 Knowledge Sharing

Lee (2001) has defined knowledge sharing as “activities of transferring or disseminating knowledge from one person, group, or organisation to another”. Foy (1999) defines the concept as “facilitating learning, through sharing, into usable ideas, products and processes.” This definition implies that there is a specific purpose behind knowledge sharing, and “learning” is an artefact from the knowledge sharing process. According to Hickins (2000) knowledge sharing is about capturing the tacit knowledge locked in people’s heads. As only 2% of information gets written down – the rest is in the people’s heads (Hickins, 2000) – the challenge is therefore to capture and transform such knowledge into a shareable form. Nonaka and Takeuchi (1995) explored the power of knowledge sharing to affect firm performance. Creating knowledge and using knowledge to develop successful products, services, and systems is key to a firm’s sustaining their competitive advantage.

McDermott and O’Dell (2001) find that organisational culture is more important to knowledge sharing than the approach or commitment to knowledge management. They highlight the importance of maintaining an obvious link between knowledge sharing and business problems, using tools and structures for knowledge sharing that are consistent with the overall style of the organisation, and building reward and recognition systems that support knowledge sharing. In addition, they determine that a lack of time will prevent users from sharing knowledge, even when the technology is good.

Knowledge sharing practice can bring plenty of benefits to a company. According to Ndlela and du Toit (2001) through the capturing and sharing of experiences and information, better utilisations, and professional bodies can be achieved. Giannetto and Wheeler (2000) also mentioned that the competitive edge of a company is gained with knowledge management, where new knowledge is quickly disseminated and shared across the business. Any projects or new work should be reviewed and the learning points shared with others – through a lessons learned programme discussed later. As a result, new employees quickly become effective and the organisation becomes flexible, reacting quickly to change.

Irrespective of whether or not constructability knowledge can be codified, sharing of the knowledge still remains a great challenge not only due to the technical, but also the social effects of organisational operation. Knowledge, be it in tacit or explicit form, needs to be shared to yield some perceivable effect. With reference to the more comprehensive SECI model, knowledge sharing actions mainly constitute the last two steps: “combination” and “internalisation”. However, knowledge sharing does not have to exclusively imply explicit knowledge sharing. Tacit knowledge sharing (through socialisation) is equally important as it is the main knowledge creating process.

This research looks at the extent and modes of knowledge sharing in consulting and contracting companies in South Africa. The sharing of not only explicit knowledge, but also the sharing of tacit knowledge is explored. This research also explores industry perceptions to knowledge sharing, which will be crucial in identifying a strategy in the implementation of knowledge management and sharing approaches.

5.7.1 People orientated perspective

The construction industry exists as one of the most people-orientated industrial sectors (Loosemore et al., 2003). However, the management of the people within construction organisations remains a complex and difficult issue (Dainty et al., 2002). UK construction organisations are increasingly becoming aware of the potential of the tacit knowledge held by their employees and the need to manage it (Carrillo & Chinowsky, 2006); an issue which has received widespread coverage in KM literature.

Although employees play a vital role in ensuring the successfulness of an organisation, the significance of people-related practices in providing effective KM solutions within construction firms, particularly in relation to rewards and encouragement for KM, has received a lack of coverage in the literature (Carrillo, 2004).

Many academics have identified the importance of people-focussed aspects of KM as the area for greatest potential. Numerous authors have identified the dependence of KM solutions on the staff and

managers within an organisation, and the importance of their willingness and ability to act cooperatively and share their knowledge with that of others (Fong, 2005; Kamara et al., 2005).

McKenzie et al. (2001) examined the conditions necessary for gaining commitment from employees to KM initiatives and state that:

“Organisations cannot assume that if they build a knowledge management system, people will embrace it wholeheartedly...Somehow we have to convince individuals to work in groups and voluntarily commit their energies to business objectives.”

Their key findings showed that gaining commitment requires support from senior management, the allocation of sufficient resources and funds, a dedicated champion, and recognition of the behavioural types of those involved. However, he states that the most important factor is ensuring that the staff members recognise the value of KM. The IRS Management Review (2000) provides a number of recommendations for getting staff to share knowledge, stating that it is, “often the most difficult aspect of KM to accomplish.”

It has been suggested that in order to gain enthusiasm for KM, staff will want to see that their knowledge contributions have been acknowledged and rewarded, through financial or non-financial means. However, it continues by stating that some authors have advised against financial rewards, recommending intangible rewards instead, such as peer recognition, learning opportunities and greater autonomy.

Bishop et al. (2008) identified two different opinions on the correct approach for integrating a KM system into an organisation’s processes. While some recommended integration with policies and procedures, others suggested integration with daily and project activities. A key suggestion was that it is important to integrate KM with every-day activities rather than processes and procedures. The reason was cited as the need for KM to be intuitive and embedded, which means that its integration with policies and procedures, “forcing someone to do something”, is not necessarily effective.

It has been found that creating and sustaining the best-suited culture for knowledge sharing is a key factor in ensuring KM successfulness (Bishop et al., 2008). The importance of culture to KM is outlined by McKenzie et al. (2001) who state that a culture, which achieves a best-fit with an organisation’s KM practices, is one where the employees do not feel any inhibitions about sharing knowledge.

5.7.2 Conditions to encourage knowledge sharing

The transformation of raw data into relevant information and then into shared, meaningful and useful knowledge, according to Davenport and Prusak (1998), requires a sense of reciprocity,

acknowledgement and a degree of altruism on the part of the people. They suggest there are three conditions which facilitate individual sharing valuable knowledge:

1) Reciprocity. The time, energy and intelligence of people are all finite, and people take time to help a colleague if they think they are likely to receive valuable knowledge in return, either now or in the future.

2) Repute. It is the interests of people to be viewed as expert. If people have a reputation for expertise this is a source of power. They need to be certain colleagues will acknowledge the source of this knowledge and will not claim credit for it.

3) Altruism. People find some subjects particularly fascinating, and may be eager to talk about them as much from self-gratification as wanting communicate knowledge (Davenport & Prusak, 1998)

Trust is an essential condition for the effective functioning of knowledge markets. This trust can exist at an individual level, through close working relationships between colleagues. Or trust can be developed at an organisational level by the creation of a culture context, which encourages and rewards knowledge sharing and discourages and penalises knowledge hoarding. A dilemma remains that organisations cannot create knowledge. Individuals create knowledge, not organisations. Knowledge generation therefore can be seen as a process of converting tacit and individual knowledge into explicit and collective knowledge.

5.8 Lessons Learnt Programme

A lessons learnt programme can be regarded as a vital tool in attaining effective knowledge management in the industry – especially of constructability knowledge. Organizations in the construction industry cannot afford to make repetitive mistakes on major projects. Conversely, there are great benefits to repeating positive experiences from past projects. This need for institutional memory is amplified by the reality that in the course of normal turnover and retirement, people with years of experience leave their organizations. An effective lessons learned program is a critical element in the management of institutional knowledge; it will facilitate the continuous improvement of processes and procedures and provide a direct advantage in an even more competitive industry.

Each constructability issue experienced during a project acts as an opportunity for a lesson to be learned, analysed and implemented, thus improving project performance by allowing future teams to avoid specific mistakes. In practice, many constructability problems are still repeated from project to project, because there is no effective process where lessons learned are shared with different project participants through different phases. This is attributed to the fragmented nature of the project teams.

Many organisations in the construction industry have come to recognize the importance of a lessons learned program (LLP) as a vital asset that plays an essential role in knowledge management systems. In these organisations, project team members generally acquire new knowledge as their careers progress. Thus knowledge, which includes both successes that organisations want to repeat and problems that they do not want repeated, may not be routinely disseminated throughout the organisation. The value of optimizing the dissemination of this gained knowledge highlights the importance of LLP.

With reference to the SECI knowledge flow model, the socialisation and explication phases of constructability knowledge may pose an overwhelming challenge to effective constructability knowledge management. Lessons learned programmes will facilitate the “socialisation”, “explication” and also “combination” processes, where previous lessons – especially issues related to constructability – from each project can be collected or identified, analysed and implemented. The conceptual process of lessons learned programmes is described in more detail in the following sections. Significant advancements in technology are allowing organisations in the construction industry to improve their identification, analysis, and implementation of lessons. Although many organisations have put LLPs in place, they not know how to evaluate the maturity and effectiveness of the program.

5.8.1 Definitions of Lessons Learned Programme

The Construction Industry Institute (CII) defines the term “lesson learned” as the knowledge gained from experience, successful or otherwise, for the purpose of improving future performance (CII, 1998; CII, 2007a). Examples include:

- A lesson learned that is incorporated into a work process
- A tip to enhance future performances
- A solution to a problem or a preventative action
- A lesson that is incorporated into a policy or a guideline
- An adverse situation to avoid

Harrison (2003) defines a lessons learnt programme as “a good work practice or innovative approach that is captured and shared to promote repeat application or an adverse work practice or experience that is captured and shared to avoid recurrence.” The European Space Agency (2006) describes it as “a knowledge or understanding gained by experience. The experience may be positive, as in a successful test or mission, or negative, as in a mishap or failure. Successes are also considered a source of lessons learned. A lesson must be significant in that it has a real or assumed impact on operations; valid in that it is factually and technically correct; and applicable in that it identifies a specific design, process, or decision that reduces or eliminates the potential for failures and mishaps, or reinforces a positive result.”

Some organisations believe that lessons learned must be incorporated into work processes, whereas others believe that a lesson is anything that will improve organisational performance. Therefore, it is important to adopt the definition that best fit the needs of each organisation. No matter the specific definition used, lessons learned are always used to help an organisation achieve its business needs and goals (Weber et al., 2001)

It is evident that lessons learned programmes can pose as a key component in promoting the knowledge management of constructability related issues, which consist of a myriad variety of problems, the inconsistency of which makes it very hard to handle explicitly. The continuous identification, analysis and implementation of specific constructability lessons with lessons learned programmes from project to project, will result in a growing pool of constructability knowledge.

5.8.2 Conceptualisation of lessons learned programmes

A lessons learned programme (LLP) consists of the people, processes, and tools that support the identification, analysis, and implementation of validated lessons learned in organisation. The use of a LLP is to help to implement knowledge management within the organisation by collecting and disseminating information and experiences. People, processes, and technologies are crucial to the implementation of an effective LLP (Collision & Parcell, 2005). Lessons learned programs can be classified further as formal or informal. Formal LLP employ a standard documented work process for lessons learned. They also are consistent across an organisation and are well resourced. Informal programmes, on the other hand, are more inconsistent and ad hoc. These programmes may even be a grassroots effort with no official action taking place (CII, 2007b).

The lessons learned programme includes three key processes: identification, analysis and implementation.

Identification

Identification or collection is the gathering of knowledge and experiences from individuals in the organisation. Individuals may submit lessons by electronic means or by communicating ideas in formalized workshops. Identification or collection can occur at various stages of the project execution by different members of the organisation including project managers and project teams.

Analysis

After lessons are collected, they must be analysed and validated before they are disseminated through the organisation. Analysis can be conducted in a team setting or by an individual. This crucial portion of the lessons learned process guarantees that the information shared throughout the organisation is correct and easily interpreted.

Implementation

Lastly, the lessons can only help an organisation if they are put into action (Collision & Parcell, 2005). Implementation can take many forms, ranging from publication of lessons in an electronic database to the changing of practices and procedures to reflect lessons learned.

Today's economy is driven by information and the value of an organisation has become increasingly dependent on knowledge assets rather than tangible ones (Anumba et al., 2005). Knowledge management systems play a crucial role in organisations and are generators of innovation and competitive advantage. A lessons learnt programme (LLP) is a crucial component of knowledge management systems in organisations. In order for an individual to benefit from knowledge management and gain information and insight from an experience, he or she must consider the activity that occurred and extract a lesson learnt (Collision & Parcell, 2005). This is especially true for the construction industry and in the context of constructability knowledge, as constructability lessons learnt from project to project. Implementation of an effectively functioning lessons learnt programme is the first step in creating sensible constructability knowledge. This pool of knowledge can then be shared through other knowledge management approaches with different discipline of project participants – especially during the design and planning stages of construction projects.

This research will give specific focus on the implementation of lessons learnt programmes in consultants and contractors. The nature of the LLPs, the three processes making up the lessons learnt programme will be investigated.

5.9 Summary of Knowledge Management Literature Review

This section sets out to understand knowledge management from a general perspective to its application in the construction industry. Constructability knowledge is difficult to handle as it is very abstract, highlighting its tacit nature. To understand constructability as a knowledge resource, it is necessary to understand the nature of knowledge itself and all the related concepts linked to knowledge management.

Numerous definitions of knowledge management can be found in literature. The generic definition for knowledge management is proposed and used in this research as follows:

“The process associated with the creation of new knowledge, the sharing and transfer of new and existing knowledge, the capture, storage, exploitation and measurement of the impact of knowledge, in such a way that it benefits the unit of adoption, which can be the organisation.”

Data, information, knowledge and wisdom are all differentiable terms each with a specific definition within the spectrum of intelligence. Their relationship with each other and how one can evolve into

another form is discussed in detail. The understanding of these differentiable components is important in understanding the nature of constructability knowledge.

Knowledge can be broadly categorised into tacit and explicit formats. Basically, explicit knowledge refers to the part which is codifiable and thus measurable in one way or another. Explicit knowledge can be in the form of codes, books, guidelines or databases and can easily be shared. Tacit knowledge refers to the part which exists in the minds of individuals, in the form of experiences and expertise. Tacit knowledge is not easy to classify or codify (if possible at all) and thus difficult to share, because of its inconsistent nature. However, tacit knowledge holds great value in improving project performance. Given the highly tacit nature of constructability knowledge, the understanding of tacit knowledge management models is essential in ultimately attaining control over constructability knowledge.

A knowledge flow model, known as the SECI model consist of four main processes, as discussed. The “SECI” model is very comprehensive in describing the process, from the inception of ideas through socialisation, to the explication and combination of tacit knowledge and finally the implementation of the knowledge to effect changes for improvement. It also describes the nature of knowledge flow and how knowledge needs to be translated between tacit and explicit forms during the process to form the knowledge creation and sharing cycle within organisations. Another model – Construction Knowledge Model – is discussed, where three different categories are identified for construction knowledge, namely domain, organisational and project knowledge. The different models are merely different perspectives of the concepts and classifications of knowledge and should not be confused to being mutually exclusive of each other. The tacit-explicit classification of knowledge, the SECI model and the Construction Knowledge Model discussed, relate to each other in a complex fashion. However, it would be useful to use the SECI model as a template to which all the other models and processes can be related, as the SECI model covers all the different phases in knowledge creation and knowledge flow.

Creation of knowledge – regardless of tacit or explicit – naturally results in knowledge sharing and implementation, in order to yield the positive effects of knowledge. Different sharing practices, its benefits, challenges and significance are discussed. Along with knowledge sharing and the implementation of certain knowledge management initiatives, are the social and human-related issues. Gaining commitment from personnel in embracing knowledge management initiatives is key to the effective implementation. The human-related issues and some conditions to encourage knowledge sharing are discussed.

The lessons learned programme, being an important knowledge management initiative in the context of construction, is discussed in detail. Lessons learnt programmes covers most processes described by the SECI model and can be easily related to by the construction engineering community. All relevant aspects of lessons learnt programmes are discussed, including its definition,

conceptualisation, benefits and its relevance to capturing constructability related lessons – the key process in constructability knowledge creation and explication.

Knowledge management and constructability needs to be regarded inclusively of each other in order to fully understand the complex network of the associated problems within the research context. In the following chapter, a synthesis is produced from the literature on constructability as well as knowledge management. The material of the synthesis provides the basis for the questionnaires, personal correspondences and case study of the research.

Chapter 6 Synthesis of Literature Study

This chapter describes some results and deductions from the literature review. A broad picture of the significance of the literature review is presented and some conclusions can already be made. This chapter further presents the principle questions that are evoked and how they contribute to the compilation of the questionnaires. All this is done with the broad aim in sight – improving constructability through implementation of knowledge management principles.

To broadly conclude from the literature study, the key to improving constructability lies in improving the knowledge management of constructability knowledge, so that all project participants can make informed decisions, knowing the implications of their decisions on subsequent project phases. This is especially applicable for the design and planning personnel to ensure better constructability of design by using knowledge from the other phases – a great deal of which is constructability knowledge. It is thus critical to understand the concepts of knowledge creation and sharing, as well as the translation of knowledge between different forms. This provides a framework of how constructability knowledge can arise, conceptualised, maintained and managed.

The syntheses and questions evoked from the literature study presented in the sections below are used as the primary material for each of the two (Phase-1 and Phase-2) questionnaires. The points below are reorganized and set out logically and concisely in the questionnaires, to obtain the most objective answer possible from the respondents. The detailed rationale, constitution and findings for each of Phase-1 and Phase-2 questionnaires, are presented in the subsequent sections respectively. Note that the order in which the syntheses below are provided, do not necessarily correspond to that of the questionnaires.

6.1 Archival data

From knowledge management literature, different forms of intelligence can be identified – data, information and knowledge. Theoretically, data can be derived to form information and information can further be derived to form knowledge. With respect to constructability, this suggests that data from construction projects can be derived eventually to create so-called “constructability knowledge”.

This leads the research direction to investigate the availability of data in the archives of consulting/construction firms. It is thus of interest to explore the following aspects in more detail:

- Contents of project archives and what data is actually available
- Perceptions whether current archives hold sufficient data/information/knowledge
- The nature of data-capture activities (if any)
- The accessibility of data for the project personnel

The above aspects will ultimately give light whether or not archival data in the organisational archives is sufficient to be used to derive lessons and knowledge.

6.2 Criteria of constructible design

Constructability has many definitions and has been the topic of research since the 1960s and 70s. However, concepts of constructability have not been defined to the extent that allows a comprehensive and practically feasible means of measuring constructability.

Some principles are identified in literature that further defines the concept of constructability. Amongst these are the “buildability factors” identified in the literature in Chapter 4 (section 4.6), which can be seen as criteria for constructible design.

As a further step to conceptualize constructability, it is pertinent to understand how the industry perceives the relative importance of these constructible design criteria and whether these criteria are fulfilled in projects.

The criteria from the literature study are presented again as follows:

1. Allowing economic use of contractors resources
2. Enabling design requirements to be easily visualised and co-ordinated by site staff
3. Enabling contractors to develop and adopt alternative construction details
4. Enabling contractors to overcome restrictive site conditions
5. Enabling standardisation and repetition
6. Enabling freedom of choice between prefabricated and onsite works
7. Enabling simplification of construction details in case of non-repetitive elements
8. Minimising the impact due to adverse weather by enabling a more flexible construction programme
9. Allowing design to achieve safe construction sequence on site

The industry perceptions towards these criteria in literature are investigated in this research.

6.3 Labour-efficiency principle of constructability

The codified appraisal systems implemented by Singapore have shown that constructability can indeed be quantified somehow, although under numerous constraints, many of which are unique to the local industry environment and have little to do with scientific theories.

Currently the quantification of constructability, achieved by the Buildable Design Appraisal System (BDAS) in Singapore, is essentially based upon principles. The BDAS is based on the principles of labour-saving or labour-efficiency. This implies that the specified construction processes that makes

the most efficient use of labour is of a “good constructability”, which logically promotes the use of pre-cast systems over cast in-situ concrete wherever possible. The calculation of the constructability scores are dependent on indices generated on the basis of labour saving.

In South Africa, the typical industry culture prefers the use of in-situ concrete. One of the many reasons may be that it generates the human labour and thus arguably increases employment – regardless of the efficiency of the labour. Due to common usage of in-situ concrete over the years, pre-cast methods holds uncertainty that may be interpreted as potential project risks. South African industry personnel are speculatively more comfortable employing in-situ concrete methods. This industry trend seems contradictory of the labour-efficiency principle of the Singaporean codes and thus needs to be investigated in more detail.

It can be concluded that that good constructability (and thus labour-efficiency according Singapore’s system) is equated to the employment of more equipment-intensive methods, associated with pre-cast concrete, rather than the more labour-intensive, in-situ concrete construction.

To gain understanding on the perception of constructability principles, the favourability between the following is specifically investigated in this research:

- Equipment-intensive vs. Labour-intensive construction
- Cast in-situ vs. Precast concrete

6.4 Constructability of different configurations of building components

In the Singaporean code, following the labour-efficiency principles, labour saving indices are determined and calibrated with extensive industry input. These labour saving indices essentially determine the constructability score of the appraisal system, and is the crux of constructability quantification. Labour saving indices are different for different variations of building components and sub-components.

Based on a similar methodology, this research identifies variations of different building components and investigates the perceptions of industry personnel concerning their constructability. The typically major building components are identified as follows:

- Structural Frame
- Slab
- Façade wall
- Roof
- Roof support
- Internal wall

The perceptions of the industry regarding the favourability of different variations/configurations of the above building components is the first step in attaining better and more explicit understanding of constructability. This research will carry out the investigation accordingly and initiate some basis for the quantification of constructability.

6.5 Lessons learnt programme

Knowledge management literature concludes the highly tacit nature of construction knowledge in general, which includes constructability knowledge. For this reason constructability knowledge cannot be managed as a tangible asset (such as explicit knowledge in documents and codes etc.). Lessons learnt programme have been identified in literature as an important initiative (both as a knowledge management and constructability initiative) to manage tacit constructability knowledge.

Following the literature on lessons learnt programme and the different processes associated, this research will investigate in detail the current trends in the implementation of lessons learnt programmes in the industry. This is done according to the three lessons learnt processes comprising the lessons learnt programme:

- 1) Lessons identification
- 2) Lessons analysis
- 3) Lessons implementation

Associated with lessons learnt programme, the project close-out meeting can be an important avenue to implement lessons learnt activities and is thus given specific attention. It is assumed that at least a great deal of the discussions and conclusions from project close-out meetings form part of the documentation in project archives. The investigation of project close-out meetings can be seen as a direct broadening of the investigation on archival data (section 6.1). This research investigates whether companies carry out such close-out meetings and if so, who are the personnel (by discipline and responsibility) that attends these meetings. Attendees of project close-out meetings roughly indicate the different sources of knowledge flow present at the meeting. It is an important occasion where discussions and analysis of issues during the project can occur, and from numerous perspectives – especially between design and construction.

6.6 Knowledge sharing

The literature review covers knowledge sharing and the people-related aspects of knowledge sharing. It is important to understand the status quo of knowledge sharing activities in the industry as it is the bases of how constructability knowledge can be transferred within an organisation or between organisations. For this research, a list of knowledge sharing modes is established, on which the

investigation is based. The results offer strategic direction regarding the implementation of general initiatives to disseminate knowledge – here, specifically constructability knowledge.

The specific avenues for detailed investigation presented in this chapter are further explored in the research. The procedures and findings of questionnaires, correspondences and case study are presented in the following chapters.

Chapter 7 Phase-1 Questionnaire

The topic of the Phase-1 questionnaire is data-capturing for projects, which essentially covers the retention of specific project information (in whichever form), after the completion of the project. The aim of the Phase-1 questionnaire is to explore the nature of data-capturing or knowledge management (KM) initiatives (if any) within the South African construction industry and to understand the perceptions towards the favourability of such initiatives. This questionnaire addresses the points under the section on archival data (section 6.1) of the literature study synthesis (Chapter 6) previously.

7.1 Phase-1 questionnaire rationale

One can regard constructability issues to be, in principle, attributed to a lack of integrated design procedures. In other words there is no dynamic flow of relevant construction knowledge between construction personnel and the designer. This logically traces the focus of the problem to knowledge management (KM) of construction knowledge. KM principles deal with the creation, organization and eventual sharing of knowledge – knowledge being actual lessons and expertise gained and stored in one way or another, to be freely accessible at a later stage. KM initiatives can present themselves in many forms and be facilitated through many different methods..

In order to explore the role of KM and thus the status quo of KM, it is useful to start with the most elementary form of analytical intelligence – data. According to the intelligence hierarchy (discussed under section 5.3), data acquisition is the foremost step in knowledge creation and relevant data can be derived into lessons, through analysis and triangulation. However, the data capture- and handling-process has many technical, operational and social challenges.

The question that arises is whether it is possible to derive sensible lessons/knowledge from historical data alone, and the extent to which this can be done. The question implies, for example, if an organisation or researcher desires the average cost of a specific type of project, would this be possible to achieve through historical data analysis? Or, to name a more relevant example, if one (a designer or contractor) desires to know what sort of constructability issues are typically associated with the construction of say pre-cast concrete columns, is one able to derive the relevant “lessons” from analyzing historical data of the organisation; and is the relevant data required indeed available in a codified format. Needless to say, the former example seems much easier to achieve as the variables and parameters associated with costs and types of projects (possibly with other specifications) are easy to represent and captured in archives. In theory, an item such as cost can be captured quite conveniently in pure data form, whereas the latter constructability example requires a more advanced form of intelligence and may even need the understanding of numerous lessons learnt in the past to foresee the types of constructability issues, in order to either avoid or solve them. In the case of constructability, even the nature of the problem itself poses a challenge, because constructability concepts are still not explicitly describable in full, and thus not completely quantifiable. This will be explored in detail after this questionnaire.

Typically, construction projects retain project information in the form of drawings, meeting minutes, and other documents etc. which are usually stored in archives after the completion of the project. The general hypothesis is that this information, however thorough or complete, is not easily available for future access. Furthermore, the content of this information is limited in scope and not sufficient for analysis of more specific issues. Central to knowledge management principles, companies can benefit a great deal from information and knowledge produced during a construction project, provided that this information is captured and then organised in such a way that it can be meaningfully accessible in future. Data-capturing can be seen as an elementary component of knowledge management, as “data” implies a very specific quantifiable entity with a unit of measure (e.g. length, time, density, pressure, force etc.). Comprehensive knowledge management should cover all the subsequent activities following data-capture, where data undergoes some interpretation or analysis to eventually become meaningful lessons and knowledge. Data-capturing initiatives, if successfully implemented will, at most, result in the retention of masses amounts of sensible data, which can be synthesized into information or even lessons (thus knowledge) to be stored in the archives and accessed for the numerous purposes to promote project performance.

To explore whether constructability problems can be solved by lessons derivable from existing organisational data, it is instrumental to understand the nature and extent of data-capturing activities. In other words, one needs to recognize what is being captured, how it is being captured and whether or not the captured data is able to provide the basis for constructability lessons synthesis.

7.2 Phase-1 questionnaire objectives

Information available in archives typically do not cover areas such as specific financial strategies, design/construction process information, design/construction change management, safety considerations, contractual relations and procurement processes (amongst other issues), all of which are associated with risks that can be potentially harmful to the project. The Phase-1 questionnaire thus only explores data-capturing and project archives. The understanding of data-capturing activities and the contents of project archives will enable the formulation of more specific solutions regarding the improvement of constructability through knowledge management.

From the literature study synthesis, some aspects of archival data (section 6.1) are identified to be explored further. Those aspects are refined to a list of objectives for the Phase-1 questionnaire as follows:

- 1) Identify the constituents of project archives
- 2) Explore the perception whether current archives hold sufficient data/information/knowledge
- 3) Investigate possible additional items worth capturing, other than existing contents of project archives
- 4) Investigate the existence of data-capturing system whether it be procedural or electronic

- 5) Investigate the existence of a database/framework/KM system, where data is organised to enable effective accessibility in future.

The outcomes of the Phase-1 questionnaire will indicate the nature of typical project archives and thus the extent of intelligence retention, as well as the attitudes among industry personnel regarding such initiatives. An important result of this questionnaire would be the indication of the potential that data-capturing can be relied upon in identifying lessons for further analysis – in the case of this research, specifically constructability related lessons.

7.3 Questionnaire distribution platforms

Knowledge needed to be extracted from the experience of personnel in the industry. The questionnaire provided a suitable method to achieve this. The sample group consists of some attendees of the CMP – Construction Management Programme – held at the University of Stellenbosch. The CMP is an annual programme stretching over a few weeks where the attendees are required to be on campus in person. This presented the possibility of a non-electronic questionnaire to be completed within short amount of time, while the CMP delegates are available in person as respondents. The questionnaires were printed in paper form and distributed for the delegates to be completed by hand, which are collected after the completion for detailed analysis.

7.4 Profile of Respondents

The attendees of the CMP were chosen as prospective respondents as they consist of industry personnel with substantial practical experience of 15 years on average. Another importance factor is that they were available in person to act as respondents. For the Phase-1 questionnaire, 11 responses were received. The profile of the sample group is summarised in the tables below. This questionnaire does not present any statistical value and the questions were designed as such, thus no percentage distributions are presented for deductions during analysis. Also, extensive quantitative analysis is avoided to prevent statistical misnomers in the outcome. Table 7-1 shows the different affiliations of the respondents and the number of respondents belonging to each affiliation. Table 7-2 shows the different technical disciplines and the number of respondents belonging to each. Table 7-3 shows the different professional titles or positions of the respondents within their organisations.

Table 7-1 Types of affiliations and number of respondents

Nature of affiliation	No. of respondents
Client	6
Construction	3
Consultant	2

Table 7-2 Main technical disciplines of respondents

Discipline	No. of respondents
Building, bridges	3
Roads, Civil	7
Electrical	1

Table 7-3 Professional position of respondents

Position	No. of respondents
Project Manager	7
Site agent	2
Engineer	1
Director	1

The investigation on archival data is generic and is not limited to a specific discipline. Thus, as can be seen, respondents from a few disciplines are involved here. To offer clarity on the positions and titles of the sample group, respondents were asked to provide a short description of their responsibilities as Project Manager; Site agent; Engineer; or Director. The descriptions of the responsibilities for each of the positions in table 7-3 were summarised and put into the lists below. The lists are thus generated as a collective summary of the responses, where redundancies are removed.

Project Manager respondents' responsibilities:

- Roads design and supervision
- Maintenance and upgrade of infrastructure
- Managing state toll plaza operations
- Management of activities related to pre-vendor's site establishment on large projects
- Project identification
- Engineer appointment
- Construction appointment
- Programming
- Site management
- Management of site agents
- Technical administration and procurement
- Contract administration
- Budget control
- Financial management

Site Agent respondents' responsibilities:

- Running of site
- Quality control

- Site safety
- Clients and consultant relations
- Human resource development

Engineer respondents' responsibilities:

- Technical design
- Site inspections
- Project administration

Director respondent's responsibility:

- Managing director and technical support

7.5 Questionnaire compilation

The complete Phase-1 questionnaire, as presented to the respondents, can be found in Appendix C.

The length of the questionnaire was kept to a minimum in consideration of the availability of the respondents' time. According to the five Phase-1 questionnaire objectives (as shown in section 7.2), eight main questions were established to address these objectives. The eight main questions consists of a combination of yes/no and open questions, where respondents were only asked to list entities from previous experience. The questionnaire was designed so that little or no creative thought was required, thus focussing solely on extraction of existing knowledge, making it considerably simple to answer. The questions were structured to follow a logical sequence. The eight questions, with a brief discussion of each, are as follows:

- 1) This is an open question where the respondents were asked to list the items of project information currently available within the project archives at his/her organisation. The responses are used to establish an inclusive list of the project archive constituents.
- 2) Respondent were asked whether the capturing of more data, additional to what is currently available, would be beneficial for future use. The yes or no answers are to give an idea of whether the current existing archival data is sufficient or if more data is required.
- 3) The respondents, who answered "yes" in question 2, were asked to list the additional items that he/she thinks would be beneficial to capture during the project. The responses are used to draw up a list of additional desirable items to capture.
- 4) The respondent were then asked to provide a short description of how each of the listed items (to be additionally captured) in question 3 can be beneficial to future projects. This gives an

indication of the nature of the additional items and why they are desirable. The analysis of this background information offers clarity whether the problem really lies in data deficiency.

- 5) The respondents were asked whether there is currently some system within the organisation, with which data is captured – a data-capturing system. The key here is to identify how many respondents already have some capturing system in place, but who still desire additional items to be captured. This would indicate that whichever system is currently in place is inadequate.
- 6) If there is indeed such a data-capture system (as determined in question 5), the respondents needed to describe the system. This would give clarity for the research as to how the respondents define a “data-capture system” and whether the respondent’s understanding of a “data-capture system” is consistent.
- 7) The respondents, who answered “yes” in question 5 (that there is indeed a data-capture system), are further asked whether there is a database, framework or knowledge management (KM) structure, whereby captured data/information is meaningfully organised and made accessible.
- 8) The respondents, who answered “yes” in question 7 (that there is some form of KM system), needed to describe the system briefly. This would further clarify how the respondents define a “KM system” and whether the respondents’ understanding of a “KM system” is consistent.

7.6 Questionnaire results and discussion

7.6.1 Project archive contents

The respondents were asked to list the items of project information currently available within the project archives at his/her organisation.

The items presented in table 7-4 are an inclusive summary of all the respondents’ lists. All the items from the responses were combined and redundancies were removed, then items were categorised for better structure. It can thus be assumed that a good comprehensive project archive should include all the items presented in this list. The items shown are not analysed in terms of frequency of occurrence between all the respondents, as it would not be sensible to make such deductions from the small group of respondents. However, a good idea of the constituents of a project archive, or what information a good project archive should include, is generated here.

Table 7-4 Categories and contents of project archives

Categories	Items in Project Archives
Project information	Construction start date, end date Extensions of time Contractor and consultant details Project Programmes Project close out reports Lessons learnt reports
Technical details	Design drawings and specifications As-built drawings and specifications Construction specifications Material test results Design reports Quality control reports Current condition of infrastructure
Contractual details	Contract documentation Tender documentation Completion certificates
Financial and procurement	Project Budgets and cash flow Procurement documentation for contractors and consultants Payment files Purchase orders Costs and payment certificates for all vendors Retentions and amounts outstanding Subcontractor final payments
Site records	Site instructions Health and safety records Accident records Training records
Correspondences	Contractual information flow Letters and emails Minutes of meetings, Variation orders All project related correspondences between key project participants

7.6.2 Need for additional data-capture

The respondent was asked whether he/she believes that the capturing of additional data/information/knowledge (other than what is available in the project archives) is beneficial for future projects. A short motivation is also given by each respondent. Table 7-5 shows the number of correspondents answering positively and negatively:

Table 7-5 Opinions on additional data-capture

Additional data-capture	Nr of respondents
Agrees with additional data-capture	9
Disagrees with additional data-capture	2

Note that the numbers are not of specific significance considering the size of the respondent group and the nature of the analysis. Rather, it is of particular importance to understand the reasons behind why the respondent answers positively or negatively through the motivations given for the answers accordingly by the respondents. The following paragraphs discuss the motivations of their opinion on additional data-capture followed by a brief synthesis of the deductions.

For negative answers (disagree with additional data-capture), several motivations are given. One respondent claimed they archive everything, thus there is no need for additional data-capture. There is already an abundance of data and that the data is not yet used at full potential. Another respondent is of the opinion that the problem does not lie in the data-capturing, rather the problem is associated with the willingness of the personnel (who needs the knowledge) to make the effort and take the time to access this knowledge from some pool. The respondent expresses that most people work under high pressure and do not have the time to comb through masses of historical data. However, the respondent also convinced that if a standardised system is widely used, the processes can get more streamlined and that data/information can start to be captured exactly the way the end user would need it. It was further mentioned that the focus should not so much be on data-capture, but rather on lessons learnt systems. According to a respondent, many departments such as that of procurement (which would directly benefit from previous lessons) do not make use of such lessons learnt retrieval systems and make repetitive mistakes from project to project.

Looking at the motivations above, one respondent claims no need whatsoever for data-capture, while additional points gives other insight into the problem. The motivation implies that there is unwillingness amongst personnel to retrieve and utilize existing information. This can be attributed to time-related work circumstances, but also indicates that the systems currently in place does not allow for speedy retrieval of knowledge thus impeding knowledge dissemination in general. This can be due to the fact that such a system does not directly deliver the functions sought by the personnel. Furthermore, the information available is regarded more as raw "historical data" rather than synthesized knowledge or lessons. There is little differentiation within industry between the handling

of data, information and knowledge or lessons learnt, the combination of which seem to be unorganised and unstructured. It requires the user or personnel to comb through masses of material in order to extract useful and relevant information, in other words, the synthesis of lessons or knowledge is left to the end user.

It was mentioned that many of the additional information is indeed captured, although on progressive schedules of project management software (such as Primavera) and not in accessible archives or databases. In other cases, only the project manager has access to specific information. However, this is also not documented to be shared for the benefit of other parties. Much data may well be captured during the project, but the data is mostly not self-explanatory and the lessons and knowledge linked to specific data are not documented. One of the respondents believes these very lessons can mean the success or failure of the project. Another respondent expresses that lots of information gets lost before it gets captured, which indicates that information waste is still common and that there is no adequate system to document and record lessons efficiently, leading to loss of information before they can even be captured in some form or another.

7.6.3 Additional items to capture

For the respondents who answered positively (agree that additional data capture would indeed be beneficial) they were asked to list the items that they think should be additionally captured. The items shown in table 7-6 are an inclusive summary of all the listed responses. In other words, if one respondent mentioned the item, it is included in the table, to comprehensively show all the additional data that respondents would find beneficial.

Table 7-6 Additional items to be captured (continues to next page)

Categories	Items
Risks related	<ul style="list-style-type: none"> • Risk identification of project • Risk quantification of project • Risk mitigation procedures • Updates and changes to risk register
Planned-vs.-actual	<ul style="list-style-type: none"> • Project schedule planned vs. actual • Project scope creep • Cash flows planned vs. actual
Change related	<ul style="list-style-type: none"> • Design changes • Construction changes • Schedule changes • Budget changes • Change management process

Categories	Items
Lessons learnt related	<ul style="list-style-type: none"> • Knowledge gained (challenges/victories) • Challenges faced and how they were resolved • Delays and frustrations • Good and bad lessons • Drawing receipt and revision related lessons • Programme improvement processes • Labour, plant and material related lessons • Safety and accidents that occurred • Effective use of conditions of contract • Use of labour laws • Claims evaluation • Variations lessons • Labour costing lessons • Tendering and programming improvement
Additional miscellaneous data	<ul style="list-style-type: none"> • Project start, end dates, extensions • People involved – key project team • Contact details of key stakeholder • Rates for all items • Budgeting information • Costs for overall contract • All estimates • Details of all the tasks and site instructions • Labour costing schedules • As built data • Schedules • Site diaries • Key design information • Important reports

Upon inspection, the combined list in the table 7-6 is considerably irregular, consisting of lessons learnt from different processes, risk management issue, changes and variations and some raw data, all to which deeper knowledge can be derived. The best effort has been done to categorize them for more sensible presentation. However, it is important to note that the categories are not mutually exclusive and many items in the list are related to one another on different aspects.

The lists of additional items to be captured (table 7-6) include quite a variety of project intelligence. There are data that respondents would like to have captured. However, it is evident that there is a

greater focus rather on the knowledge or lessons linked to the different types of data. These knowledge or lessons is not contained in the data by itself, but must be derived through analysis and some interpretation process of the data. The items listed are as given (some with brief description) by the respondents, though the categories are additionally assigned for logical presentation. The items in the “risk related”, “planned-vs.-actual”, “change related” and “lessons learnt related” categories all imply some interpretation and synthesis of the data, beyond its simple form – basically quantities of units. Except for the items in “additional miscellaneous data” category, all the other items are strictly speaking not mere data, but information, knowledge, lessons or even expertise – according to the definitions in from the literature and adopted in the research.

The “risk related” items aims to record and document the processes of risk management, how the risks were identified and quantified, essentially understanding the negative and positive risks of projects. The “planned-vs.-actual” and “change related” items should essentially offer insight into the reasons for the changes and variations, while the “lessons learnt related” items explicitly aim to extract lessons and knowledge from the different aspects of the project. Logically speaking, all the categories, accept the “additional miscellaneous data”, are geared towards identification and analysis of lessons learnt, thus the creation of knowledge, and documenting it in a way to be effectively accessed and understood in future. Most of the additional items to capture given by respondents were lessons and knowledge orientated material, rather than “primitive” data.

The trends in the responses further indicate little or no differentiation among industry personnel between data and knowledge. This differentiation is important when establishing or improving data/knowledge capture systems (regardless of electronic or procedural) to be able to clearly classify and thus organise the intelligence in a consistent structure. If no clear understanding is achieved in this regard, it would result in pools of intelligence having data, information as well as knowledge or lessons in combined disorder. This is extremely difficult to organise and thus creates further confusion for the user who attempts to access this.

7.6.4 Data-capturing system

The respondent was asked whether there is currently some existing system within the organisation, whereby the additional items (listed earlier table 7-6), is captured.

The absolute numbers are not of specific importance. On the other hand, it is indeed notable to compare the results here with the number of respondents agreeing with the need for additional data-capture. In other words, the key is to identify how many respondents, who already have some data-capturing system at their organisations, still want more additional data to be captured. The number of respondents desiring additional data-capture from the previous question is used as reference to the responses from this question. From the section 7.6.3 previously, 9 respondents believe that additional items should be captured and would pose specific benefits for the organisation.

Detailed analysis shows that, out of the 9 respondents who agreed to additional capturing, 8 have indeed some capturing system in place at their organisations. Thus, it can be deduced that the respondents find the existing systems generally unsatisfactory. This indicates that the capturing systems, to one extent or another, are inadequate in fulfilling the needs of the personnel, in terms of capturing enough and/or relevant intelligence.

7.6.5 Knowledge Management (KM) system

The respondents who indicate they have data-capturing systems are further asked whether there is a database, framework or some Knowledge Management (KM) structure, whereby the captured data/information can be analysed, meaningfully organised and made accessible for future use. From the previous section, 8 respondents indicated that data-capturing systems exist. Here, the respondents with KM systems are represented as a fraction of the respondents having data-capturing systems.

Detailed analysis shows that out of the 8 respondents who indicated they had data-capturing systems, 4 of them indicated the existence of some knowledge management system where the data captured is analysed, organised and stored for future accessibility. Bear in mind that the 4 respondents who indeed have a KM system at their organisations, are part of the 9 that desired the capturing of additional items. This means that even with a KM system (as understood by the respondents), there are some dissatisfaction towards the existing available archival data.

7.6.6 Descriptions of data-capture and KM system

The respondents with data-capture systems and/or KM systems are asked to describe the nature of the systems, to offer clarity in their definition of a “data-capture system” and/or “KM system”. This is essential, as these terms may be ambiguous and even though they can generally be interpreted similarly, there are likely fine differences in implication between different perceptions of different people. This research must explore this in detail to gain an accurate picture of the problem. The following discusses the findings regarding the definition of data-capture and KM systems, as understood by the respondents.

The list below shows the summary of descriptions of data-capturing and Knowledge Management systems as described by respondents. Since there seem to be little discernable different between the descriptions of the two (i.e. data-capture and KM system) as given by the respondents, they are presented collectively in one list:

- SAP (software)
- ITIS (software)
- Citrix (software)
- MAINTCOST (software)

- Scanned-in registers of documents
- Electronic archiving system – correspondences, programme updates and cost reports
- Document management system – document numbers, types, document approvals, revisions and control, minutes, spreadsheet,
- Project information management system
- Costing systems
- Records of material usage and control
- Records of plant usage

The descriptions of data-capture and KM systems are found to be very erratic and some were unsure, as they have never used such a system firsthand, but are merely aware of it. However, irrespective of the nature of these systems at hand, the erratic answers and the prevalent uncertainty in description holds some deductive value. Such responses indicate that the respondents themselves are generally not considerably involved in using previously captured data or knowledge in a codified format or from some database. This can be attributed to many of the reasons mentioned earlier, that personnel do not have the time and are unwilling to make the substantial effort required. The implication here is that such information systems are not functional and are regarded too time- and effort-consuming. The ineffectiveness of the system can further be traced to a number of more specific problems. One of these can be the systems' inability to ensure the capture of relevant items (or enough items) as reflected in the responses of the preceding questions pertaining to the need of additional capturing.

7.7 Phase-1 questionnaire conclusions

In general, one of the main challenges faced in this questionnaire (and likely all of CEM research for that matter) is the subjective understanding of concepts, as different people may interpret different concepts subjectively. In this case, respondents easily confuse data, information and knowledge and there is little differentiation between a data-capture- and Knowledge Management system. This issue is of great significance as different interpretations of the same term results in a contrasting understanding of the problem at hand; and thus affects the way problems are solved. The triangulation principle is employed in the questionnaire to accurately capture different interpretations from different perspectives.

In principle, the Phase-1 questionnaire aims to explore and obtain better understanding in the role of data, and data-capturing, in promoting lessons learnt and knowledge creation – whether or not data can be used to derive related lessons and knowledge. This leads to the formulation of the following objectives as already mentioned in section 7.2:

- 1) Identify the constituents of project archives
- 2) Explore the perception whether current archives hold sufficient data/information/knowledge

- 3) Investigate possible additional items worth capturing, other than existing contents of project archives
- 4) Investigate the existence of data-capturing system whether it be procedural or electronic
- 5) Investigate the existence of a database/framework/KM system, where data is organised to enable effective accessibility in future.

The above objectives have been met and the research queries answered. However, it is important to note that the results arising from the Phase-1 questionnaire should not be statistically interpreted, due to the nature of the analysis and small respondent group. The analysis bears little statistical value and thus the results are to only be used as guidelines of theoretical information rather than that quantity or frequency.

The conclusions to each of the objectives above are presented in the following sections. Note that objective 4) and 5) – on data-capture and Knowledge Management systems respectively – are discussed under one section below.

7.7.1 Project archives

As per questionnaire objective 1) – to identify the constituents of project archives – the starting point in exploring the nature of data-capturing actions is to determine the existing project information, which is mostly found in project archives. From the responses, a collective summary of the contents of a comprehensive project archive is identified and an inclusive list of project archive items is drawn up. This gives a good idea of the constituents of project archives and can be used as a basic guideline to measure the completeness of other project archives in general.

7.7.2 Need for additional items to be captured

This is a response to objective 2) – explore the perception whether current archives hold sufficient data/information/knowledge. Considering the items in the archives, nine out of eleven respondents answered that there is a need for the capture of additional data. While the numbers, strictly speaking, cannot justifiably reflect the trend in the industry as a whole, the reasons behind them are indeed worthy of note, presented in the following paragraphs. Looking at the motivations, some conclusions can be made about the current state of data-capturing. There is an evident need for the capture of items, additional to what is currently available in the archives. The responses show a problem with the capturing of data itself. In addition, the incentive for personnel to access the information also poses a challenge. Lack of motivation by user to extract knowledge is attributed to the fact that the documented material is not properly organised into sensible packages to be stored. This causes the problem of excessive effort and time required by the user, who essentially is carrying out the filtering of materials in order to obtain the relevant applicable knowledge. Information available is regarded more as raw “historical data” rather than synthesized knowledge or lessons. Furthermore, lots of

information gets lost before it gets captured. This indicates that information waste is still common and there is no adequate system to record lessons or knowledge efficiently.

7.7.3 Additional items to capture

Objective 3) is to investigate possible additional items worth capturing, other than existing contents of project archives. When analyzing the additional desirable items to capture, it is apparent that the problem does not reside in data-capturing alone. Closer inspection revealed that the items listed by respondents to be additionally captured, mostly do not fulfil the theoretical definition of “data”. The additional items listed are in fact more to do with lessons learnt within specific circumstances or stages during the project and implies a result of some degree of data analysis and interpretation. Even though the lessons may be linked to or arise from data captured, capturing more “data” alone will still not be able solve many prevalent problems. Rather, more processes must be introduced or improved to promote the analysis and organisation of this wealth of data, synthesizing data into knowledge/lessons, which can be stored structurally and therefore accessed quickly and efficiently by future personnel. It is also found that there is little or no differentiation among industry personnel between data, information and knowledge or lessons. There is a lack of understanding of the nature of these components of intelligence, and the acquisition of these entities in record, which are currently handled in combined confusion, making it even more difficult to access by other personnel.

7.7.4 Data and Knowledge Management Systems

Questionnaire objectives 4) and 5) – to investigate the existence of data-capturing system and a database/framework/KM system – is addressed here. The responses yield some interesting results. Eight, out of the nine who desired additional data-capture, already has a data-capture system. Furthermore, four out of these eight, indicated the existence of a KM system at their organisations. This indicates that there is general dissatisfaction regarding the current state of data-capture and KM systems.

Here the numbers are of secondary importance; rather the definition or description given by the respondents regarding the systems is of interest, as it clarifies the way different terms are understood by different people. The descriptions of data-capture and KM systems are found to be very inconsistent and some were unsure, as they have never used such a system firsthand, but are merely aware of it. The systems listed by the respondents consist of software packages, document management systems, records of technical data, electronic archiving and project information management systems, most of which capture data alone and there was little indication of systematic analysis and synthesis of this data into higher level lessons or knowledge.

7.8 Outcome of Phase-1 questionnaire

Considering the conclusions of the questionnaire, it can be generally assumed that it is very difficult, if at all possible, to extract meaningful lessons and knowledge from data, given the current state of project archives, data-capturing systems and the general perception among industry personnel regarding data, information and knowledge. The lack of differentiation between data, information and knowledge/lessons leads to the disorderly storage and handling of all of these components. This thus creates a disarray of data, information and knowledge, which is extremely difficult to further process and undergo analysis or synthesis. Even if the data is available somewhere in an organisational repository, it is difficult to access, moreover to further organise this data sufficiently, to allow lessons to be sensibly synthesized.

The outcomes, arising from the Phase-1 questionnaire can be condensed in point form as follows:

- The project or archive, however thorough or complete, is not easily available for future access.
- The content of the project archives is limited in scope and items are not sufficient for historical analysis of more specific issues later on, such as constructability lessons.
- Numerous potential lessons can be learnt from captured data. However, there is in principle dissatisfaction of the data-capturing activities.
- It is beneficial to capture more data, information and knowledge.
- The capturing systems have premise for improvement in terms of offering more relevant data
- There needs to be focus on the analysis of the captured data in deriving lessons learnt.
- There needs to be focus on the direct extraction of lessons and knowledge from personnel (not from data) through lessons learnt programmes.
- There needs to be focus on the structured or organised storage of data, information and knowledge in order to achieve time- and effort-efficient accessibility for the user.

Knowledge Management systems needs to be implemented to address these problems. Essentially data/information needs to be made accessible in the form of knowledge, so that there is no lengthy combing of historical data required on the part of the user. This would lead to reduced time and effort of knowledge acquisition. A standardized system can be devised and information technologies can even be used to fulfil knowledge management functions, which otherwise can also be accomplished by an assigned individual – as a dedicated knowledge management champion.

Constructability related challenges can be improved with good construction integration in the design. The integration aspect can be brought about by the sharing of lessons and knowledge between the contractor and designer. The outcomes and problems identified in the Phase-1 questionnaire is an apt reflection of how constructability data, information and knowledge are handled and managed. Regardless of the explicit definition of constructability – which is covered in the Phase-2 questionnaire

– an effective and comprehensive data-capture system needs to be in place, in order for sensible constructability knowledge to be synthesized from data and shared accordingly.

Further questions arising from the literature study, as well as from the Phase-1 questionnaire, are translated into the investigations in the Phase-2 questionnaire. The Phase-2 questionnaire is discussed in detail in the following 2 chapters (Chapter 8 and 9).

Chapter 8 Phase-2 Questionnaire Administration

The Phase-1 questionnaire investigated in detail different aspects of archival data in organisations. The general conclusion is that constructability knowledge and lessons are difficult, if at all possible, to be derived from archival data alone. Respondents are generally not satisfied with the current state of available data/information/knowledge in the project archives and generally sought for better systems to capture data and manage knowledge. The reasons have been discussed in detail in the previous chapter. This chapter describes the ensuing investigations of the Phase-2 questionnaire. The rationale of the Phase-2 questionnaire, compilation and distribution, and the profile of the respondents are presented in this chapter, while the discussion of the findings and subsequent conclusions are presented in the following chapter.

8.1 Phase-2 questionnaire rationale

From the synthesis of the literature study (Chapter 6), many further questions are identified. Besides aspects of archival data, which is already investigated in the Phase-1 questionnaire, the following points from the literature study synthesis are covered in the Phase-2 questionnaire:

- 1) Labour efficiency principles of constructability
- 2) Criteria of constructible design
- 3) Constructability of building components
- 4) Project close-out meetings
- 5) Knowledge sharing
- 6) Lessons learnt programmes

The motivations for each of these points are already covered in Chapter 6 (on the synthesis of the literature study) and thus will not be discussed in this section. Rather, this chapter covers the details within each of these points and how the specific research questions are formulated.

Note that the Phase-1 questionnaire investigated the possibility that raw, explicit data can be derived to form lessons and knowledge – as a starting point of knowledge management – which is shown to be ineffective for numerous reasons. The conclusions from the Phase-1 questionnaire support the direction of the Phase-2 questionnaire, where the investigation shifts more to the management of constructability knowledge primarily in tacit form. The points listed above are all geared to further explicate constructability knowledge, explore a means to quantify constructability further and implement initiatives to manage constructability knowledge given its tacit nature.

Points 1), 2) and 3) above seek to further refine the understanding of constructability and by exploring the perceptions from industry on the different aspects. Points 4), 5) and 6) take the investigation

further to aspects of implementation, by exploring industry perceptions surrounding management and sharing of constructability knowledge.

Through the literature review deductions, it is evident that the key to improving constructability lies in improving the knowledge management of constructability knowledge, so that all project participants can make informed decisions, knowing the implications of their decisions on subsequent project phases. Project phases can be rationalized to two distinct components: design and planning; and construction and execution. It can thus be deduced that the main contributor to constructability problems is the fact that designers and planners do not embody sufficient knowledge and expertise from subsequent phases (construction or execution) of the project. It is prevalent that the planning and design, carried out by consultants, are done without proper communication and alignment of interests with construction and execution, which is carried out by contractors.

This is a crucial guiding factor for the Phase-2 questionnaire. The Phase-2 questionnaire seeks to understand the discrepancies between consultants and contractors, the way different interpretations and interests occur, regarding each of the points mentioned in the list above. This questionnaire also explores in detail the reasons behind these discrepancies. Understanding the two perspectives – of consultants and contractors – is a significant feature of the Phase-2 questionnaire.

The research findings and discussions are presented in the following chapter. This chapter covers the details of the Phase-2 questionnaire itself – such as the specific questionnaire objectives; distribution platform; selection and profile of respondents; and the compilation of the questions in the questionnaire.

8.2 Phase-2 Questionnaire Objectives

The Phase-2 questionnaire addresses the 6 points mentioned in the previous section, which are investigated in detail with respect to both the consultant and the contractor. The aim of this questionnaire is to regard the trends prevalent among the two groups, and to discuss and mediate the differences between them. The 6 points from above can be translated into six explicit objectives. An additional 7th objective is added in order to gain in-depth understanding of specific cases of constructability problems experienced on site. This is extremely important in giving a realistic and practical perspective to the rest of the questionnaire. Furthermore, the 7th objective enables a more accurate viewpoint for specific constructability problems on-site, for better implementation of improvement measures. The 7 explicit objectives of the Phase-2 questionnaire are as follows:

- 1) Explore the perceptions of labour efficiency principle of constructability, and understand the preference between equipment- or labour-intensive work, concurrently between in-situ and pre-cast concrete.

- 2) Investigate industry opinions regarding criteria of constructible design, and the extent that they are fulfilled in the experience of the respondents
- 3) Explore the constructability of different versions of building components – structural frame, slab, façade wall, roof, roof support, internal wall.
- 4) Investigate the attendance of project close-out meetings and the attendees.
- 5) Investigate the popularity of different modes of knowledge sharing as employed in the industry.
- 6) Investigate the perceptions regarding the nature and implementation of lessons learnt programmes in the industry, the activities associated with the identification, analysis and implementation of lessons.
- 7) Explore real/practical constructability problems in the field during project execution, through open answers by respondents.

The outcome of the Phase-2 questionnaire address the discrepancies between the consultant and contractor – in terms of interests; knowledge; perceptions on design criteria, principles and subsequent quantification of constructability; and the implementation of Knowledge Management initiatives. In doing so, a more explicit model of constructability can be established and thus creates a clearer premise for the identification of solutions to improve the non-integration and misalignment between design and construction expertise. The findings and conclusions of this questionnaire directly contribute to the formulation of a broad strategy to improve constructability through knowledge management, presented at the end of the thesis.

8.3 Questionnaire Distribution

A great deal of qualitative data needs to be extracted from experienced personnel in the industry, from both consulting and contracting disciplines. Unlike the Phase-1 questionnaire, where the respondents are reachable in person, the Phase-2 questionnaire requires remote distribution of these questionnaires.

A list of potential respondents was first drawn up. To ensure optimal response rates, each respondent was contacted in person, with a brief introduction to the research, and prompted to reply with their willingness to take part in the research. All the potential respondents that replied positively were sent the questionnaire. Respondents were given three weeks to respond with a completed questionnaire. The detailed records were kept of all correspondences, emails, replies and the dates involved. One

week before the specified response deadline, a reminder was sent out to those that has not yet responded.

8.4 Profile of Respondents

Respondents are required to be of both consultants and contractors – approximately the same number of respondents for each, so as to allow sensible comparison of the results. Consulting and contracting personnel are chosen, all of which has leading roles at their organisations, substantial amounts of professional experience, and familiar with Civil and Building projects. Also, only contractors with CIDB (Construction Industry Development Board) grading of 9CE and/or 9GB are chosen. The description of the “CE” and “GB” designations are shown in table 8-1 below. There are a few other designations – Electrical Engineering Works (EE); Mechanical Engineering Works (ME); Specialist Works (SA to SP) – which are not shown here to prevent excessive irrelevant information.

Table 8-1 CIDB designations CE and GB for contractors

Description	Designation	Definition	Basic work types
Civil Engineering Works	CE	Construction works that are primarily concerned with the materials such as steel, concrete, earth and rock and their application in the construction, operation, maintenance and management of hydraulic, structural, environmental and systems aspects of infrastructure works and services.	Water, sewerage, transport, urban development and municipal services
General Building Works	GB	Construction works that: a) are primarily concerned with the provision of permanent shelter for its occupants or contents; or b) cannot be categorised in terms of the definitions provided for civil engineering works, electrical engineering works, mechanical engineering works, or specialist works.	Buildings and ancillary works other than those categorised as being: a) civil engineering works; b) electrical engineering works; c) mechanical engineering works; or d) specialist works.

According to the CIDB grading system, the grading value goes from 1 (lowest) to 9 (highest). The grading value of an organization is dependent on several main criteria required by the organisation:

- Best annual turnover over 2 years immediately preceding application
- Available capital
- Largest contract over 5 years immediately preceding application
- Number of ECSA registered professionals employed
- Maximum contract value contractor is considered capable of

Details of classifications can be found on CIDB's website: <http://www.cidb.org.za>

For the Phase-2 questionnaire, a total of 50 potential respondents – 21 consultants and 29 contractors – had been initially identified and eventually 28 respondents returned completed questionnaires. The total 28 respondents form the total sample group, consisting of 11 consultants and 17 contractors. The details of the consultant and contractor respondents, as well as their profiles are shown in table 8-2 and table 8-3 respectively. The lists of “job position” and “main business discipline” are generated comprehensively for each respondent, exactly as given by them.

Table 8-2 Consultant respondents' profiles (continue to next page)

Consultants	
Nr of respondents	11
Years of experience	Average: 23 years Range: 15 to 36 years
Job position for each respondent	<ol style="list-style-type: none"> 1. Designer 2. Technical director, senior engineer 3. Principal structural engineer 4. Owner 5. Owner, designer, project manager 6. Structural engineer 7. Director 8. Technical director 9. Technical director 10. Principal engineer 11. Director

Consultants	
Main business discipline for each respondent	<ol style="list-style-type: none"> 1. Building structures 2. Building structures 3. Civil and building structures 4. Design and project management 5. Buildings 6. Buildings 7. Buildings, structural, industrial and mines 8. Buildings 9. Buildings 10. Civil and building structures 11. Buildings

Table 8-3 Contractor respondents' profiles (continue to next page)

Contractor	
Nr of respondents	17
Years of experience	<p>Average: 21 years</p> <p>Range: 5 to 40 years</p>
Job position for each respondent	<ol style="list-style-type: none"> 1. Contracts manager 2. Project manager 3. Operations director 4. Contracts director 5. Alternate contracts director 6. Engineering manager 7. (not given) 8. Site agent 9. (not given) 10. Director, production and site construction 11. Contracts director 12. Contracts director 13. Director 14. Contracts manager 15. Senior contracts manager 16. Contracts director 17. Director of major building works

Contractor	
Main business discipline for each respondent	<ol style="list-style-type: none"> 1. Building and Civil 2. Building 3. Building 4. Civil structures 5. Civil structures 6. Civil structures 7. Civil structures 8. Civil structures 9. Precast concrete structures 10. Precast manufacturer 11. Civil and roads 12. Building, civil, roads and earthworks 13. Building 14. Building 15. Roads, buildings, civil structures and mining 16. Building 17. Buildings, civil and roads

8.5 Phase-2 questionnaire compilation

This section covers some considerations and activities during the compilation of the questionnaire to ensure optimum results. Furthermore, the questions of the questionnaire are briefly described with a short motivation or explanation as applicable. For the full Phase-2 questionnaire, as distributed to the respondents, please refer to Appendix D.

The length of the questionnaire required careful consideration as the questionnaire is intended for distribution in an electronic format. The tentative questionnaire was first reviewed by three individuals – research supervisor, peer researcher and one personnel in the industry – to scrutinize the following points of consideration:

- Length of the questionnaire
- Clarity of the questions
- Ambiguity in the questions or potential misinterpretation, causing incorrect answers
- Confirm that the data input function works
- Ease of use of the platform

The final questionnaire is the optimal result of the above points of consideration. The questionnaire consists mostly of multi-choice and closed questions where respondents are required to input a

choice or a qualitative ranking depending on their perception of a certain issue in question. Open questions are also employed to extract un-biased, accurate details of the constructability problems in the experiences of the respondents. The open questions' part requires some memory recall and reasoning. It is thus kept as short and concise as possible, to prevent any strain from respondents' completion of the questionnaire and placed strategically within the questionnaire to follow where the frame of thought is optimal for answering the open questions. Essentially the same questionnaire is sent to both the consultants and contractors. However, the wording of some questions is re-phrased to fit the context and understand of the two backgrounds.

An important principle in this questionnaire is that the respondents are never asked to directly define "constructability" exclusively. It is after all one of the objectives of this research to more explicitly define constructability in quantifiable terms. Constructability can itself be an ambiguous and interpreted differently by different people. The concepts of constructability has to a great extent been broken down and refined in this research, from literature, deductions in the synthesis of the literature review and some results of the Phase-1 questionnaire. This Phase-2 questionnaire breaks down constructability into its defining components, identified earlier; and poses specific questions to the respondents to target a certain perspective of constructability. The phrasing of each question in the Phase-2 questionnaire is designed to handle a specific perspective of constructability, the total combination of which should define constructability comprehensively. This feature upholds the principle of triangulation further in this manner.

The questionnaire is based on the 7 objectives of this questionnaire as discussed previously, and is set out as 7 specific questions in the Phase-2 questionnaire. The following sections cover the questions with a short explanation for each.

8.5.1 Labour efficiency principles of constructability

The contractor respondents are asked how they would prefer to construct a typical building project, while the consultants are asked what principles they would apply during conceptual design, for better constructability. Respondents need to choose between labour intensive and equipment intensive work; and between in-situ and precast concrete methods.

The responses offer some insight to how respondents view the traits of good constructability. The results are compared to the principle that labour-efficiency is central to constructability – as adopted by the Singaporean Buildable Design Appraisal system.

8.5.2 Criteria for constructible design

A list of “buildability factors” is already identified from the literature study (section 4.6), which can be regarded as criteria for sound design – thus constructible design. These 9 criteria for sound design are presented to the respondent as follows:

- 1) Allow economic use of contractor’s resources
- 2) Enable design requirements to be easily visualised and co-ordinated by site staff
- 3) Enable contractors to develop and adopt alternative construction details
- 4) Enable contractors to overcome restrictive site conditions
- 5) Enable standardisation and repetition
- 6) Enable freedom of choice between prefabricated and onsite works
- 7) Enable simplification of construction details in case of non-repetitive elements
- 8) Minimize the impact due to adverse weather by enabling a more flexible construction programme
- 9) Allow design to achieve safe construction sequences on site

The respondents must, according to their perspectives and experience in their specific discipline (consultant and contractor), identify the 5 most important criteria, and then rank these 5 criteria in order of importance from 1 to 5 (1 being most important). Furthermore, the respondents are asked to identify 3 criteria that are least fulfilled in the project designs that they have worked with.

The criteria contribute to defining the constructability of project designs more clearly. The results would show the perspectives of industry regarding which criteria are more important than others. This question is based on the premise that the more important a criterion is regarded, the more it will contribute to constructability – thus being a better constructability “factor” or “principle”.

8.5.3 Constructability of building components

The components of a typical building are presented to the respondents. Each component can be designed or built in different configurations, as shown in table 8-4. Respondents are asked to qualify each design/building configuration with regards to “ease of construction”.

Table 8-4 Building components and configurations

Building Components	Design/Construction configuration
STRUCTURAL FRAME	<ul style="list-style-type: none"> • Precast RC frame • In situ RC frame • Structural steel frame with fire proof • In situ load-bearing wall • Steel sections encased in concrete (composite) • Concrete filled steel hollow section (composite)
SLAB	<ul style="list-style-type: none"> • In situ RC flat slab • In situ RC slab upon beams • In situ RC slab with post tensioning • Precast slab with in situ topping • Steel deck as permanent shuttering
FAÇADE WALL	<ul style="list-style-type: none"> • Glass curtain wall (glass façade panels) • Concrete curtain wall (concrete façade panels) • Concrete masonry (brick) wall with applied finishes • Precast RC wall with pre-installed windows and finishes • In situ RC wall with applied finishes
ROOF	<ul style="list-style-type: none"> • In situ concrete roof • Precast concrete roof • Steel truss roof with composite decking • Steel decking with in situ concrete topping • Timber roof trusses
ROOF SUPPORT	<ul style="list-style-type: none"> • In situ concrete ring beam • Precast concrete ring beam
INTERNAL WALL	<ul style="list-style-type: none"> • Dry wall (partitions) • Concrete masonry wall with applied finishes • In situ RC wall with applied finishes • Precast RC wall with applied finishes

For each configuration, the respondent must qualify the ease of construction of each configuration by selecting from the 4 progressive choices given. This question is designed with 4 choices, so that the respondent cannot select a neutral choice, which will make sensible analysis difficult. The 4 degrees of “ease of construction” are as follows:

- Impossible to build
- Very difficult to build
- Buildable
- Easily buildable

Since “constructability” itself has not been explicitly (or quantifiably) defined, the phrase “ease of construction” is used in this question to guide the respondent to make the relative comparison. This phrasing of the question is based on the premise that the easier a specific configuration can be built (according to respondents), the more it embodies constructability traits, and thus the more constructible it is. An important outcome of the results here, besides the relative comparison of different degrees of constructability between different configurations, is the broader understanding of how constructability is defined, by regarding different building components’ configurations.

8.5.4 Project close-out meetings

The respondents are asked if project close-out meetings are carried out at their organisations. If yes, respondents are asked to list the typical attendees.

Substantial amounts of project knowledge flow occur at project close-out meetings – including constructability and risk related knowledge, tying closely with lessons learnt programmes. Attendees are typically debriefed and experiences shared and documented. The attendees of a project-close out meeting give a good indication of the types/designations of knowledge present. In principle, it would be ideal to have personnel from all project phases present at the close-out meeting to share their experiences on the project. This question investigates the nature of project close-out meetings by analysing the attendees.

8.5.5 Knowledge sharing

Knowledge sharing is discussed briefly in the literature study. This question focuses on the human factors of knowledge sharing, which also includes constructability knowledge. This is done by investigating the frequency or popularity of the different knowledge sharing modes. A list of knowledge sharing modes in an organisation is presented to the respondents as follows:

- Internal databases
- Emails
- Memoranda and letters
- Knowledge sharing boards
- Internal newsletters and circulars
- Phone calls and tele-conferencing
- Meetings
- Project briefing and review sessions
- Newsgroup and web-based discussions
- Training/mentorship programme
- Talks and seminars

The respondent is asked to qualify each of these modes based on “popularity of used” to share knowledge in general, by selecting from 5 progressive choices given:

- Never used
- Unpopular
- Neutral
- Popular
- Very popular

The results are used to draw up a list of most popular modes of knowledge sharing. To investigate how knowledge is shared within an organisation, it is crucial in determining the potential effectiveness of constructability knowledge dissemination, given the tacit nature of constructability. This also contributes directly to the formulation of the overall strategy of implementing knowledge management initiatives.

8.5.6 Lessons learnt programmes

This part consists of several questions investigating the current status of lessons learnt actions in the industry. The following presents the 3 main questions in the lessons learnt programme part of the Phase-2 questionnaire:

- 1) The respondents are asked to choose whether the lessons learnt activities at their organisations are: formal, informal or does not exist at all. Respondents are given the following guidelines:

Formal – standardized protocol built into organisational process, with designated coordinator

Informal – occurs haphazardly, no standard process, no designated process coordinator

Does not exist – no lessons-learnt actions whatsoever

- 2) Only the respondent who chooses “Formal” or “Informal” previously may complete this question. From literature, the lessons learnt process consists of 3 main processes – lessons identification, lessons analysis and lessons implementation. The respondents are given the lists of methods/occasions where each of the 3 processes can be carried out, as shown in table 8-5.

Table 8-5 Lessons learnt processes and methods where they can be carried out

Lessons learnt processes	Methods to carry out lessons learnt processes
LESSONS IDENTIFICATION	<ul style="list-style-type: none"> • Project close-out meetings • Intermediate meetings • Interviews • Electronically • Paper forms • Informally (word of mouth) • Outside consultant
LESSONS ANALYSIS	<ul style="list-style-type: none"> • Project close-out meetings • Intermediate meetings • By a subject matter expert • Electronically • By an outside consultant
LESSONS IMPLIMENTATION	<ul style="list-style-type: none"> • At meetings • As part of changes to a work process • At project kickoffs • Through electronic databases • Through training programmes • Informally (word of mouth) • Training/mentorship programmes

For each of the 3 lessons learnt processes, the respondents are asked to indicate the activities/occasions where the respective lessons learnt process is carried out. Respondents are to tick off from the list of methods/occasions listed or if there are activities/occasions not on the list, they are requested to specify them. Furthermore, respondents are prompted to comment whether the methods/occasions ticked off are carried out “during” or “after” the project.

- 3) Lastly, the respondents are asked to rate the effectiveness of lessons learnt programs currently implemented at their organizations. Then they are prompted to rate what they believe to be the full potential of lessons learnt programmes. The scale of effectiveness for both questions is given as follows:

Very effective
Somewhat effective
Neutral
Not effective
Detrimental

The answers from the 3 questions give an indication of the perception of current state of lessons learnt programme and whether there is avenue for improvement in the opinion of the respondents. This also indicates the respondents' susceptibility or potential likelihood to support further improvement actions with respect to lessons learnt programmes.

8.5.7 Constructability open questions

The respondents are asked to think back on the last 5 South African projects undertaken, or any 5 that are fresh in their memory, list them and provide a short description of each. Then, the respondents are asked to identify, with a short description, up to 5 considerable "constructability issues" from any of the projects listed previously. Lastly, for each of the "constructability issues" identified, the respondent is asked whether or not the specific constructability issues "could have been avoided, if the design possessed better constructability" – in other words, whether or not the constructability problems are rooted in the design from the start.

The analysis of these specific constructability issues and cases are essential in seeing the perceptions of constructability in practical perspectives. These further clarify the implications of the responses from other constructability related questions and create a means to validate the implementation of certain knowledge management initiatives to improve constructability.

The following chapter presents the results of the Phase-2 questionnaire, followed by the discussions of ensuing deductions. The open questions, regarding the real constructability cases/issues in practice (described in section 8.5.7) are covered in a separate chapter (Chapter 10).

Chapter 9 Phase-2 Questionnaire Findings and Discussion

This chapter presents the results from the Phase-2 questionnaire as described and motivated in the previous chapter. For each part of the questionnaire, the data handling and calculations are briefly explained, followed by the results and discussions. Results for both the consultant and contractor respondents are presented separately and possible discrepancies are identified and analysed. In the end of the chapter, a summary of the outcomes or conclusions of the Phase-2 questionnaire is given. The open questions on real constructability cases/issues in practice will be covered in the following chapter, separate to this chapter.

For better readability, consultant and contractor respondents are referred to simply as “consultants” and “contractors” in the discussions of this chapter. Note that the references to “consultants” and “contractors” in this chapter thus do not imply consultants and/or contractors collectively in the industry as a whole.

Many of the results are presented in percentage form or normalized cumulative weights (also averages), obtained through the calculations. The analyses are handled critically with these numbers. It is important not to read too much into these output results, as they are obtained through statistical analysis of qualitative data based on perceptions. Therefore the results are interpreted with a reasonable degree of scepticism and tolerance. The numerical outputs are accepted more as suggestive indicators, rather than precise, absolute values, which may be dogmatic in this case. The research takes care to consider all the limitations implicit in the research principles and questionnaire processes.

Furthermore, regarding the interpretation of numerical outputs, a point/weighting system is used for many of the quantitative activities. When these points/weights are summed, cumulative weights in absolute form is obtained firsthand; then it is normalized to represent a percentage weight for comparison between consultants and contractors. It is also important to note that the cumulative weights do not represent any absolute value or meaning on its own, but are all regarded relatively and in comparison to other cumulative weights, for ranking purposes. The reason for normalizing these weights is so that a consistent comparison can be done between consultants and contractors, as both these are made up of a different number of respondents. Without normalizing the cumulative weights, comparison between consultants and contractors is impossible.

9.1 Labour-efficiency principle of constructability

The respondents are asked what principles/methods they would prefer to employ in their projects. They must choose between labour- and equipment intensive (work principle); and between precast- and in-situ (concrete system). The results are presented in table 9-1, as the numbers and (in brackets

next to it) percentages of respondents that made the specific choices. The discussions of the results follow.

Table 9-1 Principle for work and choice of concrete system

	Work		Concrete	
	Equipment intensive	Labour intensive	Precast	In-situ
Consultant	11 (100%)	0 (0%)	1 (9%)	10 (91%)
Contractor	16 (94%)	1 (6%)	12 (71%)	5 (29%)

9.1.1 Preference of work principle

All the consultants favour equipment intensive work, and almost all of the contractors feel the same. It is interesting to note that contractors are also in favour of equipment intensive work over labour intensive. This may be due to a variety of reasons, not investigated in detail in this research, but can include the inherent risks in quality, workmanship, safety and general inconsistencies of labourers. There may also be a tendency for labourers to go on strike, which can be closely related to the nature of South African workers' unions and general socio-political condition, out of the control of the project team.

9.1.2 Preference of concrete system

According to the construction culture in South Africa, it is typically assumed that in-situ concrete is preferred. This is true with the results from consultants, most of which indicated that they would prefer to use in situ concrete. However, the contractors (with a 70-30 distribution in favour of precast) can be said to prefer precast concrete in construction. This misalignment between consultants' and contractors' perceptions regarding the concrete system is worthy of note.

9.2 Criteria of constructible design

9.2.1 Relative importance of constructability criteria

Respondents are given 9 criteria of constructible design, as discussed in the previous chapters. They are asked to identify what they think are the top 5 criteria and rank these 5 in order of importance.

Each set of rankings are translated into weight points – the 1st rank (top importance) is given a weight point of 5 and linearly decreasing so that the 5th rank is given 1 point. For each criterion all the points are summed to give an absolute cumulative weight, which represents its importance. These absolute cumulative weights are normalized to percentage form (out of 100), to represent the relative importance of each constructability criterion. The 9 constructability criteria are then ranked in order of

importance, as shown in figure 9-1 and figure 9-2. For ease of reference and comparison, the criteria below are numbered (C1-C9) and presented as such in the figures of this section.

- C1 Allow economic use of contractor's resources
- C2 Enable design requirements to be easily visualised and co-ordinated by site staff
- C3 Enable contractors to develop and adopt alternative construction details
- C4 Enable contractors to overcome restrictive site conditions
- C5 Enable standardisation and repetition
- C6 Enable freedom of choice between prefabricated and onsite works
- C7 Enable simplification of construction details in case of non-repetitive elements
- C8 Minimize the impact due to adverse weather by enabling a more flexible construction programme
- C9 Allow design to achieve safe construction sequence on site

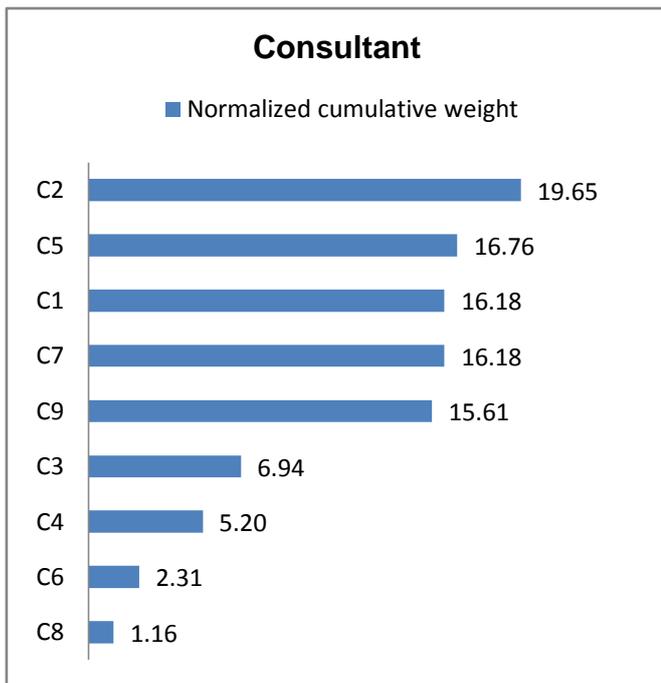


Figure 9-1 Relative importance of constructability criteria by consultants

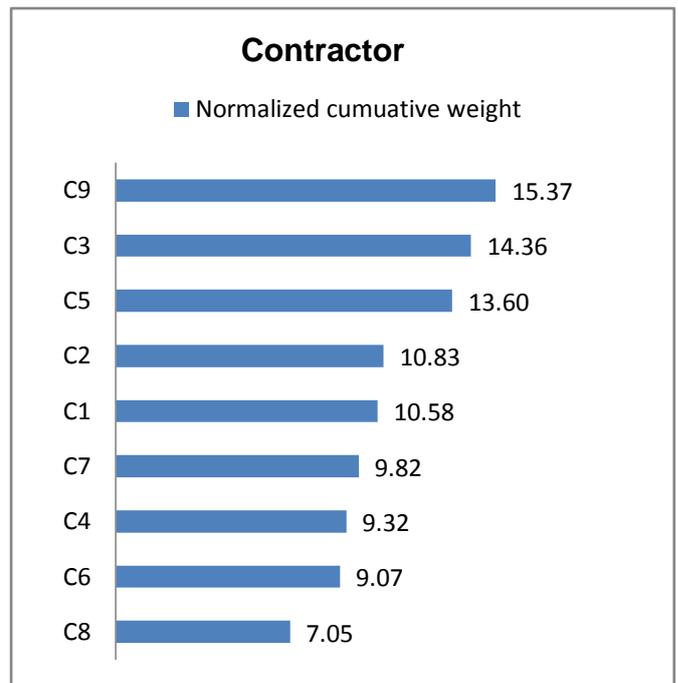


Figure 9-2 Relative importance of constructability criteria by contractors

Note that the normalized cumulative weights do not represent a degree, on some scale of importance. Rather, it represents the relative importance to all the other criteria – in other words, how much more/less important is one criterion than another.

Looking at the figures of relative importance alone, one can see that consultants seem to exhibit more assertive or decisive results overall. In other words, variation of answers is more distinct, indicating that the consultants agree more with each other. From figure 9-1, the top 5 criteria by consultants distinctly show more importance than the rest. On the other hand, the contractors exhibit a more gradual gradient of relative importance, which shows that their opinions on criteria importance form a

wider spread. This suggests that consulting work is more consistent (leading to more similar overall opinion), where contracting is less standardized and consists of a more diverse variety of overall opinions. However, it is interesting to note that not one criterion is left unselected by respondents, meaning that every criterion bears enough significance to a respondent to be ranked as the top 5 most important, according to him/her subjectively.

The constructability criteria's ranking positions for both contractors and consultants are presented in table 9-2, listed with respect to contractors ranking.

Table 9-2 Ranking table of constructability criteria with respect to contractors

Nr	Constructability criteria	Rank of Contractor	Rank of Consultant
C9	Allow design to achieve safe construction sequence on site	1	5
C3	Enable contractors to develop and adopt alternative construction details	2	6
C5	Enable standardisation and repetition	3	2
C2	Enable design requirements to be easily visualised and co-ordinated by site staff	4	1
C1	Allow economic use of contractor's resources	5	3
C7	Enable simplification of construction details in case of non-repetitive elements	6	4
C4	Enable contractors to overcome restrictive site conditions	7	7
C6	Enable freedom of choice between prefabricated and onsite works	8	8
C8	Minimize impact due to adverse weather by enabling more flexible construction programme	9	9

Interpretation and comparison of these criteria is based on the premise that the opinion of the contractors is primary reference. Discrepancies are identified with respect to the ranking of the contractor. It is difficult to find correlation among the higher ranked criteria; a few major discrepancies can be identified. Nevertheless the bottom 3 criteria – C4, C6 and C9 – have exact correlation. From this, it can be said that the consultant and contractor agree with regards to the least important constructability criteria.

More correlation can be observed with regards to the "relative ranking" (as opposed to the ranking position). For example: according to both consultants and contractors, C9 is more important than C3; C2 is more important than C1; C1 is more important than C7; and C7 is more important than C4. (Refer to table 9-2 for description of criteria)

Criteria C9 (regarding construction safety) is ranked 1st by contractors, but ranked only 5th by consultants. This suggests that construction safety is typically viewed to be achieved during project execution and thus rests with the responsibility of the contractor. However this is not completely true, as the design phase often dictates the ensuing construction details on site, and may thus contribute to safety implications.

Criteria C3 (regarding flexibility in construction details) is ranked 2nd, but only 6th by consultants. This is a key discrepancy that needs to be addressed. Consultants need to provide more flexible designs that enable contractors to develop or adopt alternative construction details.

Criteria C5 (regarding standardization and repetition) correlates well between consultant and contractor, ranked 3rd and 2nd respectively. It can thus be deducted that standardisation and repetition principles are equally highly regarded by both consultants and contractor.

Criteria C1 (on economic use of contractors' resources) and C7 (on simplification of construction details) correlates reasonably. For both these criteria, the consultants' ranks are a bit higher than that of the contractors (2 ranks apart), suggesting that it is unlikely that related problems (or misalignment of interests) on these 2 criteria would arise during project execution.

9.2.2 Least fulfilled constructability criteria

The respondents are asked to select 3 criteria from the 9 given, that are least or "most seldom" fulfilled in their project experiences. It is decided to phrase the question negatively, (as opposed to asking "which criteria are the most fulfilled?") because it gives the respondents a sense of problem-identification. It is easier and probably more accurate to recognize hindrances in the past rather than successes, especially when these criteria can be flexibly interpreted. This question thus takes specific interest in the problems of non-fulfilled constructability criteria, comparing it to the criteria that are deemed most importance.

Every time a criterion is selected, it is given a weight point of 1. All the weight points are then summed to obtain cumulative weight points for each criterion. These cumulative weight points represent the number of respondents that chose a specific criterion as one of the "least fulfilled". The number of respondents for each criterion is presented as a percentage of total respondents, and then the criteria are ranked accordingly. It is assumed that the more respondents select a certain criterion, the less this criterion is fulfilled. The results according to consultants and contractors are represented in ranked decreasing order of least fulfilled criteria in figure 9-3 and 9-4 respectively. The numbering of the criteria is as previously indicated. As an example for clarity, the figure 9-3 can be interpreted as follows: according to consultants, criteria C6 is selected, by 73% of respondents, to be one of the least fulfilled constructability criteria etc. Furthermore figure 9-5 is an overlay of both the consultant and contractors results to better observe any correlation.

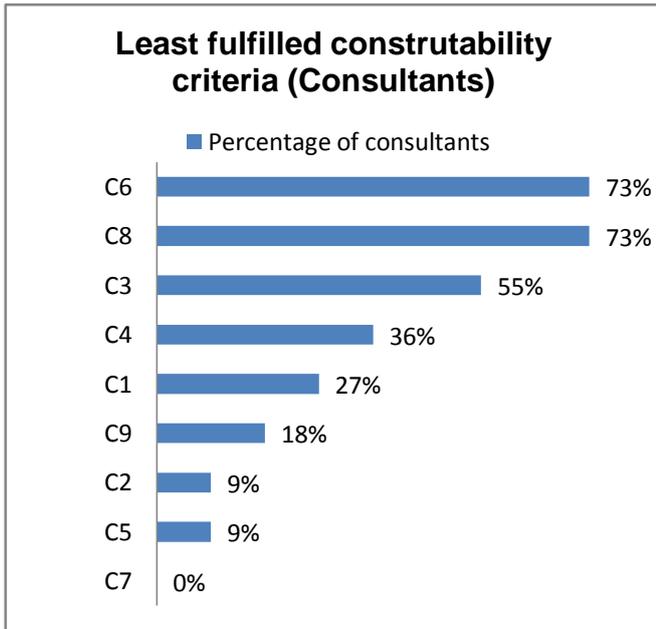


Figure 9-3 Least fulfilled constructability criteria according to consultants

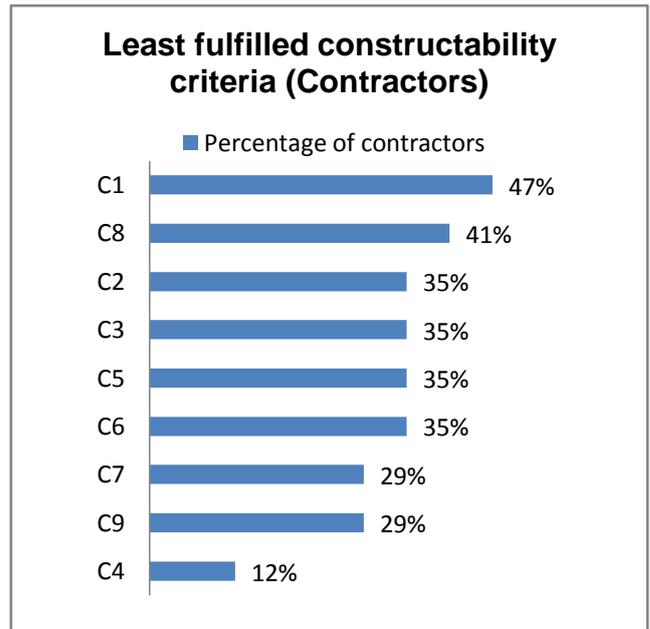


Figure 9-4 Least fulfilled constructability criteria according to contractors

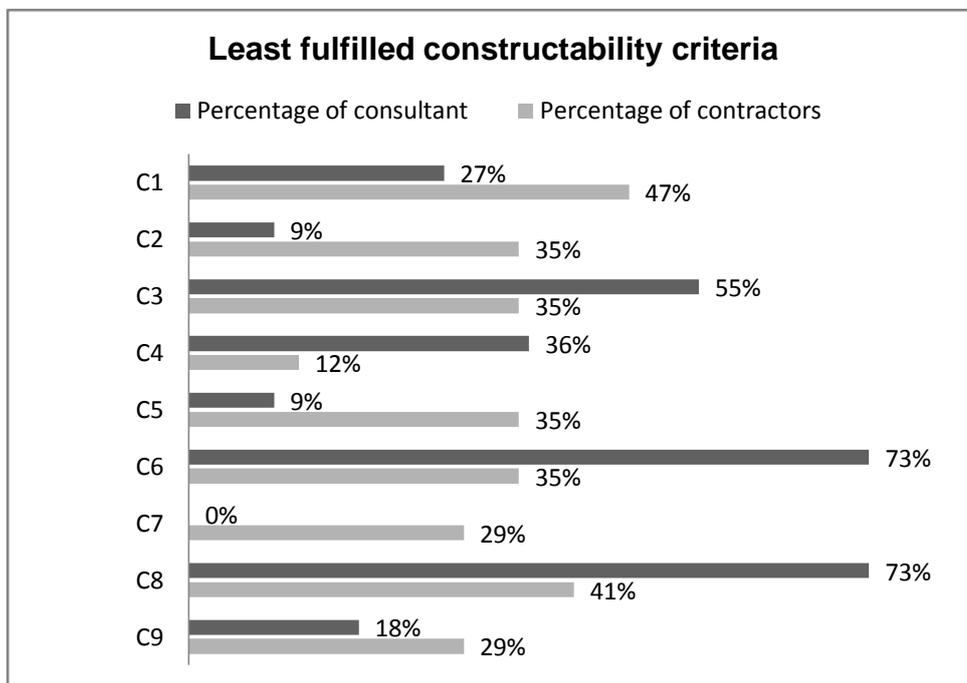


Figure 9-5 Overlay of least fulfilled constructability criteria according to consultants and contractors

From the figures above, the following paragraphs discuss the observations and interpretations.

Figure 9-3 and 9-4 shows a wider spread of opinions for the contractors. Closer attention needs to be given to the opinions of the contractors in this part of the analysis, because it can be assumed that contractors embody more constructability knowledge. Therefore, the contractors' perceptions of the

constructability criteria are more accurate and should be used as a reference point for the interpretation of the other results. Consultants' least fulfilled criteria are only regarded here for correlation.

As can be seen in figure 9-5, there seems to be no discernable correlation at all between the results of consultants and contractors. It can only be said that there is indeed a misalignment in the perceptions between consultant and contractor, regarding the fulfilment of certain constructability criteria.

It is thus not so meaningful to create a full ranking table for comparison. Instead, it is rather pertinent to take a closer look at the top 2 least fulfilled criteria of contractors – C1 (allow economic use of contractor resources) and C8 (minimize impact due to adverse weather by enabling flexible programme). It is needed for the designers to regard these two criteria with higher priority during the design stage, to improve their fulfilment for construction.

It is interesting to note that C8 (as a contractor's least fulfilled criteria) is only ranked 9th in importance by consultants (table 9-2). In other words, C8 is regarded least important by consultants, but is one of the least fulfilled criteria according to the contractor.

9.3 Constructability of building components

The components of a typical building (structural frame, slab, façade wall, roof, roof support and internal wall) are presented to the respondents. Each component can be designed or built in different configurations as indicated in the previous chapter under section 8.5.3. Respondents are asked to qualify each design/building configuration with regards to "ease of construction", the choices of which is shown in table 9-3.

Table 9-3 Ease of construction and corresponding weight points

Scale of increasing ease of construction	Weight point
Impossible to build	0 point
Very difficult to build	1 point
Buildable	2 points
Easily buildable	3 points

The quantitative analysis is done with a point system – each choice is given a weight point as shown in table 9-3. The weight points corresponding to the choices made by the respondents for each configuration are totalled to obtain the cumulative weight, and then normalized so that consultants' and contractors' rankings can be compared. Note that the normalized cumulative weight for each configuration is meaningless on its own, and must be compared relatively to the normalized

cumulative weights of other configurations. The normalized cumulative weights are used to rank the “ease of construction”, which should translate to constructability, of each configuration.

Furthermore, the average weight point of each configuration is obtained, which is a value that reflects a certain degree of “ease of construction” and can be interpreted as such, using the scale and corresponding weight point in table 9-3 as reference. These averages are used to overlay both the consultants’ and contractors’ results, for each configuration, on one graph for comparison of correlation with respect to the degree of “ease of construction” or degree of constructability. In all cases, the ranking of the contractors constructability is used as primary reference, as constructability knowledge is embodied mostly by contractors.

The following sections presents the questionnaire results as described in the paragraph above, for each building component, followed by some interpretation, analysis and deduction. Each building component section is set out in two parts: Firstly, the relative rankings of different configurations, which essentially indicate the preference of one over another. This dictates design choices in the case of consultants, and thus the construction specifications in later phases. Secondly, the correlation between consultant and contractor with regards to the degree of constructability (the average of each configuration’s constructability weight point) is covered. This shows more detail regarding the actual degree of constructability or “how easy it is to build”.

9.3.1 Structural frame

Relative constructability ranking of structural frame

The ranking of the structural frame configurations, according to contractors is explicitly tabulated in table 9-4. The relative ranking of structural frame configurations is done according to the normalized cumulative weight as described in the previous section. The results for consultants and contractors are shown in figures 9-6 and 9-7 respectively.

Table 9-4 Constructability ranking of structural frame configurations according to contractors

Constructability Rank (Contractor)	Configurations of structural frame
1	In situ RC frame
2	Precast RC frame
3	In situ load bearing wall
4	Steel frame with fire proof
5	Steel sections encased in concrete (composite)
6	Concrete filled steel hollow section (composite)

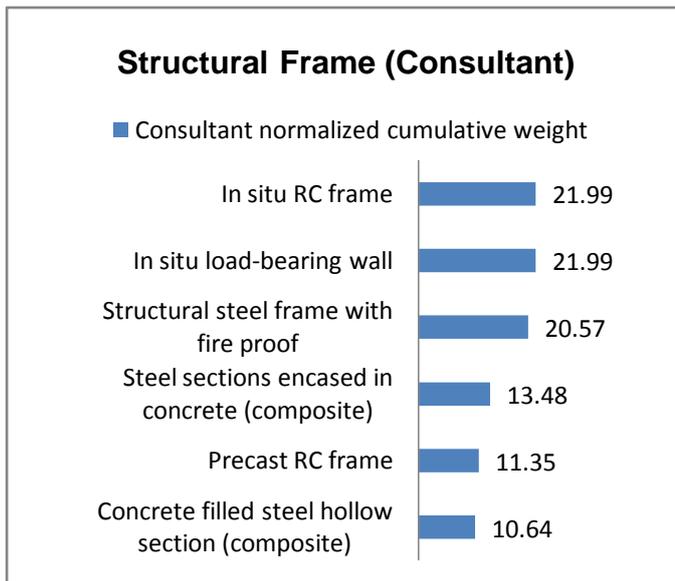


Figure 9-6 Constructability of structural frame configurations according to consultants

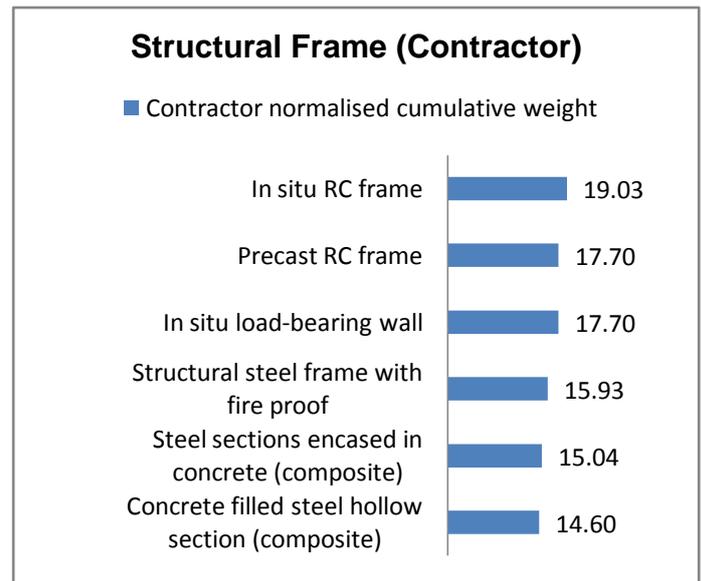


Figure 9-7 Constructability of structural frame configurations according to contractors

The constructability ranking of contractors is as expected – in situ RC frame being ranked 1st and above precast RC frame, which has the same constructability as in situ load-bearing wall, as can be seen in figure 9-7. Here is a notable point of contradiction. Under the previous section 9.2 on labour efficiency principles, 94% of contractors indicated that they preferred equipment intensive work and 71% indicated the favour of precast concrete over in-situ. This is contradictory to the results seen under this question where in-situ RC frame is favoured over precast for contractors. Interestingly, under the previous section, 91% of consultants chose in-situ over precast concrete, which in fact is the reflection of the consultants' constructability results here.

The composite configurations taking the lower ranks is as expected – composite construction being less common than the rest and thus hold inherent risks of uncertainty. Composite construction procedures may also hold unique complexities (not explored in this research) even though composite systems typically have higher structural efficiency and would probably save on material.

Structural frame correlation between consultant and contractor in terms of degree of constructability

The average weight point for each configuration is obtained, which can represent a degree of constructability based on the "ease of construction"- or constructability-scale shown previously in table 9-3: (0) impossible to build; (1) very difficult to build; (2) buildable, (3) easily buildable. The results of both consultants and contractors are overlaid for easier comparison in figure 9-8.

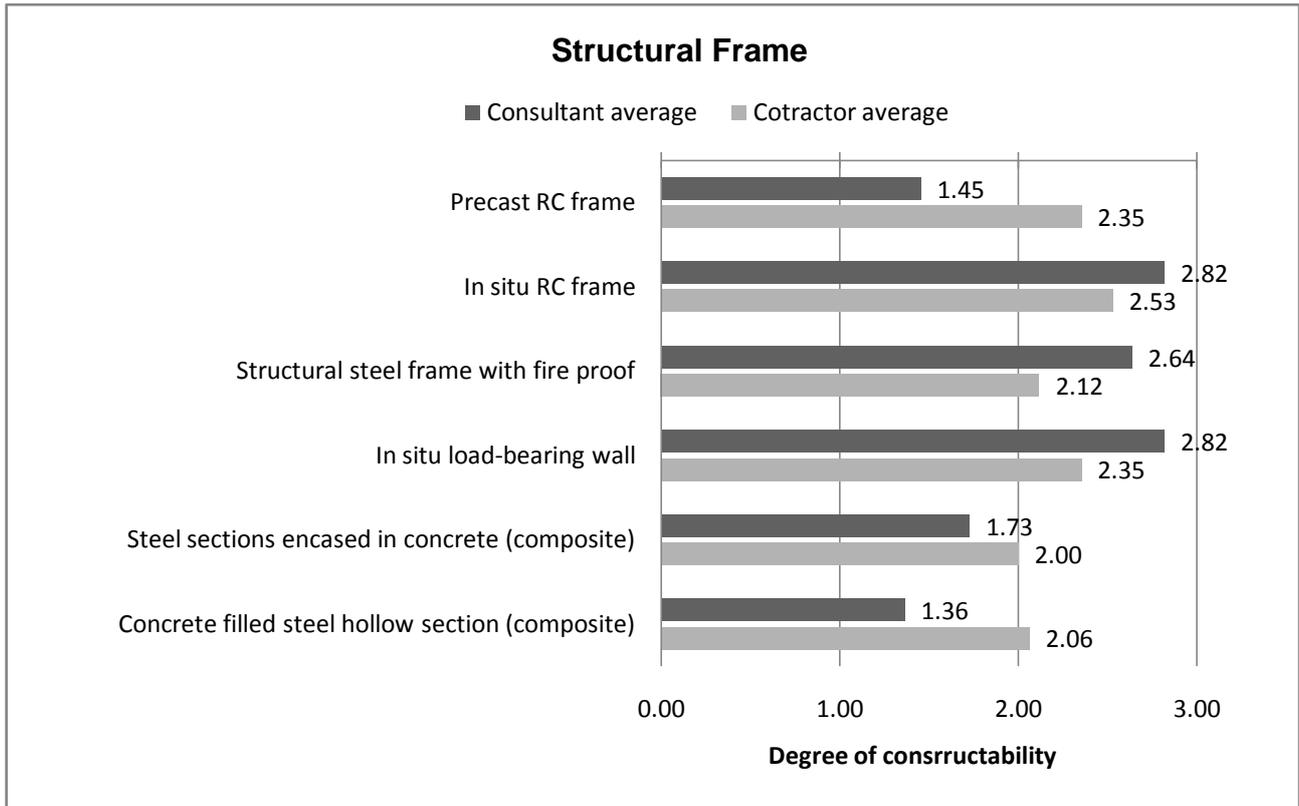


Figure 9-8 Combined overlay of structural frame configurations constructability

There seems to be good overall correlation (figure 9-8) between consultant and contractor, except for the perceptions regarding the precast RC frame as mentioned earlier. Here one can see that the consultants average is 1.45, which is (according to the constructability scale on table 9-3) approximately between “very difficult to build” and “buildable”, while the contractors deem precast RC frame just easier than “buildable” with an average weight of 2.35. The average weights of other configurations do not differ substantially. Perhaps the two composite configurations are notable – having a higher constructability according to contractors than what the consultants perceive. This perhaps suggests that contractors are more willing to execute such construction processes, than what consultants perceive.

9.3.2 Slab

Relative constructability ranking of slab

The ranking of the slab configurations, according to contractors is explicitly tabulated in table 9-5. The relative ranking of slab configurations is done according to the normalized cumulative weight as described previously in the beginning of section 9.3. The results for consultants and contractors are shown in table 9-9 and 9-10 respectively.

Table 9-5 Constructability ranking of slab configurations according to contractors

Constructability Rank (Contractor)	Configurations of slab
1	Precast slab with in situ topping
2	In situ RC flat slab
3	Steel deck as permanent shuttering
4	In situ RC slab with post tensioning
5	In situ RC slab upon beams

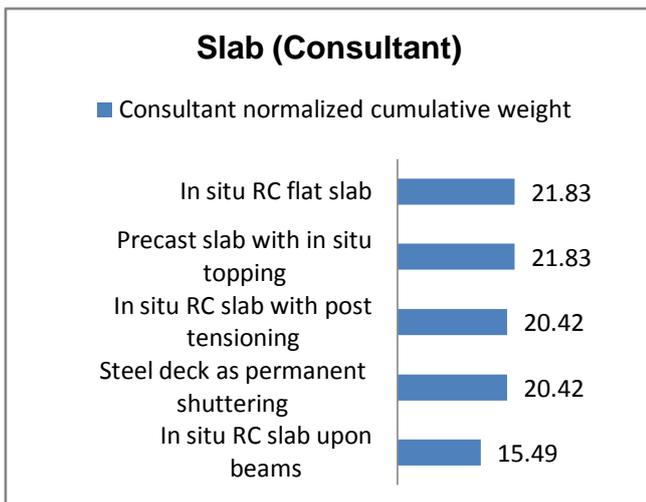


Figure 9-9 Constructability of slab configurations according to consultants

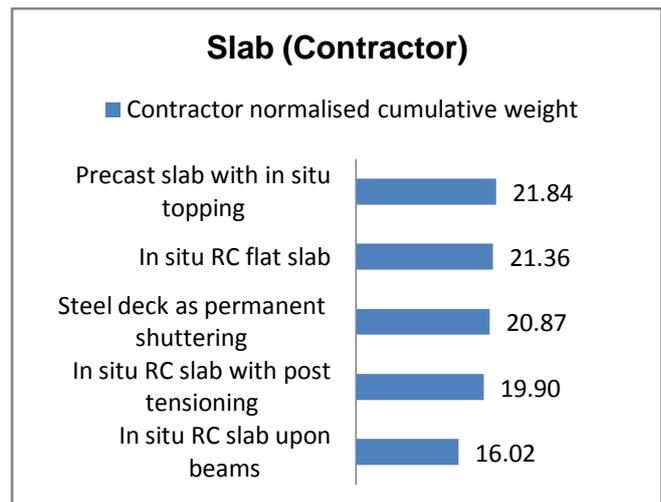


Figure 9-10 Constructability of slab configurations according to contractors

Looking at table 9-5, it is notable that contractors rank the precast slab with in situ topping very close to in situ RC flat slab. It is to be expected that the steel deck as permanent shuttering and the in situ slab with post tensioning are less constructible. It is interesting to see that the in situ RC slab upon beams is ranked last (even by consultants), while this is a very common configuration in building slabs, arguably much more so than say precast slabs, slabs with steel permanent shuttering or post tensioning. This result suggests that it would be better for consultants and designers to first consider all other types of slab configurations before incorporating the in situ slab upon beams into the design.

Slab correlation between consultant and contractor in terms of degree of constructability

The average weight point for each configuration is obtained, which represents a degree of constructability based on the “ease of construction”- or constructability-scale shown previously in table 9-3: (0) impossible to build; (1) very difficult to build; (2) buildable, (3) easily buildable. The results of both consultants and contractors are overlaid for easier comparison in figure 9-11.

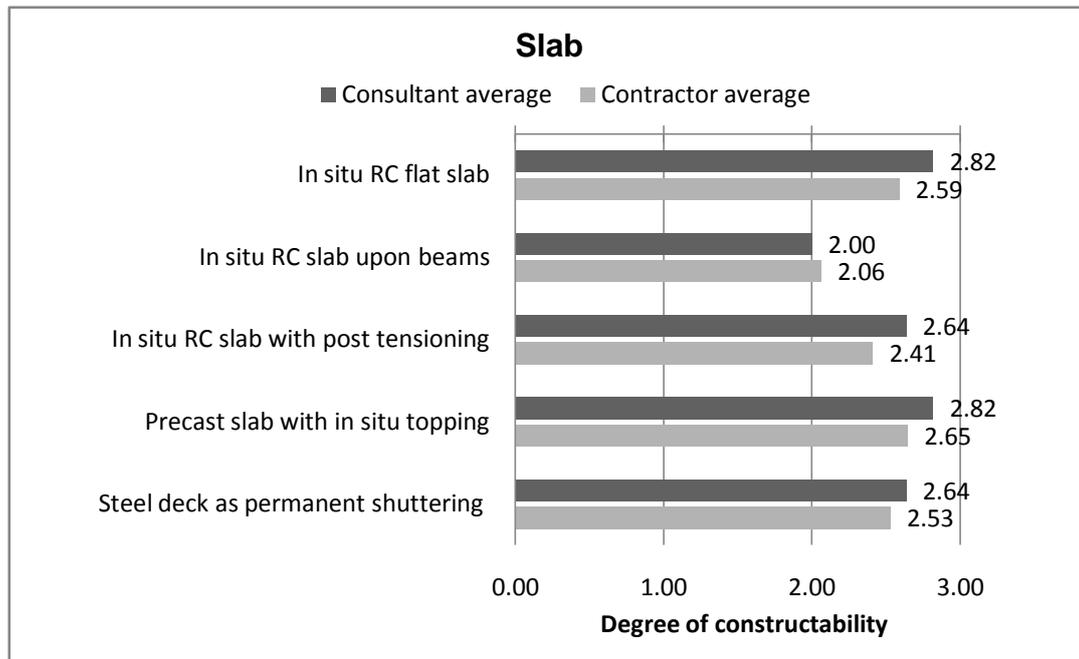


Figure 9-11 Combined overlay of slabs configurations constructability

The correlation is very close between consultant and contractor for all of the slab configurations (figure 9-11). One can see in figure 9-11 that the In situ RC slab upon beams bears notably lower constructability average weights than other configurations, however it is not low – average weight of 2 and 2.06 equates to “buildable” according to table 9-3. All the other configurations show good constructability with all of contractors’ average weights being between “buildable” and “easily buildable”, except that of the in situ RC slab upon beams.

9.3.3 Façade wall

Relative constructability ranking of façade wall

The ranking of the façade wall configurations, according to contractors is explicitly tabulated in table 9-6. The relative ranking of slab configurations is done according to the normalized cumulative weight as described previously in the beginning of section 9.3. The results for consultants and contractors are shown in table 9-12 and 9-13 respectively.

Table 9-6 Constructability ranking of façade wall configurations according to contractors

Constructability Rank (Contractor)	Configurations of façade wall
1	Concrete masonry wall with applied finished
2	Glass curtain wall (glass façade panels)
3	Precast RC wall with pre-installed windows and finishes
4	In situ RC wall with applied finishes
5	Concrete curtain wall (concrete façade panels)

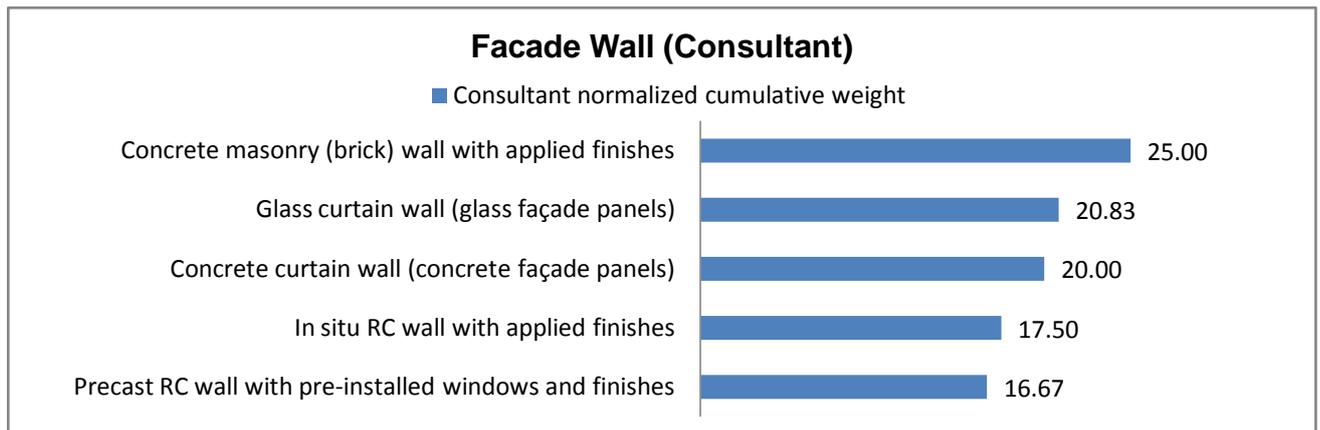


Figure 9-12 Constructability of façade wall configurations according to consultants

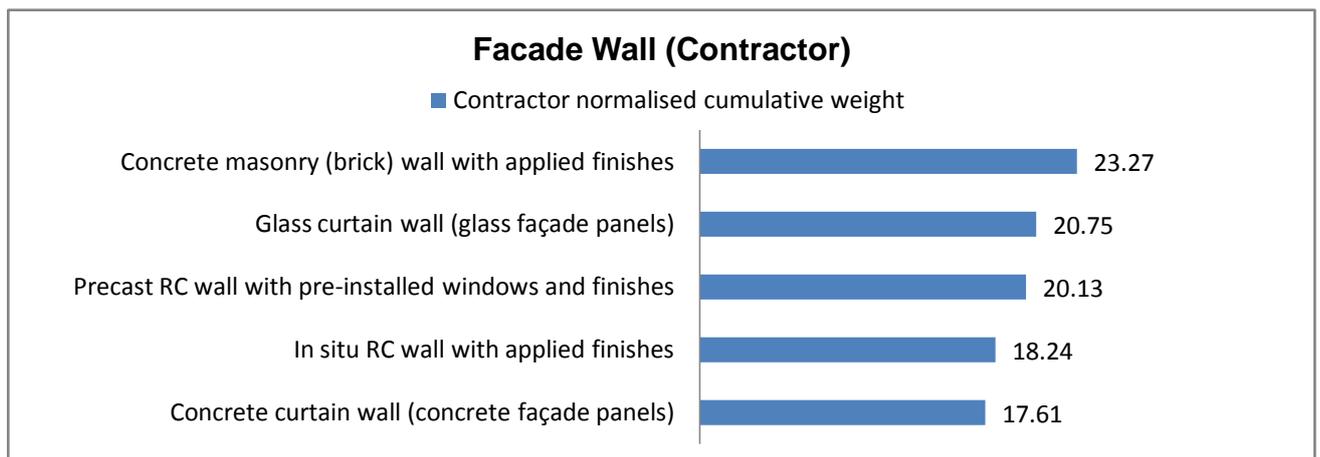


Figure 9-13 Constructability of façade wall configurations according to contractors

Looking at the rankings on table 9-6 and figure 9-13, the highest ranked is masonry (brick) walls, which is the expected trend in construction of walls. However, this is interestingly another contradiction from contractor response. As shown in the previous section 9.1, most of the contractors preferred equipment intensive work, contrary to construction of masonry walls, which is highly labour intensive. Precast RC wall is ranked even lower than glass curtain wall, with the in situ concrete wall and concrete curtain wall ranking last.

Façade wall correlation between consultant and contractor in terms of degree of constructability

The average weight point for each configuration is obtained, which represents a degree of constructability based on the “ease of construction”- or constructability-scale shown previously in table 9-3: (0) impossible to build; (1) very difficult to build; (2) buildable, (3) easily buildable. The results of both consultants and contractors are overlaid for easier comparison in figure 9-14.

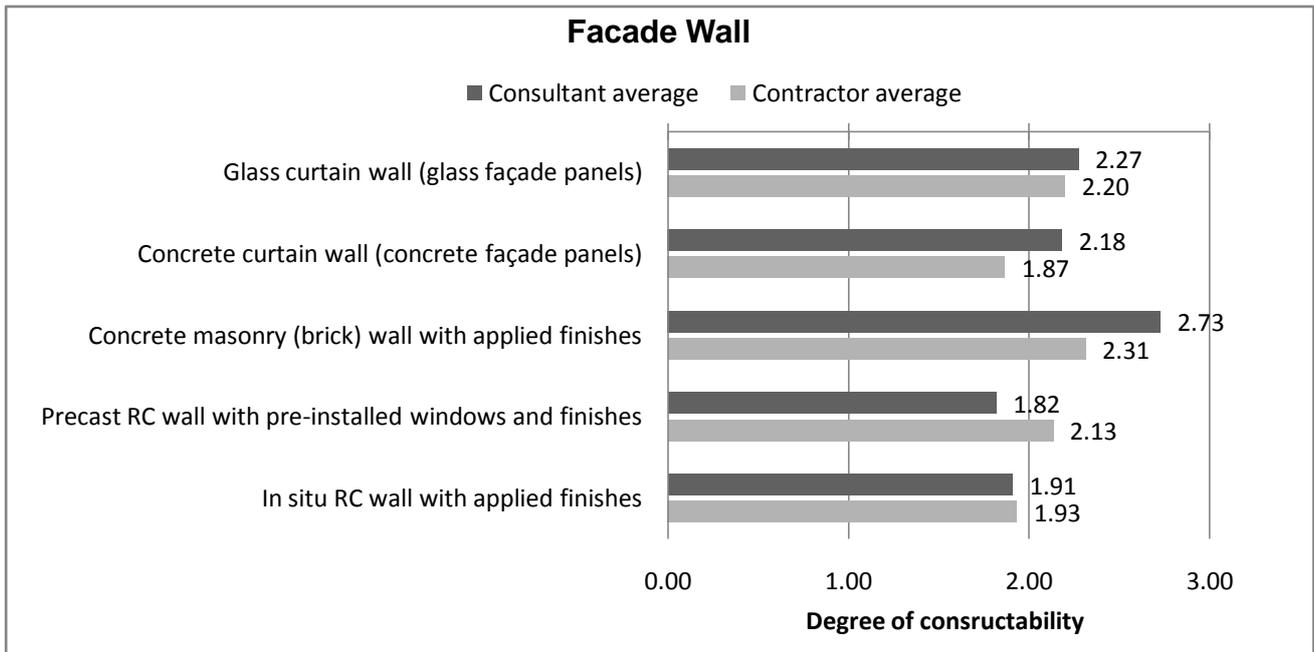


Figure 9-14 Combined overlay of façade wall configurations constructability

The correlation (figure 9-14) is very close between consultant and contractor for all the façade wall configurations. There are thus no notable discrepancies regarding perceptions of the constructability of façade walls. The degree of constructability of the configurations is also good overall – the worst being just below buildable. According to contractors, the masonry wall, precast RC wall and glass curtain wall are all above “buildable”, with in situ RC wall and concrete curtain wall just below.

9.3.4 Roof

Relative constructability ranking of roof

The ranking of the roof configurations, according to contractors is explicitly tabulated in table 9-7. The relative ranking of slab configurations is done according to the normalized cumulative weight as described previously in the beginning of section 9.3. The results for consultants and contractors are shown in table 9-15 and 9-16 respectively.

Table 9-7 Constructability ranking of roof configurations according to contractors

Constructability Rank (Contractor)	Configurations of roof
1	Timber roof truss
2	In situ concrete roof
3	Precast concrete roof
4	Steel decking with in situ concrete topping
5	Steel truss roof with composite decking

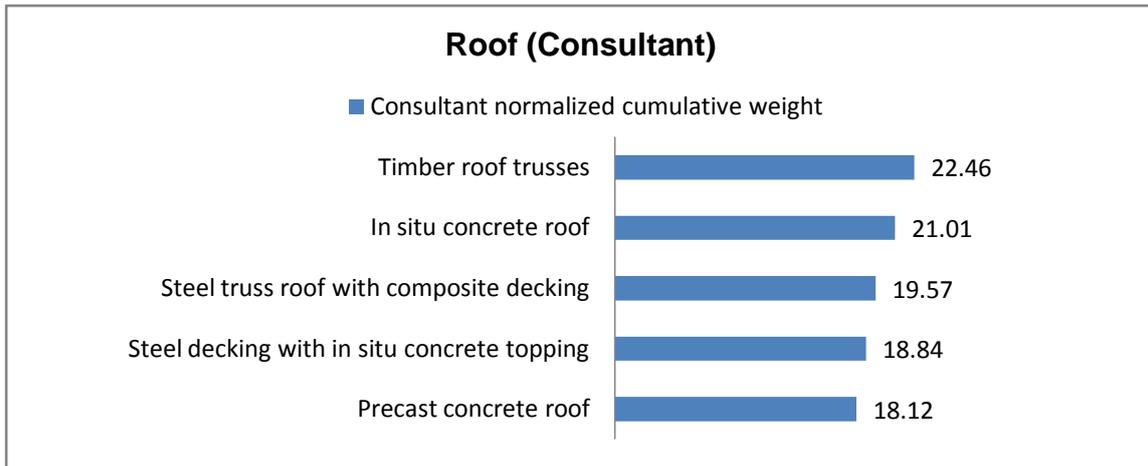


Figure 9-15 Constructability of roof configurations according to consultants

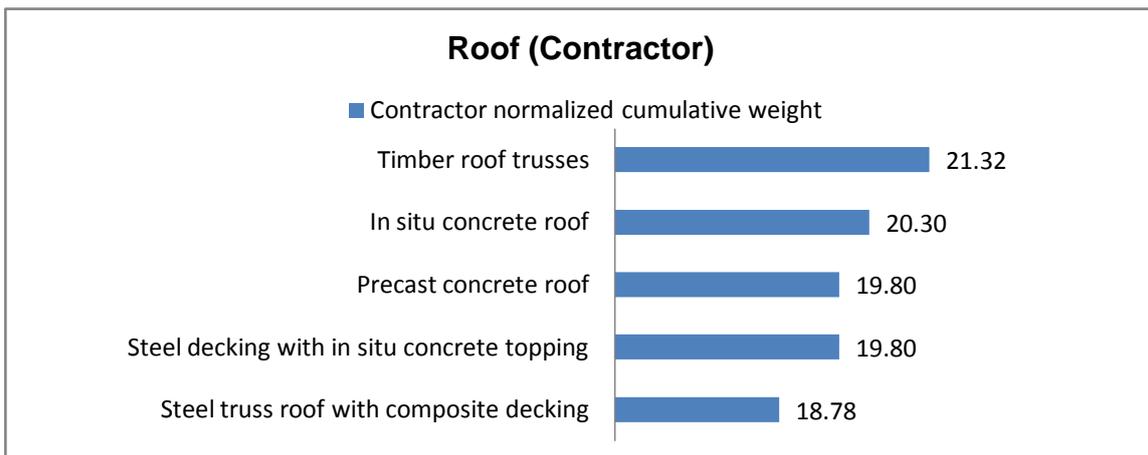


Figure 9-16 Constructability of roof configurations according to contractors

Considering the ranking on table 9-7 and figure 9-16, the order of the configuration is expected. The timber roof truss is typically the most commonly used roof configuration, concurred by both consultant and contractor. The in situ concrete roof ranking 2nd followed by precast roof. Again a contradiction of contractors' opinion is evident. In situ concrete roof takes preference over precast (albeit slightly), while in the labour efficiency principle section 9.1, contractors favours precast concrete systems. According to the consultants' ranking (table 9-15) the precast roof is ranked the lowest – considerably lower than contractors. This indicates that consultants are unlikely to use precast concrete roofs in their designs.

Roof correlation between consultant and contractor in terms of degree of constructability

The average weight point for each configuration is obtained, which represents a degree of constructability based on the “ease of construction”- or constructability-scale shown previously in table 9-3: (0) impossible to build; (1) very difficult to build; (2) buildable, (3) easily buildable. The results of both consultants and contractors are overlaid for easier comparison in figure 9-17.

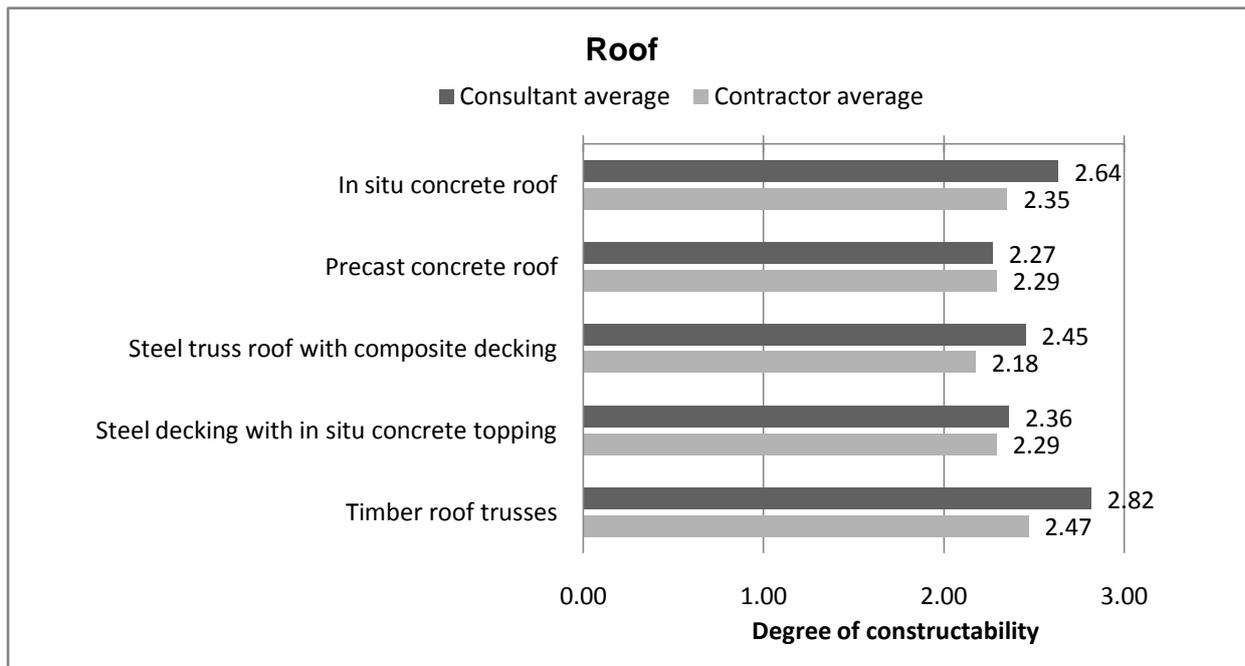


Figure 9-17 Combined overlay of roof configurations constructability

The correlation (figure 9-17) is very close between consultant and contractor or all the roof configurations. There are thus no notable discrepancies regarding perceptions of the constructability of roof configurations. The degree of constructability is also very good overall – no configuration falling below “buildable”. Even the contractors’ 2 lowest ranked configurations – steel decking with in situ topping and steel truss with composite decking – are considered better than “buildable”.

9.3.5 Roof support

Relative constructability ranking of roof support

The ranking of the roof support configurations, according to contractors is explicitly tabulated in table 9-8. The relative ranking of slab configurations is done according to the normalized cumulative weight as described previously in the beginning of section 9.3. The results for consultants and contractors are shown in table 9-18 and 9-19 respectively. There are only two configurations for the roof support component. Nevertheless, the ranking table and the graphs are provided for completeness sake.

Table 9-8 Constructability ranking of roof support configurations according to contractors

Constructability Rank (Contractor)	Configurations of roof support
1	Timber roof truss
2	In situ concrete roof support

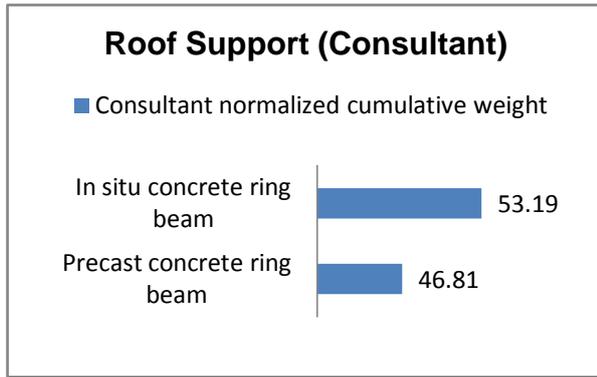


Figure 9-18 Constructability of roof support configurations according to consultants

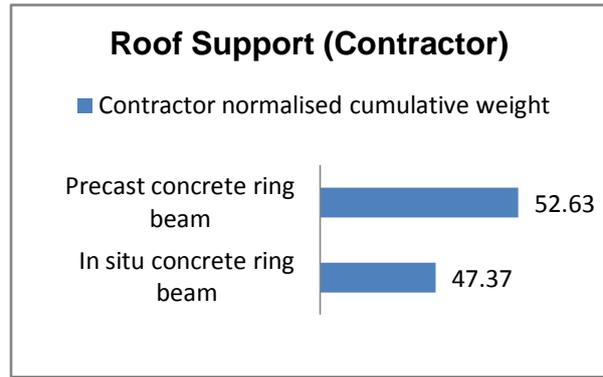


Figure 9-19 Constructability of roof support configurations according to contractors

Contractors prefer precast concrete ring beam over in situ ring beam (table 9-8 and figure 9-19), which concurs with their preference of precast concrete over in situ concrete, as shown in section 9.1. Furthermore, it is interesting to note that while the precast ring beam is preferred for the roof support, the contractors favour in situ concrete for structural frame, slab and roof. The consultant prefers the in situ beam for roof supports (figure 9-18) and has been quite consistent with the choice of in situ configurations previously – structural frame, slab and roof.

Roof support correlation between consultant and contractor in terms of degree of constructability

The average weight point for each configuration is obtained, which represents a degree of constructability based on the “ease of construction”- or constructability-scale shown previously in table 9-3: (0) impossible to build; (1) very difficult to build; (2) buildable, (3) easily buildable. The results of both consultants and contractors are overlaid for easier comparison in figure 9-20.

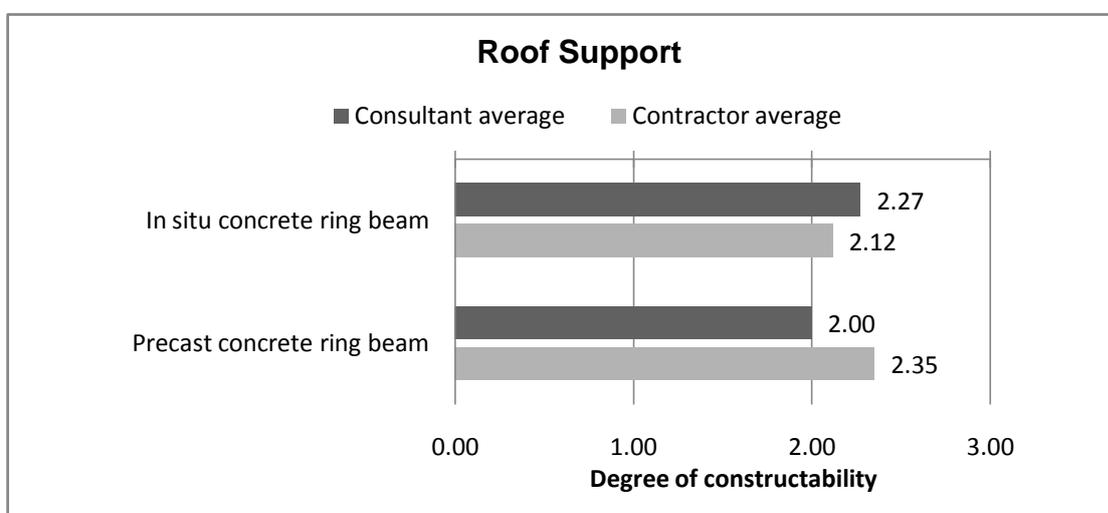


Figure 9-20 Combined overlay of roof support configurations constructability

Even though the ranking is different between the consultant and contractor, closer inspection (figure 9-20) shows that the perception of degree of constructability is indeed not substantially different. Despite the slight discrepancy, the general degree of constructability is good – with none of the two choices lower than “buildable”. However, it is still evident that contractors prefer precast ring beam and consultants in situ ring beam.

9.3.6 Internal wall

Relative constructability ranking of internal wall

The ranking of the internal wall configurations, according to contractors is explicitly tabulated in table 9-9. The relative ranking of slab configurations is done according to the normalized cumulative weight as described previously in the beginning of section 9.3. The results for consultants and contractors are shown in table 9-21 and 9-22 respectively.

Table 9-9 Constructability ranking of internal wall configurations according to contractors

Constructability Rank (Contractor)	Configurations of internal wall
1	Dry partitions
2	Concrete masonry wall with applied finishes
3	Precast RC wall with applied finishes
4	In situ RC wall with applied finishes

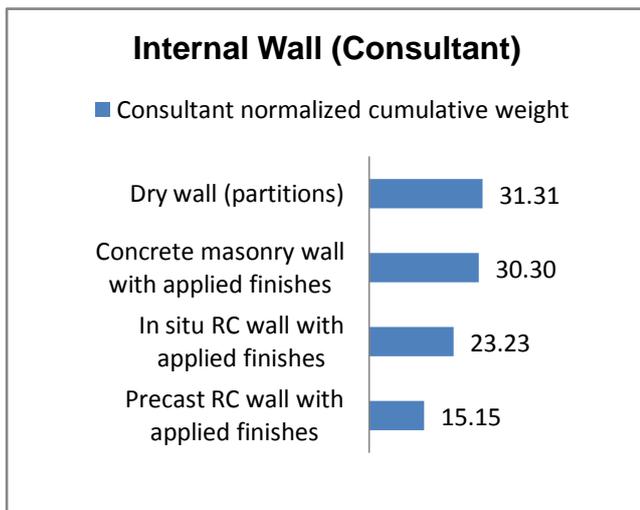


Figure 9-21 Constructability of internal wall configurations according to consultants

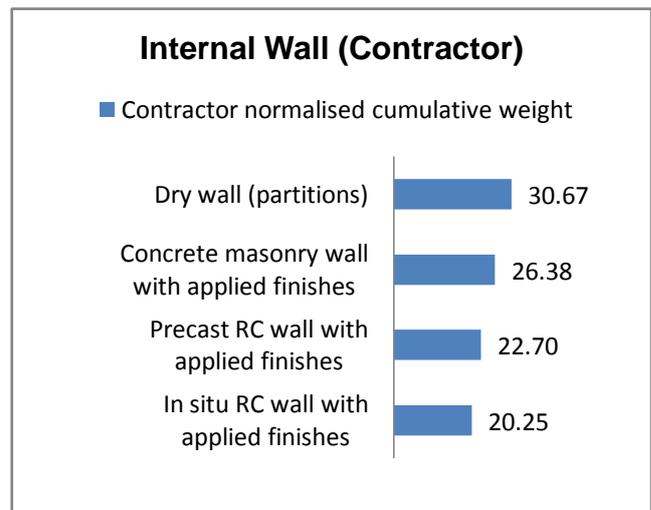


Figure 9-22 Constructability of internal wall configurations according to contractors

Looking at contractors’ results (table 9-9 and figure 9-22) dry partition wall is ranked the highest, which makes sense since it requires no bricks or concrete and can be executed with light labour. A thing to note here is that, just as the façade wall, the masonry wall is ranked higher than precast, which contradicts with the contractors’ preference of equipment intensive work over labour intensive.

In situ wall is ranked last by the contractor. The consultants' ranking (figure 9-21) of dry partitions and concrete masonry wall is the same as that of the contractor – top rank. Consultants rank precast RC wall last – as consistent with many of the other precast configurations of building components.

Internal wall correlation between consultant and contractor in terms of degree of constructability

The average weight point for each configuration is obtained, which represents a degree of constructability based on the “ease of construction”- or constructability-scale shown previously in table 9-3: (0) impossible to build; (1) very difficult to build; (2) buildable, (3) easily buildable. The results of both consultants and contractors are overlaid for easier comparison in figure 9-23.

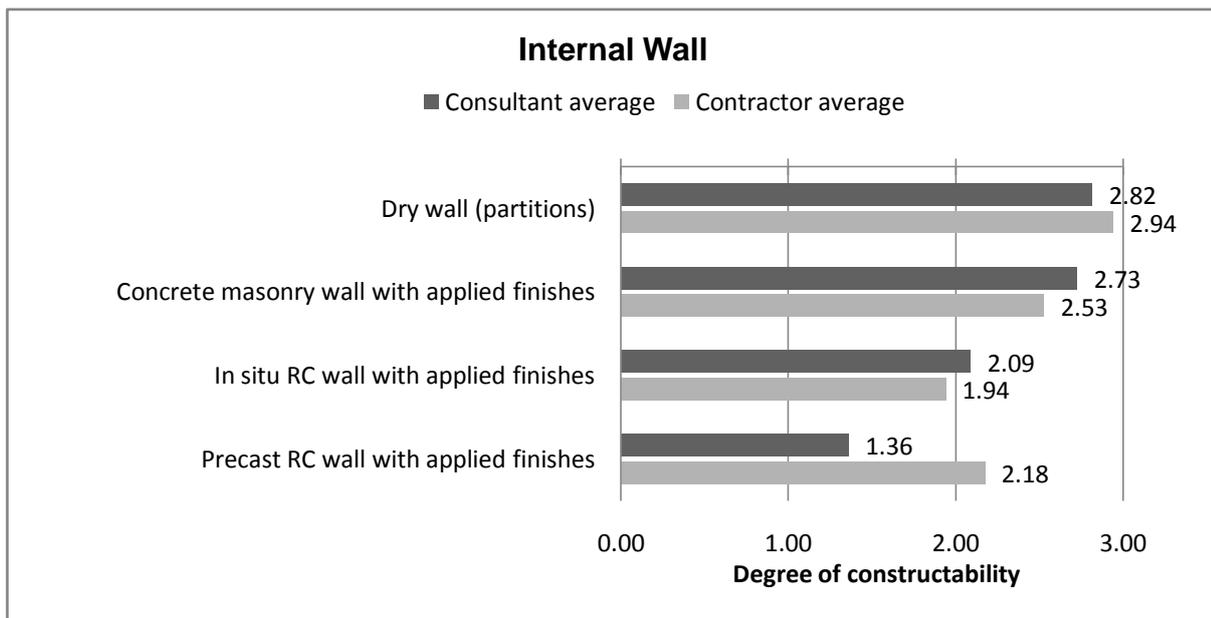


Figure 9-23 Combined overlay of internal wall configurations constructability

The correlation of the degree of constructability is close (figure 9-23) for most of the configurations, except for the precast RC wall, where the consultants indicated quite a low constructability weight – about half way between “very difficult to build” and “buildable”. Both the dry partition and concrete masonry wall have high degrees of constructability according to both consultants and contractors. The in situ RC wall seems to be just around buildable.

9.3.7 Overall perspective of building component constructability

This section regards different configurations of major components of a typical building and seeks to qualify the constructability of each, while analysing the comparison between consultant and contractor perspectives. The structural frame, slab, façade wall, roof, roof support and internal wall are investigated. Regarding the overall constructability of building components some points are worthy of note, set out in the following paragraphs.

Contradictions in respondent perceptions

In section 9.1 it is shown that contractors indicated the preference of equipment intensive work over labour intensive work; and concurrently precast concrete over in situ concrete. However, in the constructability analysis of building components, some in situ configurations are ranked above that of precast by contractors – as is the case for the structural frame and roof. Also, in the case of the façade and internal wall, the masonry configurations, being much more labour-intensive, are ranked above that of precast, which is more equipment intensive.

As for the consultants, the perceptions of constructability with regard to precast vs. in situ configurations are consistent. In all cases for the consultants, preference is placed on in situ configurations over that of precast. For the façade wall and internal wall, masonry configurations are preferred over both in situ and precast, despite the fact that all consultants previously indicated they preferred equipment intensive work (section 9.1). This is also a contradiction on the consultants' part.

Assuming that all the respondents read the questions clearly and answered assertively, a possible deduction can be made from this contradiction. Regarding the contractors, it would seem that they are keen or willing to pursue increased use of precast construction, as indicated by the preferred precast concrete system. However, considering constructability on site, in situ concrete remains the most widely used (and trusted) system, even though it may be less labour efficient and thus chosen over precast concrete on some cases. The less used precast systems may hold risks of uncertainty – though likely only due to its subdued popularity compared to in-situ concrete. It can also be possible that other external factors, such as the availability of precast manufacturing plants, or other circumstantial trends, may cause the contractor to choose in-situ over precast. In essence, it is likely that contractors' choices are not always based on simply precast or in situ; equipment intensive or labour intensive, but also on the many unknown factors that often manifest eventually as some standard practice in the field. In the case of the consultants' contradiction, it is also likely that, on a principle level, equipment intensive work is desired, but the choices made with regards to constructability of certain configurations in design (for instance masonry wall over precast wall) are motivated by perceived construction trends, essentially set by the contractors.

There are certainly logical explanations for each case of contradiction identified, which are likely dependent on very specific practical conditions on site. Unfortunately this research does not investigate the specifics of each case and thus do not possess sufficient information to make a concrete conclusion on the contradictions. Nevertheless, this is the result of the analysis.

Another trend that can be observed is that the consultants rank the preference for precast configurations lower than that of contractors. This indicates that consultants are less likely to employ precast designs; even though contractors have a higher susceptibility to using precast construction.

Degree of constructability and correlation

For the contractors, very few configurations dropped below “buildable”. Out of all of them, only 2 configurations are rated lower than “buildable”: concrete curtain wall (for façade walls) and in situ RC wall with applied finishes (for façade and internal walls). Everything else ranged between buildable and easily buildable. It is assuring to see that none of the configurations provided are qualified as “very difficult to build” or “impossible to build”. This suggests that even if consultant and contractor perceptions are substantially misaligned, and design decisions are based on a distorted precedence, at least the results (in terms of constructability) will not be too detrimental.

Correlation between consultants and contracts are good on most of the building components, except for a few distinct cases, which should be addressed separately as discussed in each case under the relevant building component’s section. By inspection of all the combined overlay graphs, it can be observed that consultants seem to rate constructability slightly higher than the contractors for most configurations, except the precast configurations, where consultants rated it considerably lower than contractors.

9.4 Project close-out meetings

Respondents are asked to comment whether project close-out meetings are employed at their organisations. If so, they are asked to provide a list of the typical attendees of these meetings. The responses are presented in table 9-10 as shown below. Since there are few respondents, each respondent’s response (each of the 17 contractors and 11 consultants) is presented below in full for a comprehensive interpretation. The left column is that of contractors and the right column that of consultants. The left and right columns do not bear any relation to each other; the horizontal alignment is only for neatness in the layout.

Table 9-10 Project close-out meeting attendees (continue to next pages)

Nr	Contractor attendees	Consultant attendees
1	Contracts managers Senior site managers Procurement Quantity surveyor Directors	N/A – no close-out meetings
2	Projects director Estimators Quantity surveyor Project manager Site manager	Project director Project leader Project manager Technical design team members

Nr	Contractor attendees	Consultant attendees
3	Project director Contracts manager Site agent Quantity surveyor Client/professional team	Engineers
4	Senior project team – team that was on site Peers of the above team in the company Estimators Business unit board of directors Contracts manager from other projects Heads of support service departments Some invited people from other business units	Main agent All engineering disciplines Architect Client Contractor Subcontractors
5	Project manager Commercial manager Quantity surveyor Safety representatives Human resource personnel Foreman Client and Engineer	Project close-out meeting is a process and part of the quality procedures.
6	Project manager Project team Executives	N/A – no project close-out meeting
7	N/A – no information provided	Director
8	Project manager Site agent Client Architect Consulting engineers Client Quantity Surveyor Commercial director	Close-out meetings usually internal, with high level briefing with client (rather than contractor)

Nr	Contractor attendees	Consultant attendees
9	Client Representative Architect Engineer Main contractor and nominated/selected specialist sub-contractors	Director All designers involved
10	N/A – no close out meeting (pre-cast)	N/A – no project close-out meeting
11	Directors Contracts manager Site manager	Not common
12	Contracts manager Quantity surveyor Client	
13	Contract director Site agent	
14	Contracts Director Contract manager Site agent Foremen Quantity surveyor	
15	Chief operating officer Divisional managing director Contracts director Commercial director Project manager Quantity Surveyor Estimator	
16	Site management Admin staff	
17	Contractor senior staff Consultants	

9.4.1 Relevance of close-out meetings

The attendees of project-close out meetings roughly indicate the different sources of knowledge flow present at the meeting. It would seem that the project close-out meeting is an important occasion or method where discussions and analysis of issues during the project can occur, and from the

numerous perspectives of different project participants. It is therefore of great significance to see whether there is contractor and consultant presence, and thus flow of knowledge between them during project close-out meetings. The ideal case would be for consultants and contractors to both engage in discussion about constructability during these meetings. In other words, the issues regarding positive and negative influences of design on the construction can be addressed openly. In doing so, constructability problems can be identified, which pose as lessons learnt by both contractors and consultants for use in future projects. Good examples of points for discussion may include (and not exclusive of) all the issues and discrepancies identified in the previous section 9.3 regarding different perceptions on constructability of components of a building.

It is assumed that a great deal (if not all) of the discussions and conclusions from project close-out meetings form part of the documentation in project archives. Theoretically, there should be substantial lessons-learnt output from project close-out meetings that can be used in later projects to aid decisions and minimize problems. However, we have seen in the Phase-1 questionnaire that project archives are insufficient in offering project knowledge and lessons learnt. The Phase-1 questionnaire shows a great deal of desire for more data, information and knowledge to be captured.

From the conclusion of the Phase-1 questionnaire, it is to be expected that there is great premise for improvement in the implementation of project close-out meetings. This part of the questionnaire investigates the nature of this problem in more detail, by identifying the typical attendees of project close-out meetings, which will contribute to the formulation of the strategic solution to improve constructability knowledge sharing.

9.4.2 Discussions on project close-out meetings

Referring to table 9-10, contractors show a larger variety of project attendees and seem to employ project close-out meetings with more prevalence than consultants.

A few consultants do not have project close-out meetings at all, this should however not be a definitive negative reflection on these consultants, as there may be numerous other occasion or methods where lessons can be identified and discussed apart from project close-out meetings for consultants. One consultant respondent mentioned that the “project close-out meeting is a process and part of the quality procedure”.

From table 9-10, project close-out meetings are common among contractors. Only one contractor (contractor nr 10), indicates that there is no project close-out meetings carried out. Other contractors indicate a variety of attendees at project-close out meetings. Different managers (contracts, project, site) and directors; site agents; estimators; quantity surveyors are mentioned numerous times. However, it is notable that consulting engineers or clients are only mentioned in a few cases

(contractors nr 3, 8, 9 and 17). Therefore 4 out of 17 contractors explicitly mentioned the involvement of consultants (supposedly design personnel) at their project close-out meetings.

The findings of Phase-1 questionnaire already indicated shortcomings with project archives, which suggest poor implementation of project close-out meetings. Not only are project archives deemed insufficient and hold little or no value in project lessons, there is a larger problem overall. This section indicates that there is very limited consultant presence at contractors' project meetings. This implies that issues and problems experienced on site that may have been attributed to a design with poor constructability, cannot be discussed in full with engagement of design personnel. Even if the project close-out meetings are implemented prevalently and lessons learnt activities are carried out, it may still not achieve the required benefits without the engagement of both the consultant and the contractor simultaneously.

9.5 Knowledge sharing

9.5.1 Introduction

Different modes of knowledge sharing are identified (as shown previously in section 8.5.6) and presented to the respondents. They were asked to quality each mode of communication or knowledge sharing based on "popularity of use" to share knowledge in general, the choices of which are shown in table 9-11.

Table 9-11 Popularity of knowledge sharing mode and corresponding weight points

Scale of popularity	Weight point
Never used	0 point
Unpopular	1 points
Neutral	2 points
Popular	3 points
Very popular	4 points

The quantitative analysis is done with a point system similar to the methods used to analyse the constructability of components of buildings in section 9.3. Each of the choices in table 9-11 is given a weight point as numerical representation of the popularity. For each knowledge sharing mode, the weight points are summed and the average is calculated to obtain an average popularity for the specific knowledge sharing mode. The results are shown in figure 9-24 in no particular order. The order of ranking is not of particular importance in this case, rather the correlation of popularity of specific modes, between consultant and contractor. The results aim to identify popular knowledge sharing modes as well as the corresponding nature of knowledge (e.g. tacit or explicit) shared through each mode. The conclusions of this section contribute to the formulation of the strategic solution in improving constructability knowledge sharing.

From inspection of figure 9-24, one can see distinct differences in popularity of use between the different modes of knowledge sharing. The answers range from “unpopular” to just above “popular”. No respondents indicate modes that are “never used”; also no mode is on average “very popular”.

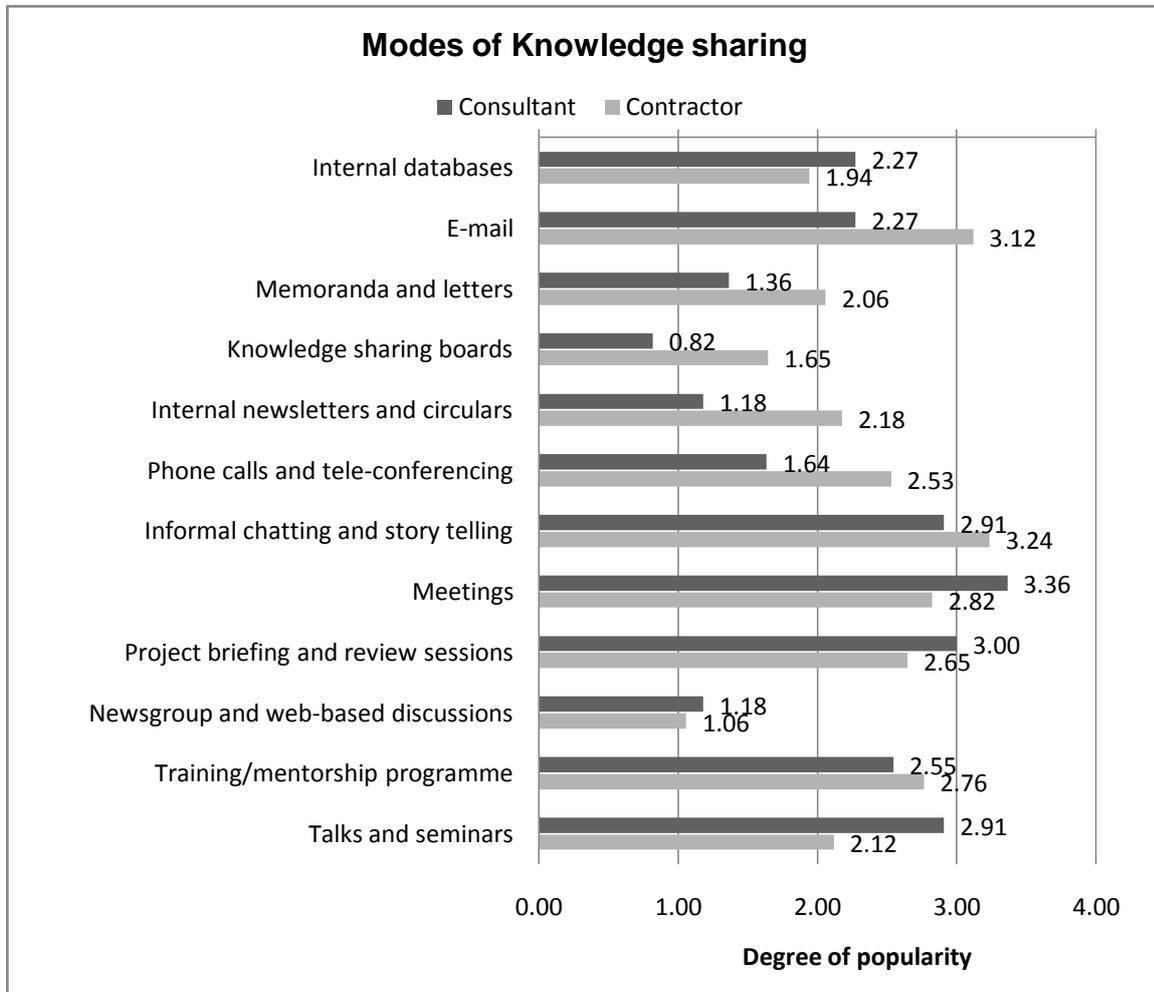


Figure 9-24 Popularity of knowledge sharing modes

9.5.2 Findings of knowledge sharing modes

Results discussed under this paragraph refer to figure 9-24. For consultants, one can safely deduce that memoranda and letters, knowledge sharing boards, internal newsletters and circulars, and newsgroup and web based discussion are not promising modes of knowledge sharing – having popularity points of around 1 (unpopular). Modes that lie in the neutral zone for consults include internal databases, emails, and phone calls. Modes to focus on are ones closer to 3 (popular), such as informal chatting and storytelling, meetings, project briefing and review sessions, training and mentorship programme, and talks and seminars.

Overall, contractors show higher popularity for most of the modes than consultants. There is only one mode indicated to be unpopular – newsgroup and web based discussions. Most of the modes are of neutral popularity, having a popularity score of around 2. These are internal databases, memoranda and letters, knowledge sharing boards, internal newsletters and circulars, talks and seminars. The most popular modes for contractors are emails, phone calls, informal chatting and storytelling, meetings, project briefing and review sessions, and training and mentorship programmes.

The higher popularity modes generally correlate well between consultants and contractors. There are however a few less popular modes where the discrepancies are large. Consultants rated emails 2.27 (around neutral popularity) while contractors rate it 3.12 (very popular). For memoranda and letters, knowledge sharing boards, and phone calls; the contractor rated about one unit higher in popularity than consultants. Consultants rate the popularity of talks and seminars considerably higher than contractors.

For easier reference, the modes for consultants and contractors can be roughly categorised into three main groups as shown in table 9-12.

Table 9-12 Major categorize of popularity

	Consultant	Contractor
Unpopular	Memoranda and letters Knowledge sharing boards Internal newsletters and circulars Newsgroup and web based discussion	Newsgroup and web based discussions
Neutral	Internal databases Emails Phone calls	Internal databases Memoranda and letters Knowledge sharing boards Internal newsletters and circulars Talks and seminars
Popular	Informal chatting and storytelling Meetings Project briefing and review sessions Training and mentorship programme Talks and seminars	Emails Phone calls Informal chatting and storytelling Meetings Project briefing and review sessions Training and mentorship programme

9.5.3 Discussion and outcome of findings

There are no major discrepancies between the opinions of consultants and contractors – only that contractors rate many of the modes higher than consultants. However, this trend is consistent (table 9-12) as some popular modes of contractors are merely one step less popular for consultants.

It is interesting to note that the most popular modes all focus on the sharing of knowledge of a tacit nature and involve socialisation and or human interaction. This highlights the tacit nature of knowledge flow in engineering organisations. This indicates that the implementation of constructability or knowledge management initiatives should ideally be of a people-orientated nature and preferably embedded within the popular modes of knowledge sharing. This also supports the relevance of lessons learnt programmes investigated in the following section. Lessons learnt programmes can be readily integrated into procedures involving popular knowledge sharing modes – such as meetings, review sessions, structured talks and storytelling, mentorship etc.

From this part of the questionnaire, knowledge sharing modes such as meetings, project briefing and review sessions, training and mentorship programmes, talks and seminars, emails, phone calls, and informal chatting and storytelling are all popular. These are thus important mediums for disseminating knowledge. This is similarly applicable to the sharing of constructability knowledge. When strategic solutions are to be drawn up to improve constructability knowledge sharing, these popular modes should readily be used as main targets of implementation.

9.6 Lessons learnt programmes

The lessons learnt programmes, in principle, capture experiences of successes and failures during the project so that the former successes can be maximized and failures minimized, in future projects. It also poses as an opportunity for different perspectives from different project personnel to be discussed and eventually endorsed by the project team.

Lessons learnt activities can take the shape of many forms, which do not necessarily need to be a formal standard. Some organisations may carry out lessons learnt activities subconsciously at an ad hoc basis, while others may have set organisational protocols to facilitate the process. This research investigates the nature of lessons learnt programmes in the industry by verifying the existence and subsequently the “formality” of lessons learnt activities.

The literature study (section 4.8.2) identified three lessons learnt processes – namely, lessons identification, lessons analysis and lessons implementation. Each of these processes can be fulfilled with numerous methods during and/or after the project. This research investigates which methods are used to carry out each of these three lessons learnt processes among consultants and contractors.

The following 5 sections presents the questions asked regarding: the formality of lessons learnt programmes, each of the 3 lessons learnt processes, and the perceived full potential of lessons learnt programmes compared to the current condition. The corresponding results are discussed in full.

9.6.1 Formality of lessons learnt programmes

Respondents are asked to choose the nature of their lessons learnt activities at their organisations, based on formality. The choices as a brief clarification of each are as follows:

Formal – standardized protocol built into organisational process, with designated coordinator

Informal – occurs haphazardly, no standard process, no designated process coordinator

Does not exist – no lessons-learned actions whatsoever

The results are shown (table 9-13) first as the number of respondents and the percentage of the total respondents in each case. The results are shown in table 9-13, where 36% of consultants indicated their lessons learnt programmes as a “formal” process, higher than that of contractors (29%). Furthermore, 64% of consultants and 59% of contractors indicated “informal”, while 12% of contractors do not have lessons learnt processes at all.

Table 9-13 Formality of lessons learnt activities

	Formal	Informal	Doesn't exist
Consultant	4 (36%)	7 (64%)	0 (0%)
Contractor	5 (29%)	10 (59%)	2 (12%)

The results here seem to be contrary to the impression from the previous question (section 9.5) on project close-out meetings. The previous section shows that contractors seem to employ project close-out meetings more comprehensively and with more structure than the consultants. Since it is assumed that many lessons learnt activities would take part during these project close-out meetings, it suggests that more contractors would have a formal lessons learnt programme than consultants. However, this is not the case here – more consultants employ lessons learnt programme formally than contractors (table 9-13). This could be due to different perceptions of what a lessons learnt programme is, between consultant and contractor respondents. It may also be that the lessons learnt activities by consultants have little to do with project close-out meetings and are carried out through other methods such as change-, risk- or design management activities. More details in this investigation is obtained in the following sections, which investigate the specific methods or occasions where each of the three lessons learnt processes (identification, analysis and implementation) are carried out.

9.6.2 Lessons identification

Ranking of lessons identification methods

Lessons identification can be carried out at various occasions with “lessons identification methods” during and/or after the project. The respondents are presented the lessons identification methods and

asked to indicate which methods are used for lessons identification. The results are presented as the percentage of total respondents using each method; then methods are ranked as shown in table 9-14.

Table 9-14 Lessons identification methods and percentage of respondents

Ranking	Consultant		Contractor	
	Method	%	Method	%
1	Intermediate meetings	91%	Project close-out meetings	82%
2	Informally (word of mouth)	91%	Intermediate meetings	82%
3	Project close-out meetings	73%	Informally (word of mouth)	76%
4	Electronically	55%	Interviews	59%
5	Paper forms	36%	Electronically	59%
6	Interviews	27%	Outside consultant	59%
7	Outside consultant	18%	Paper forms	53%

The results can be presented graphically as in figure 9-25. Correlation between consultant and contractor is not of particular importance here, rather to understand the nature of the methods, in which most lessons are identified by both contractors and consultants.

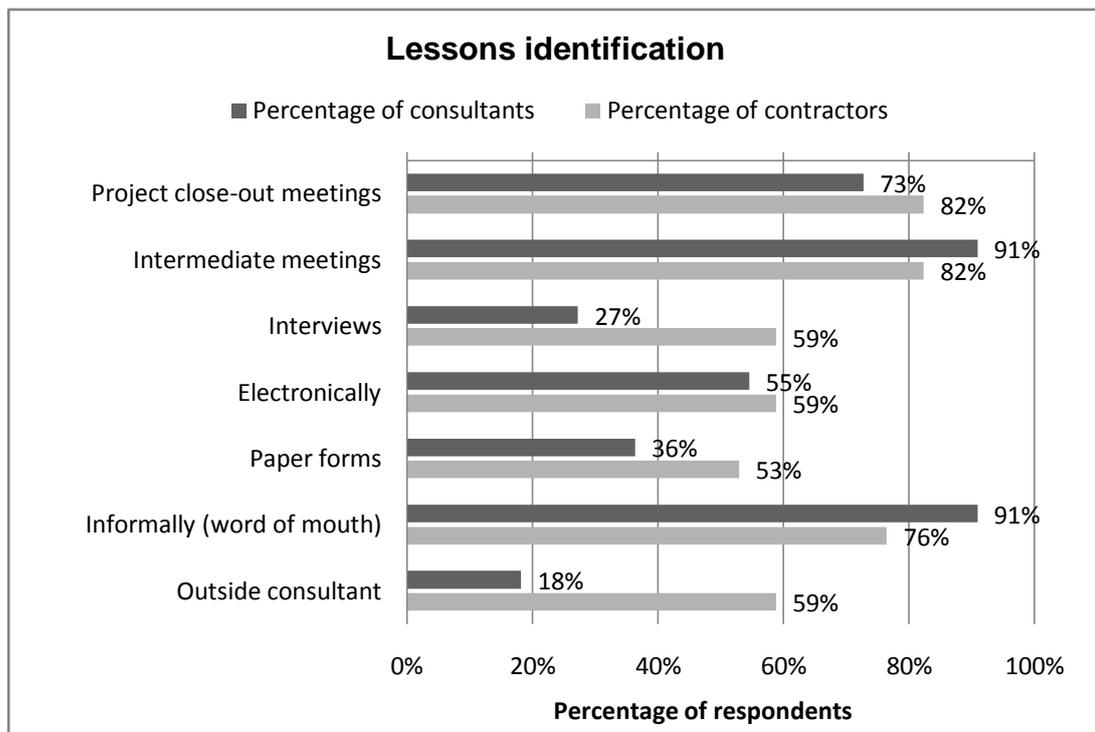


Figure 9-25 Lessons identification methods graph with percentages of respondents

The top 3 ranks of consultant and contractor are the same (project-close out meetings, intermediate meetings and word of mouth). However, project close-out meetings are used more by contractors than consultants in identifying lessons. It is important to note that the top ranked lessons identification methods all involve dynamic platforms where knowledge can be exchanged and require substantial

human interaction to facilitate the processes. This highlights the importance of tacit knowledge within the industry. The fact that electronic and paper-form methods are lowly ranked here aligns with the findings of the Phase-1 questionnaire, where databases and data capture systems are concluded to be inadequate in identifying (or capturing) lessons.

Other additional lessons identification methods are given by contractors, which are not in the list presented to them. These are monthly quality inspections, continuous mentorship and contract review meetings.

Time at which lessons identification takes place

For each lessons identification method, respondents are also asked to indicate whether lessons are identified “during” or “after” the project. For each method, the percentages of respondents that carry out identification “only during the project”, “only after the project” and “during and after the project” are obtained. The average percentages of respondents are calculated in each case, which gives a rough indication of the time when lessons are identified overall. The results for consultants and contractors are shown in table 9-15. As an example for clarity of interpretation, table 9-15 shows that 32.7% of consultants overall identify lessons “during the project only”, 12.4% identify lessons “after the project only” and 54.9% identify lessons both “during and after the project”.

Table 9-15 Lessons identification during or after project

Time of lessons identification	Consultant	Contractor
During the project only	32.7%	58.0%
During and after the project	54.9%	21.6%
After the project only	12.4%	20.4

The ideal case would be for lessons to be identified as soon as possible after they have occurred. This ensures that the lessons identified are all noted with maximum accuracy at the time an issue takes place, which can be readily done according to the top ranked identification methods, such as intermediate meetings and word-of-mouth. The least ideal case would be identification of lessons after the project only, because many of the finer issues may have slipped the mind of personnel by the time the project ends. Furthermore, personnel may also be inclined to rush through this stage with haste, for sake of finishing and thus identify lessons with reduced diligence. This trend seems prevalent among the execution of construction projects.

The results in table 9-15 for both consultant and contractor are generally favourable – both having the least percentage of identifying “after the project only”. It can be deduced that there is no problem with “when” the lessons are identified, rather “how” the lessons are identified and whether they are noted regularly during and after the project for more detailed analysis later on.

9.6.3 Lessons analysis

The lessons identified would need to be analysed, where issues can be interpreted and discussed with the relevant personnel and eventually reach some closure regarding each matter. The analyses of these issues essentially establish understanding, the process without which the lesson cannot really be “learnt”. The respondents are presented with a list of lessons analysis methods and asked to indicate which methods they use to analyze lessons at their organisation. The results are presented as the percentage of total respondents for each method; then the methods are ranked as shown in table 9-16.

Table 9-16 Lessons analysis methods and percentage of respondents

Ranking	Consultant		Contractor	
	Method	%	Method	%
1	Intermediate meetings	91%	Project close-out meetings	71%
2	Project close-out meetings	64%	Intermediate meetings	71%
3	By a subject matter expert	45%	Electronically	47%
4	Electronically	45%	By a subject matter expert	24%
5	By an outside consultant	18%	By an outside consultant	18%

The results can be presented graphically as in figure 9-26. Once again, the correlation between consultant and contractor is not of particular importance here. It is perhaps more relevant to understand the nature of the methods, in which most lessons are analysed in the case of consultants and contractors.

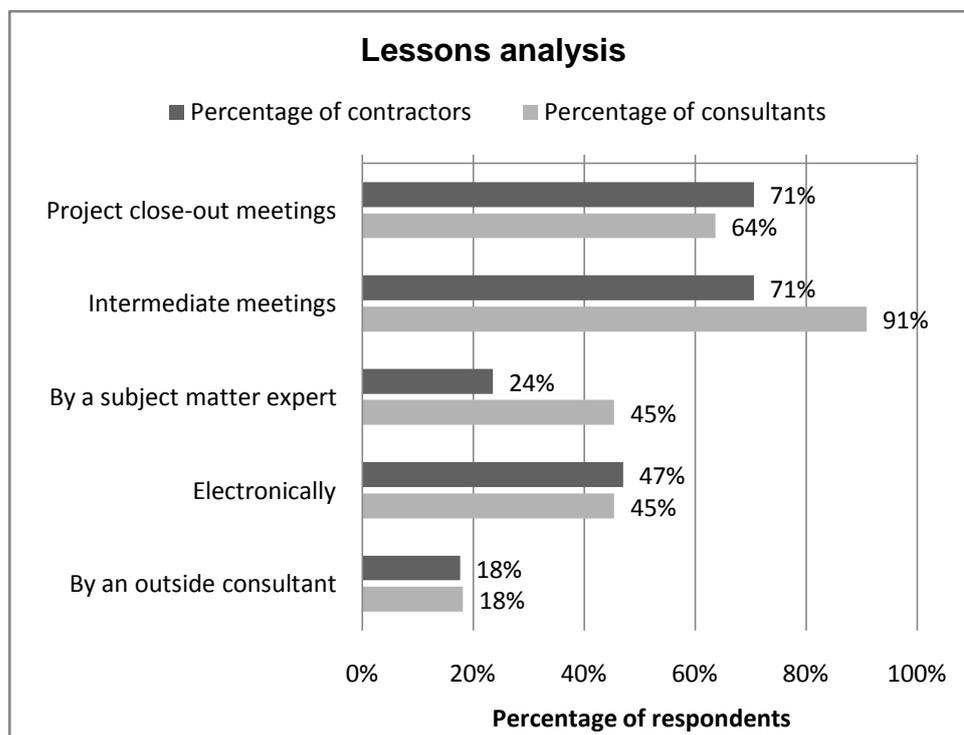


Figure 9-26 Lessons analysis graph with percentage of respondents

The top 2 ranked methods for lessons analysis, for both consultant and contractor, clearly show more use than the others. Project close-out meetings and intermediate meetings have much higher percentages than the others. Once again it is notable that social methods are mostly used to analyse lessons – project close-out meetings and intermediate meetings – indicating the prevalence of tacit knowledge sharing during meetings. Same as previously, electronic means of data analysis is ranked low for both consultant and contractor.

Consultants additionally indicate that technical quality procedures are also used as methods to analyse lessons. Contractors also mentioned other lessons analysis methods not originally on the list provided: external quality auditor, protocol meetings and on site discussions.

9.6.4 Lessons implementation

After lessons have been analysed and understood, this knowledge and experience must somehow take effect and be used in one way or another in future endeavours. Typically, it would be ideal to avoid past mistakes and repeat past successes. The lessons implementation is the process where lessons learnt is put into effect through the use of lessons implementation methods. The respondents are presented with a list of lessons implementation methods and asked to indicate which methods they use to implement lessons at their organisation. The results are presented as percentage of total respondents for each method; then the methods are ranked as shown in table 9-17

Table 9-17 Lessons implementation methods and percentages of respondents

Ranking	Consultant		Contractor	
	Method	%	Method	%
1	At meetings	82%	At project kickoffs	71%
2	Informally (word of mouth)	82%	Informally (word of mouth)	71%
3	As part of changes to a work process	73%	At meetings	65%
4	At project kickoffs	45%	As part of changes to a work process	65%
5	Training/mentorship programmes	36%	Training/mentorship programmes	53%
6	Through electronic databases	18%	Through electronic databases	29%

The results can be presented graphically as in figure 9-27. Once again, the correlation between consultant and contractor is not of particular importance here. It is perhaps more relevant to understand the nature of the methods, in which most lessons are analysed in the case of consultants and contractors.

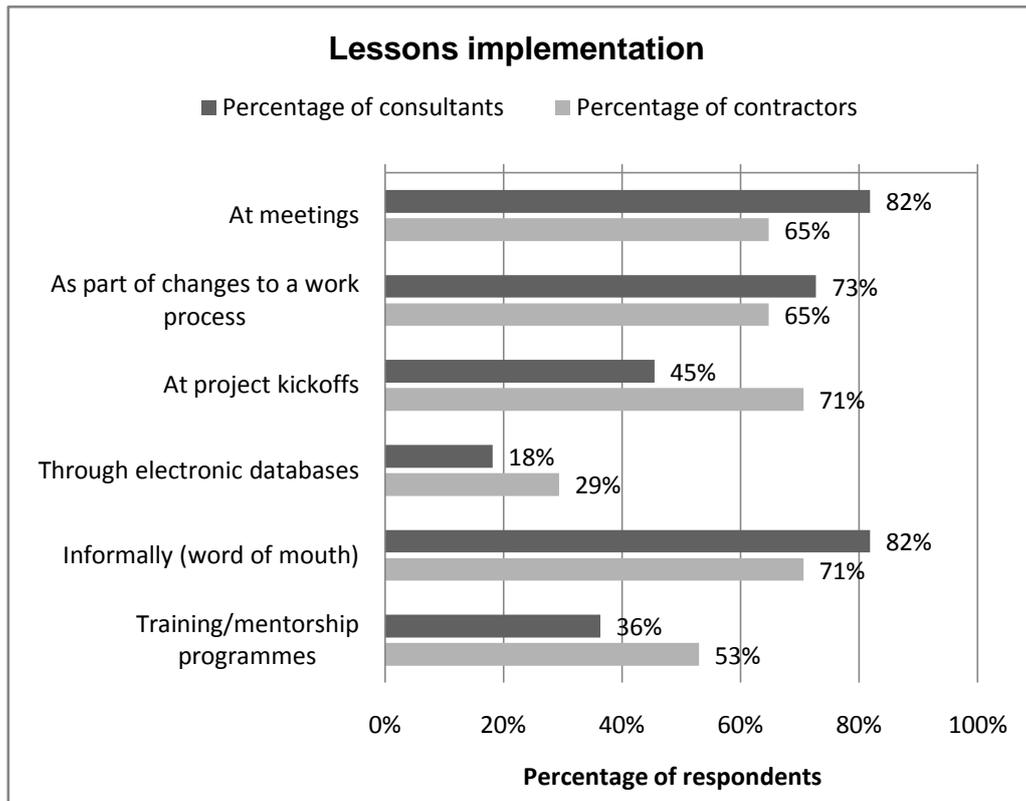


Figure 9-27 Lessons implementation graph with percentage of respondents

Meetings, informal word-of-mouth and changes to a work process are ranked high for both consultant and contractor. Lessons are thus mostly “implemented” or disseminated through the organisation via these methods. For the contractor the project kick-off is also an important method/occasion for implementing lessons, though ranked considerably lower by the consultant. Training and mentorship programmes imply the teaching of lessons to less experienced personnel; these are used more by contractors than consultants. The electronic database is again ranked low for both consultants and contractors.

9.6.5 Perceptions on the effectiveness of lessons learnt programmes

The respondents are asked to qualify how they perceive the effectiveness of lessons learnt programmes/activities currently being carried out at their organization, as well as its full potential, based on the effectiveness scale shown in table 9-18.

Table 9-18 Effectiveness scale and corresponding weight points

Scale of effectiveness	Weight point
Detrimental	0 point
Not effective	1 points
Neutral	2 points
Somewhat effective	3 points
Very effective	4 points

The choices made by the respondents are translated to weight points. The average weight points are obtained for both the currently implemented lessons learnt programmes and the full effectiveness potential of what it can attain. The results for consultants and contractors are shown in table 9-19.

Table 9-19 Effectiveness of current lessons learnt programme vs. full potential

Current vs. potential	Consultant	Contractor
Current implementation effectiveness	3	2.87
Full potential effectiveness	3.55	3.67

The results show that current lessons learnt activities are rated “somewhat effective” by both consultants and contractors. Both also rated the full potential of lessons learnt programmes higher than the current state – halfway between “somewhat effective” to “very effective”. These perceptions indicate that respondents see substantial premise for improvement in lessons learnt programmes and thus are probably open to new initiatives and measures to improve lessons learnt programmes. One respondent openly mentions that if any lessons learnt initiatives are to be introduced and carried out, they must be supported and enforced by organisational culture wholeheartedly, implying that it needs to be a structured formal process that does not happen only on an ad hoc basis.

9.7 Outcomes and conclusions of Phase-2 questionnaire

This chapter covers the questions and results of the Phase-2 questionnaire in detail. This questionnaire essentially aims to define constructability more explicitly and investigate the nature of how knowledge and lessons learnt initiatives are implemented. Different potential characteristics and principles of constructability are explored to give constructability some structure; and knowledge sharing and lessons learnt trends are explored to see how constructability knowledge can be better created and disseminated within the industry – especially between consultant and contractor. The outcomes and conclusions in this section are presented into 2 major parts: constructability related and knowledge management related sections, as set out below.

9.7.1 Constructability related

From this Phase-2 questionnaire, constructability related investigates are: labour efficiency principle, criteria for constructible design, and the constructability of specific configurations of different building components. The conclusions of these three aspects are discussed separately in the following sections, followed by a concise conclusion of constructability related conclusions/outcomes (in point format for easy reference)

Labour-efficiency principle

Labour-efficiency is adopted by in the Buildable Design Appraisal System in Singapore as the key principle to quantify constructability. The questionnaire results show that both consultants and contractors prefer equipment intensive work over labour intensive. However consultants prefer the use of in situ concrete, while contractors prefer precast concrete construction. The concurrent preference of equipment intensive work and in situ (by consultants) may appear to be contradictory since in situ concrete implies more labour intensive work than precast. This can be explained with the traditional trends of the construction industry – where in situ concrete is most widely used.

Criteria for constructible design

Some criteria for constructible design are given and qualified by the respondents. The importance of some constructability criteria differs between consultant and contractor. For example, contractors regard the “flexibility in adopting alternative construction details” and “safety” to be very important (section 9.2), while consultants place those criteria considerably lower than that of contractors. The explicit reasons behind these discrepancies are not fully investigated, but at the very least, the conclusion can be made that it is very important for consultants to be mindful of such discrepancies in criteria of constructible design. The different constructability criteria may well be used as a checklist for designers to consider and in principle appraise their designs. Different contractors may also have different perceptions regarding the importance of certain criteria, due to contractors’ own personal experience or some external condition, unique to the project. However, this investigation does show some correlation. Both consultant and contractors highly regard the importance of the criteria of “standardization and repetition”. Furthermore, the two criteria: “economic use of contractors’ resources” and “simplification of construction details”, correlate reasonably well between consultant and contractor.

Investigation on the least fulfilled criteria shows no correlation between consultant and contractor. It can thus be said that there is misalignment in the perceptions regarding the fulfilment of certain constructability criteria. Contractors regard “allow economic use of resources” and “minimise impact due to adverse weather by enabling flexible programme” to be the 2 least fulfilled criteria, which

suggests that consultants also need to consider these with more diligence and, where applicable, integrate these criteria into the design.

Constructability of building component' configurations

Building components and possible configurations of each are identified, and qualified by respondents with regards to ease of construction. The rankings and correlations are discussed in detail under the respective sections. Overall, consultants ranked precast configurations consistently low, while contractors show favour of precast configurations, except for the structural frame and the roof where the in situ configurations are ranked above precast. There seems to be fundamental misalignment of constructability perceptions here between the consultant and contractor. Consultants seem to definitively perceive precast to be of “poor constructability”, while contractors are quite open to using precast for most of the building components.

It is also notable that, for the façade wall and internal wall, the masonry configurations (labour intensive in nature) are ranked higher than the precast by both consultants and contractors, despite the preference of equipment intensive work for both, as indicated earlier. This construction trend and the reasons behind the preference of masonry walls need to be investigated in more detail – whether it is indeed technically justifiable, rather than merely as a default choice.

As mentioned before, the rankings of constructability of building components is only as obtained in this survey, and reflects the trend of the respondents alone. However, at the very least, these results of the building component configurations can be readily used as a basis for consultants to pose relevant questions regarding constructability during their designs, to maximize constructability in accordance with contractor opinions. The traits that this research uses to define constructability – labour efficiency principle, criteria for constructible design and the constructability of building components' configurations – can potentially be used as a checklist for points to consider between design and construction. At the same time, this can be a measure to increase diligent and collaborative mentality in the industry.

Phase-2 questionnaire constructability related conclusions (in point form):

The key outcomes for constructability related investigations of the Phase-2 questionnaire can be condensed into concise points as follows:

- Both consultants and contractors prefer equipment intensive work over labour intensive.
- Consultants prefer the use of in situ concrete, while contractors prefer precast.
- Contractors highly regard “flexibility in adopting alternative construction details” and “safety” as important constructability criteria, while consultants rank these considerably lower.

- Both consultants and contractors highly regard the constructability criterion: “enable standardization and repetition”.
- Both consultants and contractors agree on the importance of criteria: “enable economic use of contractors’ resources” and “simplification of construction details”.
- Contractors regard “allow economic use of resources” and “minimise impact due to adverse weather by enabling flexible programme” to be least fulfilled.
- There is fundamental misalignment of constructability perceptions between consultant and contractor on the configurations of different components of a building.
- Consultants consistently rate precast building configurations of lower constructability than contractors.
- Despite contractors’ indication that precast concrete is preferred over in situ (confirmed earlier), in situ roof and in situ RC frame configurations are ranked above precast roof and precast RC frame configurations respectively.
- Despite preferences of equipment intensive over labour intensive work for both consultants and contractors (confirmed earlier), both prefer masonry wall configurations (more labour intensive) over the precast wall configurations.
- None of the building components’ configurations provided is qualified by respondents as “very difficult to build” or “impossible to build”.
- Composite configurations (e.g. concrete filled steel sections or steel encased in concrete) are typically of very low constructability according to both consultants and contractors.

The configurations that are ranked highest by contractors for each building component are as follows:

Structural frame:	In situ reinforced concrete frame
Slab:	Precast slab with in situ topping
Façade wall:	Concrete masonry wall with applied finishes
Roof:	Timber roof truss
Roof support:	Precast concrete ring beam
Internal wall:	Dry wall partitions

It can thus be concluded from this investigation that a building design consisting of: an in situ reinforced concrete frame, precast slabs with in situ topping, concrete masonry façade walls, dry internal partition walls with applied finishes, timber roof trusses on precast concrete ring beams as roof support; best represent a constructible project, according to contractor respondents. The detailed information on the rankings of all the configurations can be found under section 9.3, and is not presented again here in the summary.

9.7.2 Knowledge management related

From the Phase-2 questionnaire, knowledge management related investigates are: project-closeout meetings, knowledge sharing modes and lessons learnt programmes. The conclusions of these three aspects are discussed separately in the following sections, followed by a concise knowledge management related conclusions (in point format for easy reference).

Project close-out meetings

Following the Phase-1 questionnaire (Chapter 7) where it is concluded that project archives, and data capture activities need improvement. It is assumed that substantial amounts of lessons and knowledge about the project can be exchanged during project close-out meetings, the outputs of which probably form the main constituent of project archives. The Phase-1 questionnaire, indicating that project archival data is insufficient, suggests the insufficiency of the project close-out process, which is studied further in the Phase-2 questionnaire.

The profile of attendees of project close-out meetings is established for both consultants and contractors. The results show that contractors carry out project close-out meetings more, and with more attendees, than consultants. The main problem identified here is that even though contractors engage in project close-out meetings, the presence and participation of the consultants seems feeble. While different contracts-, project-, and site managers and directors, site agents, estimators, and quantity surveyors are commonly mentioned as attendees, only 4 out of 17 contractors explicitly mentioned the involvement of consultants at their project close-out meetings. In this case, issues and problems on site that may have been attributed to unsound design, cannot be discussed in full without engagement from both design and construction personnel. This results in many of the issues being essentially unresolved and not fully understood, making it very difficult for similar issues to be avoided in the future. Measures need to be introduced to improve the simultaneous attendance and engagement of design and construction personnel, whether it is during or after the project.

Knowledge sharing modes

Analysis on knowledge sharing modes within the organization shows the prevalence of human interactions and tacit knowledge sharing, such as through informal chatting and storytelling, meetings, project briefing and review sessions, mentorship and training programmes, talks and seminars, emails, and phone calls. These are thus important mediums for improving the dissemination of constructability knowledge. Tacit knowledge sharing and socialisation is much more popular than modes that contain written, explicit knowledge, such as databases, memoranda, internal newsletters and circulars etc. This suggests that if a new knowledge management initiative is to be introduced and implemented, it is likely to gain the most effect if it embodies a human-orientated nature.

Lessons learnt programmes

The lessons learnt programme can be carried out with many methods to fulfil the three main processes – lesson identification, lessons analysis and lessons implementation. Results show that most lessons learnt activities occur as an unstructured process on a haphazard, ad hoc basis. This indicates that there may be little distinction between lessons identification, analysis and implementation, thus creating confusion when carrying out lessons learnt activities. Constructability lessons and issues are difficult to manage due to its complex tacit nature; a formal process is ideally required to maximize its full potential. From the results for all three lessons learnt processes, lessons learnt activities mostly consist of human-orientated methods: project close-out and intermediate meetings, review sessions, word of mouth and storytelling, and changes to a work process.

This indicates the importance of human- and social integration of the strategies, which are needed to improve constructability, which may in itself pose a great challenge due to the inconsistencies of human management. Lessons learnt programmes thus need to be formalized and regulated as systematic processes for its functionality to improve, while harnessing social and human-orientated methods.

For both consultants and contractors, lessons are mostly identified “only during” and “during and after” the project. None are identified “only after the project”. This suggests that there is no problem with “when” the lessons are identified.

Generally respondents perceive lessons learnt programmes to have a higher potential than the current state. This indicates some degree of dissatisfaction of the current state of lessons learnt programmes. There is thus premise for improvement in lessons learnt programmes. Furthermore, such endeavours must be supported and enforced by organisational culture wholeheartedly, implying that it needs to be a structured formal process that does not happen only on an ad hoc basis. More can definitely be done to investigate the barriers and challenges of lesson learnt programmes implementation, as it has direct relevance to the sensible capture of constructability issues, and the subsequent dissemination of knowledge to relevant project participants.

Phase-2 questionnaire knowledge management related conclusions (in point form):

The key outcomes for knowledge management related investigations of the Phase-2 questionnaire can be condensed into concise points as follows:

- Contractors carry out project close-out meetings more than consultants.
- Consultants’ attendance/presence at contractors’ project close-out meetings is feeble, thus many issues cannot be addressed with collaborative engagement from both consultant and contractor.

- Most common attendees of project close-out meetings are: contracts-, project- and site managers and directors, estimators, and quantity surveyors.
- Knowledge sharing modes employed are mostly human-orientated methods requiring socialisation, such as informal chatting and storytelling, meetings, project briefing and review sessions, and mentorship and training programmes.
- Knowledge management initiatives need to embody human-orientated principles.
- Lessons learnt programmes mostly occur as informal, haphazard processes.
- Similar to the results from general knowledge sharing modes, lessons learnt programmes are mostly carried out via human-orientated methods: project close-out and intermediate meetings, review sessions, word of mouth and storytelling, and changes to a work process.
- Respondents indicate that a higher potential of lessons learnt programmes can be reached if better implemented, and see substantial premise for improvement in lessons learnt programmes.
- Lessons learnt programmes need to be formalized and regulated as systematic processes.

In the next chapter the synthesis of open questionnaires is done. The open questions prompted respondents for the description of specific real constructability issues experienced in their projects. This is very important as it gives practical insight into all the data and results obtained elsewhere in the questionnaire regarding constructability, and it establishes a more accurate perspective for the sensible implementation of lessons learnt programmes or other knowledge management initiatives to improve constructability.

Chapter 10 Constructability Cases/Issues in Practice

The Phase-2 questionnaire has advanced the definition of constructability, by investigating the different perceptions regarding criteria for a buildable design, as well as the perceived constructability of configurations of major building components. The previous chapters thus focus more on the “what” of the problem, while this chapter attempts to explore the “why” – the reasons behind the decisions and trends reflected in the respondents’ choices regarding constructability.

The chapter describe the rationale behind the analysis of specific constructability issues in practice and the deductions and conclusions that follow. Further problems surrounding the project design and construction relationship that arises are also noted. Considering all the project cases and details on constructability issues analysed, this can also be regarded as a large-scale case study, each with a specific scope on constructability. The combined impression of all the cases gives a clearer interpretation of the nature of constructability problems in practice.

10.1 Introduction

This chapter analyzes the results from the open questions on constructability, forming part of the Phase-2 questionnaire. The respondents were asked to think back on the last 5 South African projects undertaken, or any 5 that is fresh in their memory, to list them and to provide a short description of each. Then, they were asked to identify, with a short description, up to 5 considerable “constructability issues” from any of the projects listed previously. Lastly, for each of the “constructability issues” identified, the respondents were asked to indicate whether or not the specific constructability issue could have been avoided if the design possessed better constructability. This essentially indicates whether or not the constructability problems are rooted in the constructability of the design from the start, rather than from construction decisions during project execution.

The understanding of specific on site conditions and unique environmental circumstances gives insight to the reasons for the decisions and preferences from previous chapters regarding different constructability choices. The results from the synthesis of these open descriptions of “constructability issues” also give deeper insight to the relationship between consultant and contractor – design and construction – in practice during a project. This knowledge of the environment is important for identifying problems on different levels and subsequently proposing strategies to improve them.

The rest of the chapter presents the results and discussions from these two main parts: (1) preventability of constructability issues by better design and (2) the constructability issues/case themselves. Afterwards, a comprehensive synthesis is drawn from the interpretation of the constructability issues/cases, with discussions on the constructability lessons extracted. In the end, a conclusion recapitulates the analysis of open constructability issues/cases and describes the major outcomes and implications of the findings.

10.2 Preventability of issues by better design

A total of 61 constructability issues are given and described by the contractors. Out of the 61 constructability issues, 58 of them are indicated to be preventable by “better design”. “Better design” may be subjective to the contractors’ perspective, and more often than not contractors tend to hold the design accountable for subsequent problems, while sometimes not knowing the exact reasons for the consultants design decisions. On the other hand, 41 constructability issues are given by consultants, of which only 15 are indicated to be preventable by design. This shows a contrast in opinions regarding the nature of constructability issues mentioned. Discussions between consultants and contractors on the specific issues are thus necessary to reach reconciliation. The in depth understanding of constructability issues contributes to the knowledge capacity of both consultants and contractors and thus improves the capacity to manage and foresee similar cases from project to project.

The contrasting opinions on whether the problems are preventable by design indicate that these are indeed issues that the contractor would wish to address together with consultants, especially when almost all of the issues given by contractors are deemed preventable by design. This supports the implementation of improved project close-out discussions and lessons learnt programmes, where these issues can be openly engaged by both contractors and consultants. It may be true that by the time the project ended, the “damage” would have been done. However, the valuable knowledge and lessons generated and learnt can greatly empower future projects. It can be seen as a continuous improvement process from project to project, so past mistakes can be avoided and work is done with higher diligence from previous lessons learnt.

10.3 Constructability issues/cases

Respondents were first asked to provide some descriptions of the projects, from which the constructability issues/cases are extracted. The variety of projects described is quite comprehensive, consisting of a wide range of industrial and commercial and infrastructure projects. This includes the construction of all the different building components in different configurations, involving a variety of precast and in situ methods and associated works, employing different types of construction methods. The typical project costs range between millions to units of billions, and project durations range between a few months to a few years.

The specific constructability issues are described by respondents. Since it is accepted that contractors embody more knowledge regarding the execution phase and the practical details of the construction environment, the cases provided by contractors are primarily regarded and analyzed.

A large number of constructability cases/issues are given by respondents and thus not sensible to present them all in this section, and is place in Appendix E. It is also difficult to categorize them due to the uniqueness of each case. The cases are condensed and analyzed individually, similar cases are consolidated together, and the findings and deductions are presented in a logical flow as far as possible. All the cases given are not covered comprehensively, as some of them are not of direct relevance to the research question. The cases are regarded as per research relevance and deductions are made accordingly.

In the analysis, the constructability cases have been condensed and categorised as follows:

- 1) Design problem
- 2) Timing of design issuance
- 3) Alternative construction or design from contractors' input
- 4) Simplicity and standardization
- 5) Site related issues
- 6) Aesthetics

Note that these categories are not definitive, but are roughly done to compartmentalize the readability of all the constructability issues/cases. Many constructability issues can well be associated with a few different categories and thus not necessarily confined to one specific category. Even though the cases are combined and condensed, the text is kept as original as possible for objective interpretation. Thus note that many of the opinions regarding the soundness of the design or construction systems are presented as it is given by respondents and thus are not that of the researcher. The synthesis discussion is done as a narrative to incorporate the complex network of reasons for the preference of certain decisions and the respective implications.

The condensed constructability cases from the questionnaire response can be found in Appendix E, under roughly the same categories as above. Within each category are further subcategories (as underlined headings), which represent types of constructability problems. The condensed cases are laid out further under these subcategories (as bullets points). Refer to appendix E for details. It is decided only to have the combined synthesis and discussions in this chapter (following section).

10.4 Synthesis and discussions

The constructability issues and cases given by respondents hold valuable lessons to be extracted. The practical cases offer insight to the nature of problems as experienced on site between construction and design. The syntheses of the given constructability cases are presented in the sections below, with a discussion of the key lessons extracted. The sections are presented in the 6 categories (as mentioned in the previous section) for ease of readability and understanding. However,

note that these categories are usually not mutually exclusive and can relate to other categories in different situations.

10.4.1 Design problem

There are cases given where the problem is described to be solely attributed to the design - where the structural design itself is unsound or incomplete. These problems can be attributed to the incompetence of the designer and have little to do with the actual constructability of the design, as the requirements for the designs are not met. These problems include excessive deflections during construction, structural failures due to the design, lack of provision for certain components (e.g. services, water/electricity reticulation, ceiling voids etc.) and neglect of inherent distortion of building materials during the fabrication or construction (e.g. flat plate galvanised box gutters distorted).

10.4.2 Timing of design issuance

The timing of design documentation issuance to the contractor poses challenges in construction in schedules. Typically the drawings are issued to the contractor just in time, or later. This may result in delays for the construction. Also this greatly diminishes the capacity for design drawings to be evaluated or changed to optimize the construction process, because of the lack of time. However the accountability does not necessarily lie with the designer alone. It is mentioned that often the designers are waiting for details from vendors, who must be employed first by the clients. The clients themselves are sometimes also delayed in conveying their requirements. The overall opinion regarding the timing of design is that it is poorly done and very seldom allows flexibility in subsequent phases for changes and alternative solutions.

10.4.3 Alternative construction or design from contractors' input

Quite a few case mentioned successful outcomes resulting from contractors' input. These include changes to the original design in one way or another (e.g. re-sequencing of work, changing configurations of building components, alternative construction methods). It is described that many of these changes are instrumental for the completion of the project on time. Thus providing an effective change management environment is also of great importance, which has its own barriers and challenges, such as the timing of the issuance of design documentation mentioned earlier, amongst other factors. Other cases, describing challenges in adopting alternatives by contractor, are also mentioned where such alternatives are simply not considered – resulting in a much more expensive and difficult construction process. It was mentioned that often, if contractors propose alternative designs or construction specifications, the contractor must also bear the accountability and supply guarantees for the life of the proposed structure. Design is not the core business of the contractor and is perceived as excessive risk exposure and thus discouraged. Therefore, many potentially beneficial alternatives are not pursued further. This, together with the pressure involved in the project schedule,

are great barriers to the adoption of alternative (better) design and construction. These barriers will need to be addressed explicitly.

Specific cases are given of alternative construction methods or designs for different building components. Some are notable and can be discussed with reference to the findings of the Phase-2 questionnaire (regarding the preferences of one configuration over another). Each of these cases contains practical lessons and is discussed respectively under the different building components in the paragraphs below.

In situ concrete

Sometimes self compacting concrete is employed over specified normal in situ concrete to reduce the time of construction (as vibration would be unnecessary) or in cases where reinforcement steel details are too dense for concrete aggregates to move smoothly through the openings. However, self compacting concrete has implied additional costs. The ingredient of the self compacting concrete is more expensive (e.g. use of plasticisers) and the shuttering needs to be much stronger as the hydrostatic pressure of self compacting concrete is much higher than that of normal concrete.

Slabs

It is mentioned that in situ slabs with down-stand beams are very difficult, time consuming and expensive. A precast alternative or even one of in situ with permanent formwork would have been much better. Furthermore, even in the case of flat slabs, in situ slabs often require a back propping period during curing. This causes massive delays with the succeeding activities, which is not taken in to consideration in the design of these slabs. Therefore, the design decisions of building component configurations not only have a direct constructability implication, but also may indirectly affect the succession of building tasks in the scheduling.

Structural steel

One case mentioned that extremely light structural steel roof forced contractors to assemble large portions of the roof and then hoist into position. The contractor had to allow for bigger lifting equipment, which escalated the costs. The light steel structure was perceived to be a disadvantage to heavier structural steel structure, in which case it could be assembled normally.

This shows that a presumably favourable configuration (such as light structural steel) may be perceived to be difficult, depending on the conditions and specific circumstances of the construction. It is thus important for consultants and contractors to have opportunities to discuss and clarify these types of issues.

Columns

Problems with columns involve excessively slender designs, which are described to be difficult to construct. A case mentioned that the rebar cages in the columns were very dense, heavy and long,

which made slip-form construction impossible. If the columns were only made thicker, it would have dramatically reduced the reinforcing requirements (with increased stiffness) and thus the density of the reinforcement and overall cost of these structures.

Another case described columns with massive cast-in items. Together with congestion of reinforcing, it made the vibration of the concrete impossible, thus required the use of self compacting concrete, which escalated the costs drastically. These columns could easily have been precast, which would have avoided these problems and yielded much higher quality finish and cheaper concrete design.

Ring Beams

It is mentioned that for fast track projects, it is not preferable to use in situ concrete ring beams, rather box steel beams or precast beams would be more beneficial.

Beams

Precast beams are used for better finish, consistent colouration and standard dimensions of the moulds.

Masonry walls

Masonry allows chasing for services. However, one of the cases mentioned that the masonry wall was so thin that the chasing compromised the stability of the wall as electrical boxes were situated back to back. This indicates negligence in the design, which did not take this into consideration. Chasing poses other disadvantages such as material waste, dust and health & safety implications during chasing.

Another case mentioned that less chasing is beneficial in principle. In that particular project, plumbing, water, electrical and waste supply needed to be implemented in a kitchen behind some cupboards. The original design specified chasing the walls behind the cupboards. However, the contractor later decided to move the cupboards 60mm from the wall to provide the space needed for the services and avoid the chasing. This resulted in substantial benefits; only to additionally provide a backing board for the cupboard to cover up the services. The services, not being embedded in the walls, also provide easy accessibility and maintenance.

Rebar related problems

Some cases specifically mentioned problems with reinforcement bars. Small spacing of rebar seems to be a common problem. It makes it very difficult or impossible to vibrate and compact the concrete afterwards. Sometimes, the spaces are so small that the large aggregates in the concrete are unable to pass through. High density and heavy rebar design also makes it difficult to handle (in one particular case even by crane) and poses constraints on the type of construction method possible. Another potential problem is the installation of bolts where the holes clash with the rebar while drilling. Rebar that are too long is difficult to man-handle. It is evident that rebar design needs to integrate the

construction processes on sight. Therefore the consultant must have practical perspective of the conditions and construction processes that are proposed for the specific designs. Another case mentioned that the designer did not consider the yield length of rebar after bending, resulting in bars becoming too long and must each be cut to fit.

10.4.4 Simplicity and standardization

There are cases that reflect the benefits of standardising the formwork as far as possible. The example given was making a beam 450mm wide instead of 425mm, which makes no significant difference in the design, but makes the construction much faster and cheaper. Formwork standardization is typically not considered in the majority of projects.

A case described a design with columns within a wall, but the columns had a different width to the wall. The columns could have been made the same width as the walls for consistent shuttering and finishing purpose.

Architects sometimes specify products that are new to the market or not within familiarity of the contractor. This can cause delays and may even require training to use these products. This also causes some frustration due to the lack of knowledge of the products. It would be better to specify products in which the contractor has confidence installing.

A simple concrete wall would be preferred over a brick skin wall with concrete cavity. However, it may be that the brick skin is an architectural requirement that must be fulfilled. Nevertheless there is a need for consultants and contractors to clarify such cases.

A few cases explicitly mentioned that coordination of services is always problematic. Evidently, different services and components are not comprehensively considered during planning. Clashes often occur, due to the complicated installation process. This also causes delays and additional costs.

10.4.5 Site related issues

There was mention of safety issues that were associated with local site conditions. One case mentioned that high altitude work needs to be better planned and integrated into the design. The particular example had polystyrene copings on high parapet walls where materials must be hoisted into position, creating considerable risks. In another case the contractor was of the opinion that the material specified was impractical – referring specifically to the design of a glass roof, where the installation was perceived to be risky.

Access to site may also pose construction difficulties. Two cases described poor in situ site material (sand), which made access and supply of equipment very difficult, and is also vulnerable to rain. This resulted in much rework and increased difficulty and time of construction.

The cranes that are needed on site may also be difficult due to congested sight conditions. Sometime, mobile cranes cannot access the site, so tower cranes must be used. Access of site and in situ conditions associated, must be taken into account during design. Some design configurations makes it very difficult for the contractor to build due to required access.

Excavations must be provided with proper drainage to prevent flooding, which disrupts work and may cause additional damage.

10.4.6 Aesthetics

Numerous examples of cases were mentioned where the aesthetics took priority over practicality and resulted in very difficult construction processes. In a way, there is no solution to this as it is the client's or architect's choice to enforce certain features into the design. However, if an open platform of discussion and understanding can be created, there is a possibility that contractors would be able to make informed, feasible suggestions to construction alternatives and potentially save the project a lot of money and time. Regardless of the flexibility of architectural or aesthetic requirements, without open discussions, there would be no premise whatsoever for improvement changes, where potentially better suggestions to be made and adopted.

10.5 Conclusion and summary of constructability cases and lessons

In this section the conclusions to the analysis and reasoning of all the constructability cases/issues are presented as two parts: (1) discussions of key conclusions arising from the cases in narrative, and (2) summary of the lessons extracted from these cases/issues presented (in point form) under the 6 categories in which the cases have been divided as presented in the previous section.

10.5.1 Narrative conclusion of key issues

The respondents' constructability cases offer a considerable amount of information on practical situations where constructability concerns take place. Clearly it is very seldom that a constructability issue is mutually exclusive to another. Usually a problem consists of a combination of many constructability issues and choices with implications that may lead to other constructability issues. It was very difficult to categorize and condense some of the issues given. In practice if constructability knowledge is to be explicated, it would follow a similar, probably more elaborate and challenging, process. This highlights the complex nature of constructability knowledge – or construction knowledge for that matter – which is most aptly represented as a pool of cause and effect. It is a network of

different events, where each event has a probability of occurrence that may lead to any other event in the network. Despite the inherent challenges to document constructability knowledge systematically, this simple exercise can show that substantial amounts of constructability knowledge can be extracted from experiences and explicated for sharing. Even on this small experimental scale it is possible for constructability lessons to be established. It is thus pertinent for such activities to take place on a larger, more systematic scale. More in-depth research needs to be done to develop feasible, practical tools to facilitate such processes and optimize them accordingly. This must be done in conjunction with the human-orientated nature of knowledge sharing within the industry.

Numerous constructability lessons could be extracted from the constructability issues given. Some are more general and can apply to a large variety of situations; others are very specific and only likely to occur in unique situations. Nevertheless, all these issues contribute to the knowledge pool of constructability, which, when disseminated thoroughly through any organisation, empowers the capabilities of project participants to question the most relevant issues. This thus improves the ability to foresee certain problems through insight into constructability. Such pools of knowledge can be readily used for inexperienced personnel (such as graduate engineers) as guidelines and decision aids, in addition to the tacit knowledge sharing that occurs during meetings, mentorship activities or seminars. This can be an accelerator to obtaining constructability experience.

Comparing the practical cases in this chapter with the results from the Phase-2 questionnaire regarding preferences of certain building component configurations, there is good alignment. From construction perspective, it appears common for precast systems to be implemented over in situ systems, due to its numerous benefits (time saving, no curing, standardized and simple, no shuttering needed etc.). Even though precast may be more expensive to build, precast gains advantage in schedule, reduced risks and reduced probability of further constructability problems. The trend that emerges from analyzing the constructability cases is that shuttering is typically not favoured as it poses many indirect risks and problems. The less shuttering is used, or the simpler the shuttering, the better is the constructability. Shuttering implies in situ concrete, which inherently requires curing and compacting (unless self compacting concrete is used); in situ concrete is also very difficult in terms of schedule.

Numerous problems related to masonry walls were mentioned. It suggests that chasing of masonry is undesirable as it creates premise for further problems. It would appear that chasing should be avoided when possible, unless it is very well planned and integrated with components.

The principle of standardization and simplicity is commonly applied in many situations and are preventable by diligence from the designer. The design of the rebar can be done so that it compliments construction processes. This seems to be something that is quite achievable, but often not fulfilled and needs to be improved. Design of dense, heavy or lengthy reinforcement steel is

typically undesirable. One may even consider increasing the dimensions of building components to increase the stiffness and reduce the density of rebar cages in the design.

The issue with complex designs dictated by the aesthetic requirements is one that needs to be clarified between consultant and contractor. There needs to be open platforms of knowledge exchange. It can be assumed that the aesthetic requirements, regardless of the functionality, are nonnegotiable. However, there is indeed a possibility that contractors can use their in-depth knowledge of construction to propose alternative methods, while still being able to bring about the same aesthetic effects that are desirable in the first place. This can only be achieved provided that the contractor is knowledgeable of the intentions and aesthetic requirements – not merely following the design that is specified by the consultant.

Regarding all the cases as a whole there seems to be great emphasis on time, more so than quality or cost. The design may well be sound and constructible, but often become problematic due to the imposed project time. In that case, contractors need to give their input where relevant and propose potentially better construction techniques, while negotiating or modifying the imposed schedule in agreement with other project participants. This was seen a few times in the cases presented and yielded successful results.

In many cases, it would seem that the design is able to prevent constructability problems. This would imply the responsibility lies in the designers to prevent these problems from the start. This is true in many cases, but most of the significant constructability problems, however, are not the “designs”, rather the problem is the capacity for downstream considerations to be made known to the designer during earlier stages of the project. Many of the constructability issues would not have been able to be detected during design stage – not even by contractors who hold most of the construction knowledge. Many constructability problems manifest only during construction, as on site work circumstances become clearer. These are problems that are unlikely to be identified even if the contractor is involved in the design stages, and are issues that are best managed through remedial actions (such as change management or back and forth negotiations) during the execution, rather than a preventative approach through intensive appraisal of the design itself. It is both the contractors’ and consultants’ responsibility to ensure an efficient problem remedial process. The contractors should actively share their knowledge with consultants, who should actively implement the knowledge for the benefit of the project. The consultants must also initially design the project with inherent flexibility to expect possible changes or better alternatives that may occur later on – changes that are in the best interest of the project and thus all the project participants.

In any case, which ever approach is followed to improve constructability, there is a need for open and dynamic knowledge sharing between project participants. The dynamic and systematic knowledge exchange can be brought about through initiatives such as lessons learnt programmes, which may include change management techniques. In principle, the more insight full project participants are, the

better they are able to make informed decisions and foresee potential risks and constructability problems, or at the very least, be able to question the most relevant issues at any one time during the project.

10.5.2 Summary of the lessons extracted from these cases/issues (in point form)

The summary of the specific cases is presented in a more concise form in this section for easier reference. The points are presented under the 6 categories in which the constructability cases/issues were divided and presented earlier: Design problem, Timing of design issuance, Alternative construction from contractors' input, Simplicity and standardization, Site related issues, and Aesthetics. The condensed cases as given by respondents can be found in Appendix E.

Design problem

- Inherent incompetence of the design results in problems such as: excessive deflections during construction, structural failures due to the design, lack of provision for certain components (e.g. services, water/electricity reticulation, ceiling voids etc.) and neglect of inherent distortion of building materials during the fabrication or construction (e.g. flat plate galvanised box gutters distorted).

Timing of design issuance

- Drawings are issued late or just in time, stifling the motivation for change or optimizing of design.
- Designers often wait for vendors or clients themselves for information, who are late in issuing.

Alternative construction from contractors' input

- Alternative construction involve changes to the design e.g. re-sequencing of work, changing configurations of building components, alternative construction methods, leading to a better solution.
- Changes that lead to alternative (better) construction are often instrumental for the completion of the project on time.
- Alternatives are often simply not considered – resulting in a much more expensive and difficult construction process.
- If contractors propose alternative designs or construction specifications, the contractor must often also supply guarantees for the life of the proposed structure; contractors are thus discouraged to do so.

- The pressures involved in the project schedule are a great barrier to the adoption of alternative (better) design and construction. Many potentially beneficial alternatives are not pursued further due to time constraints.
- Self compacting concrete saves time as no vibration is needed; however, they are more expensive and need stronger shuttering.
- In situ slabs with down-stand beams are best avoided; precast alternative or permanent formwork is preferable in most cases. Back propping of in situ slabs also cause delays.
- Weight and density of structural steel implies the way it is assembled – e.g. put together in position or first assemble aside and then lift into position with crane. This must be discussed between consultant and contractor to prevent misunderstandings.
- Very slender columns are difficult to construct. Together with dense rebar specifications, causes limitations to construction procedure and delays. It would be better to make the column thicker with less dense rebar details.
- In situ ring beams should not be used for fast track projects, rather box steel beams or precast beams.
- Precast beams are used for better finish, consistent colouration and standard dimensions of moulds.
- Chasing of masonry walls causes numerous potential problems, such as compromising the stability of the wall, material waste, dust and health and safety issues. Less chasing is better in principle.
- Excessively dense rebar cages or long rebar are difficult to lift with the crane and difficult to handle on site. Sometimes it does not allow the large concrete aggregates to pass through the openings between the rebar. Dense cages sometimes make vibration of the concrete impossible; this and dictates the use of self compacting concrete, which is more expensive and require stronger shutters.

Simplicity and standardization

- Formwork standardization is typically not considered in the majority of projects, but makes a great difference for improving construction processes.
- Specification of products that are new to the market or not within familiarity of the contractor causes delays and inherent uncertainty risks, and may also require additional training of personnel carrying out installation or construction.
- It is better to use a simple concrete wall over a brick skin wall with concrete cavity, which makes construction more difficult.
- Coordination of services is typically problematic, with clashes in components and procedures occurring often, causing delays and additional costs.

Site related issues

- Safety issues of working at high altitudes need to be considered during the design.
- Access to site may be a problem if in situ material is poor, which makes the supply of equipment very difficult. The material is also more vulnerable to rain, resulting in much rework and delays. Site congestion may prevent the use of the mobile cranes if there is not enough space to allow access for mobile cranes.
- Excavations must be provided with proper drainage to prevent flooding.

Aesthetics

- Aesthetics requirements are sometimes absolute, and take priority over practicality, resulting in very difficult construction processes. Contractors need to be more insightful of aesthetic requirements so that they are also able to make suggestions to alternative approaches, while maintaining the aesthetic requirements – instead of merely responding to consultant design details, which typically embody little constructability.

The following chapter is a case study of the integrated design development process of the Tubular Track ladder rail system. The evolutionary nature of their design process integrates knowledge from every part of the project (product) lifecycle. The model holds valuable lessons concerning the integration between design and construction – reducing fragmentation of different processes. The case study conceptualizes this process in detail and aims to extract feasible procedures or principles to be implemented in the construction industry.

Chapter 11 Tubular Track Case Study

Throughout this research the understanding of constructability issues and their implications are progressively being refined. Constructability knowledge remains difficult to quantify and define explicitly, due to the uniqueness of the circumstances in which these problems manifest. Nevertheless one can see from previous chapters (especially from the open constructability issues given by respondents) that constructability problems are experienced prevalently in the building industry. This can be directly attributed to unsound design – one which does not integrate project execution sufficiently into the design. More accurately, the problem is attributed to the poor identification, understanding and sharing of relevant construction knowledge between contractor and consultant. This trend is evident in the conventional design and construction environment where fragmentation is widespread. With this case study, the research explores solutions in an alternative industry where fragmentation is better handled and aims to extract principle lessons that can be applied within the conventional construction industry.

This case study investigates such an organisation – Tubular Track (Pty) Ltd – where design and construction is well integrated into a cyclic improvement process. In addition to the lessons learnt from the case study, the results are also used to validate the deductions made from the findings on constructability in the research, and thus ultimately establish a better strategy for the implementation of knowledge management initiatives to improve constructability.

This chapter covers the case study done on Tubular Track (Pty) Ltd, the evolutionary nature of its development and investigates how specific processes implemented at Tubular Track can be applicable to the traditional design and construct environment.

11.1 Rationale and objective

Contrary to the conventional design and construction project approach, Tubular Track has a semi-simultaneous or interactive development process. In other words, Tubular Track has an integrated design process, where factors from every phase of the Tubular Track life-span are considered and incorporated automatically into the design of the product. Along with continuous improvement and testing, it can almost be seen as an evolutionary design process, rather than a deterministic design and construction activity. This allows the “constructability problems” to be avoided or reduced to a great extent. The degree of integration at Tubular Track holds many lessons to be learnt. Furthermore, these lessons can be equivalently applied in the building industry.

The Tubular Track case study aims to extract meaningful knowledge regarding Tubular Track’s integrated design and explore the prospects of applying similar philosophies in industries beyond rail. In order to gain a comprehensive picture of the integrated design process, the Tubular Track configuration and components are clearly defined, along with the manufacturing and installation

processes. Furthermore, the Tubular Track design development and quality management processes, which are embedded within their project delivery mechanism, are covered. The evolutionary nature of Tubular Track design improvement is studied in detail. The case study basically constitutes the following:

- Tubular Track brief company history
- Definition of Tubular Track design configuration, manufacturing and installation
- Conceptualization of project design processes
- Evolutionary capacity of the Tubular Track

From the above, applicable principles and lessons are identified. The Tubular Track project delivery mechanism is documented and the knowledge streams within the organisation, bringing about the evolutionary design improvement process, are explored. The case study was done on a personal interview basis with key project personnel from Tubular Track (Kusel, Tengstrom & Shaw, personal communication, 19 July 2012).

11.2 Brief history of Tubular Track (Pty) Ltd

Tubular Track is a rail company, using manufactured precast concrete to longitudinally support the rail, in a ladder-track configuration. Contrary to conventional track, the tubular track does not involve ballast and sleepers. Figure 11-1 shows the Tubular Track system implemented in an arid environment.



Figure 11-1 Tubular Track system in arid environment

In 1989 Tubular Track was first offered to the South African mining industry, introduced initially to solve water drainage issues. The first South African and International patents were also registered in 1989. Since then some 600 km of track has been installed in the mining environment.

In 1993/94, Transnet Freight Rail's Track Testing Centre was commissioned to carry out comprehensive testing to validate the early theoretical work on the Tubular Track. A control test was carried out on an equivalent length of conventional track. These tests validated the design procedure, and demonstrated reduced stress levels and deflections in Tubular Track as compared to conventional track. Further confirmation was obtained from in-track tests, and on this basis Transnet Freight Rail approved the system for use in yards and sidings.

In 1995, Transnet Freight Rail approved the installation of a test section adjacent to a platform at Braamfontein Station in Johannesburg, a busy commuter station with freight and mainline passenger traffic. This Tubular Track installation carries in excess of 15 million tons per annum.

The development of Tubular Track turnouts followed. These have been constructed at sidings on the coal export line and at the Richards Bay Coal terminal, and carry axle loads up to 32 tons. Geometric stability and reduced maintenance have been achieved.

During 2003, precast modules designed for main line (22 ton axle loads) conditions were tested at the Transnet Freight Rail Track Testing Centre in Johannesburg. After simulating a five year main line usage period, settlement of about 1mm was measured in the system, with no damage to the precast modules or the grout underlying the modules. In-track testing then took place on a clay section on an ore line, where a total of one million net tons of coal and iron ore are transported monthly. Some 25 million tons have since passed over this section, which has required minimal maintenance.

Tubular Track design is continuously being improved through design development and has been followed by many successful applications since the early days of implementation.

Today Tubular Track rail has been installed in numerous rail applications, such as mainlines, turnouts, level crossings, bridge and viaducts etc, extending internationally to countries such as Namibia, Zambia, USA, Canada and Saudi Arabia. The Tubular Track's modular and standardized configuration allows it to be readily implemented in traditionally sensitive environments such as deserts, savannahs, tundra and underground.

11.3 The Tubular Track system

To understand the nature of the evolutionary design process of the Tubular Track system, it is important to clearly define the components of the Tubular Track design configuration and the manufacturing and installation processes.

11.3.1 Components of the Tubular Track design configuration

Tubular Track is basically a non-ballasted railway system, having rails continuously supported on twin reinforced concrete beams laid on a designed geotechnical formation. The concrete beams are tied together with galvanised steel tie-bars, the ends of which encircle the beams. Figure 11-2 shows the design configuration of the Tubular Track system and its components.

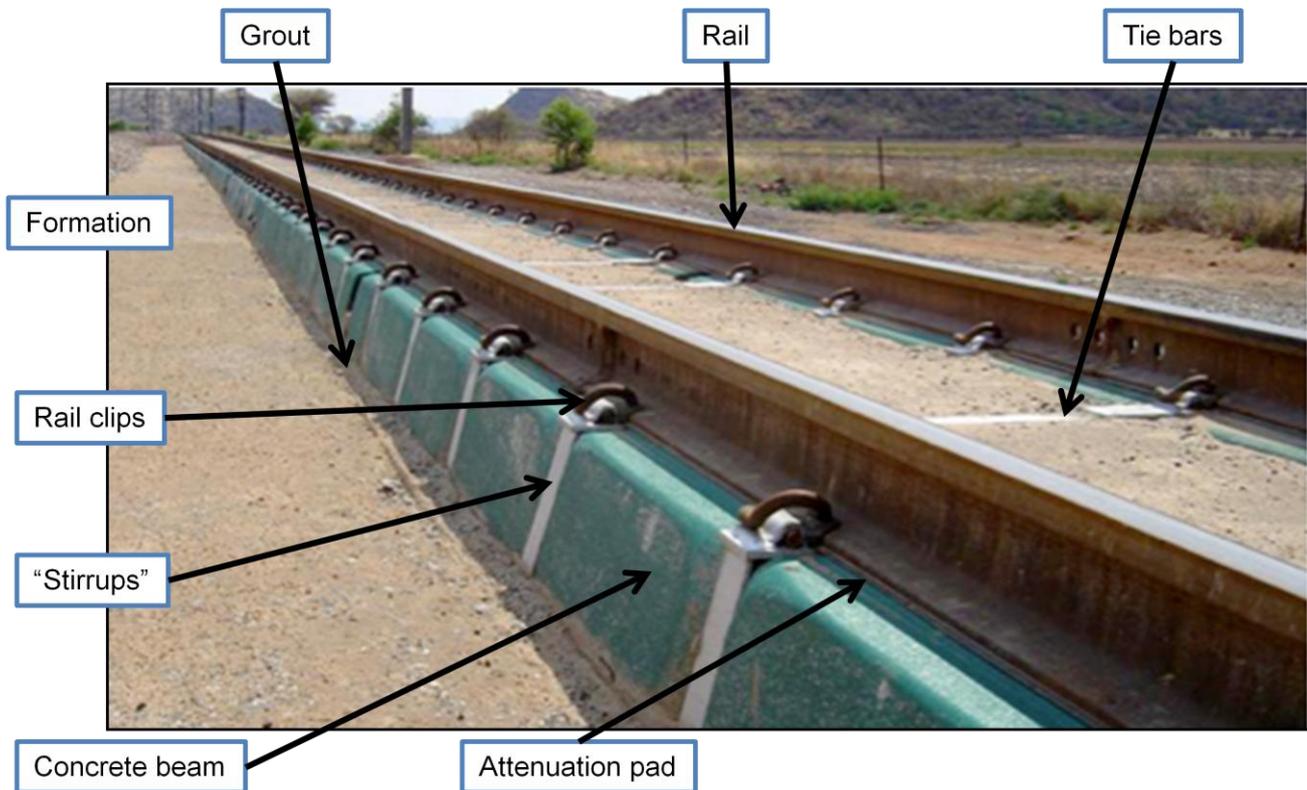


Figure 11-2 Tubular Track design configuration

The steel components include the steel galvanised gauge bars as connectors, the “stirrup”, which is the bracket encasing the concrete beam, and the base plate (not clearly visible in figure 11-2). The complete steel component is the tie-bar, consisting of the two stirrups/brackets connected by the steel galvanised gauge bar in between. The base plate is a steel plate welded on top of each stirrup/bracket, on which the rail clips are eventually fastened. The tie-bars are typically spaced at 3m intervals from another on a straight track. The interval distance is reduced on the curved sections of the track. Stirrups/brackets not cast into the concrete beam and ensures easy replacement.

The tie-bars encase and connect the twin concrete trapezoidal beams, which consist of 30MPa concrete. The beams are cast by pumping the concrete (without coarse aggregates) into green geotextile bags under high pressure, hence the green colour in the figure. A pipe is embedded within the concrete beam (not visible in figure 11-2, clearly seen in figure 11-3). The cast-in conduits in both

beams allow for various forms of cable to be installed, such as power cables, telecommunication cables, signalling cables etc. The conduits negates the need for trenching or open type cable trays, which are prone to damage and vandalism. Figure 11-3 shows the Tubular Track module, where the steel tie-bars are clearly visible.

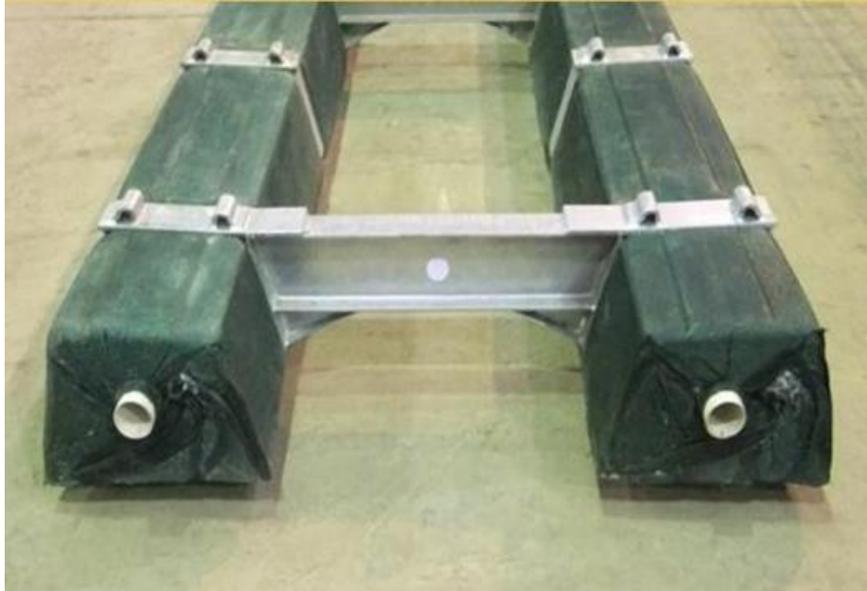


Figure 11-3 Tubular Track module without attenuation pad and rail

Below the beam is a layer of grout (figure 11-2), which transfers the load to the designed geotechnical formation below. This layer of grout also ensures optimal alignment of the rails, by allowing varying thicknesses as adjustment during installation.

The attenuation pad is a resilient strip, made of rubber bonded cork (figure 11-2), to absorb dynamic forces and reduce noise and vibration through damping. The rail is kept in place on the concrete beam by rail clips attached to the base plate of the stirrups, with the attenuation pad in between.

11.3.2 Manufacturing and installation process

The manufacturing of the Tubular Track system is done in three main phases: the manufacturing of the steel components, the concrete precast module to form the complete Tubular Track system, and the field installation.

The design specifications for the respective project would be received from their design office (the design development process is covered in the following section). The steel tie-bars are fabricated according to the designs. The steel is first accurately cut and bent, after which it is welded to form the complete steel galvanized tie-bars as describe earlier. The cutting, bending and welding are done at separate stations within the factory shop. Figure 11-4 shows the completed tie-bars, stacked.



Figure 11-4 Completed stacked tie-bars awaiting further process

The steel tie-bars and stirrups/brackets are integrated into the concrete beam component. This involves a few concurrent processes that lead to the final casting of the concrete beams.

The concrete is mixed for 30MPa characteristic strength of the precast concrete beams. The beams are cast by the pumping of the concrete under high pressure, thus no coarse aggregates are used in the concrete – only sand, water and cement. Concurrently the steel reinforcement cage for the beams is made. This is accurately and systematically done on a template dedicated for this purpose.

The final integration of the Tubular Track modules is done in purpose-built moulds (figure 11-5). The process is as follows; first the tie-bars are placed at the intervals on the mould, then two steel reinforcement cages are inserted into each of the twin trapezoids, through the opening of brackets/stirrups of the tie-bar (at right angles). The geo-textile bag is then slipped over the steel reinforcement cages, after which the mould is closed and concrete is pumped. Modules are cast upside-down ensuring tolerances within 1mm. The geo-textile bag facilitates the pumping process by keeping the concrete aggregates together under the high pressure, and creates an aesthetic finish on the completed product. This pumping fabrication process is unique to the company and is in fact the origin of the name “Tubular Track” – describing the filling up of the concrete in the mould resembling of toothpaste filling a tube. The mould, before pumping is shown in figures 11-5.



Figure 11-5 Tubular Track mould with only stirrups/brackets in place

The pumped Tubular Track is left to cure for about 24 hours, after which it is removed from the mould, ready for transport to site for construction or installation. The manufacturing process is simple and standardized, and is able to maintain the desirable quality and tolerances even at an on-site fabrication installation. This is applicable for projects situated far from developments. Figure 11-6 and 11-7 shows an on-site fabrication plant and completed Tubular Track modules respectively.



Figure 11-6 Tubular Track fabrication plant installation on site



Figure 11-7 Completed Tubular Track modules on site, ready for transport to installation point

The completed Tubular Track modules are transported to site for installation. Installation of Tubular Track can be done with a normal fork lift, a crane (figure 11-8) and/or a purpose-built hand operable gantry, which places the Tubular Track modules on the alignment of the track. More accurate adjustments can then be made, using jacks and wooden wedges to shift the modules into its exact position. The grout is applied under the Tubular Track modules while they are in place. For installation of Tubular Track in tunnels or confined shafts a special machine is used as shown in figure 11-9.



Figure 11-8 Installation of Tubular Track on site with a crane

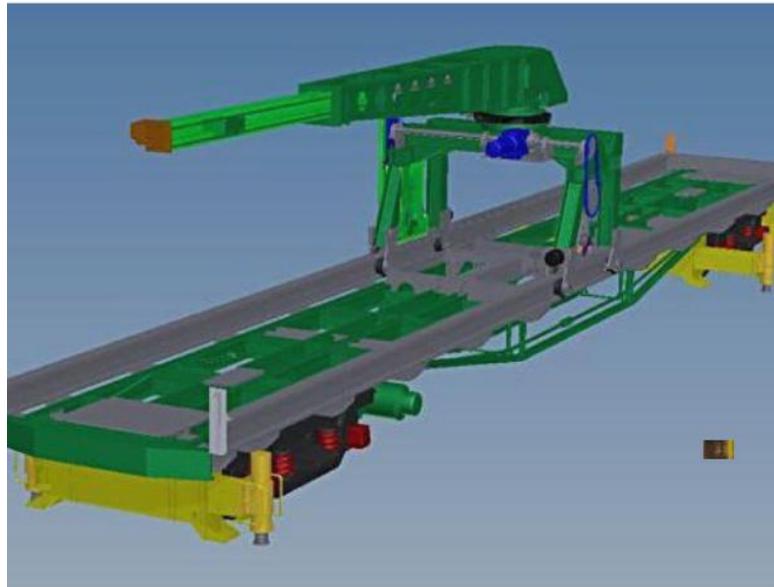


Figure 11-9 Machine for installation in tunnels and confined shafts

After the Tubular Track modules are in place, the attenuation pad (of resilient rubber bonded cork) is laid over the beams, upon which the actual rail is installed. The rail is fastened onto the top of the steel brackets/stirrups of the Tubular Track module with rail clips.

The manufacturing and installation process of the Tubular Track can be summarized in figure 11-10 below.

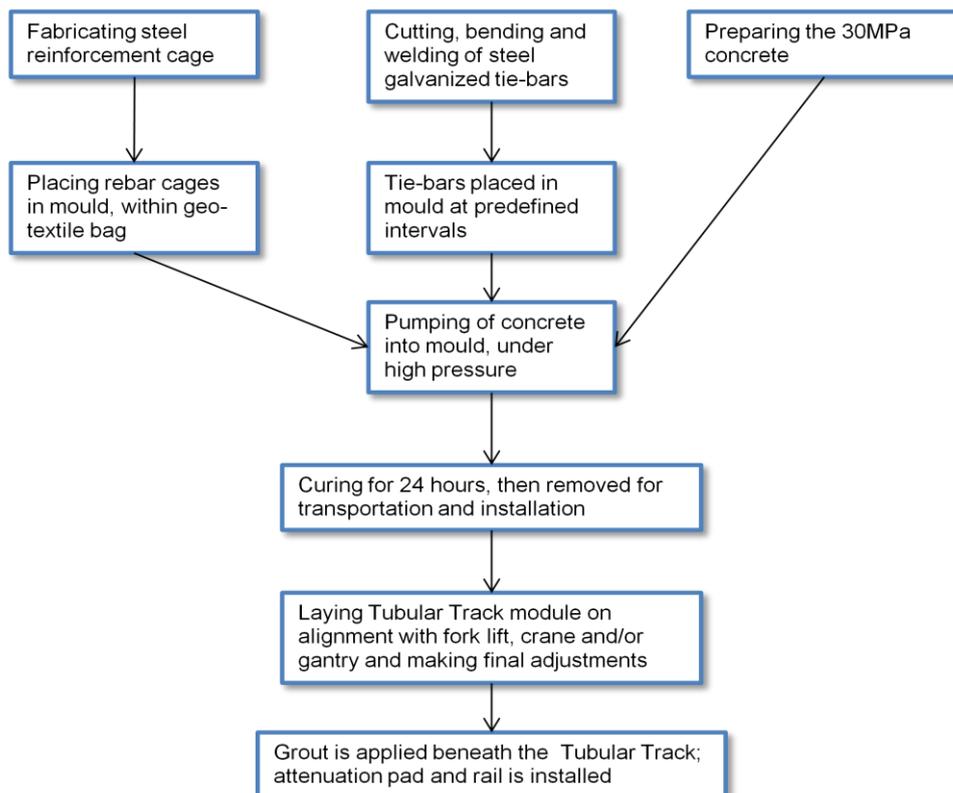


Figure 11-10 Summary flow chart of Tubular Track manufacturing and installation

11.4 Conceptualization of project design processes

This part of the case study conceptualizes the project design process of the Tubular Track system. This section will cover the process following the receiving of client's request, leading up to the formulation of Tubular Track design specification.

The design development process referred to in this section is the standardized deterministic activities that form part of every project depending on the varying inputs of the specific project. These deterministic calculations are based upon engineering or scientific principles and occur within the limit of the current Tubular Track configuration. This should not be confused with the inherent evolutionary process of Tubular Track, where knowledge and experience from manufacturing, installation and operation phases are channelled back to modify the Tubular Track configuration, little bit at a time. However, the Tubular Track design processes do contribute to the evolutionary capacity of the Tubular Track on a wider level. This is discussed in more detail in the following section.

The design development process discussed in this section is merely the progression of structural design activities followed, given inputs from the client, rail performance requirements and environmental conditions, to realize the product in each project. On this level, the configuration of the Tubular Track remains unchanged, except for the few parameters that vary according to the inputs for the specific project (such as reinforcement steel, gauge bar and stirrups, beam size etc.).

The design process has 3 main components:

- 1) Design planning
- 2) Design inputs
- 3) Product design and outputs

11.4.1 Design planning

After a request is received from the client, some fundamentals need to be established in order for the project to commence. The communication methods are determined and a channel is defined for the discussion of requirements. The following items outline the activities fulfilled in the design planning stage.

Obtain client product/rail-track requirements

Requirements may include: tender requirements, consultant requirements, client requirements, design parameters including axle loads and train speeds, and regulatory standards.

Client communication

Appointment of responsible person needed to oversee new design product
Establish communication methods with the client and or client's representative

Review and verification

Verify and validate product criteria with client requirements
Verify adequate support resources (outsource specialists if needed)
Cover specific legal requirements (if any)

11.4.2 Design inputs

All identified requirements need to be translated into explicit parameters to enable product realization. The following are used as inputs to the design of the Tubular Track modules or the specific project:

Functional and performance requirements

Track specification and requirement from the client
Environment/geotechnical conditions and product criteria including:

- Climate – wind, rainfall, and temperature ranges etc.
- Installation environment – coastal, dessert wetlands etc.
- Axle loads, rail size and specified track
- Gross annual tonnages
- Speed
- Rolling stock properties/parameters
- Applicable dynamic or static impact factors

Applicable statutory and regulatory requirements

Client specification and requirements
SABS/SANS Standards and International Standards (if applicable)

Information derived from previous similar designs

If a new design is similar to an existing design and has minor changes to be made, an existing design is used as a base for the new design, in which the above mentioned criteria are achieved.

Other requirements essential for design and development

In most cases, durability reports are conducted for abnormal conditions or on the client's request.

11.4.3 Project design and outputs

Once all the inputs have been obtained, the actual design of the following Tubular Track components can commence. The following components in particular are designed:

- Gauge bars (tie-bars)
- Stirrups (tie-bars)
- Beam size
- Beam reinforcement
- Formation/layer work (Geotechnical design)

Finite element models are used where applicable to achieve the final product design. The complete Tubular Track design specifications are reviewed and approved before being sent to the drawings department. The Tubular Track project design process can be summarized in figure 11-11.

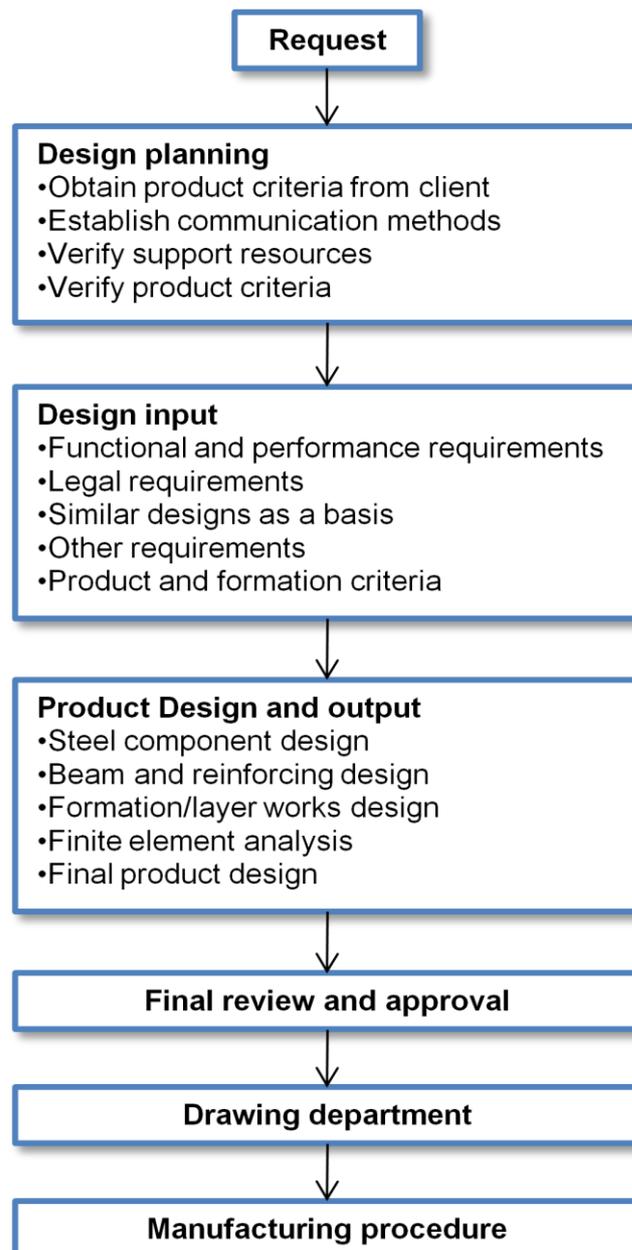


Figure 11-11 Summary flow chart of Tubular Track project design process

11.5 Evolutionary capacity of the Tubular Track

The project design process discussed above (section 11.4) is not of an evolutionary nature, because it does not actually follow an iterative development process on that level. The calculations done on that level do not imply any change of the Tubular Track configuration, only the few parameters, which are determined depending on the numerous criteria identified earlier. As can be seen, the design process described provides for the requirements identified before the project, and not as a response to issues identified in later phases of the project as part of a cyclic process. That said, the Tubular Track evolutionary improvement process does indeed occur, though on a higher level. The entire Tubular Track project aspects discussed above – configuration, design and even the manufacturing and installation processes – can be regarded as the result of this “evolution” of the Tubular Track concept over the years. The evolutionary nature of Tubular Track concept is explained and discussed in more detail in this section.

It is important to understand the Tubular Track configuration and all the processes involved in the project, as they relate to one another coherently, instead of being mutually exclusive or linear successive processes. This section describes the characteristics and mechanisms within Tubular Track that allows the inherent evolution to take place over long periods of time, from one project to the next. This occurs without conscious design and/or implementation, rather the diligent compliance of procedures that respond timeously to issues identified in the respective project phases. The following covers the attributes that makes the evolution of the Tubular Track possible.

11.5.1 Customer related process

Tubular Track has an active and dynamic customer relations procedure. Direct engagement is established with both the client and the consultant, enabling insight into the requirements and implications of technical decisions. Tubular Track has implemented systematic procedures for communicating with clients in relation to product information, enquiries, contracts and order handling, as well as feedback and complaints. There is active presence of Tubular Track in catering for client requirements from clients’ response regarding project delivery. The knowledge streams are important in making necessary improvement adjustments from project to project.

11.5.2 Standardization

Due to the nature of the Tubular Track’s precast business, a high extent of standardization is innately achievable – both in configuration and procedures. This makes it possible for the design team to be aware and insightful of the phases of construction of their product – including both manufacturing and installation.

11.5.3 Open interdepartmental communication

The manufacturing environment also allows factory managers and supervisors to be in direct contact with the design and drawing department, enabling an open platform for knowledge flow and quick response to issues identified.

11.5.4 Design construction integration

The configuration, project design, manufacturing and installation process are integrated parts of the delivery process. In other words, the specific configuration of Tubular Track, and each of its components, has a function in each of the other phases of the project. The current configuration of Tubular Track is not just a result of structural design, but embodies the requirements and functions of many aspects pertaining to the manufacturing, installation and operation phases.

To clarify and elaborate on this concept, several examples can be identified and discussed. The discussions below are presented for specific Tubular Track components. However, note that the integration concepts associated with each Tubular Track component are not exclusive and may well be related to that of another. The design and concept development of the following components are discussed below.

Geo-textile bag

This is an integral component of the Tubular Track system which sets it apart from other precast structural elements. The geo-textile bag has no structural contribution; however, it delivers its value indirectly in many ways. The bag contains the concrete (pumped) under high pressure used in conjunction with the steel (tie-bars). The geo-textile bag also acts as an anti-adhesive interface between the concrete and the mould, ensuring easy removal of the Tubular Track from the mould after curing.

Concrete without course aggregate

With normal structural concrete principles, course aggregates are typically used, which hold many advantages. Tubular Track, on the other hand, employs concrete without course aggregates for a combination of reasons.

An important requirement was to allow the concrete to flow into the geo-textile bag, thus requiring sufficient workability. It was decided not to use plasticizers as the mixing would become difficult to control and thus it increases the risk of inconsistencies in concrete quality. There was thus a need for concrete without plasticizers, and that still achieved the workability required without vibration. Furthermore the requirement for the pumping is difficult or impossible to fulfil with course aggregates in the concrete. It was decided to employ a concrete mix without course aggregates, which achieves

the workability requirements and allows the concrete to be pumped under high pressure, without the use of plasticizers.

Another key reason for not using coarse aggregates is the potential lack of availability of gravel as a construction material. Tubular Track is often installed in remote areas and desert conditions, where an on-site fabrication installation is necessary. This means that the unavailability of quarries may pose an overwhelming obstacle to the project. The presence of quarries is not always guaranteed and the use of gravel in the Tubular Track system leads to further complication of the process. The fact that coarse aggregate is disregarded in the design thus also allows principles of simplicity and standardization to be achieved, while avoiding the risk of material unavailability.

The concrete mix design is therefore a good example of Tubular Track's evolution to arrive at the desired result, through the response of issues especially from manufacturing, installation and site conditions. The decision could not have been achieved by design alone without keen insight of the implications and interests of each of the fine manufacturing and installation requirements. This is a good example of how knowledge (in our case: "constructability knowledge") from subsequent phases of the project can be sensibly captured from the perspectives of the personnel involved in all the phases of the project.

Steel tie-bars

Its sole function is to maintain the rail gauge. They are not cast into the twin beams and enable some flexibility at the interface with the concrete beam and thus avoid unnecessary stress build-up during operation. Not casting the steel into the beam, also allows the pumping of the concrete to be done "independently" and thus better process control to be achieved. It also makes the replacement of the tie-bars much easier, allowing it to be done modularly. Furthermore the current tie-bars configuration is easy to fabricate and thus high quality can be achieved.

As can be seen in the numerous pictures of the Tubular Track configuration (particularly in figure 11-3 and 11-4), the gauge bar is aligned with the top of the concrete beam. However, this was not originally the case. Initially the gauge bars were located to be aligned with the bottom edge of beam. This had caused many problems with longitudinal drainage, where the lateral tie-bars essentially posed an obstruction to the flow. This resulted in an additional drainage channel to be provided above the tie-bars. Many related problems were bypassed by aligning the gauge bar with the top edge of the concrete beam, which is also made easier by the casting of the beams up-side-down in the mould. The longitudinal drainage can now be provided without obstruction beneath the tie-bars.

The tie-bars brackets/stirrups encasing the beams have been a key characteristic of the Tubular Track configuration since the beginning. This goes hand in hand with the use of geo-textile bags to contain the concrete during pumping. The current configuration of the tie-bar can be seen as a result of an iterative evolution of the Tubular Track configuration over many years of experience and

mediation of numerous issues identified not only during design, but also in subsequent phases – manufacturing, installation and operation. The evolution is evidently not an independent process and takes place with other aspects of the Tubular Track product and processes.

Another evolutionary aspect is that initially an “angle iron” (L-profile steel beam) was used as the gauge bar. This evolved eventually to the I-profile steel beam we see in the current configuration for simplicity in geometry (symmetry) and analysis, as well as added strength of the tie-bar.

Upside down casting

Initially the Tubular Track beams were pumped “right-side-up” with the rail contact surface on top of the mould. This had worked previously, however, the current casting method, where the mould is pumped upside down, allows higher accuracy for the top longitudinal surface on which the rail is in contact, because the bottom of the mould (the top of the Tubular Track) is a continuously fixed mould surface. Any slight unevenness of the contact surface with the rail can cause unnecessary stress especially during cyclic loading patterns of rail operation. The consistent accuracy of the contact surface also minimises the likelihood of friction induced longitudinal stresses between the rail and the Tubular Track. Upside down casting is significant in achieving this.

The upside down casting also assists with the alignment of the gauge bar to the top edge of the Tubular Track (bottom of the mould), where the tie-bar is fitted accurately to the mould. Furthermore, together with the trapezoidal section of the Tubular Track beam, the upside down casting ensures easy removal of the Tubular Track after curing.

Once again, it is evident that each component does not function independently. They usually cause and are affected by other components’ configurations for a variety of reasons arising from different phases of the project.

Tubular Track concrete beam

Initially, the section of the beam was of a rectangular profile. The current trapezoidal section seems to be the optimal configuration, and holds many advantages integral to the Tubular Track manufacturing and installation. The trapezoidal shape, as mentioned previously, allows the easy removal in an upside down position from the mould. It also ensures added stability of the beam by lowering the centroid of the section closer to the ground – thus reducing the likelihood of overturning (along the longitudinal axis). It also provides a higher contact surface with the soil to reduce bearing pressure, thereby limiting deformation.

The length of the Tubular Track beam sections facilitates the relocation, transport and handling of the Tubular Track modules without structural damage. The limited length (5m – 6m) allows it to be loaded onto trucks and it is light enough to be handled with small cranes or forklifts on site, while ensuring an undamaged state during transport and installation.

Grout

The grout beneath the Tubular Track beams transfers the loading into the formation/geotechnical material beneath. It does not fulfil any particular structural function, but plays an important role in facilitating accuracy of the rail alignment during the installation process. The grout enables a margin of flexible adjustment for the beams to be perfectly aligned before the grout is applied, thus fixing the final position of the Tubular Track modules.

Design construction integration general deduction

All the above discussions presented for specific components and associated processes (geo-textile bag, concrete, steel tie-bars, pumping and casting, grout) should not be independently interpreted. The decision of one component or process leads to that of another component or process. The configuration must embody requirements from all the phases – design, manufacturing, installation and operation – and optimise them coherently to minimize waste. This was done by Tubular Track through an iterative evolutionary development, which will be discussed later in the chapter.

11.5.5 Monitoring and testing

In addition to the standardized processes in each project, Tubular Track undertakes continuous testing and monitoring activities as part of their quality management system. The quality of materials and quality related issues can be very closely handled as they are all built into the standardized processes at the factory shop. Concrete cube testing is done regularly to validate the consistency of the concrete in the Tubular Track beams. Strain gauges are placed on some projects to monitor displacement data over longer periods of time.

The quality management system of Tubular Track is maintained and continually improved through the use of the quality policy and objective, audit results, data analysis, corrective and preventative actions and management reviews. Tubular Track ensures the availability of the information necessary to support the operation and monitoring of all the processes and establishes systems to do so. Furthermore, the documented records are readily identifiable, retrievable, protected and stored/archived at the retention time.

Continuous research and development is still being done to improve the Tubular Track. Different analyses are being carried out to study more specific responses of certain components and the performance capacity of different materials. Special avenues of research are also still being employed to compare traditional ballast-and-sleeper rail with Tubular Track systems over the life-cycle implementation.

11.6 Synthesis and outcomes of case study

The case study sets out to conceptualize processes employed at Tubular Track and understand the nature of these processes, their relationships with one another, as well as the implications of these relationships in the product configuration and performance. All of this has been done, and this section presents a deductive outcome of the case study and extracts principles and lessons that can be applied in the industry at large to improve constructability.

11.6.1 Tubular Track principles

The understanding of the Tubular Track configuration and project processes made it possible to regard the evolutionary capacity of Tubular Track. This is central to Tubular Track's ability to continuously improve the product configuration, taking the whole life-cycle into consideration.

There are specific attributes of Tubular Track processes, the combination of which enables their evolutionary capacity. These major attributes can be summarized as follows:

- Close relationship between the contractor, client and consultant – insight to all requirements
- Systematic and diligent response to issues from all project phases
- High level of design and construction integration
- High level of standardization and simplicity
- Efficient quality control measures – testing and monitoring
- Dynamic platform of knowledge sharing within all departments

The combination of the above attributes identified in the case study ensures that constructability problems are minimal. The lack of constructability problems is a result of an evolutionary development process of the Tubular Track system made possible by the attributes above. As can be seen, one attribute may only be possible with the fulfilment of another, thus these should not be regarded as points on a checklist, rather an integrated network of interdependent relationships with one another.

11.6.2 Tubular Track evolution

The evolutionary development of the Tubular Track system can be described more as a passive, inherent process, rather than that of an intention-driven design. The configuration of the Tubular Track remains similar from project to project with small gradual changes over time. The current Tubular Track configuration, as described previously, is the result of a long evolutionary process over many years where issues from the manufacturing, installation and operation phases are constantly regulated and addressed and, when applicable, changes to the Tubular Track configuration was made. These changes from the Tubular Track evolutionary process imply that the configurations of components are not necessarily designed, but rather “evolved” in response to the issues identified in

subsequent phases of the Tubular Track life-cycle. In other words the manufacturing, installation and operation are integrated into the physical appearance/configuration and thus the function/performance of the Tubular Track. Constructability problems, to which the design phase is usually oblivious (in construction projects), can be addressed through evolution – through corrective actions, while back-channelling the knowledge to be integrated into the design. The nature of organisational operations at Tubular Track enables this to be done effectively.

Referring to the Chapter 10, the specific constructability issues, it is evident that most constructability problems are not detected during design stages, even by experienced designers. It can thus be questioned whether it is possible at all that constructability problems can be resolved or avoided by design philosophies, as it implies knowledge of preconceived risks and requirements, and then responding to them through design. Constructability issues, however, are often not known until after the design phase, thus an evolutionary measure would be more appropriate in addressing constructability in the industry at large. The key Tubular Track attributes listed in the points above may well pose as principles to improve constructability in general. These principles concur with the findings and deductions from previous chapters, indicating that constructability issues can be addressed and eventually be improved through a more collaborative mentality. The required level of collaboration is difficult to achieve in the traditional construction industry due to its fragmented nature, unlike Tubular Track. It is therefore pertinent to introduce initiatives – particularly that of knowledge management – to reduce the fragmentation in the construction industry by creating, capturing and sharing of relevant knowledge with relevant parties.

11.6.3 Lessons learnt from Tubular Track organisational procedures

Tubular Track is able to passively address constructability problems through the organization's operational procedures. These procedures allow a high level of integration – particularly knowledge integration – so that all aspects of a Tubular Track project (configuration, design, manufacture and installation) compliment and support one another cohesively.

Merely regarding how the various components of the Tubular Track configuration came about (as discussed in section 11.5.2) imparts many lessons that can be applied in the construction industry in general. None of the Tubular Track components was a result of pure “design”; they rather represent the end point of a variety of constructability reasons later on in the project, all of which must also embody the performance requirements.

Tubular Track exemplifies the principle of simplicity and standardization – both in procedures and physical configurations. This allows many of the quality and constructability risks to be addressed in detail early in the project, by departments that are most capable to do so. Very simple and repetitive work is left for on-site operations, where the project is most subjected to external risks.

These attributes allow Tubular Track to manage their knowledge well, and achieve dynamic feedback and response between different in-house departments, as well as consultants and clients. An integrated solution is achieved through the particular integration of knowledge. The tubular track evolutionary development allows the organisational knowledge to grow progressively and to be channelled back perpetually into the Tubular Track configuration.

As a conclusive remark on the case study, the nature of Tubular Track's business is one of high standardization. This implies that the processes and knowledge associated with them are easily explicated and thus can be quantified and managed. Traditional construction knowledge on the other hand, due to unique operations and the wide variety of circumstances, is mostly in a tacit form, and may not even be made explicit or quantifiable. The explicit nature of Tubular Track's knowledge resources is a powerful quality and should be encouraged within the construction industry, which can only be brought about by increased standardization. However, this is obviously not always possible in the general industry. To overcome this, an alternative (probably more relevant) approach can be adopted. The explicit contents of constructability knowledge should be regarded as a lesser concern. Instead, the primary focus should be on the actual capacity to learn lessons and apply them. In other words, initiatives should well be introduced as tools to facilitate the learning process, rather than to identify explicitly what should be learnt, which evidently is often impossible in the case of construction knowledge due to the uniqueness of individual projects. Empowering the learning process inherently empowers the evolutionary capacity to solve problems as a continuous mechanism. This can be demonstrated by studying the nature of Tubular Tracks organisational procedures.

The case study on the Tubular Track systems and processes has brought numerous characteristics to light, which enables Tubular to inherently remove constructability problems. This is achieved through an evolutionary mechanism, brought about by the combined effects of their standard operations. The lessons and principles identified in Tubular Track are readily applicable in the traditional construction environment and can be related to many of the results and deductions from previous chapters. The following chapter is a comprehensive discussion of the outcomes of all the research and investigations carried out in this research.

Chapter 12 Research review and discussions

This research constitutes a number of investigations, from different perspectives, through several phases. The outcomes of these research activities are presented under the respective relevant chapters. This penultimate chapter of the research thesis aims to combine all the deductions into a cohesive interpretation and discussion, with the broad objective in sight – to improve constructability through knowledge management principles. This chapter will review logical progression of the research, summarise all key outcomes and conclusions arising from the several research investigations, and discuss the ensuing recommendations that follow. In the following chapter, the conclusions and recommendations, including future research prospects, are concisely presented in a condensed format.

12.1 Review of research rationale

This research sets out to examine how knowledge management can contribute to improving constructability. In logical deduction, constructability problems are caused by poor coherence between design and construction – poor integration of knowledge from subsequent phases of the project during the design phase. This has been verified throughout the research. From this, a few fundamental research questions that can be inferred to trace the cause or causes of the problem at large. Answering these questions will narrow down and refine the problem to a more explicit form, which this research has done. To a great extent, the research has validated what needs to be done to improve constructability, through better defining the concept of constructability and understanding the nature of constructability knowledge and the management thereof within the industry.

This research essentially investigates and formulates an ideal scenario that must be adopted in the industry to improve constructability. Following this, the research identifies where the problem lies – and why these problems occur, posing barriers to the realization of an ideal scenario. Considering the management constructability issues the ideal scenario is one where:

- 1) The definition and different implications of constructability – in terms of procedure as well as product – is understood.
- 2) There is a high level of collaborative project decision making, taking into consideration the perspectives and knowledge of different project participants.
- 3) Mediations and negotiations occur regularly and with good speed and response, continuously seeking better, more constructible solutions as integrated procedures and designs.
- 4) Project participants have the ability to identify, analyse and implement lessons learnt systematically, with cooperative approaches between disciplines.

- 5) These lessons are documented systematically (as explicit knowledge) to be shared with others, complementing and accelerating the process of gaining experience (as tacit knowledge) on constructability issues.

The points of an ideal scenario are not mutually exclusive, and as can be seen, one point may only be fulfilled with the help of another point. This research covers each of the points in the scenario and investigates why problems arise, preventing points to be fulfilled. The fulfilment of these points of an ideal scenario is dependent on numerous factors during the project life-cycle. These are identified as avenues of investigation in the research, set out in the objectives in Chapter 2.

12.2 Summary of research findings from the different investigations

More detailed discussions on the findings and deductions arising from the different parts of the research can be found under the respective chapters. This section aims to summarize the major ideas and strategic directions resulting from the combined interpretation of the research findings. The following presents the thought process of the research and leads the logical progression from one concept or question to another. This is done for each of the following 6 investigations undertaken in this research:

- 1) Literature study
- 2) Project archives investigation
- 3) Constructability related investigation
- 4) Knowledge management investigation
- 5) Constructability cases/issues in practice
- 6) Tubular Track case study

The summary of the key findings for each of these 6 investigations is presented in the following sections.

12.2.1 Literature study

The broad aim of the research is to prevent or improve constructability problems. In order to do so, one needs to understand constructability more explicitly. The literature offers some principles and perspectives of how constructability can be defined. However, these are found to be broad definitions and cannot measurably capture what is, for example, “good vs. poor” constructability or how one can determine the degree of constructability of a design, and determine whether one design configuration or procedure is more constructible than another.

12.2.2 Project archives investigation

The research starts by identifying a source where constructability data, information and knowledge may be found. The project archives are an obvious target for investigation, where most aspects of the project are presumably captured, which if properly done, is assumed to contain documented constructability related intelligence. A profile of a typical complete project archive is generated (section 7.6.1 in table 7-4), which can be used as a basis to measure the completeness of the contents of other project archives. Through the Phase-1 questionnaire, the potential of archival data in project archives are investigated in full. However, it has been found that there are shortcomings in this regard. Project archiving, archival data and associated processes in their current state, is not a worthy knowledge management measure to disseminate constructability thus has very little potential of improving constructability. The outcomes, arising from the Phase-1 questionnaire, regarding the current state of project archives and data-capture, and the associated perceptions, can be condensed in point form as follows:

- A project or archive, however thorough or complete, is not easily available for future access.
- The content of the project archives is limited in scope and items are not sufficient for historical analysis of more specific issues later on, such as constructability lessons.
- Numerous potential lessons can be learnt from captured data. However, there is in principle dissatisfaction of the data-capturing activities.
- It is beneficial to capture more data, information and knowledge.
- The capturing systems have premise for improvement in terms of offering more relevant data
- There needs to be focus on the analysis of the captured data in deriving lessons learnt.
- There needs to be focus on the direct extraction of lessons and knowledge from personnel (not from data) through lessons learnt programmes.
- There needs to be focus on the structured or organised storage of data, information and knowledge in order to achieve time- and effort-efficient accessibility for the user.

12.2.3 Constructability related investigations

The question can now be posed: why are project lessons learnt and knowledge on constructability issues so poorly managed? This leads the research to concurrently investigate the nature of constructability knowledge and the reasons why it is difficult to document. It has been confirmed that constructability expertise exists in a highly tacit form and is indeed very difficult to draw consistent trends due to the uniqueness of constructability issues in practice.

However, the goal is to investigate how far constructability can indeed be explicitly defined. The research has furthered the understanding and conceptualization of constructability to a great extent. This achieved by investigating a few traits, whereby constructability can be defined:

- 1) The validity of labour-efficiency principle in constructability
- 2) Criteria for constructible design
- 3) Constructability (as defined by ease of construction) of specific building components in different configurations

With the Phase-2 questionnaire these aspects were investigated in depth, while addressing discrepancies between the results of consultants and contractors. The summary of each of these investigations is presented separately in the following sections.

Labour- efficiency principle

In terms of labour-efficiency, research shows that there is a distinct inclination to prefer equipment intensive work over labour intensive work. The following is found:

- Both consultants and contractors prefer equipment intensive work over labour intensive.
- Consultants prefer the use of in situ concrete, while contractors prefer precast.

Criteria for constructible design

Criteria for constructible design represent different interests and perspectives that the consultants and contractors may have towards the importance of certain project aspects (detailed results to be found in Chapter 9, section 9.7). The consultants and contractors concur on some criteria and differ on others. Thus it is pertinent to regard each case separately and extract the lessons accordingly. The key findings of the investigation on constructability criteria can be summarized as follows:

- Contractors highly regard “flexibility in adopting alternative construction details” and “safety” as important constructability criteria, while consultants rank these considerably lower.
- Both consultants and contractors highly regard the constructability criterion: “enable standardization and repetition”.
- Both consultants and contractors agree on the importance of criteria: “enable economic use of contractors’ resources” and “simplification of construction details”.
- Contractors regard “allow economic use of resources” and “minimise impact due to adverse weather by enabling flexible programme” to be least fulfilled.

Constructability of different configurations of components of a building

Different building components and configurations thereof are identified and the constructability has been quantified in terms of ease of construction. Chapter 9, section 9.3, presents the detailed rankings of the quantified constructability value corresponding to each building component configuration. As an evident overall trend, consultants rank precast configurations consistently low,

while contractors mostly show favour of precast configurations. There seems to be a fundamental misalignment of constructability perception here, between the consultant and contractor. Consultants seem to definitely perceive precast to be of poor constructability, while contractors are susceptible to prefer precast in many cases. Constructability is hardly determinable through the distinction of precast vs. in situ methods; however, they evidently contribute a great deal to the definition of constructability. The key findings of the constructability of different configurations of building components can be summarized as follows:

- There is fundamental misalignment of constructability perceptions between consultant and contractor on the configurations of different components of a building.
- Consultants consistently rate precast building configurations of lower constructability than contractors.
- Despite contractors' indication that precast concrete is preferred over in situ (confirmed earlier), in situ roof and in situ RC frame configurations are ranked above precast roof and precast RC frame configurations respectively.
- Despite preferences of equipment intensive over labour intensive work for both consultants and contractors (confirmed earlier), both prefer masonry wall configurations (more labour intensive) over the precast wall configurations.
- None of the building components' configurations provided is qualified by respondents as "very difficult to build" or "impossible to build".
- Composite configurations (e.g. concrete filled steel sections or steel encased in concrete) are typically of very low constructability according to both consultants and contractors.
- The following are configurations that contractor respondents ranked highest in constructability for each component: in situ reinforced concrete frame, precast slabs with in situ topping, concrete masonry façade walls, dry internal partition walls with applied finishes, timber roof trusses on precast concrete ring beams as roof support. It can thus be said that a design with these configurations best represent a constructible project, according to contractor respondents of this research. The detailed information on the rankings of all the configurations can be found under section 9.3, and is not presented here in the summary.

12.2.4 Knowledge management related investigations

The Phase-2 questionnaire also delves into the management of constructability knowledge, by investigating the following:

- 1) Project close-out meetings
- 2) Popularity of specific knowledge sharing modes
- 3) Current state of lesson learnt programmes in the industry.

The discrepancies between results of consultants and contractors are addressed. The summary of each of these three investigations is presented separately in the following sections.

Project close-out meetings

Following the conclusion that archival data in company project archives are incapable of delivering constructability knowledge, the focus now shifts to the processes upstream (processes leading to the compilation of the project archive), to trace the problem deeper. The project close-out meeting is investigated in detail. A collective profile of typical attendees of project close-out meetings is generated (section 9.4 table 9-10) for both consultants and contractors. The key findings of the project close-out meeting investigation can be summarized as follows:

- Contractors carry out project close-out meetings more than consultants.
- Consultants' attendance/presence at contractors' project close-out meetings is feeble, thus many issues cannot be addressed with collaborative engagement from both consultant and contractor.
- Most common attendees of project close-out meetings are: contracts-, project- and site managers and directors, estimators, and quantity surveyors.
- The dynamic exchange of interdisciplinary knowledge and discussions of constructability issues are not substantial at project close-out meetings.

Knowledge sharing modes

Analysis on knowledge sharing modes within the organization shows the prevalence of human interaction and tacit knowledge sharing, such as meetings, briefings, storytelling, correspondences etc. Tacit knowledge sharing and socialisation is much more popular than modes that contain written, explicit knowledge, such as databases, newsletters, memoranda etc. This also implies that knowledge sharing is done on a less formal basis. Findings can be summarized as follows:

- Knowledge sharing modes employed are mostly human-orientated methods requiring socialisation, such as informal chatting and storytelling, meetings, project briefing and review sessions, and mentorship and training programmes.
- Knowledge management initiatives need to embody human-orientated principles.

Lessons learnt programmes

The lessons learnt programme can be carried out with many methods to fulfil the three lessons learnt processes – lesson identification, lessons analysis and lessons implementation. Results show that most lessons learnt activities occurs as an unstructured process on a haphazard, ad hoc basis. From the results, lessons learnt methods consists mostly of human-orientated and socialisation activities.

Generally, respondents perceive a higher potential for the implementation of lesson learnt programmes than the current state. The findings can be summarized as follows:

- Lessons learnt programmes mostly occur as informal, haphazard processes.
- Similar to the results from general knowledge sharing modes, lessons learnt programmes are mostly carried out via human-orientated methods: project close-out and intermediate meetings, review sessions, word of mouth and storytelling, and changes to a work process.
- Respondents indicate that a higher potential of lessons learnt programmes can be reached if better implemented, and see substantial premise for improvement in lessons learnt programmes.
- Lessons learnt programmes need to be formalized and regulated as systematic processes, integrating human-orientated methods.

12.2.5 Constructability cases/issues in practice

The research investigated real constructability cases/issues in the practical context. The results and deductions are used as an added perspective to constructability, and compliment the findings of the previous investigations. It is clear that constructability issues are seldom mutually exclusive; they are usually the consequence as well as the cause of other constructability issues, thus making it very difficult to even categorize, let alone explicate into consistent principles. This highlights the tacit nature of constructability knowledge, which is most aptly represented as a complex pool of cause and effect – a non-linear network of different events. There is an evident lack of collaborative decision making. In many cases, alternative (better) construction solutions could have been adopted, but were simply not considered. There is also a distinct thrust towards the preference of precast concrete systems in construction. In general, the project environment, in which all work must be done, makes it difficult for collaboration and integration to occur. The relationship between client, consultant and contractor imposes substantial pressures on all project participants, resulting in most parties taking a defensive stance in terms of risk management and accountability.

The constructability cases/issues given by the respondents hold substantial amounts of knowledge and lessons to be learnt. These cases/issues have been categorized into 6 groups, the details of which are presented in section 10.3. These categories are:

- 1) Design problem
- 2) Timing of design issuance
- 3) Alternative construction or design from contractors' input
- 4) Simplicity and standardization
- 5) Site related issues
- 6) Aesthetics

In essence, there is a lack of cooperative culture in the industry, leading to increased barriers to the dissemination of constructability knowledge. Together with the complexity and tacit nature of constructability knowledge, which makes it very difficult to manage, issues and problems are not transparent and many project decisions are taken notwithstanding the perspectives of other phases of the project. This leads to substantial amounts of waste in the construction stage – waste which eventually affects all project participants. The consultant, who is primarily responsible for the realization of the design from client's requirements, seems to only manage and mediate constructability issues when prompted to do so, and process client's requests on a reactive basis. There is thus feeble initiative in promoting creative or innovative advice to the client and the project.

12.2.6 Tubular Track case study

Tubular Track has a very integrated operational system; together with their other attributes identified in the research, Tubular Track is able to inherently address/remove their constructability issues through an evolutionary improvement process of their design configuration. Some of their attributes identified in the case study, allowing them their evolutionary capacity can be summarized as follows:

- Close relationship between the contractor, client and consultant – insight to all requirements
- Systematic and diligent response to issues from all project phases
- High level of design and construction integration
- High level of standardization and simplicity
- Efficient quality control measures – testing and monitoring
- Dynamic platform of knowledge sharing within all departments

These attributes may well be applicable as principles to be complied in the construction industry as guidelines to improving constructability. The core value of Tubular Track lies in their procedures, standardization, simplicity and high level of integration. This allows their constructability problems to be addressed through an evolutionary process over time. The lesson to be learnt here is that initiatives need to be introduced as tools to facilitate the learning process. A sound learning process creates and shares the knowledge necessary for the principles mentioned above to be realized, and subsequently fostering the capacity to address constructability issues. The outcome of the Tubular Track case study concurs with the principles and deductions from previous investigations to improve constructability, and supports the implementation of knowledge management initiatives, such as lessons learnt programmes, to achieve the goal.

12.3 Discussion of research recommendations

Considering the findings and conclusions, a problem solving approach is adopted to establish some strategic solution to solving constructability related problems, which involves industry fragmentation and the lack of knowledge integration on numerous levels of the project. This research has

contributed in setting the basis of the problem by narrowing down and refining the direction of research. The results have achieved better understanding of the complexities of constructability knowledge and allowed more relevant questions to be established in order to prompt for relevant solutions. This section discusses the recommendations that can be made from the conclusions of this research.

12.3.1 The procurement limitation

The procurement standard poses a fundamental barrier to integration. Client, consultant and contractor relationships are dictated by the procurement progression. The project design would usually already have been completed by the time the contractors are appointed, inherently excluding contractor expertise in the design stage. The consultants' and contractors' incoherence can thus be seen as a direct consequence of the procurement standards. In sight of constructability and fragmentation related issues, more avenues of research needs to be opened in design-build or design-build-operate projects, where the circumstances are more favourable for integration, particularly between construction and design. Investigations need to be done on how the relationships of project participants differ, the implications of the relationship model and the effects thereof on the project life-cycle.

This current research, however, is only done on the premise that traditional procurement procedures are absolute. It is assumed here that there is no opportunity for contractors' input before the tender stage.

12.3.2 Constructability codes

In principle, constructability problems can be solved or at least reduced through the compilation of constructability guidelines or codes. A constructability code, such as the Buildable Design Appraisal System (BDAS) in Singapore, would contain explicit constructability knowledge and quantifiable principles. Essentially this explicit set of constructability documentation, when used as an appraisal system, takes the place of the construction expertise, which otherwise could have been provided by a contractor in person. It would be ideal if this can be achieved, as project contractors are typically not known during the design of the project, dictated by procurement standards. That said, constructability knowledge in the practical context remains very complex, due to the unique circumstances, in which they manifest and the variables that are associated with them. Quantification of constructability as achieved by the BDAS is only possible with a high level of standardization and conformity, as well as the intelligence resources to carry out the research and compile such a set of codes. In Singapore, the Buildable Design Appraisal System (BDAS) requirements are also legally enforced and the construction practice is much less erratic. Standardization can thus be ensured in Singapore, also considering that the scope of the BDAS is limited to the building industry. In South Africa however, explicating and quantifying constructability is very difficult if at all possible, unless a high level of

standardization can be assured. Furthermore, research capacity in the construction environment is very limited locally. For these reasons, research focussing on constructability explication and quantification is only feasible with a very limited scope of application in a standardized industry, with high amounts of repetition. For example, large scale housing developments, schools, workshops etc. or where precast concrete is substantially used. In the case of the Tubular Track system, their standardization is crucial to their management and allows them to achieve the high level of integration. Another inspiration can be drawn from the steel construction industry, where the design and detailing of steel is integral to the construction, allowing constructability issues to be addressed through the compliance of the steel handbook by the designer, without contractor input. This again is only possible because steel members are all standardized, which goes hand in hand with standardized construction/installation procedures of steel configurations.

From the research, in particular the analysis of the constructability cases/issues presented in Chapter 10, it can be demonstrated that a great deal of constructability knowledge can already be learnt from such a simple research exercise. There is no doubt about the amount of knowledge (constructability related or otherwise) that can be extracted from industry under more structured activities. It is the sensible management and explication of this knowledge that poses the challenge. Nevertheless, there is definitely a premise for the formulation of refined rules or guidelines to help as decision aids for the designer, regardless of how limited the scope of these guidelines may be. The findings from the research investigations – in particular, that of the constructability criteria, constructability of building components, and the 6 categories, in which the constructability cases/issues are divided in Chapter 10, can readily be used as a basis for the compilation of a constructability guideline. Organisations are recommended to assume deeper responsibility in defining their own databases of lessons and knowledge. An improvement of organisational repositories of documented and codified knowledge within the company is readily achievable considering current conditions. This would become a great contributor to the ultimate goal improving constructability at large, and is highly recommended for organisations to initiate or optimize such endeavours.

12.3.3 Precast systems and standardization

It is not the intention of this research to promote the precast industry. However, the research results evidently show thrust towards precast construction systems, as they inherently hold less risk and variation. Constructability principles of simplicity and standardization are also embodied in precast methods. It can be recommended that more standardization be promoted in the construction industry, which can be brought about through employing precast methods. As mentioned previously, this goes in conjunction with the extent that constructability can be codified. Precast methods not only imply the standardization of the physical configurations, but also (perhaps more importantly) standardization of construction processes. It is recommended that consultants should also consider precast methods in their designs, as opposed to the prevalent adoption of in situ methods, traditionally seen in the industry.

12.3.4 Human-orientated knowledge sharing

This research shows that constructability knowledge is of a highly tacit form and shared mainly through social methods in the organisations, e.g. word of mouth, meetings, seminars, mentorship sessions etc. Considering the current construction industry, where most knowledge is in any case shared through social means, it is quite apt for organisations to assess the implementation of these methods more diligently, and determine whether these opportunities indeed enable the creation of knowledge and the acceleration of fostering professional competence among its employees. This has a direct implication on the capacity for personnel to learn constructability lessons from past projects, through other, more experienced employees. This solution is based on the fact that constructability knowledge is mostly contained within the minds of experienced personnel. It is pertinent for organisations (especially the consultants) to extract and disseminate such knowledge through increased focus on social interaction during the aforementioned knowledge sharing occasions. It is recommended that organisations, especially the individuals of the management level, should initiate and take the lead in promoting an effective knowledge sharing culture. Creating an organisational culture that embodies these principles is more of a management responsibility than a technical one.

Existing models and procedures such as lessons learnt programmes can be used as a vehicle or tool to drive this process and identify, analyse and eventually implement relevant lessons. This research have shown that most lessons learnt activities in the industry are carried out on a haphazard basis, some organisations do not have any lessons learnt activities at all. It is thus strongly recommended for organisations (both consultants and contractors) to adopt and optimize lessons learnt activities, integrating them systematically into operational procedures, with focus on the human-orientated nature of knowledge sharing.

12.3.5 Collaborative mentality

Given the recommendation for improvements on social knowledge sharing and lessons learnt methods, it is obvious that substantially more collaboration must be embraced. This research has shown that the industry lacks integration on many levels, not only between personnel from different project disciplines, but also the knowledge and interests from each of these disciplines, in particular between design and construction. Because of the fact that constructability knowledge is of such a tacit nature, it is important for social collaboration to also take place. In other words, frequent and consistent occasions must be provided where an open platform of discussion can be achieved regarding the numerous constructability issues, with engagement from both consultant and contractor backgrounds. The analyses of practical constructability cases, in conjunction with deductions from other results, indicate that there is substantial dissatisfaction regarding collaboration. There are a considerable number of cases, where misalignment of interests and misunderstanding between construction and design is prevalent, posing additional risks to the project at large.

The implementation of project close-out meetings by contractors must be improved. It is the role of management to ensure that effective project close-out meetings are carried out. This implies meetings where lessons learnt activities can take place (consisting of lessons identification, analysis as well as implementation) and that an open platform is established for constructability issues to be discussed with the engagement of both consultants and contractors.

This recommendation is based on a preventative approach, where lessons learnt in one project can be used to prevent similar problems from arising in future projects. This is pertinent for the work of the consultant, who dictates the design and thus to a great extent also the construction processes that ensue. The designer would eventually over time be able to design configurations and systems that are most constructible for the contractor. For both consultant and contractor, the knowledge exchange empowers the capacity and insight to these problems altogether. The in-depth understanding enables contractors and consultants to pose the most relevant questions, thus inherently improving the problem solving capabilities of both through integration.

Collaboration and integration (both socially and intellectually) is the responsibility of all project participants. However, from the analysis of the constructability cases, it would seem most appropriate for consultants to instigate the process. Consultants, as the title indicates, are responsible for consulting, which implies advising the client on all aspects contributing to the project realization. This also involves the negotiation activities with contractors and establishing solutions that meet the needs of the client, while optimizing the project circumstances for execution to be carried out favourably. This research has shown that there are numerous significant constructability related issues prevalent in every project, attributed to the misalignment of consultant and contractor perspectives. It would seem most pertinent for consultants to be more involved as an instigator of collaboration, looking for alternative solutions, offering advice and constantly mediating issues from later stages of the project. On the other hand it is the contractors' responsibility to cooperate and sensibly offer their constructability experience where relevant. This relationship is evidently difficult to achieve in a fragmented industry. As a measure to improve this, higher levels of trust (as discussed in the literature study section 4.7.2) need to be fostered.

12.3.6 Change management or design management

The principles behind lessons learnt programmes and project-close out meetings are of a preventative problem solving nature. In other words, these initiatives endeavour to capture and disseminate lessons from past mistakes so that they can be prevented or better addressed in future. For the consultant, this constitutes creating future designs that are well constructible, before the contractor is even appointed. However, this research has shown that many constructability issues actually only become apparent after the project commences and variables begin to reveal themselves as the project progresses. In many of these cases, even an experienced construction personnel may

not be able to predict these unexpected constructability issues. A remedial or corrective problem solving approach should thus be adopted to cater for these issues.

In principle, promoting collaboration, integration and effective knowledge sharing already contributes to the personnel's capacity to handle these issues as they are empowered by the insight and knowledge. However, more direct approaches needs to be adopted, formalized and implemented. These remedial initiatives, which may well be of a knowledge management approach, should be active during the project progression. Existing approaches, such as change management and design management methods, embody the remedial problem solving principle. It is thus recommended for more research to be done within these fields, particularly to investigate their current effectiveness and ways to improve it. That said, it is also recommended that consultants should carry out their initial design considering the possibility of changes and amendments at a later stage. After all, this research has shown that contractors ranks the "option of alternative construction details to be developed and adopted" as the 2nd most important constructability criteria, after "safety of construction sequences" as most important.

12.3.7 Focus on "how" to learn rather than "what" to learn

The research has looked at constructability from many different facets, and inferred a basis for the implementation of knowledge management principles and initiatives to improve constructability. Two main approaches to improve constructability can be summarized: 1) explicate constructability knowledge and expertise to establish codes and guidelines and 2) improve the intrinsic capacity to learn and reason, through the implementation of initiatives as tools for organisation personnel. The former approach regards constructability explicitly and thus manages the knowledge as explicit resources. This, as discussed, it is only possible given a highly standardized industry with a very limited scope in the application. The latter approach is logically more holistic, but relies heavily on diligence not only of the organization's technical capacity, but also that of management. However, with the proper implementation and outcome of the second approach, the benefits of the first approach (explicating constructability knowledge) would naturally follow.

Ultimately, considering the complex tacit nature of constructability, it would be of equal or more significance to focus on the industry's capacity to learn and empower its own knowledge pool, than to focus on explicating construction knowledge. Only with increased intellectual capacity, is one able to formulate accurate explicit models, principles and theories to represent constructability. A multipronged approach must be adopted in this regard

12.3.8 Research structure as a practical tool

This research has demonstrated that substantial amounts of lessons can be extracted from the tacit pool of constructability knowledge, even through a simple research procedure such as this.

Consulting and contracting firms are essentially knowledge enterprises, where processes and products are developed from innovation in knowledge and solutions. The potential for generic business empowerment of relevant knowledge and insight is obvious. Organisations should consider more investment in such research and development on their own accord, with their own explicitly defined objectives.

Organisations can make use of the progress and development structure in this research as a template for their own knowledge acquisition. For instance, the topics and principles in the Phase-1 and Phase-2 questionnaires can readily be used as a checklist for organisations to consider relevant questions and appraise their own systems sensibly. This acts as an additional measure for improving diligence and awareness of the project at large, which is currently a great challenge to achieve.

Organizations are able to use the material of this research to investigate and refine the sources of similar problems within their operating environment. Furthermore, databases and knowledge management structures can be established based on the outcomes and recommendations of this research. This can be especially in accelerating the learning curve of younger, less experienced, professionals, for whom constructability problems are most difficult to foresee and thus manage.

The next chapter presents the summary of the thesis process and key achievements in each investigation. The points arising from the comprehensive interpretation in this chapter, with regards to the conclusions and recommendations of this research, are presented concisely in the next chapter.

Chapter 13 Final conclusions and recommendations

In this chapter, the summary of the thesis process is presented to highlight key achievements in each stage of the research. The condensed conclusions and recommendations arising from the comprehensive discussions in the previous chapter are formulated concisely in this chapter. This chapter essentially presents the general trends of the constructability problem identified through this research, and the ensuing final recommendations that can be made.

13.1 Summary of thesis process and findings

This section presents a brief development of the key thesis phases and achievements under each phase. The thesis poses the broad questions: whether knowledge management can play a role in improving constructability and how?

1. Literature study and synthesis

Existing research in constructability and knowledge management (KM) was investigated in detail. The concepts and principles of constructability were explored and possible traits were identified to define constructability more explicitly. General KM literature as well as concepts relating to construction knowledge was studied in detail, as well as measures and initiatives to improve both were studied. The problem statement is refined and research objectives are established. From the literature study, a synthesis was done to extract the material and formulate explicit goals needed for the finer investigations. The goals are fulfilled by the ensuing investigations in the Phase-1 and Phase-2 questionnaires, the analysis of open constructability cases/issues, and the Tubular Track case study. It is worthy to note again that the questionnaire findings shown below are based only on the profile of respondents discussed earlier (presented in section 7.4 and 8.4 for Phase-1 and Phase-2 questionnaires respectively). This research does not verify, and thus cannot claim, that the findings do or do not represent that of the industry average. Nevertheless, the lessons learnt from these surveys are significant regardless.

2. Phase-1 questionnaire

Archival items in organisational project archives were investigated in detail. A profile of typical project archive contents was established. Deductions were made from respondent perceptions on the effectiveness of archives and, if any, data/knowledge-capture systems. The key findings can be summarized as follows:

- A project or archive, however thorough or complete, is not easily available for future access.
- The content of the project archives is limited in scope and items are not sufficient for historical analysis of more specific issues later on, such as constructability lessons.

- Numerous potential lessons can be learnt from captured data. However, there is in principle dissatisfaction of the data-capturing activities.
- It is beneficial to capture more data, information and knowledge.
- The capturing systems have promise for improvement in terms of offering more relevant data.
- There needs to be focus on the analysis of the captured data in deriving lessons learnt.
- There needs to be focus on the direct extraction of lessons and tacit knowledge from personnel (not from data) through lessons learnt programmes.
- There needs to be focus on the structured or organised storage of data, information and knowledge in order to achieve time- and effort-efficient accessibility for the user.

3. Phase-2 questionnaire

Further concepts were used to define constructability, concurrently for the nature of the constructability issue to be refined. The labour efficiency principles, possible criteria of constructible design were investigated in full. The constructability of different configurations and building components were established. From the above, preference and importance rankings were achieved. As a result, some principles of constructability were formulated and a means was achieved to quantify them. The key findings of traits/concepts, posing as possible explicit definitions of constructability, can be summarized as follows:

- Both consultants and contractors prefer equipment intensive work over labour intensive.
- Consultants prefer the use of in situ concrete, while contractors prefer precast.
- Contractors highly regard “flexibility in adopting alternative construction details” and “safety” as important constructability criteria, while consultants rank these considerably lower.
- Both consultants and contractors highly regard the constructability criterion: “enable standardization and repetition”.
- Both consultants and contractors agree on the importance of criteria: “enable economic use of contractors’ resources” and “simplification of construction details”.
- There is fundamental misalignment of constructability perceptions between consultant and contractor on the configurations of different components of a building.
- Consultants consistently rate precast building configurations of lower constructability than contractors.

Knowledge management aspects of constructability were investigated in detail in the Phase-2 questionnaire, following the Phase-1 questionnaire. The project-close out meeting was given focus; the popularity of specific knowledge sharing modes were identified and quantified; the current state of lessons learnt programmes implementation in the industry was investigated in full, as well as the perceptions towards the potential of such initiatives. The key findings can be summarized as follows:

- Contractors carry out project close-out meetings more than consultants.
- Consultants' attendance/presence at contractors' project close-out meetings is feeble, thus many issues cannot be addressed with collaborative engagement from both consultant and contractor.
- The dynamic exchange of interdisciplinary knowledge and discussions of constructability issues are not substantial at project close-out meetings.
- Knowledge sharing modes employed are mostly human-orientated methods requiring socialisation, such as informal chatting and storytelling, meetings, project briefing and review sessions, and mentorship and training programmes.
- Lessons learnt programmes mostly occur as informal, haphazard processes.
- Respondents indicate that a higher potential of lessons learnt programmes can be reached if better implemented, and see substantial premise for improvement in lessons learnt programmes.
- Lessons learnt programmes need to be formalized and regulated as systematic processes, integrating human-orientated methods.

4. Analysis of constructability issues/cases in practice

Real constructability issues, given by respondents were analyzed. Substantial insight could be extracted from these cases and deeper understanding achieved regarding the conditions in practice. The results achieve deeper knowledge of the nature of constructability problems and the reasons for the respondent's perceptions from previous investigations. The cases have been divided into 6 main categories as follows:

- 1) Design problem
- 2) Timing of design issuance
- 3) Alternative construction or design from contractors' input
- 4) Simplicity and standardization
- 5) Site related issues
- 6) Aesthetics

Under "Alternative construction or design from contractors' input", numerous specific issues were discussed associated with specific construction components: in situ concrete, slabs, structural

steel, columns, beams, masonry walls, and rebar related problems. These hold many valuable lessons to be learnt concerning constructability problems related to each component. The details are not presented here again, and can be found in Chapter 10.

These details of the 6 categories (together with the findings from particularly the constructability related investigations in the Phase-2 questionnaire) can be used as a template or basis for the compilation of “constructability guidelines” or “constructability codes”. The cases under each category are unique and best observed individually, so the summary of the lessons learnt is not presented here again as it would be quite excessive. For the details, refer to either Chapter 10 or Chapter 12 (section 12.2.5) for the summary of lessons under each category.

5. Tubular Track case study

The Tubular Track integrated evolutionary development process was investigated in detail. This constituted the in depth study of the Tubular Track configuration and associated processes in manufacturing, installation and operation. Lessons were extracted from the operational model of Tubular Track and principles, and characteristics were identified that allows Tubular Track to achieve the high level of integration and thus innately remove constructability problems. The lessons extracted concur with findings from previous sections (on constructability and knowledge management) and confirms the validity of knowledge management initiatives (such as lessons learnt programmes) to improving constructability at large. These principle lessons and characteristics can be readily applied in the construction industry on a broad level. The following is a summary of characteristics of Tubular Track identified as key attributes that allow them to achieve the evolutionary capacity, and should pose as guidelines for the traditional construction industry:

- Close relationship between the contractor, client and consultant – insight to all requirements
- Systematic and diligent response to issues from all project phases
- High level of design and construction integration
- High level of standardization and simplicity
- Efficient quality control measures – testing and monitoring
- Dynamic platform of knowledge sharing within all departments

13.2 General conclusions

This section presents the major trends arising from the research, which has been confirmed through the numerous investigations in this research. Note that detailed reasoning leading to these points is not included here; these are only the final conclusive remarks.

- Existing research in literature could only define constructability as a concept or principle; explicit definition is very difficult due to the complex nature of the constructability knowledge and related problems.
- Project archives are inadequate in providing constructability lessons and knowledge. Furthermore, there is no effective data/knowledge management structure to accommodate the needs of learning and acceleration in fostering professional experience.
- Constructability knowledge exists predominantly in tacit form; form complex networks of cause and effect; and related issues occur under unique circumstances. Thus it is best managed as a tacit knowledge resource rather than an explicit one.
- There is prevalent misalignment between project participants, in particular consultants and contractors, regarding perception of certain construction decisions and their implications on the project. This includes perception on the preferences and importance of certain design or construction choices over others.
- Quantification of constructability is difficult, but not impossible. It requires high levels of intelligence- and social-integration, which can be brought about by standardization and employment of repetitive processes.
- Knowledge sharing is done on an ad hoc basis, using mostly social and human-orientated means within organisations. There is dissatisfaction regarding the management of knowledge within organisations.
- Lessons learnt programmes are carried out mostly informally and lacks the collaborative engagement needed to extract accurate lessons.
- There is generally a lack of integration between construction and design, due to poor collaborative mentality, which may be imposed by procurement standards, project risks, project delivery pressures or simply the lack of effective tools or initiatives to aid the collaborative processes.

13.3 Recommendations

The recommendations from this research should be seen as a strategic framework solution to improve constructability through knowledge management initiatives. The recommendations complement one another, and should not be seen as linear or mutual exclusive initiatives.

The difficulties concerning constructability, along with that of industry incoherence and fragmentation, consist of numerous different problems, intertwined with one another. An attempt for research to implement a universal solution seems unrealistic, due to the complexity of the problem, which is usually of a multi-dimensional nature. It is rather more apt for researchers to regard these problems from different angles (e.g. constructability, knowledge management risk management, change management to name a few) and develop a wide variety of initiatives with respect to different angles of perception. Evidently, what may seem like a problem from one perspective may not be so apparent through another. Therefore, a multipronged approach to improving constructability needs to be adopted. It is true that each initiative has its own strengths and limitations. A multipronged approach attempts to minimise the relative disadvantages of respective methods, while gaining the advantage of each, thus gaining a multi-dimensional view of the subject through synergy between respective approaches.

Further research and investigations can be done on the numerous avenues mentioned in the previous chapters. Research, however, does not only imply that of academia, but also industrial research that can be carried out by organizations. More attempts should be made by organisations to formulate some guidelines concerning constructability that is readily usable in-house, within their respective operational conditions – to establish some constructability related guidelines or rudimentary constructability code. More research – academic or industrial – is needed to further the formulation and application of such guidelines. It was mentioned before that it is difficult to achieve the requirements needed for the explication and quantification of constructability knowledge. However, as the case study on Tubular Track has demonstrated, substantial amounts of knowledge can already be extracted through limited scopes of investigation. Similar investigative approaches can be based on the process followed in this research to formulate more specific principles or tools to be applied in limited scopes of industry, even within single projects.

A strategic framework can arise from this research to improve constructability. This can particularly be achieved through the implementation of knowledge management principles. The strategy to improve constructability is shown in figure 13-1, embodying the multipronged approach to problem solving.

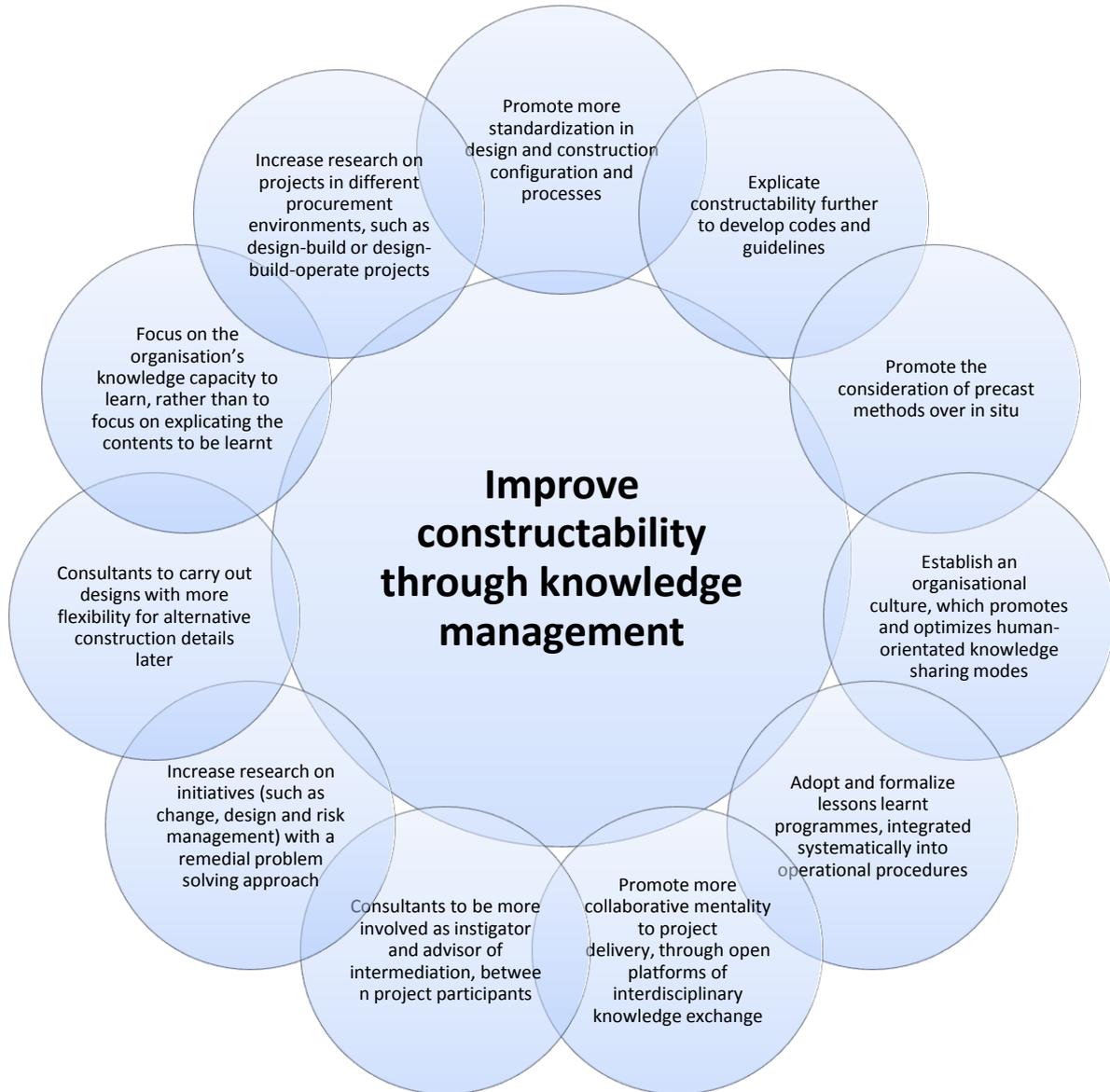


Figure 13-1 Comprehensive strategy solution to improving constructability

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Appendix A-1: BDAS Table 1

Table 1 Structural Systems – S_s Value

STRUCTURAL SYSTEM	DESCRIPTION	LABOUR SAVING INDEX S_s
Precast Concrete System	Full precast	1.00
	Precast column/wall ⁽²⁾ with flat plate and no perimeter beams	0.95
	Precast column/wall ⁽²⁾ with flat plate and perimeter beams (beam depth \leq 600 mm) ⁽³⁾	0.85
	Precast column/wall ⁽²⁾ with flat slab and no perimeter beams	0.90
	Precast column/wall ⁽²⁾ with flat slab and perimeter beams (beam depth \leq 600 mm) ⁽³⁾	0.80
	Precast beam and precast slab	0.90
	Precast beam and precast column/wall ⁽²⁾	0.90
	Precast column/wall ⁽²⁾ and precast slab	0.90
	Precast slab only	0.70
	Precast column/wall only ⁽¹⁾⁽²⁾	0.70
Structural Steel System <i>(applicable only if steel decking or precast slab is adopted)</i>	Steel beam and steel column <i>(without concrete encasement)</i>	0.95
	Steel beam and steel column <i>(with concrete encasement)</i>	0.85
Cast In-situ System ⁽¹⁾	Flat plate with no perimeter beams	0.90
	Flat plate with perimeter beams (beam depth \leq 600 mm) ⁽³⁾	0.80
	Flat slab with no perimeter beams	0.85
	Flat slab with perimeter beams (beam depth \leq 600 mm) ⁽³⁾	0.75
	One-directional beam	0.70
	Two-directional beam	0.45
Roof System (non-RC)	Integrated metal roof on steel truss	0.90
	Metal roof on steel truss or timber truss	0.85
	Tiled roof on steel beam or precast concrete beam or timber beam	0.75
	Metal roof on cast in-situ beam	0.60
	Tiled roof with cast in-situ beam	0.55

Appendix A-2: BDAS Table 2**Table 2** Wall Systems – S_w Value

WALL SYSTEM	DESCRIPTION	LABOUR SAVING INDEX S_w
Curtain wall / full height glass partition / dry partition wall ⁽²⁾ / prefabricated railing	Curtain wall / Full height glass partition	1.00
	Prefabricated railing	1.00
	Dry partition wall	1.00
	Dry Partition wall with tile / stone finishes	0.90
Precast Concrete Panel / Wall ⁽³⁾	Precast concrete panel / wall with skim coat	0.90 ⁽¹⁾
	Precast Concrete panel / wall with plastering, tile / stone finishes	0.60
PC Formwork ⁽⁴⁾	PC formwork with skim coat	0.75 ⁽¹⁾
	PC formwork with plastering, tile / stone finishes	0.40
Cast In-situ RC Wall	Cast in-situ RC wall with skim coat	0.70 ⁽¹⁾
	Cast in-situ RC wall with plastering, tile / stone finishes	0.40
Precision Blockwall	Precision blockwall with skim coat	0.40 ⁽¹⁾
	Precision blockwall with plastering, tile / stone finishes	0.10
Brickwall / Blockwall	Brickwall / blockwall with or without plastering	0.05

Bonus Points

DESCRIPTION	LABOUR SAVING INDEX S_s
Off-form external finished wall/column (for Cast in-situ RC wall and PC formwork) ⁽⁵⁾	0.15

Appendix A-3: BDAS Table 3
Table 3 Other Buildable Design Features – N Value

BUILDABLE FEATURES		MODULE	UNIT OF COVERAGE	N VALUE	
				PERCENTAGE OF COVERAGE ⁽⁴⁾	
				≥70% TO < 90%	≥ 90%
1. Standardisation					
1.1	Columns (3 most common sizes)	0.5M ⁽²⁾	no.		2.00
1.2	Beams (3 most common sizes)	0.5M ⁽²⁾	no.		2.00
1.3	Door leaf openings (width) (3 most common sizes)	0.5M	no.		1.00
1.4	Windows (3 most common sizes) ⁽¹⁾	1M/1M ⁽³⁾	no.		1.00
2. Grids					
2.1(a)	Repetition of floor-to-floor height (For blocks more than 6 storey) <i>The repetition should omit bottom floor, top floor and above.</i>	0.5M	no.	1.50	2.00
2.1(b)	Repetition of floor-to-floor height (For blocks up to 6 storey) <i>The repetition should omit bottom floor, top floor and above. Only applicable if there are at least 2 floor heights remaining after the floor omission.</i>	0.5M	no.	0.75	1.00
2.2(a)	Vertical repetition of structural floor layout (For blocks more than 6 storey) <i>The repetition should omit bottom floor, top floor and above.</i>		area	1.50	2.00
2.2(b)	Vertical repetition of structural floor layout (For blocks up to 6 storey) <i>The repetition should omit bottom floor, top floor and above. Only applicable if there are at least 2 floors remaining after the floor omission.</i>		area	0.75	1.00
2.3	Repetition of Horizontal Grids	6M	no.	1.50	2.00
3. Others					
3.1	Multi-tier precast columns		no.		2.00
3.2	Precast or pre-assembled/ metal staircases		no.		2.00
3.3	Precast meter chambers (for landed residential developments)		no.		1.00
3.4	Precast refuse chutes		no.		1.50
3.5	Precast service risers		no.		1.00
3.6	No screeding for any flooring		area		3.00
Bonus Points		MODULE	UNIT OF COVERAGE	PERCENTAGE OF COVERAGE⁽⁴⁾	
				≥65% TO < 80%	≥ 80%
Single Integrated Components					
A.1	Prefabricated bathroom/toilet units complete with piping/wiring		no.	3.00	4.00
A.2	Precast household shelter		no.	2.00	3.00
Industry Standardisation					
A.3(a)	Typical storeys standardised to either 2.8m, 3.15m, 3.5m, 4.2m or 4.55m height and with precast staircase of riser height of 175mm & tread width of 250mm or 275mm		no.		2.00
A.3(b)	Typical storeys standardised to either 3.15m or 4.2m height and with precast staircase of riser height of 150mm & tread width of 300mm		no.		2.00

Appendix B-1: CAS Table 1

Table 1 Structural System

STRUCTURAL SYSTEM (MAXIMUM 60 POINTS)		
Construction Technologies / Methods	Allocated Points	Computation Method
1. External Access System (Maximum 15 points)		
(a) No external scaffold	15	$\frac{\sum(\text{Length with external access system/no external scaffold} \times \text{Allocated pts})}{\text{Total Building Perimeter}}$
(b) Self-climbing perimeter scaffold	15	
(c) Crane-lifted perimeter scaffold / fly cage	14	
(d) Traditional external scaffold	1	
2. Formwork System (Maximum 30 points)		
A. Vertical Contact Area		
(i) No formwork (precast construction)	15	$\frac{\sum(\text{Vertical Formwork Contact Area} \times \text{Allocated points})}{\text{Total Vertical Formwork Contact Area}}$
(ii) Traditional timber/metal formwork	1	
(I) Vertical Formwork¹		
(i) System Formwork (Band 1)	15	
(ii) System Formwork (Band 2)	14	
(iii) System Formwork (Band 3)	13	
(iv) System Formwork (Band 4)	11	
(v) System formwork (Band 5)	8	
B. Floor Area		
(i) No formwork (precast construction)	15	$\frac{\sum(\text{Floor Area} \times \text{Allocated points})}{\text{Total Floor Area}}$
(ii) Traditional timber/metal formwork	1	
(I) Horizontal Formwork¹		
(i) System Formwork (Band 1)	15	
(ii) System Formwork (Band 2)	14	
(iii) System Formwork (Band 3)	13	
(iv) System Formwork (Band 4)	11	
(v) System formwork (Band 5)	8	
3. Structural Innovative Methods, Systems, Processes, Plant & Equipment (Maximum 15 points)		
(a) Use of self compacting concrete	2	Points are given if usage is $\geq 5\%$ of total superstructure concrete volume
(b) Use of hydraulic stationary placing boom for concreting	2	Points will be given once used
(c) Use of tower crane (tip load ≥ 10 tonnes at maximum reach)	3	Points will be given once used
(d) Strut free deep basement construction ²	4 (max)	Applicable for projects with restricted site access. Normal earth slope with or without concrete lining is excluded.
(e) Any other innovative methods, systems, processes, plant & equipment	Points to be awarded only for high impact items that improve labour efficiency ³	

Appendix B-2: CAS Table 2

Table 2 Architectural, Mechanical, Electrical & Plumbing System (AMEP)

ARCHITECTURAL, MECHANICAL, ELECTRICAL & PLUMBING SYSTEM (AMEP) (MAXIMUM 50 POINTS)		
Construction Technologies / Methods	Allocated Points	Computation Method
1. Architectural		
(a) No screeding on floors (not stipulated in tender drawing): (i) To immediately receive tile/stone finish using thin bed adhesive (ii) Carpet or raised floor finishing	5	$\frac{\text{Floor Area with no screeding} \times \text{Allocated points}}{\text{Total Area (excluding wet areas}^1)}$
(b) Off form RC walls to receive (not stipulated in tender drawing): (i) Tile/ Stone (ii) Wallpaper (iii) Paint (skim coat allowed)	5	$\frac{\text{RC Wall}^* \text{ Length with no plastering} \times \text{Allocated points}}{\text{Total RC Wall Length}^*}$ <i>* Refers to RC walls with finishing including tile/ stone, wallpaper & paint</i>
(c) Use of spray painting	3	Points are given if usage \geq 50% of total internal painted area
2. Mechanical, Electrical & Plumbing (MEP)		
(a) Pipe Works (i) Pre-insulated chilled water pipes	3	Points are given if usage \geq 80% of total pipe length
(b) Air-Con Ducting (i) Prefab ducts OR (ii) Prefab & Pre-insulated ducts	3 6	Points are given if usage \geq 80% of total duct length
(c) Use of flexible pipes ¹ for domestic water system	3	Points are given if usage \geq 80% of total pipe length
(d) Use of mechanical joints for M&E piping	2	Points are given if usage \geq 80% of total pipe length
3. AMEP Innovative Methods, Systems, Processes, Plant & Equipment (Maximum 25 points)		
(a) Use of ceiling inserts	2	Points are given if once used for at least one complete floor
(b) Prefab plant / piping modules	3	Points are given once used for at least one plant room
(c) Use of scissor lift and/or personnel lift in lieu of traditional scaffold for AMEP works	2	Points will be given once used
(d) Use of boom lift in lieu of traditional scaffold for AMEP works	2	Points will be given once used
(e) Any other innovative methods, systems, processes, plant & equipment	Points to be awarded only for high impact items that improve labour efficiency ³	

Appendix B-3: CAS Table 3**Table 3** Good Industry Practices

GOOD INDUSTRY PRACTICES (MAXIMUM 10 POINTS)	
Description	Allocated Points
(a) To use Building Information Modelling (BIM) for whole project duration to: <ul style="list-style-type: none"> (i) Check for clashes between M&E services, structural provision and architectural objects (ii) Produce M&E Coordination Drawings, Architectural Shop Drawings and Concrete Body Plan for construction purposes (iii) Simulate construction schedules and resource planning 	5
(b) To adopt a trade productivity monitoring system for whole project duration to: <ul style="list-style-type: none"> (i) Establish "workers' productivity norms" (ii) Conduct work studies on the processes if the productivity levels deviate from the norm (iii) Implement measures to improve productivity whenever possible 	2
(c) To produce and distribute step by step work manuals for all trades and set up site mock-ups to show how works should be done properly for whole project duration for: <ul style="list-style-type: none"> (i) Wall installation (ii) Waterproofing (iii) Suspended ceiling installation (iv) Window installation 	2
(d) To conduct monthly work study sessions, to scrutinise and improve the work process on site, as well as minimising wastage and improve productivity	2
(e) To use tools like CCTV to conduct real time monitoring on site to study resource flow, schedule and work process flow	2
(f) To conduct the following daily: <ul style="list-style-type: none"> (i) Tool box meeting (every worker to be informed on his task for the day) (ii) Sub-contractors coordination meeting (to coordinate on work process & resource allocation) 	1

Appendix C: Phase-1 Questionnaire

CMP 2011

PHASE-1 QUESTIONNAIRE ON THE ARCHIVAL DATA ON PROJECTS

Background:

Typically, construction projects retain project information in the form of drawings, meeting minutes, and other documents etc. which are usually stored in archives after the completion of the project. This information, however thorough or complete, is not easily available for future access. Furthermore, the content of this information is limited in scope and not sufficient for analysis of more specific historic data. Recent international studies have shown that companies can benefit a great deal from information and knowledge produced during a construction project (be it contractual, technical or managerial), provided that this information is captured and then organised in such a way that it can be meaningfully accessible in future. Prospects of such a system include shortening the learning curve of amateur professionals, increasing efficiency in existing operations and improving the decision making process by offering deeper insight.

Currently, information available in archives do not cover areas such as specific financial issues, design/construction process information, design/construction change management, safety considerations, contractual relations, procurement processes etc. all of which are associated with risks that can be potentially harmful to the project. Such areas of focus can hold valuable lessons for contractors, consultants and project managers alike, if the relevant information can be captured and extracted. This can help engineers and managers recognise and identify critical project aspects in different circumstances; hence the recent growth of data-capture and knowledge-management topics in research. Knowledge management can be described as a conscious strategy of providing the right knowledge to the right person, at the right time, within an organisation. It helps people share and put information into action in ways which strive to improve organisational performance. There are many models in literature regarding the capture of data/information, from where knowledge is extracted and managed to create expertise within an organisation.

This questionnaire would like to briefly explore the perception among current South African construction professionals regarding the role of project data/information in improving the company's future performance. We would essentially like to explore whether data capture and knowledge management is currently practiced within the construction industry; and if so, what sort of data is being captured and what are the structures in place for doing so.

KINDLY ANSWER THE OPEN QUESTIONS BELOW

Please provide personal details:

- A. Type of company: (e.g. consultant, construction, project management etc.)
- B. Discipline: (e.g. roads, buildings, civil structures, mining etc.)
- C. Current position/title: (e.g. project manager, site engineer, engineer etc.)
- D. Brief job description: (e.g. responsibilities, mission, typical tasks etc.)

Questions:

1. What sort of project information is currently available in your company's project archives? Please give specific details on each if possible.

2. Do you think the capturing of additional specific data/information (other than what is currently available in the project archives) during project progress can be beneficial for future projects? Please motivate your answer.

(E.g. assist in historical analysis, improve decision making, training, accelerate experience gaining, better understanding of risks, recognise critical aspects of certain types of projects etc.)

If you answered **yes** in question 2:

3. Please list all the types of additional project data/information that you would consider beneficial for future projects and are thus worth capturing in current projects? Please be as specific as possible.

(E.g. Changes during scheduling procedures, details of all the tasks, more specific technical information on tasks, risks and problems encountered during project execution etc.)

4. In your opinion, please briefly describe how each of the listed types of project information (in question 3) can be beneficial for future projects.

5. Is there an existing system within your organisation whereby all/some of the listed types of project information (in question 3) are captured during the project progress?

If you answered **yes** to question 5:

6. Please describe the different data-capture systems currently in place at your company for different types of project information.

7. Is there a database, framework or any form of knowledge-management structure within your organisation, whereby the array of captured information is meaningfully organised and made

accessible for other personnel? If so, kindly describe the interface of such a system – how would personnel use this database and how effective is it?

Only if you answered **no** in question 5:

8. Do you think that establishing such a data capturing system within your organisation would benefit and ultimately improve company performance in future?

9. Please feel free to provide any additional information or comments.

END OF QUESTIONNAIRE

Appendix D: Phase-2 Questionnaire



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Research Input Form

Knowledge Management and Constructability (V. Kuo)
Thesis towards an MScEng in Construction Engineering and Management

Please enable Macros on your MSWord in order to fill out the questionnaire

For explicit instructions refer to Page 10 (last page of this document)

Personal Information:

Company name (Optional)

Main business: (e.g. roads, buildings, civil structures, mining etc.)

CIDB Rating:

Your name (Optional)

Your current position/title: (e.g. project manager, site engineer, engineer etc.)

Years of experience

Note: Your name and that of your company will not be disclosed in any part of the research.

The concept of **constructability** has profound implications and can thus have a substantial effect – both adverse and favourable – on the eventual project delivery. This section explores the perspectives of the industry regarding the constructability of designs and other building principles.

Suppose a standard building project in RSA. Given the option, how would you prefer to construct the project?

It is preferable to use more

and preferable to construct with

A list of criteria for a sound design is given in the table below:

Based on your experience, identify and rank the **5 most important** criteria, in order of importance (1 being most importance). Further, indicate which **3 criteria** (if any) are most **seldom fulfilled** in design, by checking the corresponding box.

A SOUND DESIGN SHOULD:	Rank 5 most important	Select 3 most seldom fulfilled
Allow economic use of contractor's resources	Click to rank	<input type="checkbox"/>
Enable design requirements to be easily visualised and co-ordinated by site staff	Click to rank	<input type="checkbox"/>
Enable contractors to develop and adopt alternative construction details	Click to rank	<input type="checkbox"/>
Enable contractors to overcome restrictive site conditions	Click to rank	<input type="checkbox"/>
Enable standardisation and repetition	Click to rank	<input type="checkbox"/>
Enable freedom of choice between prefabricated and onsite works	Click to rank	<input type="checkbox"/>
Enable simplification of construction details in case of non-repetitive elements	Click to rank	<input type="checkbox"/>
Minimize the impact due to adverse weather by enabling a more flexible construction programme	Click to rank	<input type="checkbox"/>
Allow design to achieve safe construction sequence on site	Click to rank	<input type="checkbox"/>

Components of a typical building are given below. Check the boxes to qualify each construction configurations, in terms of ease of construction.

STRUCTURAL FRAME	Impossible to build	Very difficult to build	Buildable	Easily buildable
Precast RC frame	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
In situ RC frame	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Structural steel frame with fire proof	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
In situ load-bearing wall	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Steel sections encased in concrete (composite)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Concrete filled steel hollow section (composite)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

SLAB	Impossible to build	Very difficult to build	Buildable	Easily buildable
In situ RC flat slab	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
In situ RC slab upon beams	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
In situ RC slab with post tensioning	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Precast slab with in situ topping	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Steel deck as permanent shuttering	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

FAÇADE WALL	Impossible to build	Very difficult to build	Buildable	Easily buildable
Glass curtain wall (glass façade panels)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Concrete curtain wall (concrete façade panels)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Concrete masonry (brick) wall with applied finishes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Precast RC wall with pre-installed windows and finishes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
In situ RC wall with applied finishes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

ROOF	Impossible to build	Very difficult to build	Buildable	Easily buildable
In situ concrete roof	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Precast concrete roof	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Steel truss roof with composite decking	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Steel decking with in situ concrete topping	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Timber roof trusses	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

ROOF SUPPORT	Impossible to build	Very difficult to build	Buildable	Easily buildable
In situ concrete ring beam	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Precast concrete ring beam	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

INTERNAL WALL	Impossible to build	Very difficult to build	Buildable	Easily buildable
Dry wall (partitions)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Concrete masonry wall with applied finishes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
In situ RC wall with applied finishes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Precast RC wall with applied finishes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Think back on the last 5 South African projects undertaken or any 5 vivid in your memory (not necessarily building projects). Please list them and provide a brief description of each (such as type, final cost, duration etc. as you regard relevant).

Project 1: Brief project description

Project 2: Brief project description

Project 3: Brief project description

Project 4: Brief project description

Project 5: Brief project description

Constructability issues can make the execution of a project very difficult; often attributed to an unsound design. Such constructability issues/challenges occur often on site during construction. **Please try to identify up to 5 considerable constructability issues from any of the above 5 projects. Kindly give a description for each, as you regard relevant and comment freely on any aspect of the issue (text fields below are scrollable when exceeded).**

Constructability issue 1

Could this issue have been avoided, had the designer better constructability knowledge, i.e. produced a more “sound” design?

Yes

No

Constructability issue 2

Could this issue have been avoided, had the designer better constructability knowledge, i.e. produced a more “sound” design?

Yes

No

Constructability issue 3

Could this issue have been avoided, had the designer better constructability knowledge, i.e. produced a more “sound” design?

Yes

No

Constructability issue 4

Could this issue have been avoided, had the designer better constructability knowledge, i.e. produced a more “sound” design?

Yes

No

Constructability issue 5

Could this issue have been avoided, had the designer better constructability knowledge, i.e. produced a more “sound” design?

Yes

No

Provided that your company employs project close-out meetings, who are typical attendees?

Please list typical attendees of project close-out meetings:

Knowledge sharing and lessons learned programmes (LLPs) within the organisation can help educate and prepare project personnel for handling constructability problems on site. The following section explores the situation of such knowledge sharing and LLP initiatives in the construction industry.

What modes within your organisation are used to **share knowledge in general**? Check the boxes to qualify the popularity of use for each mode in sharing knowledge.

MODES OF KNOWLEDGE SHARING	Never used	Unpopular	Neutral	Popular	Very Popular
Internal databases	<input type="checkbox"/>				
E-mail	<input type="checkbox"/>				
Memoranda and letters	<input type="checkbox"/>				
Knowledge sharing boards	<input type="checkbox"/>				
Internal newsletters and circulars	<input type="checkbox"/>				
Phone calls and tele-conferencing	<input type="checkbox"/>				
Informal chatting and story telling	<input type="checkbox"/>				
Meetings	<input type="checkbox"/>				
Project briefing and review sessions	<input type="checkbox"/>				
Newsgroup and web-based discussions	<input type="checkbox"/>				
Training/mentorship programme	<input type="checkbox"/>				
Talks and seminars	<input type="checkbox"/>				

The nature of the lessons-learned initiative in your organisation is...

- Formal (standardized protocol built into organisational process, with designated coordinator)
- Informal (occurs haphazardly, no standard process, no designated process coordinator)
- Does not exist (no lessons-learned actions whatsoever)

If you checked "Does not exist":

SKIP PAGE 7 AND 8, CONTINUE ON PAGE 9.

If you checked "Formal" or "Informal":

SIMPLY CONTINUE

Please indicate how lessons are **identified** in your organisation, and whether it is carried out during or after the project.

LESSONS IDENTIFICATION	Check all that apply	Are lessons identified during/after project?	
Project close-out meetings	<input type="checkbox"/>	<input type="checkbox"/> during	<input type="checkbox"/> after
Intermediate meetings	<input type="checkbox"/>	<input type="checkbox"/> during	<input type="checkbox"/> after
Interviews	<input type="checkbox"/>	<input type="checkbox"/> during	<input type="checkbox"/> after
Electronically	<input type="checkbox"/>	<input type="checkbox"/> during	<input type="checkbox"/> after
Paper forms	<input type="checkbox"/>	<input type="checkbox"/> during	<input type="checkbox"/> after
Informally (word of mouth)	<input type="checkbox"/>	<input type="checkbox"/> during	<input type="checkbox"/> after
Outside consultant	<input type="checkbox"/>	<input type="checkbox"/> during	<input type="checkbox"/> after
Other (please specify below)	<input type="checkbox"/>	<input type="checkbox"/> during	<input type="checkbox"/> after

Other:

Please indicate how the collected lessons are analyzed and synthesized into meaningful knowledge.

LESSONS ANALYSIS	Check all that apply
Project close-out meetings	<input type="checkbox"/>
Intermediate meetings	<input type="checkbox"/>
By a subject matter expert	<input type="checkbox"/>
Electronically	<input type="checkbox"/>
By an outside consultant	<input type="checkbox"/>
Other (please specify below)	<input type="checkbox"/>

Other:

Please indicate how the lessons learned are implemented into your organisation?

LESSONS IMPLIMENTATION	Check all that apply
At meetings	<input type="checkbox"/>
As part of changes to a work process	<input type="checkbox"/>
At project kickoffs	<input type="checkbox"/>
Through electronic databases	<input type="checkbox"/>
Through training programmes	<input type="checkbox"/>
Informally (word of mouth)	<input type="checkbox"/>
Training/mentorship programmes	<input type="checkbox"/>
Other (please specify below)	<input type="checkbox"/>

Other:

How do you view the effectiveness of lessons-learned programs currently implemented at your company?

- Very effective
- Somewhat effective
- Neutral
- Not effective
- Detrimental

How do you view the full potential effectiveness of lessons-learned programs?

- Very effective
- Somewhat effective
- Neutral
- Not effective
- Detrimental

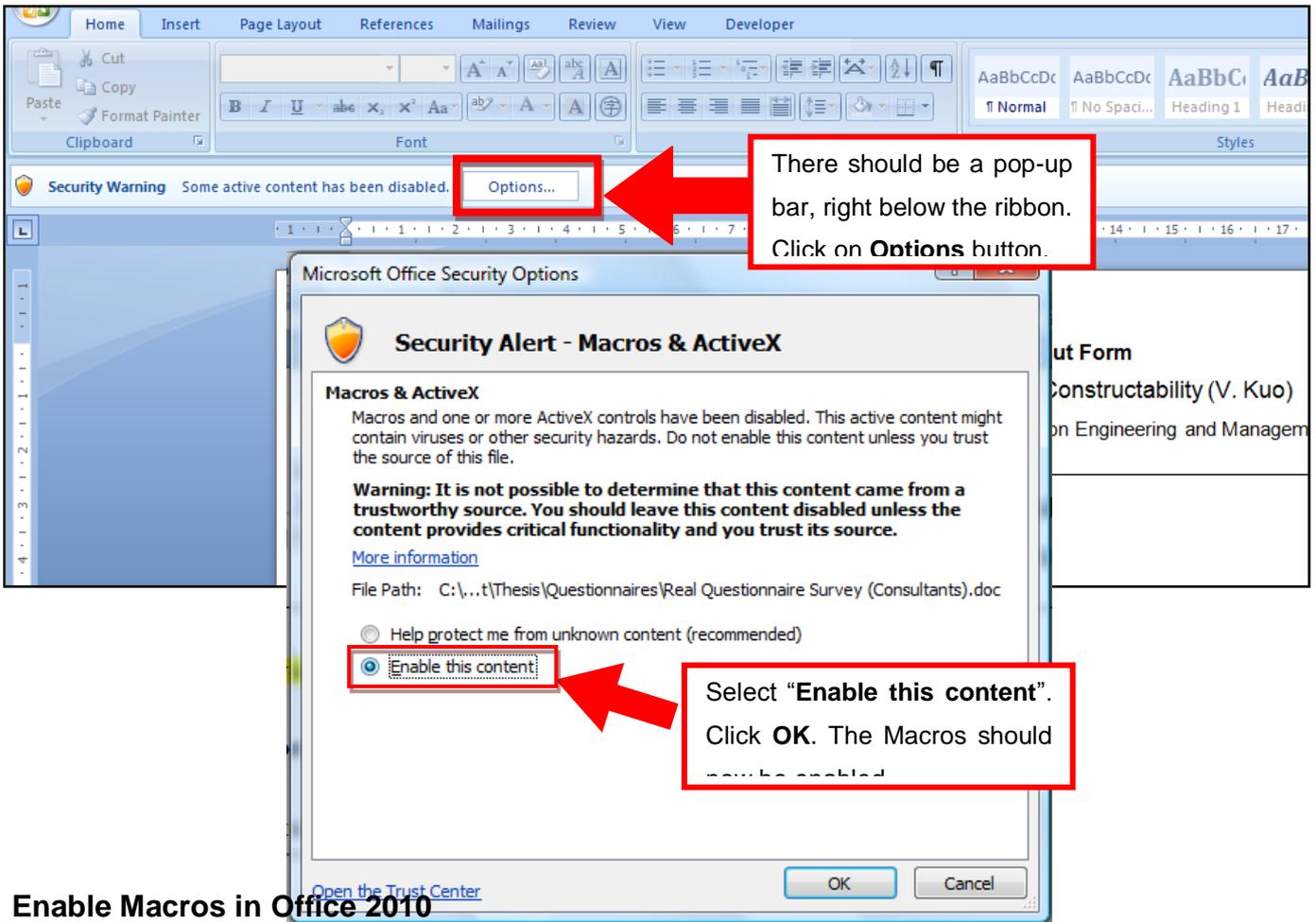
Additional comments:

Please save this document and return the form via email

END OF QUESTIONNAIRE

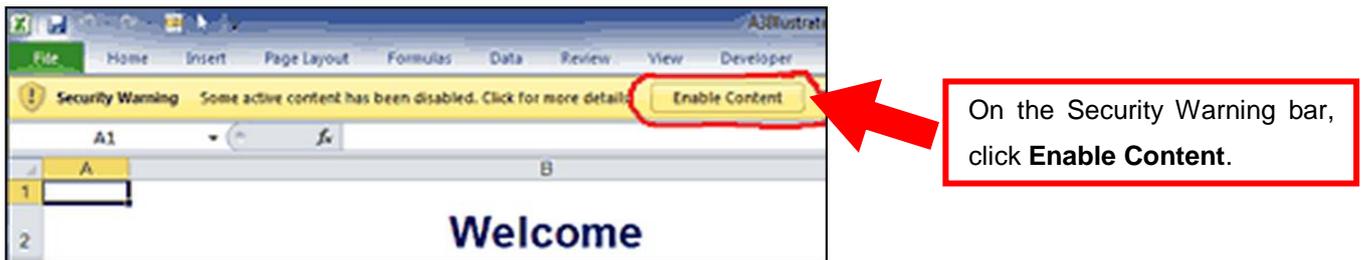
THANK YOU VERY MUCH!

Enable Macros in Office 2007



The screenshot shows the Microsoft Office 2007 interface. A yellow Security Warning bar is visible at the top, stating "Some active content has been disabled." and includes an "Options..." button. A red box highlights this button, with an arrow pointing to a text box that says: "There should be a pop-up bar, right below the ribbon. Click on **Options** button." Below the warning bar, the "Microsoft Office Security Options" dialog box is open. It displays a "Security Alert - Macros & ActiveX" message. Under the "Macros & ActiveX" section, there are two radio button options: "Help protect me from unknown content (recommended)" and "Enable this content:". The "Enable this content:" option is selected and highlighted with a red box and an arrow pointing to a text box that says: "Select '**Enable this content**'. Click **OK**. The Macros should now be enabled." The dialog box also shows the file path and "OK" and "Cancel" buttons.

Enable Macros in Office 2010



The screenshot shows the Microsoft Office 2010 interface. A yellow Security Warning bar is visible at the top, stating "Some active content has been disabled. Click for more details." and includes an "Enable Content" button. A red box highlights this button, with an arrow pointing to a text box that says: "On the Security Warning bar, click **Enable Content**." The background shows a spreadsheet with a "Welcome" message.

Enable Macros in Office 97 - 2003

In the pop-up dialog box, click the button to **Enable Macros**

Appendix E: Constructability cases/issues in practice

1. Design specifications and administration:

Design specification incomplete, excessive deflection of structure (floors)

- Floor specification did not include floor screed, and a class 2 floor was specified. This, in conjunction with the excessive deflection of the floors resulted in very uneven floors and a lot of remedial work in order to install the floor finishes.

Design failure due to poor integration between cantilever and precast wall system

- The cantilever balconies incorporated into a precast floor system was designed with a kink in the reinforcing to accommodate the difference in level. This and the fact that there was very little cover on top of the steel resulted in the balconies snapping and breaking off from the building. They were later supported by a retro-fitted steel bracket.

No provision for reticulation in load bearing walls

- No chasing was allowed on internal load bearing walls. There were thus major problems with water and electrical reticulation, which had a huge cost impact for the client.

Slender columns

- Extremely slender and tall columns were specified, which posed as construction challenge.
- The warehouse had very tall and narrow concrete columns with corbels and holding down bolts in some parts of the building. This should have been in steel as most other columns. These were difficult to construct, and had to be braced temporarily until the steel structure was up.

Ceiling voids not provided

- Accommodation for all services is within the in situ RC slabs

Distortion of metal sheets not considered in design

- Flat plate galvanised box gutters were detailed. However, no allowance made for distortion of metal sheets during galvanising process, resulting in pooling of water in gutters.

Insufficient information in construction documentation

- Insufficient information in construction documentation (drawings, specifications etc). Not enough construction specifications.
- Design drawings not showing enough details i.e. sectional details, especially for structural drawings.

Timing of drawings issuance

- Generally, the method of construction can be changed to a faster and more cost effective solution. The problem is normally that the construction drawings are issued to the contractor just in time, hence not leaving enough time to change the design.
- On the majority of projects the information flow to the contractor is late, resulting in delays to the project. The design company are normally not at fault, because they are waiting for details from vendors, which must first be employed by the client, before they will supply details required by the designer to do the foundation designs. The overall design is not done in good time, allowing as little interference to the construction works as possible.
- The design is done as the contractor progresses.

2. Alternative design or construction details

Contractor inputs on the design and construction resulted success

- The precast yard and launching facilities were designed under the supervision of the contractor. Had this not being the case, a great deal of re-work would have been required to ensure an effective system.
- The changing of the precast tilt up walls to in-situ slide wall and column combination proved to be a vital change in completing the project on time.
- Contractor changed the sequencing of the works, which required the columns to be cast with shear and moment reinforcement at deck level, prior to casting the deck. This was a contractor suggestion.
- Contractor changed the shape and size of pre-cast bridge beams. This was a contractor suggestion which improved the project.
- Engineer had scheduled an unrealistic construction period, which could not be met. Contractor had to innovate the construction methods and ultimately a schedule was agreed with client that was 50% longer than the original.

Better alternatives are unlikely considered or accepted

- The pipeline material used in the design was very expensive and unpractical. Also, the proposed alternative material was in line with the core expertise of the contractor. The alternative not only offered a financial saving, but also a reduced project risk in terms of schedule, quality and safety. The alternative was not considered.

- Normally if the contractor wants to change the conforming details, he will have to do the design of the alternative proposal and also supply guarantees for the life of the structure. This is not the core business of a typical contractor, and hence don't pursue these issues further.

Concrete design changes to fit work

- The use of self compacting concrete over normal concrete allows suitable workability, with no vibration needed.

Precast saves time

- Sound design was in place, but the tight turnaround schedule could not be met. As an alternative design, some of the elements were adopted as precast, which could be done while other work was being carried out, as no curing was needed. This ensured that the schedule was met, but using innovation & the contractor's input.

In situ slab on beam very difficult

- In situ slab with down stand beams was specified. This is always very difficult, time consuming and equipment intensive. A precast solution or an in situ solution with permanent soffit formwork would have been possible, but was not considered.

Light structural steel roof

- Extremely light structural steel roof structure forced the contractor to assemble whole portions of the roof on the ground and then hoist it into position. If the structure were heavier the contractor could have used normal erection methods to erect the roof. The contractor had to allow for bigger lifting equipment in his bid and this escalated the costs.

Design of columns did not allow slip-form construction

- A large number (125) of RC columns (50m high) were designed in such a way that the reinforcing was more than 500kg/m³ (with bar lengths up to 13m long), which not only made it very expensive, but also impossible to slide (slip-form) - the most efficient way to construct these types of columns. A small increase in diameter of the columns would have dramatically reduced the reinforcing requirements (increased stiffness) as well as the overall cost of these structures.

3. Cases where in situ concrete less favourable

Implication on schedule

- Structures are designed in a manner that doesn't make it possible to achieve scheduled milestone dates. For example suspended slabs will be designed not to support the suspended slab above during construction and curing. This then requires back propping of the bottom

slab, hence delaying the succeeding activities on the bottom slab. The problem is that the project schedule will not allow for this. If for example the schedule were the most important item, the suspended slabs could be constructed using precast beams and planks with composite in situ concrete on top.

In situ beams changed to precast

- Achieves better finish, consistent colouration and precast moulds are more consistent

Bathroom as precast

- Small bathrooms (originally in situ) are changed to pods on site. Plumbing are executed in jigs, thus no chasing required. Lack of chasing has some benefits: minimal waste, less dust and health & safety implications. Plumbing could be executed to a manufactured standard (testing was done off site to a working pressure double of the required standard).

Columns preferable as precast, due to issues with rebar

- Raking columns were designed to be in-situ, with massive cast-in items and very creative shapes. These could easily have been pre-cast, which would have yielded much higher quality finish as well as a much cheaper concrete mix design. The shape and congestion of the reinforcing, made it almost impossible to pour and compact (vibrate) with conventional concrete, thus a self compacting mix was used, which was not only very expensive in itself, but also pushed up the formwork costs tremendously (pressure much higher and water tightness requirements).

In situ concrete ring beams difficult

- Fast track project, ring beams designed as concrete. Engineer should have specified boxed steel beams for speed.

Some advantages of precast

- Precast structures allow constructability issues to be thoroughly addressed in the planning phase. Additional issues that may arise thereafter are then used to prevent the same mistakes in future. Experience and proper consultation with contractor and site personnel in our opinion is the only way in which these issues can be prevented.

4. Simplicity and standardization

Formwork standardization

- All formwork suppliers have certain standard dimensions for their formwork systems. For example, making a beam 450mm wide and not 425mm it makes no significant difference to the design, but makes the construction faster and cheaper. In the majority designs these issues are not being considered.

- All internal walls were load bearing. This resulted in a very inefficient formwork process as formwork for each room had to be constructed individually – very poor design.

Complex structural steel difficult on fast track project

- Very complicated structural steel design on a fast track project creates a great challenge.

Normal concrete wall preferable over brick skin wall with concrete cavity

- 6m high composite retaining walls constructed of 2x115mm brick skins and reinforced concrete filled cavity were specified. Concrete retaining walls would have been much easier and faster to construct.

Columns in walls should be same width as the wall

- Columns in walls should be the same width as the wall, for shuttering and better finishing purposes.

Architect specifies unfamiliar products

- On a recent project, the Architect has specified a large number of products that have never been used in our market, or installed by our contractors. This causes delays, training that is required, re-work costs, and frustrates people due to their lack of knowledge of the systems, maintenance etc.

Complicated precast panels with recesses

- Precast concrete perimeter wall panels (5m x 10m) had recesses in them. Subcontractor got a lot of the panels wrong. Substantial remedial work required. Designers should keep precast panels simple.

Coordination of services

- Poor coordination of services- especially in hospitals.
- Service co-ordination, this is always a problem, systems are designed in isolation and are poorly co-ordinated. This complicates the installation process, delays construction due to clashes having to be resolved, and also incurs costs.

5. Masonry walls related problems

Chasing problems

- Electrical boxes were back to back on 110 mm masonry walls. After chasing, the wall was destroyed and wall stability compromised.

- Kitchen walls of 230mm or 280mm required chasing for plumbing, water supply, water waste, electrical etc. Moving kitchen cupboard away from wall by 60mm. Surface mount fixtures. Testing of services and maintenance can be easily done. There is no chasing, and thus no waste. The only negative point is that cupboard requires a backing.

6. Site related issues

Safety

- Safe execution of work – designers often do not consider how activities take place on site, and do not prepare a design to safely allow activities to take place. An example is the application of polystyrene copings on high parapet walls where materials must be hoisted into position, and then rendered.
- There are poorly specified materials that are impractical when it comes to serviceability. An example is, in particular, the lack of attention to design on a glass roof, where workers are again put at risk during the installation. Also the cleaners may be at risk once the building is complete, as the glass could fail with people on it.

Site access

- The access platforms were supplied by others and were constructed out of sand – this made the access for both supply of material and equipment very difficult. This type of platform is also extremely vulnerable to rain. This ended up costing the contractor a lot of money in rework and specialised plant to move material and equipment. If the contractor was aware of this and allowed for this in his price – for instance, a 150mm layer of G5 – the final value of the project would have been lower and ease and speed of construction would have been better.
- Accommodate for poor soil conditions on site. Specify G7 gravel layers as part of tender for access to building sites in areas of soft wet clays.

Spacing and cranes

- Provide for cranes in confined city block sites. Often no place for a crane and stockpiling of materials, mainly in city blocks. Tower cranes were the only option as mobile cranes cannot access the site when columns are in place.

Excavations

- Deep excavations for footings that require lateral support was not suitable for piles.
- Excavations for footings and foundation walls may flood during heavy rain, which can be prevented by providing proper drainage on site.

7. Aesthetics

Facade aesthetics

- Facade design can have a huge impact on constructability, and designers often only consider the effect of the aesthetics of a design, rather than the practicality of implementing it. Concurrently, they have an expectation of fast-track construction, on difficult systems, which actually takes a long time.
- The facades were very cumbersome to build. It was composite brickwork plastered and rendered with lots of windows and mouldings surrounds and large architectural copings. This had to follow the structure over 36 floors and be fully supported with scaffolding over the height, because of the different trades to have access to complete the works.

Unfit construction method specified by engineer bridge

- The method of construction specified (incremental launching), governed by the design of the bridge, was very expensive and impractical for the length of the bridge. A precast beam solution was viable and much cheaper, but dismissed for aesthetic reasons.

Complex structure with post tensioning

- The Parking garage was a very long post-tensioned slab building with very heavy and numerous concrete facades and internal shear walls. It was designed to match an existing garage which preset the aesthetics of the building.

8. Rebar related problems

Large/dense rebar

- Rebar sizes too big and/or spacing is too little for concrete to be vibrated in beams and columns.
- Drilling and epoxy of bolts in columns/walls for steel brackets need to be installed but the holes clash with the rebar. It was very difficult to get all holes drilled when rebar in column/wall is Y32 or Y20.
- The bases and holding down bolts of the warehouse was heavily reinforced and this made the very bulky HD bolts impossible to install.
- Detailing of reinforcement bars for sliding shutters should preferably be of smaller diameters and short enough to be handled by staff on site, on high elevations.

Length of rebar

- Steel designers do not consider the yield length of the steel after the steel was bended, resulting in the steel becoming too long and must thus be cut.

Rebar design

- Detailing methods of reinforcing bars need to be thorough to prevent too heavy column cages for cranes to handle. Also, bars may be too long to man handle on site. Preferable to have cages for pre-assembly off site.