MAPPING INNOVATION IN THE CONSTRUCTION SECTOR: A STUDY OF NATIONAL FIRMS IN MALAYSIA

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ABSTRACT

Existing innovation in construction researches that mainly draw from manufacturing models and adopt a single dimension view of the firm or an institutional approach are limited due to the complexity of the construction sector and the nature of the innovation system that require it to be studied as a whole. Using a qualitative and inductive approach, this case study of four construction firms adopted the service sector adaptation of the Sectoral System of Innovation (SSI) framework to explain how the complex interactions, project-based nature and specific processes of construction influence construction innovation. The research questions asked what are the active components of a construction innovation system, how do institutions regulate the conduct of actors in the construction industry, and how do organizations connect institutions and firms to support innovation in the construction industry? The researcher found that innovation in construction is largely incremental and not revolutionary, typical of Schumpeterian Mark 1 systems. Construction firms are motivated to innovate for problem-centric or opportunity-centric reasons, as do firms in the service sector. Leadership is a strong determinant of innovation. Because construction involves multiple actors, innovation in construction is also a team effort that requires high levels of interaction and interdependency. In contrast to the manufacturing sector, informal forms of knowledge base and learning are considered more effective than formal systems and training. Clients provide direct or indirect input to innovation, depending on the construction subsector. Institutions regulate actors’ conduct in the construction innovation system (CIS) acting as both positive influences on and impediments to innovation. Meso-organizations play an intermediary role to institutions. Government does not play a strong role, but has the potential to play a supporting role by encouraging innovation. The CIS mapping from this research provides new knowledge to guide policy makers and the owners and managers of construction firms to increase

innovation in construction. Theoretically, it extends the service sector adaptation of the SSI framework by developing a CIS framework as well as providing an integrated understanding of the characteristics of a construction innovation system to address the limitations of extant construction innovation literature.

ABSTRAK

Penyelidikan tentang inovasi di dalam sektor pembinaan yang berasaskan model sektor pembuatan dan yang menggunakan pendekatan perspektif tunggal dari segi firma atau institusi adalah terbatas memandangkan kerumitan dalam sifat sistem sektor pembinaan dan inovasi yang memerlukan ia diselidiki secara menyeluruh. Dengan menggunakan pendekatan kualitatif dan induktif, empat kes firma pembinaan dan adaptasi sektor perkhidmatan daripada rangka kerja `Sectoral Systems of Innovation"" (SSI) untuk menerangkan bagaimana interaksi yang kompleks dan proses di dalam sektor pembinaan yang berasaskan projek dan proses khusus sektor pembinaan mempengaruhi inovasi di dalam sektor pembinaan. Soalan penyelidikan ialah: apakah komponen aktif dalam sistem inovasi sektor pembinaan (CIS); bagaimanakah institusi mengawal selia aktor di dalam inovasi sektor pembinaan dan bagaimanakah organisasi menghubungkaitkan institusi dan firma untuk menyokong inovasi di dalam sektor pembinaan? Penyelidikan ini mendapati inovasi di dalam sektor pembinaan adalah sebahagian besarnya inkremental dan tidak radikal, dengan itu ia menyerupai sistem Schumpeterian Mark 1. Sama seperti di dalam sektor perkhidmatan, motivasi firma pembinaan untuk inovasi adalah bertumpu kepada masalah atau peluang. Kepimpinan merupakan motivasi kuat di dalam menentukan inovasi. Oleh kerana sektor pembinaan melibatkan pelbagai aktor, inovasi merupakan usaha pasukan yang memerlukan tahap interaksi dan ketergantungan yang tinggi. Berbeza dengan sektor pembuatan, asas pengetahuan dan pembelajaran yang tidak formal didapati lebih berkesan daripada yang formal di dalam sektor .pembinaan Sama ada pelanggan memberikan input langsung kepada inovasi adalah bergantung pada sub-sektor pembinaan. Pengawalan selia institusi ke atas kelakuan aktor di dalam sistem inovasi sektor pembinaan (CIS) bertindak sebagai pengaruh dan penghalang dalam innovasi. Organisasi meso didapati memainkan peranan pengantara kepada institusi.Walaupun kerajaan tidak memainkan

peranan utama, tetapi ia mempunyai potensi menjadi penggalak inovasi. Pemetaan CIS daripada hasil kajian ini memberikan pengetahuan baru kepada pembuat dasar, pemilik dan pengurus firma untuk memandu mereka di dalam meningkatkan inovasi di dalam sektor pembinaan. Daripada segi teori, ia memperluaskan adaptasi sektor perkhidmatan terhadap rangka kerja SSI melalui pembentukan rangka kerja CIS. Ia juga memberikan pemahaman yang berintegrasi tentang ciri-ciri CIS untuk mengatasi keterbatasan dalam literatur inovasi sektor pembinaan.

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I dedicate this thesis to my father and mother for their sacrifices and emphasis on the importance of education that inspired me to pursue the PhD journey. To Christ be the glory for the things He has done!

Table of Contents

List of Figures

List of Tables

Glossary

Actors	Heterogeneous agents comprising firms, organizations, institutions
Appropriability	Scope (including legal mechanisms) in which knowledge and innovations can be protected from imitators
CIS	Construction Innovation System. The innovation systems framework developed in this thesis from case study analysis of innovation in the construction industry, based on the SSI & ISS frameworks
Class A contractors	Contractors registered with the Pusat Khidmat Kontraktor that can bid for projects above RM10million in value
Construction Industry Development Board (CIDB)	A statutory body under the Minister of Works, Malaysia that coordinates all activities in the construction industry and registers construction firms
Construction Research Institute of Malaysia (CREAM)	The research and development (R&D) arm of the Construction Industry Development Board of Malaysia (CIDB)
Building Construction Authority (BCA)	The government agency that develops and regulates Singapore's building and construction industry
Demand	Types of users, consumers; role of demand, i.e., user-producer relationships. In this thesis, demand consisted of clients and retail customers.
Intermediary organizations	Organizations that translate rules or institutions for public goods and collective action problems (at the macro-level) for the use of organizations and individuals, or agents, at the micro-level in an economic system
ISS	The Innovation Systems in Service framework, adapted by Tether & Metclafe (2004) from the SSI framework to examine innovation in the service sector
Knowledge base and learning	Components and coverage, accessibility and sources of knowledge, protection of innovation; firm capabilities within its institutional and cultural context (Malerba, 2002)

Networks	Agents' processes of interaction, including communication, exchange, cooperation, competition, and command (Malerba, 2002)
Opportunity-centric (Motivation)	Opportunity that motivates firms to innovate
Problem-centric (Motivation)	Problem that motivates firms to innovate
Pusat Khidmat Kontraktor (PKK)	The Malaysian government agency that registers construction firms that are interested to obtain government projects
SSI	Sectoral Innovation Systems (also known as Sectoral Systems of Innovation), a branch of the innovation systems approach, developed in particular by Malerba (2002, 2004, 2006)
Standards and Industrial Research Institute of Malaysia (SIRIM)	The Malaysian government agency that is entrusted with standards and quality regulation and promotion of technological excellence
Technological progress proposition	Explains economic growth in terms of investment in technological progress rather than efficient allocation of inputs
Technological regime	Technological opportunities, appropriability of innovations, cumulativeness of technical advances and properties of the knowledge base (Breschi et al., 2000)

CHAPTER 1

INTRODUCTION

1.1 Introduction

Construction services are significant to national economic growth because of their wide-ranging backward and forward links to other economic activities (Ofori, 1990). The contribution of the construction industry to the world's gross domestic product (GDP) is estimated at 9%, representing a global turnover of US$4.8 trillion and employment of around 110 million people (Quijano, 2014).

The construction industry serves a vital role in the Malaysian economy where it provides economic and social infrastructure for industrial production and re-production in the industrialization process (Ibrahim et al., 2010b; Kong, 2009). Basic amenities and infrastructure such as housing, roads, airports, ports, and power and communication utilities are important in improving social living standards and the growth of other sectors. Construction is an important sector in Malaysia, contributing 3.8% to her GDP in 2013 (Bank Negara Malaysia, 2014). It provides opportunities to a large number of downstream businesses, mainly small- and medium-scale firms (Megat-Rus-Kamarani, 2002).

There were 66,925 contractors registered with the Construction Industry Development Board (CIDB), the regulator of the Malaysian construction industry, in 2014 (CIDB, 2015). Similar to the construction industries of other developed and developing countries, the Malaysian construction industry is fragmented (Alashwal et al., 2011). Malaysian construction companies are categorized according to size, based on the maximum value of the projects for which they can tender (Table 1.1) and further subcategorized by specialization and subspecialty. Fragmentation is seen in the large number of small contractors in grades G1 and G2 (together, more than 60%) in contrast to the much smaller 10% of large contractors in grades G6 and G7. There are 19 subspecialties in the building category, 20 subspecialties in civil engineering construction, 15 subspecialties in mechanical specialist and 10 subspecialties in the electrical construction specialist category. A company can register in more than one category and subspecialty within a grade.

Table 1.1: Structure of the Malaysian Construction Industry, March 2014

Grade	**Firm size (allowed project bid)**	**Number of firms**	**%**
G1	Not exceeding RM200,000	34,407	51%
G2	Not exceeding RM500,000	9,510	14%
G3	Not exceeding RM1,000,000	8,863	13%
G4	Not exceeding RM3,000,000	2,498	4%
G5	Not exceeding RM5,000,000	4,147	6%
G6	Not exceeding RM10,000,000	1,580	2%
G7	Unlimited	5,343	8%
Total		66,925	100

Source: (CIDB, 2015)

Construction today faces intense competition for international job opportunities in new markets such as China and other fast developing East Asian countries (Abdul-Aziz & Wong, 2010). Cross-national trade agreements and the global free trade that ensues have provided developing countries with greater freedom of access to developed countries (MITI, 2015). These developments have generated urgency amongst construction firms and policy makers in developing countries to remain competitive. Additionally, national economic growth requires growth in construction infrastructure while increasing sophistication in societal demands and environmental pressures bring increased demand for safer, higher quality and sustainable construction, creating further challenge for policy makers.

Against this backdrop of challenges for developing countries, the construction industry worldwide faces problems in safety, quality and delays (Oakland & Marosszeky, 2006) and its public image is very poor (Samuelsson, 2003). The construction industry in Malaysia has also faced problems of time and cost overruns, quality, productivity and image (Megat-Rus-Kamarani, 2002). At the same time, innovation in supporting sectors such as information technology and engineering has created opportunities for the construction industry in its constant quest for cost-effectiveness and efficiency.

These developments also pose challenges and create opportunities for the construction industry to innovate to meet the needs and demands of clients, society and nations. Historically, innovation in the construction industry has been regarded as very conventional: innovation is incremental, and radical and revolutionary innovations are rare (Slaughter, 1998). Since the mid-2000s, particular attention has been paid to innovation in construction, when lack of investment in research and development (R&D) was identified as the main cause of low innovation in construction in several countries, including the UK, Australia, Hong Kong and Singapore (Lim, 2006). In Malaysia, policy makers and industry players observed that the construction industry was in need of enhanced capabilities and advocated capacity building through improved technologies, innovative processes and collaborations (Abdul Rahman et al., 2005). In its Master Plan 2010-2015, the CIDB nominated innovation as a strategic thrust to develop the sector (CIDB, 2005).

The CIDB, a government agency under the Ministry of Works, has held the Malaysian Construction Industry Excellence Awards (MCIEA) annually since 2000. The purpose of MCIEA is to achieve excellence in construction practices by promoting competition among industry players and showcasing best practices in project implementation. A Special Award is provided for innovation. The Award recognizes ideas, concepts, products, processes, techniques and technologies that can improve the efficiency, productivity and quality of construction project implementation and the construction industry as a whole. Evaluation criteria for this award include improved efficiency, productivity and quality of construction, economic benefits, industry acceptance or commercialization, enhancement of the sustainability of the construction industry, originality, creativity and environmental friendliness. Construction firms submit projects completed in the year of competition by way of a written statement on why they deserve to receive the award. Sub-contractors are eligible to participate with prior consent in writing from their main contractor(s). Two hundred and twelve submissions were received in 2013 (Malaysia Chronicle, 2014).

There are now signs that the Malaysian construction industry is more innovative, in some respects on a par with advanced countries. This has been noticed by other countries, as highlighted by CIDB Chief Executive, Datuk Seri Judin Abdul Karim:

> To some Malaysians, the transformation [construction firms' innovativeness] may not look obvious, but to foreigners who have made sporadic visits here, they are impressed with the changes that have taken place... We owe this transformation to the construction sector. Over the years, the sector has become more and more innovative with its technology, sometimes making us at par with the developments in more advanced countries (Malaysia Chronicle, 2014).

This transformation in construction firms' innovativeness indicates that Malaysia provides a pertinent context for study of innovation in the construction sector.

This introductory chapter consists of eight sections. Section 1.2 briefly explains the motivation of this research. The next four sections formally state the problem addressed in the research, the research contribution, the research approach, the research questions and objectives and the significance of the research. Key concepts are then defined before the chapter concludes with an overview of the structure of the thesis.

1.2 Motivation for this Research

To increase the level of innovation in the construction industry, policy makers require a profound understanding of the influences on and impediments to innovation, as well as construction firms' motivations for innovation. The purpose of this research is to study institutional and systemic influences on innovation, the impediments hampering innovation and motivations for innovation in construction firms, using Malaysia as a case study.

A summary of the motivation for conducting this research, drawn from the introduction in Section 1.1, is depicted in Figure 1.1.

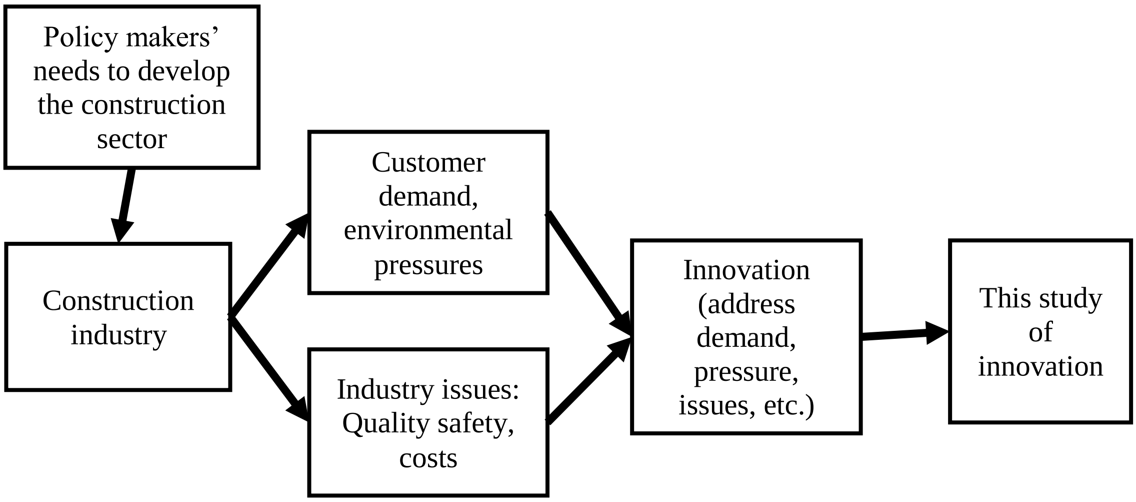

Figure 1.1: Motivation for this Research

1.3 Statement of Problem

There are two theoretical shortcomings in the existing scholarly literature of innovation in construction. Firstly, theory and methods are drawn from manufacturing, even though the activities in construction and the structure of the sector are so different from those of manufacturing that construction appears separately from manufacturing in national accounts. The second shortcoming results from reliance on the singular point of view of the firm or institution, rather than a view of the innovation system as a whole, to understanding construction innovation.

Researchers in construction and government agencies administering industry data define construction in terms of the type of activities an industry or company engages in. Construction is defined as an activity associated with physical infrastructure, superstructure and related facilities (Kong, 2009) or activities that are characterized by construction and restoration of permanent structures and facilities (Nam & Tatum, 1988). In national accounts, the construction sector is separated from services and manufacturing to denote that the sector is characterized by its own features, although the broadest definition of services includes construction due to the service elements of construction and their distinctiveness. Shapiro (1999) provides a useful discussion of the differences between construction and manufacturing systems. She describes *complex product systems* (COPS) as systems which are produced on a project basis for specific customers and markets, and notes that their innovation and production processes differ from those assumed to exist in traditional research models based on manufacturing and mass production. COPS production processes stress software development, systems integration and project management over repeated tasks (Shapiro, 1999).

The COPS characteristics of construction mean that innovation in construction needs to be examined differently, using models other than the conventional models based on mass production in the manufacturing sector. Existing construction research that is based on manufacturing models cannot provide a comprehensive account of the sector and, as a consequence, generate misleading findings about the industry. Furthermore, the construction sector is more similar to service sector than manufacturing with regards to innovative behaviour (Reichstein et al., 2005). Nonetheless, research on construction innovation has relied on theories and methods drawn from manufacturing, thus, hampering efforts to understand innovation in construction (Koskela & Vrijhoef, 2001).

Efforts to understand innovation in construction have also been hampered by reliance on a limited theoretical point of view. Two main approaches are used to investigate the causes of the low rate of innovation in construction (Koskela & Vrijhoef, 2001; Taylor & Levitt, 2004). The first takes the view of the firm or adopter, and studies the effect on innovation of organizational factors such as leadership and culture. The second approach takes an institutional view and examines factors such as clients, procurement method, market (e.g., technological opportunity and institutional requirements), and the nature of the construction industry. Although some studies use a combination of both approaches, most studies take the single view of either the firm or the institution.

The complexity of the construction sector can also be seen in the complexity of innovation itself. The innovation process is complex for three reasons. Firstly, innovation is interdisciplinary (Fagerberg, 2009) and involves all aspects of economic activity (Köhler, 2008). Secondly, innovation occurs in a non-sequential way that involves interaction and feedback (Kline & Rosenberg, 1986). Thirdly, it involves a set of variables, including cultural and philosophical differences, interconnected in complex ways (Thamhain, 1998, as cited by Ng, 2011).

The complexity of the innovation process is further compounded by the complexity of the construction sector, due to the sector's project-based nature. Numerous people, firms, organizations and operations perform related, but very different, activities ranging from providing supplies to construction and maintenance (Liebing, 2001; Oakland & Marosszeky, 2006).

The participation of diverse actors, in turn, forces the construction sector to operate as a network, resulting in multiple roles played by contractors with an often subtle variety of relationships between actors. Interactions occur within and across multiple levels, from macro-level structures to individuals at the micro-level. Any interaction can “shape” (Carassus, 2004) or change any or all of the actors involved. Nonetheless, most studies of innovation in construction examine only a limited subset of actors or interactions, producing partial explanations that do not take account of the systemic way in which actors and interactions shape innovation. Recommendations affect only part of the system, at best, and that can be counter-productive.

In addition, there is a lack of research on innovation in the construction industry in developing countries (Ibrahim et al., 2010b). This extends to Malaysia, despite the advances that the country has made over the past decade.

1.4 Research Contribution

To address the limitations of existing research, this thesis uses a branch of the innovation systems approach, the Sectoral Systems of Innovation (SSI) framework developed by Malerba (2002, 2004, 2006) to study innovation in construction. In addition, it adapts the SSI by using an application to the service sector developed by Tether and Metcalfe (2004) to formulate an inductive framework to analyse the influences of innovation on the construction industry. Adoption of the service sector adaptation of the SSI framework results in two theoretical contributions. Firstly, the findings help to explain how innovation occurs in the construction industry through a complex interplay of interactions between structures and actors across a multiple-layered network. Secondly, this study results in the formulation of a systemic model of innovation in the construction industry that recognizes the project-based nature of the industry and the specific processes within it. Thus, this study provides researchers, policy makers and construction firms with a map of the construction innovation system, the nature and types of innovation taking place in the industry. A summary of the study’s contributions are depicted in Figure 1.2.

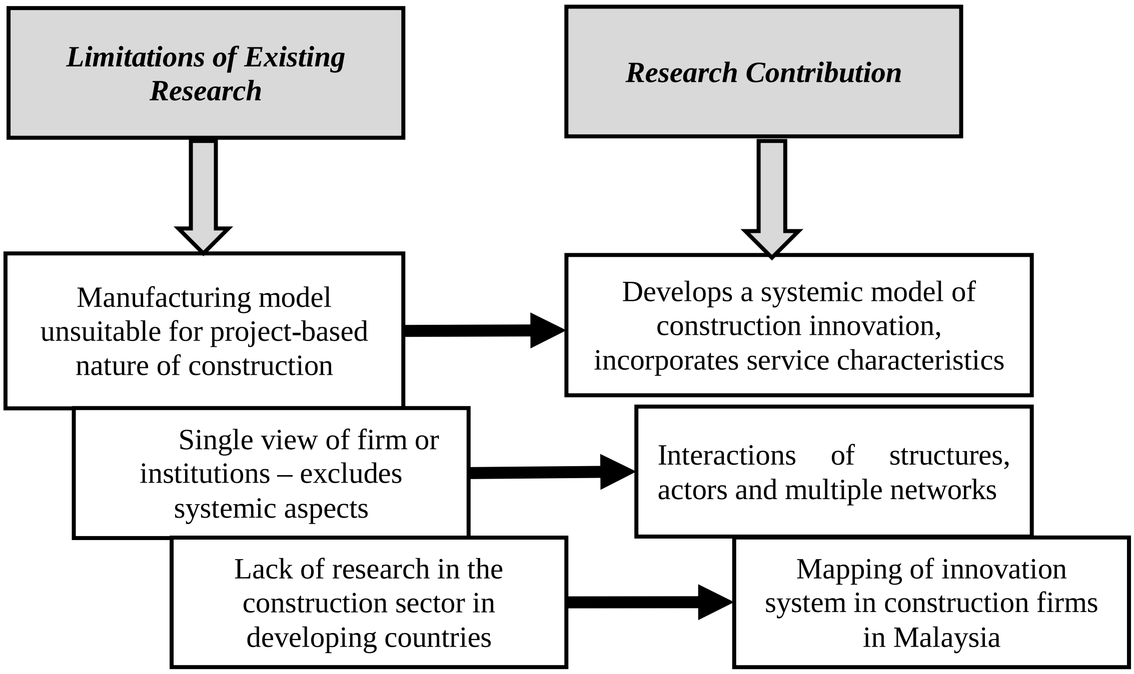

Figure 1.2: Contributions of the Study

1.5 Research Approach

1.5.1 Evolutionary Theory and Innovation Systems

Innovation in the construction sector involves actors in the sector and its immediate environment – construction firms (known as main or lead contractors), external consultants, sub-contractors, clients and competitors; and actors in its extended environment – government and other organizations that support large-scale innovation, such as research organizations. Thus, innovation in construction firms is influenced by a diversity of interrelated actors in a complex systemic network. To understand the factors that influence contractors' decisions to innovate one has to understand this complex system of innovation.

This study adopts an innovation systems approach because it permits the study of multi-faceted non-linear interactions between actors. The innovation systems approach that provides a framework to examine an industry sector in an integrated and consistent way is known as the Sectoral System of Innovation (SSI). As proposed by Malerba (2002, p. 248), the SSI examines the type, role and mechanics of production, the rate and direction of innovation and the impact of these variables on the performance of the sector.

The SSI framework is rooted in the evolutionary economics school with antecedents to Veblen (1898), the founder of institutional economics. The institutional view was further expanded by Schumpeter (1961) and Nelson and Winter (2009). As described by Hodgson (2012, p. 6&7), the four principles of evolutionary economics are a) qualitative changes in technology, organizations and the structure of the economy (Schumpeter, 1961); b) the generation of novelty in the process of change, evident in the works of Dosi et al. (1988), Nelson and Winter (2009) and Witt (2009); c) emphasis on the complexity of economic systems which involve non-linear and chaotic interactions; and d) complexity is limited by the predictability of human institutions and other social arrangements which evolve spontaneously through individual interactions, without an overall planner or blueprint.

The systemic view of the processes of innovation and diffusion of technology originated with Schumpeter (1961) and was later embraced by others. Amongst these later researchers were Kline and Rosenberg (1986) who found that the innovation process consists of a web of feedbacks and loops where these relationship are referred to as the systemic aspects of innovation–diffusion which are related to social, institutional and political factors, while Freeman (1987, p. 1) refers to the national system of innovation as the network of institutions in the public and private sectors involved in innovation.

Evolutionary theory explains the origin and evolution of different industries and technologies as being shaped by time and locality (Malerba & Nelson, 2011; Nelson, 2008b). This approach is a good fit for the study of the construction industry in Malaysia, which differs by sector in different localities with different institutional regimes and by the timing of the evolution of the sector (e.g. in the context of innovation). Specifically, the service sector adaptation of the SSI provides an integrated framework for study of construction sector innovation which has been shaped in this way by time and locality. The SSI model is robust and, to date, has been used to study other industries, such as the semiconductor, computer, pharmaceutical, aircraft, and chemical industries (Malerba, 2004; Malerba & Montobbio, 2004), as well as the furniture industry in Malaysia (Ng & Kanagasundaram, 2011).

1.5.2 Inductive Approach and Qualitative Study

The study described in this thesis uses an inductive approach to understanding innovation in construction. In adopting the inductive approach, it follows Keynes (1904) explication of inductive research, which relies considerably on deductive research findings to provide the direction for data collection and analysis. Thus, we use the SSI framework that incorporates the service elements as the starting point to identify components of innovation in the construction industry in Malaysia and how they interact to exert positive or negative influences on innovation.

The study applies a qualitative approach using multiple cases. Case studies permit investigation of a "phenomenon of some sort occurring in a bounded context" (Miles et al., 2013, p. 28) and in the context of this research, the phenomenon is innovation in construction firms in the "bounded context" of Malaysia. Multiple case studies are used rather than a single case study because firms in the construction industry are not unique, but have vastly different characteristics. The use of more than one case allows an assessment of more types of innovation characteristics in the construction industry (Yin, 2014). Four case studies, from the infrastructure, building residential and commercial building construction subsectors, were chosen.

1.6 Research Objective and Questions

The objective of the research is to provide an integrated and systemic understanding of construction innovation systems by mapping the characteristics the institutions, actors, organizations involved and the relationships between them. A model of the construction innovation system is developed by building on the studies carried out by others who have used the SSI approach in other sectors (Malerba & Nelson, 2008; Tether & Metcalfe, 2004). The research is guided by the following research questions:

1. What are the active components of a construction innovation system?
2. How do institutions regulate the conduct of actors in the construction innovation system?
3. How do organizations connect institutions and firms to support innovation in the construction industry?

1.7 Significance of the Research

This research is expected to produce results of economic, societal and scientific value, with ramifications for policy, by furnishing insights into innovation in the construction sector. The scientific significance of the study was introduced in Section 1.4. In addition, by mapping influences on innovation in the construction sector, this study is expected to provide new knowledge that will help policy makers and the owners and managers of construction firms to increase innovation in construction and, thus, enable the sector to continue to contribute significantly to the economic and social development of nations.

Finally, given the paucity of studies on innovation in construction firms in developing countries, this study seeks to add to that field. Indeed, further studies of this sort will be needed to plug existing gaps in the field.

1.8 Key Concepts

This section defines two key concepts for this study, innovation in construction and Sectoral Systems of Innovation (SSI). The terms and concepts that are discussed in other of the chapters of this thesis are presented in the Glossary of this thesis (pages xii to xiii).

1.8.1 Innovation in Construction

Innovation is commonly viewed as the basis of an enterprise's competitive advantage (Dess & Picken, 2001). Although innovation capability is described by some authors as the most important determinant of organizational performance (e.g., Mone et al., 1998), others emphasize that innovation does not result automatically in performance improvement. By contrast, the resolve to innovate might even endanger the enterprise. This leads to the "innovator's dilemma" of being aware of suitable circumstances in which to seek to innovate and in which situations to continue without innovation (Christensen, 2013).

Although there is no single accepted definition of innovation, its principal characteristic is novelty or newness in product, process, system, technology or knowledge, as can be seen from this sample of definitions:

> [*a potential new combination that*] *results in radical breaks with the past, making a substantial part of accumulated knowledge obsolete* (Lundvall, 2010, p. 9)

> [*a*] *distinct phenomenon, a spontaneous and discontinuous change that is entirely foreign to what may be observed in the circular flow of economic activity, displacing the equilibrium state previously existing* (Schumpeter, 1961, p. 64)

actual use of a nontrivial change and improvement in a process, product or system that is novel to the institution developing the change (Slaughter, 1998, p. 226)

The process of bringing new goods and services to market, or the result of that process (Expert Panel on the Commercialization of University Research, 1999, as cited by Seaden & Manseau, 2001)

The OECD (1997) refines the definition of innovation as scientific, technological, organizational, financial and commercial activities that are "technologically new or significantly improved (at least to the company) in product, production process, delivery". Various authors have also argued that necessary aspects of an innovation include: the need and adequacy (Pittaway et al., 2004), its aim (Länsisalmi et al., 2006), its advantages (Camisón-Zornoza et al., 2004), its success (Hobday, 2005; Klein & Knight, 2005) and its dissemination (Holland, 1997).

The construction industry provides an assortment of definitions of innovation, such as:

Application of technology that is new to an organization and that significantly improves the design and construction of a living space by decreasing installed cost, increasing installed performance, and/or improving the business process (Toole, 1998, p. 323)

The successful exploitation of new ideas, where ideas are new to a particular enterprise, and are more than just technology related – new ideas can relate to process, market or management (Construction Research and Innovation Strategy Panel (CRISP), 1997, as cited by Seaden & Manseau, 2001)

> *Act of introducing new ideas, technologies, products and/or processes aimed at solving problems, viewing things differently, improving efficiency and effectiveness, or enhancing standards of living* (Civil Engineering Research Foundation (CERF), 2000, as cited by Sexton & Barrett, 2003)

Ling's (2003) definition of construction innovation includes the aim of obtaining further gains from the innovation even when there is also possibility of related risks and uncertainties in the application of a new idea to construction project.

In this thesis, innovation in construction is defined as "the act of introducing a significant improvement in a process, product, or system that is novel to the organization, may cause individuals to view things differently and results in competitive advantage, increased value for the client or benefit to stockholders".

This definition is a synthesis of applications of definitions of innovation in construction by CERF (Lu & Sexton, 2006; Toole et al., 2013) and the OECD (Manley & McFallan, 2006) as it encompasses three aspects of innovation: novelty or newness to the organization; the three forms of innovation, i.e., process, product, or system; and the result of innovation to the individual, firm and client or stockholders.

1.8.2 Sectoral Systems of Innovation (SSI)

Sectoral Systems of Innovation (SSI) refers to a systemic view of innovation and an integrated model that takes account of the microeconomic actors, meso-organizations, and technological and institutional factors, and the network of interactions amongst them in an industrial sector to influence the innovation conduct of firms within the sector. The four building blocks of the SSI framework are: a) knowledge base and learning processes; b) actors and networks; c) institutions; and d) demand (Malerba 2002; 2004; 2006).

1.9 Organization of the Thesis

This thesis comprises six chapters. A graphical overview is provided in Figure 1.3.

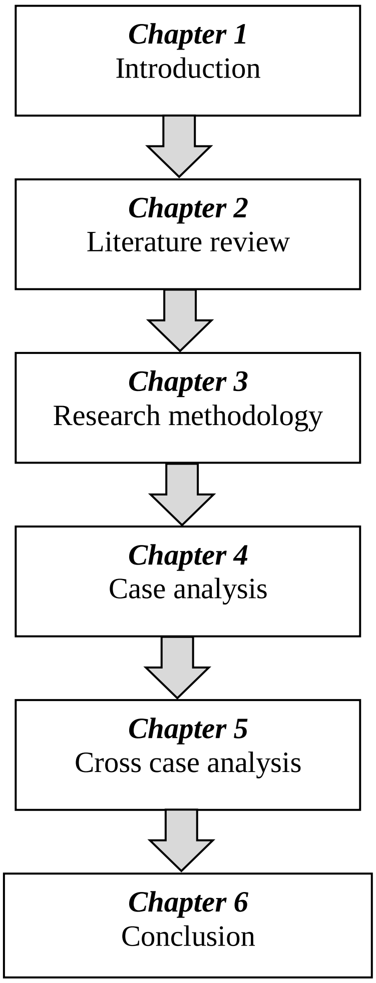

Figure 1.3: Organization of the Thesis

After this introductory chapter, Chapter 2 reviews four aspects of the related literature. The first part outlines the context of the research, namely the construction industry and innovation in construction. The second part presents innovation theories and empirical results from prior business and construction management studies. The third part establishes the framework for the study, namely the SSI and Service Innovation Systems approaches, in more detail, and discusses empirical findings from prior research in which they have been utilized. Chapter 2 concludes with the initial analytic framework developed for this study.

Chapter 3 discusses the research methodology, comprising the research philosophy, design and data collection and analysis techniques.

Chapter 4 presents the within case analysis for each of the four cases examined in this study. Each case write-up consists of a profile of each of the cases followed by an analysis of each of them according to the three research questions presented in Section 1.6.

Chapter 5 presents a cross-case analysis, which comprises an assessment of the similarities and differences between the four cases again addressing the three research questions of this thesis.

Chapter 6 discusses the findings of the study against the literature on SSI approaches and innovation in the construction industry. This chapter also considers the theoretical, methodological and policy implications of this thesis and concludes with limitations and directions for future research.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter establishes a foundation for this research on innovation in construction by outlining the context of the research, establishing a theoretical foundation, reviewing the empirical literature and developing a guiding framework on data collection and analysis.

The chapter is structured as follows. Section 2.2 provides the context of the research and a background to the discussion in the next three sections. It defines and explains the nature of construction and construction activities in general and provides an introduction to the nature of innovation in the construction industry. Section 2.3 establishes the foundation for the research. It begins with an overview of the dimensions and determinants approaches to innovation, studied in the business and construction management fields, and is followed by an examination of the theories associated with these approaches. It ends with a more detailed examination of the systems of innovation approach used in innovation research and this study. Section 2.4 summarizes the gaps in the literature that are addressed in this research. Section 2.5 provides the guiding framework used in the research, a synthesis of Malerba's (2002, 2004, 2006) SSI framework and Tether and Metcalfe's (2004) Innovation Systems in Service (ISS) framework.

2.2 Construction

An understanding of the construction innovation system requires a deep understanding of the nature of construction and how it differs from manufacturing, the sector with which it is most usually equated in discussions of innovation. This section explains the nature of construction and construction activities in order to establish the differences between construction and manufacturing. In doing so, it also draws on the literature that establishes the similarities between construction and the services industries. The final subsection demonstrates the implications of these differences and similarities for innovation in construction.

2.2.1 The Nature of Construction

Construction is one of the oldest management sciences. Studies on the use of movement, layout and transport of materials in construction sites were carried out in 400BC in Persia (Ibrahim et al., 2010a). The most general understanding is the activity view which sees construction as a set of activities that produce certain outputs, based on cost estimation. From this point of view, a building (or other structure) consists of certain components, the costs of each of which can be estimated be costing the inputs (materials and labour) needed to produce the outputs (Ibrahim et al., 2010a). The variant of this view that has been dominant in the nineteenth and twentieth centuries is the conversion or transformation model of production (depicted in Figure 2.1). The conversion model conceptualizes construction as a production process that receives inputs in the form of materials, labour or technology; converts or transforms the inputs into outputs in the form of products; and exports the outputs to the environment or into the next process (Ibrahim et. al., 2010a). The finished product of construction can be either buildings associated with offices, hospitals, airports, shopping centres, housing and factories; or civil works involving infrastructure for water supply, irrigation, transportation, power generation, etc. (Ibrahim et al., 2010a).

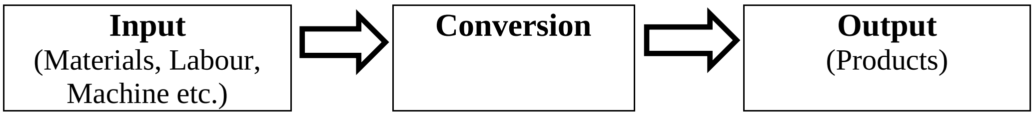

Figure 2.1: Conversion Model of Construction (Koskela, 1992)

Researchers in construction and government agencies define construction in terms of the type of activities an organization or sector engages in. Inclusive definitions are provided by researchers who define construction as:

- an activity of building physical infrastructure, superstructure and associated amenities (Wells, 1985); and
- activities that are associated with the building and restoration fixed structures and facilities (Nam & Tatum, 1988).

The US Bureau of Census (2002) defines the construction industry as comprising companies mainly involved in:

- the construction of buildings and other structures, heavy construction, additions, alterations, reconstruction, installation, and maintenance and repairs;
- the demolition or wrecking of buildings and other structures, clearing of building sites and sale of materials from building demolished structures; and
- the blasting, test drilling, landfill, levelling, earthmoving, excavation, land drainage and other preparation.

According to the Bureau, the unique production processes of the construction industry are earthwork, piling, substructure, superstructure, mechanical and electrical engineering activities. Like other industries, construction uses specialized human resources and specialized physical capital.

The Department of Statistics of Malaysia (Department of Statistics Malaysia, 2014) defines the construction sector as comprising companies engaged in the following activities:

- new construction, alteration, repair and demolition; and
- new installation of machinery or equipment which is built-in at the time of original construction or after original construction and which requires structural alteration.

The three primary sectors of the Malaysian construction industry, as categorised by the Construction Industry Development Board Malaysia (CIDB) are:

- general construction, comprising residential and non-residential construction works;
- civil engineering construction, involving roads, highways, bridges, etc.; and
- special trades work encompassing metal work, electrical work, plumbing, sewerage and sanitary, refrigeration and air-conditioning, painting, carpentry, tiling and flooring and glass work.

The work in each sector is further broken down into specific activities such as earthwork, piling, substructure, superstructure, mechanical and electrical activities. Construction may be performed at one or many different project sites while construction activities are managed at a comparatively fixed place of business. The output of construction activities ranges from buildings and other structures to prepared sites and building materials and machinery or equipment. The end products of a set of construction activities include buildings, residential or non-residential, or infrastructure for a nation's social and economic development.

The construction sector is typically separated from services and manufacturing to denote its uniqueness. However, the broadest definition of services also includes construction (Sieh-Lee, 2000). In the Netherlands, small firms (fewer than 100 employees) classified as construction firms resemble service industry firms; many of these firms provide transport services, and although classified as engineering and architecture firms, provide economic services such as accountancy and consultancy (De Jong & Marsili, 2006). Tether and Tajar (2008) suggest that, if one looks at distribution, construction resembles functional services because of its modes of cooperation. Winch (2003) emphasizes the importance that the construction process also includes the design element in the value chain, which is where most development work occurs. He suggests that the national accounts on construction, which only cover manufacturing, distribution and installation activities, do not give an accurate picture of the differences between the construction and manufacturing statistics and productivity. Thus, a broad definition of construction, which includes design, is required.

In this thesis, construction is defined as consisting activities and sectors defined by the CIDB and DOS Malaysia, also well as taking into account the definitions provided by literature that encompasses the type of activities, the project-based nature, the end products, required human capital and the services element of the sector. Drawing on this definition, the next subsection discusses the nature of construction activities in more detail before examining the differences between construction and manufacturing and the similarities between construction and services.

2.2.1.2 Nature of Construction Activity

Construction is largely project-based, with non-permanent alliances among client, consultant and contract firms forming to complete work over a defined period (Gann & Salter, 2000). The coalition of organizations is temporal and episodic in nature involving players from different backgrounds, firms, organizations and operations that perform complexly related, but very different activities ranging from providing supplies to construction and maintenance (Liebing, 2001; Oakland & Marosszeky, 2006). Thus, the construction sector is a meta-industry comprising a conglomerate of industries from the manufacturing, business services (e.g. architects, engineering, costs surveyors, etc.) and construction.

The organizations in the construction sector supply chain that conduct on-site production and assembly and installation of prefabricated components (contractors and subcontractors); suppliers, such as architects, engineering consultants, cost consultants and users; and upstream (manufacturing) and downstream activities (facility management) (Bougrain, 2006). This involvement of diverse actors, in fact, forces construction to be network- rather than supply chain-focused, and requires the lead construction firm or contractor to play multiple roles. The contractor’s main task is to assemble components and integrate systems and suppliers. Thus, the construction firm is akin to a system assembler that aggregates subsystems or *components* and assembles them on site.

Construction activities consist of separate manufacturing, design, construction and maintenance activities (Groák, 1994; Nam & Tatum, 1988) which are delivered by different firms. The lifecycle view of construction work shows that all constructions begin life as a new construction and go through an operational period in which they require management, repair and maintenance before they are finally demolished. All three of these stages typically involve briefing, design and works whose performance requires effective vertical and horizontal relationships among contractors and other actors (Figure 2.2). Vertically, contractors’ relationships involve subcontractors which may be professionals or trades, distributors and manufacturers. Horizontally, they consist of relationships within construction teams and externally with international and regional actors, state and local authorities, clients, industrial and professional organizations, and consumer organizations.

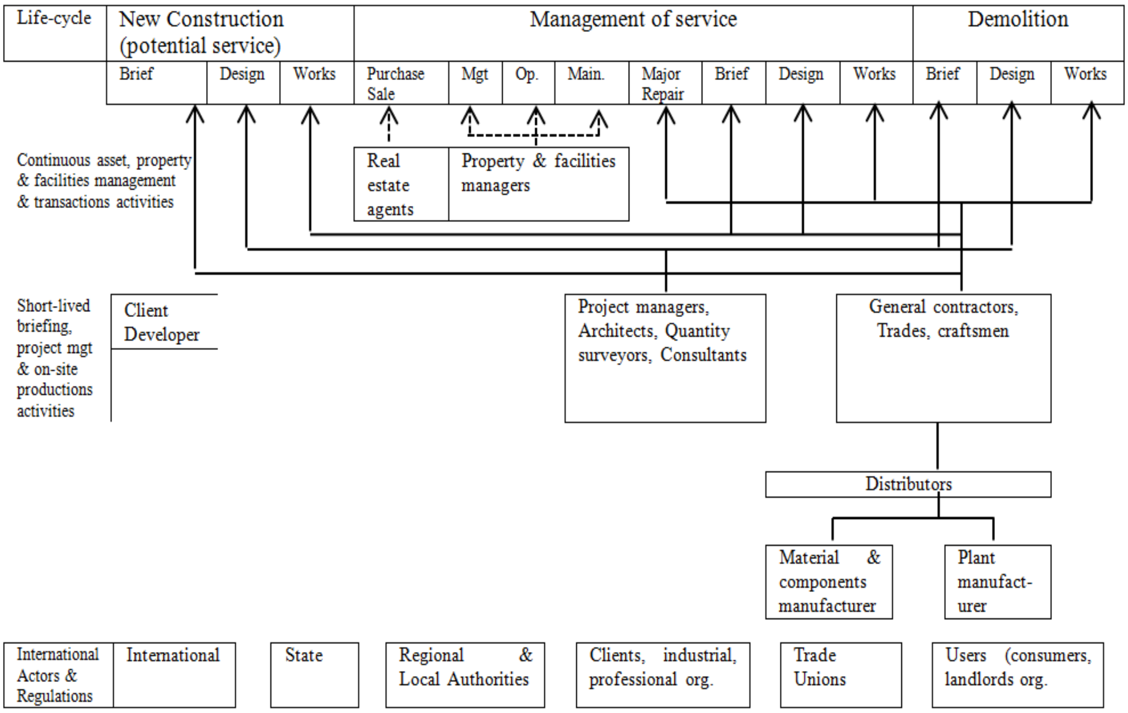

Figure 2.2: Construction Industry Lifecycle and Actors (Carassus, 2004)

The contractors play multiple roles in these relationships (Figure 2.3). In the vertical relationship, the contractor plays the role of client to the professional (e.g. engineering, architectural, surveying) consultancies and subcontractors as well as client to the raw materials and components manufacturers. In horizontal relationships within the construction team, the contractor can be either the main contractor or lead construction firm or a subcontractor. As a subcontractor, the contractor might work simultaneously in different teams on one project or several different projects with different or overlapping actors.

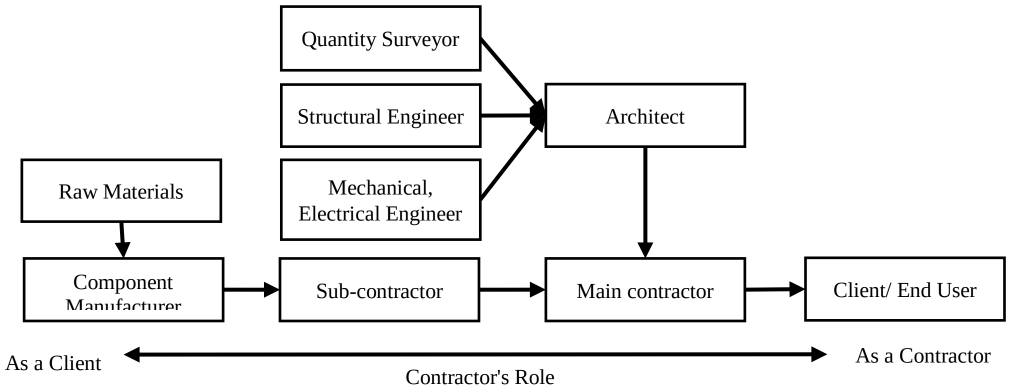

Figure 2.3: Contractors' Multiple Roles in Construction

The diversity of actor responsibilities in construction underlines the importance of effective working relationships as well as having common practices and procedures. Because construction usually proceeds in several stages, feedback from stage to stage is also important (Reichstein et al., 2005). Efforts to ensure effective working relationships, common practices and procedures and sufficient feedback and reporting include the issuance of build contracts, partnering arrangements and long-term service contracts (Barlow, 2000; Bresnen & Marshall, 2000). Construction products are distinctive in terms of in situ production or installation at site. This results in a high degree of product specificity, with construction products designed to order and having a specific price calculated on a cost-incurred basis for each project. In situ production is common because construction products are immobile; they are huge, heavy and costly products which typically occupy a wide geographical area (Nam & Tatum, 1988).

Immobility causes uncertainties in construction processes. This is very different from the controlled environment of factories in the manufacturing industries, which are able to achieve high productivity and uniform product (Reichstein et al., 2005). Nonetheless, some aspects of construction demonstrate factory-like characteristics such as in the use of modular components in industrialized building systems (IBS), where components are prefabricated in factory conditions. This is an example of the construction sector approach to increasing productivity, especially in markets such as housing (Reichstein et al., 2005).

Immobility also means that the technological requirements of construction products are highly diversified and complex (Lange & Mills, 1979). In construction, every project has a unique set of requirements in terms of materials, knowledge, skills, needs and functions to cope with differences in local conditions ranging from building codes to weather and soil type (Finkel, 1997, p. 56). The physical output of projects, the structure of the industry and the features of demand and price specification are typically distinct for each project and piece of assignment subcontracted (Hughes et al., 2001).

In addition, construction work is periodic, with a rapidly fluctuating volume of work in progress (Lange & Mills, 1979). The seasonal nature of construction work and the distinctive nature of construction products results in each construction project often fully absorbing the contractor's capacity for work at specific times. This causes a disjointed flow of activities. Because of the construction product's features, the span of a project site is restricted by contract terms, and alliances created for a project often conclude when the contract expires (Hillebrandt & Hughes, 2000). Because of this, advancement from one stage of construction work to the next is often subject to discontinuity which often results in project delays and quality issues.

Construction demand is usually dependent on the ability of consortia of stakeholders being able to raise large amounts of capital. This causes time delays and a level of complexity in the construction sector that is rarely seen in manufacturing or services (Reichstein et al., 2005). This limits the influence of construction firms on markets. In construction, clients often make design and production decisions, and thus, the industry's decisions are often mediated by clients and local conditions (Reichstein et al., 2005). This creates challenges in downstream processes, particularly production and engineering where standardized design elements are commonly used and, if modified, modified incrementally with minor additions (Utterback, 1994).

The construction industry structure is fragmented in such a way that small firms with few or no professional staff dominate whilst a small number of large, sophisticated firms control niche markets (Table 1.1). This fragmentation reflects the nature of construction activities, which involve projects of varying scales that are scattered across different locations; furthermore, the projects are often small (Ofori, 1993). Due to the physical nature of projects, the structure of the industry and the characteristics of demand, price determination usually takes place discretely and on the basis of individual project and work that is subcontracted (Hillebrandt, 2000). This partly reflects the industry structure in which several construction activities lack entry barriers and economies of scale. Because most small construction firms have few or no professional staff, they engage in little innovation.

2.2.1.2 Motivation for Construction Innovation

Innovation is pursued in construction generally to reduce costs, improve functionality and sustain market share (El-Mashaleh et al., 2006; Seaden et al., 2003; Thomas et al., 2004; Toole et al., 2013). The literature points to three main motivators for innovation: client or demand pull; construction firm or capability push; and improvement in project performance. The results of studies comparing these motivators are summarized in Table 2.1 and presented below.

Table 2.1: Findings of Studies of Motivators for Innovation in Construction Firms

Motivators Studied	**Findings**	**Researchers**
Client or demand pull vs. technology push	Both are relevant	Arditi et al. (1997), Bossink (2004), Tatum (1989)
Client or demand pull vs. technology push	Demand pull is stronger	Gann and Salter (2000), Ling (2003)
Improve project performance	Relevant motivator	Toole (1998)

Arditi et al. (1997) Bossink (2004) and Tatum (1989) show that both demand pull and technology push factors are relevant in the construction industry. However, Gann and Salter (2000) suggest that demand pull is the stronger motivator (Ling, 2003). Toole (1998) suggests that construction firms are motivated to innovate to improve project performance in terms of cost and the project's final structure or system.

Differences between Construction and Manufacturing

Construction can be understood as a mix of activities that incorporate a wide range of production activities with some characteristics of manufacturing, and at the same time a large range of activities that are characteristics of services (Leiringer & Bröchner, 2010). (The boundaries between manufacturing and services have increasingly become blurred, though, because of the proliferation of service activities – such as marketing, customer care and R&D as a purely a knowledge-based service – in manufacturing.) Project management research in construction also recognizes business logistics, which used to be considered services in the past (Wikström et al., 2009). Furthermore, services and construction firms have increasingly learnt from manufacturers to standardize their products.

It has been argued that the construction sector is more similar to the service sector than the manufacturing sector (Leiringer & Bröchner, 2010; Reichstein et al., 2005) . Fernández-Solís (2008) discusses two main views of construction to examine whether construction and manufacturing share the same characteristics, focusing on the systemic nature of construction as an industry and its complexity. Construction uses a variety of resources and skills to cater for differences in building types and subsectors (Hillebrandt, 1999). These differences cause construction to behave not as an industry but closer to a corporation of industries, an "industry of industries, a meta-industry" (Fernández-Solís, 2008, p. 1599). Thus, the behaviours of relatively homogeneous industries such as manufacturing cannot be directly translated to the construction meta-industry.

According to Koen (2003), all types of engineering and science philosophies are classified as heuristics, i.e., method that is based on a particular rationality that originated from advanced methods for an optimum solution for an uncertain environment.

Project-based construction displays such a heuristic nature: uncertainties abound in temporary coalitions that need semi-predictable or unpredictable supplies of materials and technical skills. The worldviews of construction are organized projects rather than the firm or the production process (Groák, 1994), and this differentiates construction from manufacturing.

The two metaphysical assumptions and views of "things, being, entities – products; [and] becoming, atemporal – processes" influence the subject of one's inquiry (Fernández-Solís, 2008, p. 1601). The thing-oriented view leads to "analytical decomposition and assumption of certainty and a historical-philosophical approach whereas the process-oriented view is closer to a holistic orientation, acknowledgement of uncertainty and a historical and contextual approach" (Fernández-Solís, 2008, p. 1601). The metaphysics of process are time and change. The heuristic nature of construction implies its capacity for change and construction activity is, in essence, causing environmental change through the process of construction. Hence construction can be argued as "essentially a process, but with a project (or product) as its essential secondary axis; in contrast, manufacturing is a product but with a process as its essential secondary axis" (Fernández-Solís, 2008, p. 1601).

Construction can also be differentiated from manufacturing by examining the differences in complexity and flexibility represented by the concepts of *tightly-coupled* and the *loosely-coupled* systems (Dubois & Gadde, 2002). As Dubois and Gadde point out, whereas the mass production system of manufacturing is tightly-coupled, building construction is loosely-coupled with a higher degree of complexity. In addition, in construction there is the need to generate variants, there are permutations and interdependence of activities, work redundancies and slack time (Table 2.2).

Table 2.2: Manufacturing and Construction Compared as
Tightly-Coupled vs. Loosely Coupled Systems

Tightly-Coupled System: Manufacturing	**Loosely-Coupled System: Construction**
Delays not allowed or possible	Complex operations (Gidado, 1996) , inefficient operations (Cox & Thompson, 1997) sub-optimization (Gann, 1996)
Sequence of events is invariant	Generations of variations
Alternative paths are tightly controlled or not available	Number of permutations and possible combination are enormous
	Some are tightly-coupled, some are time sensitive, specialized activities with sequentially interdependent activities with standardized elements (Gidado, 1996)
Little / no opportunity for substitution or repair (usually discarded wasted); Redundancies are designed and deliberate	Work is redone when non-conforming rather than product discarded in manufacturing
Slack is not desirable	Self-determination; coordination with different firms, each adding a measure of slack.

Source: Summarised from Dubois and Gadde (2002, p.621)

Construction can therefore be viewed specifically in terms of its complexity. Fernández-Solís (2008, p. 1609) takes a complexity-theoretical view of construction, not seeing construction itself as a special class of system, but using the concept of complexity as a way of examining “the system as a whole, without [simplification, and] observing the interactions in-between elements and systems, [as well as] the elements and systems themselves”. He suggests three categories of characteristics (from 18 characteristics developed by Lucas, 2005) be used to examine the construction system as a whole: its autonomous agents, undefined value and non-linearity. He proposes that construction systems consist of autonomous non-identical agents without any permanent leadership structure or directing nodes, making it self-organizing and nonlinear with high variability and unpredictability. The boundary of a construction system is not defined initially as it evolves to reach the optimum in quality, cost, time, efficiency and effectiveness exacerbated with changing pre-conditions such as physical structure, processes and client orders. Construction systems are non-linear as their output is not proportionate to inputs; the whole is different from the sum of its parts. The complexity and systemic nature of construction, associated with its fundamental project qualities, clearly distinguish construction from the closely-coupled routines of mass manufacturing production.

Similarities between Construction and Services

Leiringer and Bröchner (2010, p. 3) suggested three indicators of similarity between construction and the service sector. Firstly, construction is frequently referred to as a provider of construction services [in the sense that] production takes place at the point of purchase often denoted as construction services provider where production occur during purchase. This is in contrast with manufacturing that manufactures goods, distributes them and then sells them to consumers. Secondly, construction, like the service sector, has an important element of "client–producer co-production"; in construction, the differences between delivery of goods and provision of service is less distinct than in manufacturing. Thirdly, construction firms have become more service-orientated in the last decades with construction firms evolving into labour contracting firms to focus on management and coordination functions. Since the 1990s, big construction contractors have started to provide facilities management services to tenants of constructed buildings. These services aspects of construction led Leiringer and Bröchner (2010) to suggest that construction contractors be considered as service firms that offer vastly limited services for big and long-lasting objects.

2.2.2 Innovation in Construction

Researchers have categorized innovation in different sectors into various typologies. One of the most quoted is Pavitt's (1984) four categories typology. The categories are supplier-dominated, scale intensive, specialist suppliers and science based categories. Miozzo and Soete (2001) later modified Pavitt's categories into three, combining

Pavitt's science-based and specialist categories into one and including part of the specialist supplier category in the scale intensive category. In contrast to Pavitt's and Miozzo and Soete's categories, which are designed to apply to both manufacturing and service sectors, Evangelista and Vezzani (2010) develop a typology solely for the service sector. These typologies, and the relationships between them, are summarized in Figure 2.4.

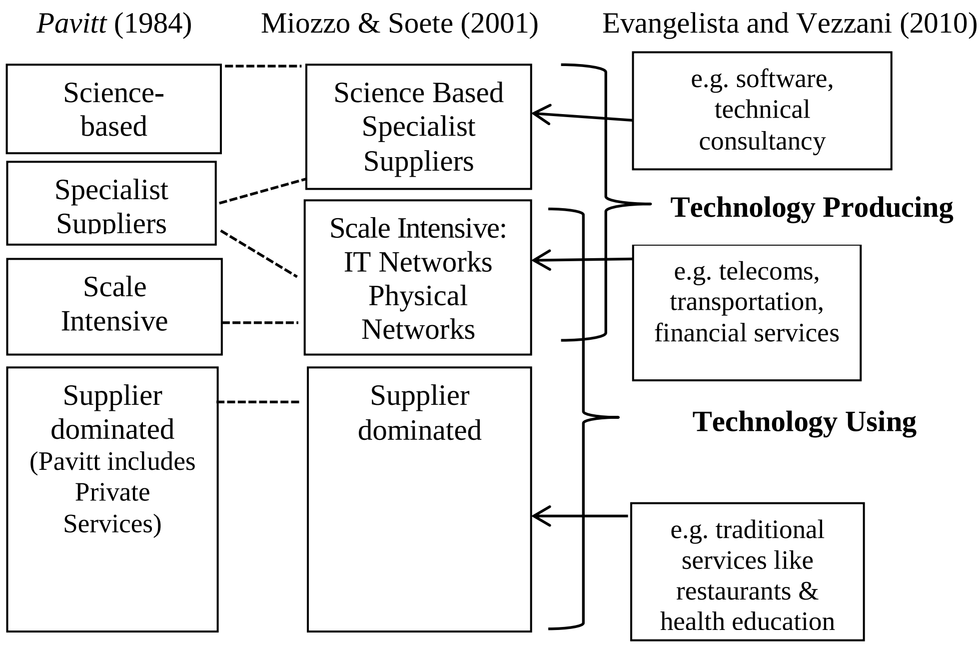

Figure 2.4: Typologies of Innovation (Based on Tether & Howells, 2007)

Based on Pavitt's (1984) typology and its derivatives, and the findings of Slaughter (1993) and Seaden et al. (2003), Bougrain (2006) summarizes the characteristics of innovation by suppliers and contractors in the construction industry (Table 2.3).

Table 2.3: Characteristics of Innovation by Contractors and Suppliers in the Construction Industry

Actor	**Typology**	**Type & Purpose of Innovation**	**Source of Innovation**
Contractors	Supplier-dominated	Processes type, little R&D. Purpose: Counter bottleneck; improve productivity & safety.	Suppliers of equipment & material.
Specialist contractors; Manufacturers of components, equipment	Specialized suppliers	Develop new services complementary to products to help client adopt, implement innovation.	In-house applied research, customers (in this case r contractors) & regulations.
Material suppliers	Science-based firms (most innovative)	Purpose: Cost-reducing, process innovation.	Internal R&D, work with research institute, universities.

Source: Summary of Bougrain (2006)

Several conclusions about innovation in the construction industry may be drawn from Bougrain's summary. In terms of actors, material suppliers are the most innovative actors in the construction industry, followed by specialist contractors and manufacturers of components and equipment. Contractors are the least innovative. In terms of interdependence of actors, innovation involves both the technology user and the developer. Other non-commercial actors such as research institutes, universities and regulatory bodies are also involved. These other actors work especially with the material suppliers. In addition to being developers of innovations, contractors can act as users that provide feedback to specialist contractors and manufacturers of components and equipment. In terms of type and purpose of innovation, contractors' innovations are the process type, designed to solve their work problems and improve productivity and safety whereas, for the specialist contractors and manufacturers of components and equipment, the purpose is to help meet the needs of contractors.

Several differences between the innovation characteristics or *traits* of services and those of manufacturing were observed. They include differences in intellectual property rights (IPR), the motivation for innovation i.e. whether innovation is technology-or demand-driven, the source of innovation, the length of innovation cycle times and product characteristics (Table 2.4).

Table 2.4: Traits of Services Compared to Manufacturing

Trait	**Manufacturing**	**Services**
Intellectual property rights	Strong, patents	Weak, copyright
Technology orientation	Technology push: science and technology led	Technology pull: consumer / client led
Research/innovation generation & supply	In-house	Mainly sourced externally
Innovation cycle times	Short	Long (except for computer services)
Product characteristics	Tangible, easy to store	Intangible, difficult to store

Source: Extracted from Howells (2000)

The characteristics of service innovation as highlighted by Tether and Howells (2007) are as follows:

i. Link between non-technological and technological innovation

In the service sector as compared to the manufacturing sector, there are stronger inter-relationships between business models, organizational forms, technology and outputs in service innovation. Organizational and other forms of non-technological innovation are particularly important in services. The non-technological innovation is linked to technological innovation.

ii. Demand as a barrier to innovation

A high degree of interaction and interdependency exists between service providers and users and between providers and equipment suppliers in the service sector. Demand is expected to be more of an impediment than the supply of technologies in the innovation of service firms.

Howells (2000) notes that the research frameworks and measurements used in many research studies have been designed mainly for the manufacturing sector. The construction sector is categorized neither in the manufacturing nor the service categories but possesses features of the service sector. The differences between the manufacturing and the construction sectors necessitate for construction sector researchers to be conducted using different researches frameworks and measurements from the manufacturing researches.

2.3 Innovation Researches and Theories

This section establishes the foundations of this study by examining the theories of innovation in the following three areas:

i. innovation research in the business and management field, specifically propositions about and studies of the determinants of innovation, consisting of organizational levers, business processes, leadership and the environment; and the dimensions of innovation consisting of innovation as an outcome and as a process;

ii. innovation research in construction management; and

iii. theories of innovation, with an emphasis on the systems of innovation literature, which provides the framework for our research.

2.3.1 Dimensions and Determinants of Innovation in Business and Management Research

Crossan and Apaydin (2010) observe that many studies in the business and management fields do not have an explicit theoretical base and that the theoretical perspectives that were used are competing and largely of a single point of view. In terms of theoretical streams, learning and knowledge theories tend to be common whereas other management theories, such as network theories, economic theories and institutional theory, theories of the strategy of the firm and adaptation theories are less employed.

The assortment of dimensions and erratic theoretical application as well as lack of theorizing across literature resulted in “fragmentation and lack of interrelatedness” in researches (Crossan & Apaydin, 2010, p. 1165).

This section discusses innovation dimensions and determinants of innovation using the framework developed by Crossan and Apaydin (2010) to organize the existing innovation literature. Crossan and Apaydin identify two dimensions of innovation – innovation as an outcome and as a process – and three determinants of innovation supported by respective theories: innovation leadership, supported by upper echelon theory; organization or managerial levers, supported by dynamic capabilities theory; and business processes supported by process theory. In addition to these determinants, this research includes the environment as a determinant because of its importance in the existing construction research and the need to capture the environmental effects specific to the construction industry. The two dimensions and four determinants are summarized in Table 2.5 and used to guide the discussion in this subsection.

The dimensions of innovation are less studied than the determinants of innovation, with the innovation process dimension less researched than innovation as an outcome (Crossan & Apaydin, 2010). Two frequently used distinctions made in dimensions in innovation research are on innovation as an outcome and as a process. Research is more commonly conducted at the firm, group and individual levels than at the higher industry, national or global levels. Studies of the type of innovation examine the forms, magnitude and nature of innovation. These will be outlined in the next section.

Table 2.5: Dimensions and Determinants of Innovation

Dimensions and Determinants	**Theoretical Elements**	**Existing Research**
Dimension– Innovation as outcome	Form: Product/Service, Process, Business Model Magnitude: Incremental/Radical	Contextual variables
Dimension– Innovation as process	Level: Individual/Group/Firm Driver: Resources/Market, Opportunity, Direction: Top-down/Bottom-up Source: Invention/Adoption Locus: Firm/Network	Stages of adoption, Organizational determinants
Determinant– Leadership *Theory* Upper echelon theory	CEO, Top management team, Board	
Determinant– Organizational levers *Theory* Dynamic capabilities	Mission, Goals, Strategy Structure & systems Resource allocation Learning & knowledge management External linkages Culture	Organizational determinants
Determinant– Business processes *Theory* Process theory	Initiation & decision making, Portfolio management, Development implementation, Project management, Communication & collaboration, Commercialization	Individual determinants, Group determinants, Internal capabilities
Determinant– Environment *Theory* To address in this thesis		Industry Environmental determinants Geo-systems: Innovation systems Linkages between innovation system levels Networks: External sources Networks: Relational capital

Source: Summarized from Crossan and Apaydin (2010), with exception of Determinant–Environment, added by author.

2.3.1.1 Dimension: Innovation as an Outcome

The outcome of innovation can be discussed in terms of its form, magnitude, and type or nature. The three forms of innovation are product or service innovation, process innovation, and business model innovation. Product or service innovations are determined by (Crossan & Apaydin, 2010, p.1168) "their newness to the company

(Davila et al., 2012), the customer (Wang & Ahmed, 2004), or the market (Lee & Tsai, 2005)". Process innovation refers to the "introduction of new production methods, new management approaches, and new technology that can be used to improve production and management processes" (Wang & Ahmed, 2004, p. 305) within the firm itself. Process innovation as an outcome is different from innovation as a process. Product innovation is mainly tacit whereas process innovation may not be clearly promoted. Business model innovation refers to "how a company creates, sells, and delivers value to its customers" (Davila et al., 2006, p. 32).

The magnitude of innovation refers to the degree of newness of the innovation to the sector. The most commonly used distinction compares incremental to radical innovation (Gopalakrishnan & Damanpour, 1997). Incremental innovation (Crossan & Apaydin, 2010, p.1168) consists of differences in existing routines and practices whereas radical innovation shows important changes and is distinct from existing practices (Damanpour, 1991; Dewar & Dutton, 1986; Ettlie et al., 1984). Researchers focus more on radical innovation (Jansen et al., 2009) although pursuing both incremental and radical innovation is important for firms (Tushman & O'Reilly, 1996).

Type of innovation can be either technical or administrative (Gopalakrishnan & Damanpour, 1997). The former includes "products, processes and technologies used to produce products or render services", while administrative innovations are "related to managerial characteristics such as organizational structure, administrative processes, and human resources (Crossan & Apaydin, 2010, p.1168).

Innovation as an outcome and innovation as a process are not considered to be equally important (Crossan & Apaydin, 2010, p.1169) whereby "innovation as an outcome is both necessary and sufficient for successful exploitation of an idea, whereas innovation as a process is necessary but not sufficient". Thus, outcome is usually the key dependent variable in empirical studies related to innovation. An overview of conceptual understanding of innovation as an outcome in terms of forms, magnitude and type of innovation is given in Table 2.6.

Table 2.6: Forms, Magnitude and Types of Innovation

Innovation Outcome	Categories	Explanation
Forms	Product or service innovation	New to the company, market, customer
	Process innovation	New production methods, management approaches, technology
	Business model innovation	How a company creates, sells, delivers value
Magnitude	Incremental	Variation in existing routines and practices
	Radical innovation	Completely new in an important way
Type	Technical	Products, processes, technologies used to produce products or render services.
	Administrative	Related to organizational structure, administrative processes, human resources

Source: Summarized from Crossan and Apaydin (2010)

All three forms of innovation, namely product or service innovation, process innovation and business model innovation have been observed in construction research, but the main form of construction innovation is process innovation. The three types of process innovation in construction are "logistical technologies (bringing products to site), site preparation (preparing the land) and assembling technologies (putting components together)" (Anderson & Schaan, 2001, p.12). Product/service innovation can take the form of renewal and extension of product ranges, service ranges, markets (European Commission, 1995) and design component (Winch, 2003). Business model and process innovation in construction is in the form of new organizational and work forms and practices (European Commission, 1995) that translate into improved quality and value (Thomas & Bone, 2000) and cost and time reduction and better safety performance (Table 2.7).

Table 2.7: Forms of Construction Innovation

Innovation Outcome	Categories	Sources
Form	New product	Sexton & Barrett (2003), Thomas & Bone, (2000), Toole, (2001)
	Improved service quality & value	
	Design	Winch (2003)
	Competitive advantage - reputation, work processes & ability to attract new employees	Slaughter (1998)

Source: Author summary of Reichstein, Salter & Gann (2005) and Sexton & Barrett (2003).

Dikmen et al. (2005) assert that the outcome of innovation can produce benefits beyond products and services. For example, innovation can provide competitive advantage through better "firm reputation, easier work processes and improved ability to attract new employees" (Slaughter, 1998, p. 226).

Innovations in construction happen more often than is acknowledged. The industry is viewed as very traditional with incremental innovation taking place over many years so that in many cases it is invisible (Slaughter, 1993). Slaughter (1998) discriminates between five magnitudes of innovation in construction: incremental, modular, architectural, system and radical (Table 2.8), according to the amount of change and the impact of the innovation on its surroundings. The change is small, significant, multi-linked or a breakthrough change. The impact on the surroundings can be limited, have many strong links or change the character of the industry.

Table 2.8: Magnitudes of Innovation in Construction

Magnitude	Amount of Change	Impact on Surrounding Elements
Incremental	Small	Limited
Modular	More significant in basic concept	Limited
Architectural	Small change in respective component	Many and strong links
System	Multiple linked innovation	Multiple
Radical	Breakthrough	Changes character of industry

Source: Summarized from Slaughter (1998)

2.3.1.2 Dimension: Innovation as a Process

Innovation as a process considers how innovation occurs, in terms of sequence of events or actors or dimensions in the sequence and typically answers how the innovation occurs. According to Crossan and Apaydin (2010, p. 1166) there are five issues in studies of innovation as a process. The five issues comprise of: steps or stages in the innovation process; the driver and source (external or internal) of the innovation; the locus or degree of innovation processes (firm only/closed process or network/open process); view aspect, i.e. whether top management (top-down) or staff (bottom-up) initiates the innovation; and level aspect, i.e. whether innovation occurs at an individual, group, or firm level.

Research on innovation as a process is scarce with scholars focusing on innovation as an outcome. Research on innovation as a process in the construction industry has focused on stage models and sources of innovation (Crossan & Apaydin, 2010).

Bernstein et al. (1998) propose a four stages of construction innovation process model, consisting of idea generation, new technology development, knowledge transfer and application for problem solving. Slaughter's (2000) six steps of innovation implementation consist of the identifying, evaluating, committing, making preparations, using, and post-use evaluation steps. Abd El Halim and Haas (2004) five stages of innovation process emphasizes problem identification, analytical investigation, development of solution, establishing validity of full-scale prototype, and commercialization. Berkhout et al. (2006) provide a "fourth generation" innovation process model that emphasizes the importance of innovation networks among project players, including innovators and adopting clients, during implementation and diffusion.

Most innovation in construction originates from material and component producers (Osman, 2008; Pries & Janszen, 1995). The firms in the construction industries are essentially adopters of innovative products rather than product innovators. This is because products from the manufacturing sector become components of subsystems of the final complex product system of construction.

2.3.1.3 Determinant: Leadership

Leadership is an attribute of both individuals and groups: individuals in terms of senior executive’s or other leaders’ roles, attributes and individual characteristics and, at the group level, in terms of the top management team. They are summarized in column 1 of Table 2.9. Leaders are considered organizational determinants of innovation, playing direct and indirect roles. Their direct role is to make innovation happen through the exercise of power, decisions and actions taken (Regnér, 2003). In addition, senior management plays an indirect role by guiding innovation champions at middle management level to execute business process that support innovations (Jansen et al., 2009).

Table 2.9: Determinants of Organizational Innovation: Leadership, Managerial Levers and Business Processes

<table>
<tr><th>LEADERSHIP</th><th colspan="2">MANAGERIAL LEVERS</th></tr>
<tr><td><u>CEO:</u>
Tolerance of ambiguity, self-confidence, openness to experience, unconventionality, originality, rule governed, authoritarianism, independence, proactivity, intrinsic versus extrinsic, determination to succeed, personal initiative, managerial tolerance to change</td><td><u>Mission, goals strategies</u>
Innovation goals match strategic objectives, organicity, explicit innovation strategy</td><td><u>Organizational culture</u>
Organizational climate scales (TCI [participative safety, support for innovation, vision, task orientation, interaction frequency]), Autonomy (quantitative & qualitative measures), morale and motivation (trust & job satisfaction), clearly stated, attainable, valuable shared vision, risk-taking culture (participative safety), cohesiveness, organizational attractiveness (number of applicants, age of scientists & engineers</td></tr>
<tr><td><u>Top Management Team</u>
Education, tenure, age, diversity (background, experience), extra industry ties.</td><td rowspan="2"><u>Structures & systems</u>
Specialization & formalization, centralization, stratification, matrix principles, number of employees, organizational complexity & administrative intensity, fit between organization design & innovation type</td><td rowspan="2"><u>Org, learning & knowledge</u>
Support for experimentation, tolerance of failed ideas, adoption of risk-taking norms, development of employees & acceptance of diversity, extent of usage of formal idea generation tools, external linkages: universities, trade shows & quality of linkages, formal info gathering, customer contact time and frequency.</td></tr>
<tr><td rowspan="2"><u>Board:</u> Diversity –occupational background; from other industries; institutional shareholding; executive stock option</td></tr>
<tr><td colspan="2"><u>Resource Allocation</u>
R&D intensity, slack resources, commitment to differentiated funding, resources annual turnover</td></tr>
<tr><th colspan="3">BUSINESS PROCESSES</th></tr>
<tr><td>Initiation & Decision-Making: Initiation & Concept Generation</td><td>Development & Implementation: Adoption, generation & implementation.</td><td>Portfolio Management: Risk/return balance, optimization tool use</td></tr>
<tr><td>Project Management: Formal PM tools, project efficiency, communications, collaboration</td><td></td><td>Commercialization: Market research, market testing, marketing & sales.</td></tr>
</table>

Source: Crossan and Apaydin (2010)

Individuals, teams and groups have been found to have an important influence on innovation in construction. The findings of prior studies are summarized in Table 2.10 and also discussed below.

Table 2.10: Leadership Determinants of Innovation in Construction

Leader	Role and Attributes	Sources
CEO, Company personnel	Role: Innovation champions & entrepreneur	Barlow (2000), Bossink (2004), Gambatese and Hallowell (2011), Koebel et al. (2004) (cited in Toole et al., 2013), Ling (2003), Mitropoulos and Tatum (2000), Schein (1999), Slaughter (1993, 1998), Tatum (1986, 1991), Winch (1998),
	Attributes: power & technical competence;	Nam and Tatum (1997)
	Strategic clarity & consistency	Laborde and Sanvido (1994), Ling (2003)
	Motivated leaders	Koebel et al. (2004)
Top management team	Role: Support from upper management	Gambatese and Hallowell (2011)
Process view	Long-term, holistic view of innovation process	Toole et al. (2013) from management literature

The leaders in construction innovation play the roles of either the innovation champions and entrepreneurs or the support provider. The involvement of innovation champions and entrepreneurs that consist of technical innovator, business innovator, product champion and the chief executives in innovating construction firms are generally reported as essential factors in construction innovation, whereas, the support providers consist of for example, the upper management. The attributes of construction innovation leaders include power and technical competence to overcome the uncertainty and challenges of innovation, possessing strategic clarity and consistency as well as being motivated.

An additional attribute of innovation leaders, discussed in the general management literature, would appear to be important in construction where the risk involved is a deterrent to investment in innovation: being able "to take a long-term, holistic view of the innovation process" (Toole et al., 2013, p. 35).

2.3.1.4 Determinant: Managerial Levers

Managerial levers refer to firm-level variables supporting innovation (columns 2 and 3 of Table 2.9). Due to constant economic and environmental changes that may lead to "creative destruction" (Schumpeter, 1961) and depleting resources, firms not only need to maximise available resources, but also to advance novel and valuable resources and competencies (Rumelt, 1984). This process requires time, financial resources, and executive resolve (Dierickx & Cool, 1989). Dynamic capabilities are a source of competitive advantage, that need to match the vibrant environment (Eisenhardt & Martin, 2000; Prahalad & Hamel, 1990; Teece et al., 1997).

According to the theory of dynamic capabilities, variations in firms' resources can give rise to differences in innovation (Eisenhardt & Martin, 2000; Prahalad & Hamel, 1990; Teece et al., 1997). The five types of managerial lever are (Crossan & Apaydin, 2010, p. 1171-1172): missions, goals, strategies; structures and systems; resource allocation; organizational learning and knowledge management tools; and culture. Their purposes and components are summarized in Table 2.11.

Table 2.11: Managerial Levers

Variables	**Findings**	**Authors**
Mission, goal, strategy	Formal innovation strategy	Walker et al. (2003)
	Role	Barrett and Miozzo (2000), Koebel et al. (2004) (both cited in Toole et al., 2013), Nam and Tatum (1992), Seaden et al. (2003)
	Recruitment strategy & innovation	Bröchner (2010)
	Customer-focus	Seaden and Manseau (2001)
Structure & system	Types–Enablers & barriers	Damanpour (1991), Tatum (1989)
Resource allocation	Slack resources	Dulaimi et al. (2002), Mitropoulos and Tatum (2000), Sexton and Barrett (2003)
	Leadership	See Tables 2.9 and 2.10
Organizational learning & knowledge management	Absorptive capacity & knowledge codification	Gann (2001)
	Organizational learning & knowledge management	Blayse and Manley (2004), Dewick and Miozzo (2004), Harty (2005), Laborde and Sanvido (1994), Sexton and Barrett (2003)
Culture	Openness to new ideas & on-going dialogue	Blayse and Manley (2004), Dulaimi et al. (2002), Ling et al. (2007), Love et al. (2002), Manley and McFallan (2006)
	Accepting conflicts; Communication	Barlow (2000)
	Employees' ability to balance efficiency & openness to change	Gambatese and Hallowell (2011), Martins and Terblanche (2003), Sexton and Barrett (2003)
	Linkages within & between organizations	Bossink (2004), Gann (2000), Ling, (2003), Ling et al. (2007)
	Ideas sourced externally to firm; Innovation networks	Blayse and Manley (2004), Bossink (2004), Drejer and Vinding (2006), Dulaimi et al. (2002)
	Culture of collaboration; understanding of each other's goals.	Barlow (2000)
	Recognize innovation is not limited to R&D, can encompass all activities	Toole et al. (2013)

The literature on managerial levers or organizational resources in construction innovation focuses mainly on the strategies, structure, resource allocation, learning and knowledge management and culture of construction firms.

Innovation strategies include the importance of having an innovation strategy; the role of the strategy, its link to processes and the firm's structure, and the link between execution of innovation and the strategy and innovation practices and business outcomes in the business environment; types of strategies in terms of successful strategies; type of employee recruitment: non-technological innovation is more closely associated than technological innovation with higher levels of education; customer-focused strategy and having close ties with customers.

Organizational culture represents common values and beliefs, which are manifested in the behaviour and actions of organizational members (Hartmann, 2006). According to Hartmann, organizational culture can have a number of positive influences on innovation, each of which can be included in research. An enabling organizational culture consists of five characteristics. Firstly, a culture that supports and provides freedom, without penalizing employees who propose innovative ideas, encouraging and supporting open ways of working and new ideas, accepting and handling conflicts. Secondly, a culture that enables the enactment of the enablers of innovation, including communication. Thirdly, a culture that frees employees to direct their cognitive capabilities to long-term performance, namely their ability to balance short-term efficiency with being open to the changes needed for long term improvement. Fourthly, a culture that is seen in financial commitment which enables increased risk tolerance. Fifthly, a culture that contributes to collaboration that comprises shared understanding among actors of each other's goals, linkages within between organizations to enable collaboration and trust, openness to external ideas including ideas from researchers and consultants sharing non-sensitive information.

The management literature also suggests the inclusion of an additional cultural perspective: employees should be able to recognize that innovation is not limited to

R&D units but can encompass or be seen in all aspects of the organization's activities (Chesbrough, 2006).

2.3.1.5 Determinant: Business Processes

The business processes studied as determinants of innovation are summarized in the lower panel of Table 2.9. Innovation can be started in an organization either by creation or by adoption (Gopalakrishnan & Damanpour, 1997). Creation involves problem solving and decision-making associated with the development of novel products and processes (Saren, 1984; Wolfe, 1994) whereas organizational change is externally induced in innovation adoption (Rogers, 1995; Wolfe, 1994).

Portfolio management refers to the decisions on strategies, technology and resources that determine project selection (Cooper et al., 1999). This is vital due to the speed at which resources are utilized in the innovation process (Cebon et al., 1999) as in the case of effective management of R&D (Bard et al., 1988).

Research concentrates on approaches and tools for portfolio management. Development implementation of innovation follows creation or adoption (Wolfe, 1994) and typically involves pilots or trials before implementation (Zaltman et al., 1973). Project management research focuses on transforming inputs into a marketable innovation and examines factors for effective innovation project management such as project efficiency, tools and communication and collaboration with internal and external parties. Commercialization of the innovation ensures that it is commercially accepted. Commercialization includes activities beginning with market research, budgeting, innovation launch and post-launch reviews. This process has been slow to develop (Adams, Bessant, & Phelps, 2006).

2.3.1.6 Determinant: Environment

Although not a specific dimension of general management and business research on innovation, the environment is an important influence on innovation in construction. Three aspects of the effect of the environment attract much attention: industry characteristics, networks and external institutional support.

The literature of industry characteristics examines the effects of the nature of the construction industry on innovation, in particular, the nature of production, the project-specific characteristics and the procurement system. The nature of production in construction hinders innovation in terms of knowledge development, transfers, storage (Dubois & Gadde, 2002); the long life of built products which minimizes opportunities for innovation (Miozzo & Dewick, 2004; Pries & Janszen, 1995); industry fragmentation in terms of diversity of firm size and the large number of small players, which results in limited resources for innovation (Barlow, 2000; McFallan, 2002; Pries & Janszen, 1995); and the hierarchical approach to management in the industry (Koskela & Vrijhoef, 2001; Winch, 2000). Relatively little is known about the effect of the project structure and need for inter-organizational management on innovation in construction (Blayse & Manley, 2004). The seminal work of Davies and Hobday (2005) provides a broad view on project management recognising the importance of front-end work, environment factors as well as the more traditional ‘execution-focused’ endogenous ones. Recent works (Winter et al., 2006)focus on several areas including, interplay between projects and business strategies (Davies & Hobday, 2005), the importance of prior experience and ‘contingent’ capabilities, effects of experience and ‘contingent’ capabilities project performance (Engwall, 2003; Flowers, 2004), projects as information-processing systems to address uncertainties (Flowers, 2004; Winch, 2010) and project management as instruments of control (Hodgson & Cicmil, 2006).

Project-specific characteristics hinder innovation in several ways (Blayse & Manley, 2004; Reichstein et al., 2005). Reichstein et al. (2005) highlight six factors, related to its project structure, that hinder innovation in the construction industry. The six factors are as follows:

i. the temporary nature of projects, which makes organizational learning and "economies of repeatability" to other projects difficult;
ii. the immobility of constructed products;
iii. uncertain demand due to fixed capital investment decisions that limit the influence that construction firms have over their own future markets;
iv. industry fragmentation with small firms with little or no professional staff and little innovative capability;
v. separation of design, production and maintenance, which causes difficulty in development of commonality of practices and procedures and in obtaining feedback;
vi. the complexities of the supply chain, which impair the pace of innovation as well as the amount of possible innovation. This is because construction comprises a variety of activities – manufacturing, distribution and installation – undertaken by a variety of enterprises accountable for on-site production, assembly and installation; suppliers of professional and expert services, including architects, engineering consultants, cost consultants; and the users of construction products and services.

Construction industry procurement systems, such as traditional lump-sum contracts, hamper innovation (Kumaraswamy & Dulaimi, 2001; Walker & Hampson, 2003) and innovative procurement systems such as partnering or alliancing are suggested as improvements (Barlow, 2000; Kumaraswamy & Dulaimi, 2001; Manley, 2003; Winch, 1998). A large part of the literature discusses the role of networks of industry players and their relationships in construction innovation; the role of clients and manufacturers; and the role of innovation brokers.

The relationships between industry players in construction are found to have significant effects on construction innovation. Collaboration between contractors and parties within the construction sector (Blayse & Manley, 2004; Dulaimi et al., 2002; Dulaimi et al., 2005) and information flows to and from external research institutions are important for technical, strategic and policy reasons in innovation (Anderson & Manseau, 1999; Anderson & Schaan, 2001; Barrett et al., 2007; Cleff et al., 2001; Dewick & Miozzo, 2004; Manley, 2003; Manley & McFallan, 2006; Reichstein et al., 2005). Dewick and Miozzo (2004) examined the consequences of strong cooperation with organizations ranging from suppliers to universities and government. Couplings and temporary coalitions are found to be particularly supportive of innovation (Dubois & Gadde, 2002).

One of the most evident themes in the construction innovation research is the major role played by clients (Barlow, 2000; Gann & Salter, 2000; Kumaraswamy & Dulaimi, 2001; Nam & Tatum, 1997; Seaden & Manseau, 2001). The roles identified include: to identify specific novel requirements (Seaden et al., 2003); acting as innovation enablers and providing support (Gambatese & Hallowell, 2011); and encouraging innovation in construction as well as other industries (Winch, 1998). Bröchner's (2010) research suggests that strong collaboration with clients results in low-level innovation, and that collaboration with other providers of services in the construction supply chain tends to be an important characteristic of more innovative construction firms.

The results of research to date on the effect of the environment on innovation in construction are summarized in Table 2.12.

Table 2.12: Effect of the Environment on Innovation in Construction

Variables	Findings	Authors
Industry characteristics	Procurement systems that discourages & encourages innovation, traditional lump-sum contract that discourages	Kumaraswamy and Dulaimi (2001); Walker and Hampson (2003).
	partnering approach, Project alliancing	Winch (1998); Bresnen and Marshall (2000); Manley (2000); Barlow, (2000); Kumaraswamy and Dulaimi (2001).
	nature of construction industry – on learning;	Dubois and Gadde (2002)
	nature of the product	Miozzo and Dewick (2004); Pries and Janszen (1995)
	large number of actors	Barlow (2000); Pries and Janszen, (1995)
	Traditional approaches in management of construction	Koskela and Vrijhoef (2001); Winch (2000)
	dividing work into discrete packages	Barlow (2000)
	Fragmentation	McFallan (2002)
	project-specific factors & inter-organizational management strategy	Tatum (1986a, 1986b, 1991); Slaughter (1993, 1998); Winch and Courtney (2007).
	collaboration between project parties	Dulaimi et al. (2002); Blayse and Manley (2004) and Dulaimi et al. (2005).
	project related factors	Gambatese and Hallowell (2011).
	temporary nature, immobility of the product, , uncertain demand, industry fragmentation, separation of design, production & maintenance, nature of the supply chain	Reichstein et al. (2005).
External sources –Institutional support	government regulatory policies, capabilities of regulators, enforcement methods	Gann et al., (1998); Gann and Salter (2000); Dubois and Gadde (2002).
Networks	Industry relationships	Anderson and Manseau (1999); Miozzo and Dewick, (2002); Dubois and Gadde (2002)
	Innovation brokers'	Gann (2001); Winch (1998); Manseau (2003); Winch (1998); Davidson (2001).
	Clients role, attributes in innovation	Seaden and Manseau (2001); Barlow (2000); Gann and Salter, (2000); Nam and Tatum (1997); Kumaraswamy and Dulaimi (2001); Winch (1998).
	clients useful in low-level innovation	Bröchner (2010).
	Manufacturing firms as key sources	Anderson and Manseau (1999)
	material & component producers	Pries (1995), Osman (2008)
	specific project related factors	Gambatese and Hallowell (2011)
	Collaboration for information flows	Anderson and Manseau (1999), Anderson and Schaan (2001), Cleff and Rudolph-Cleff (2001), Miozzo and Dewick (2004); Manley (2005), Reichstein et al., (2005); Manley and McFallan (2006), Barrett et al. (2008)

Innovation brokers, such as professional institutions, universities and other tertiary institutions, construction research bodies, and individual academics and researchers play important roles in construction innovation. Among the roles are to facilitate cooperation and knowledge growth, as producers and/or repositories of knowledge (Gann, 2001; Winch, 1998), to disseminate knowledge (Manseau, 2003) and to evaluate the suitability of competing technologies to construction (Winch, 1998). Evaluation of the suitability of competing technologies is necessary given the limited amount of research and development in construction industry, its fragmented and project-based nature, the customary use of prescriptive contract documents and price based competition (Davidson, 2001).

Industry rules administered by numerous regulatory policies (Gann & Salter, 2000), government regulations and industry standards (Dubois & Gadde, 2002) are found to impede innovation, and calls are made for a clear and uncomplicated regulatory process to encourage best practices and foster innovation (Blayse & Manley, 2004; Gann & Salter, 1998).

2.3.2 Innovation Theories in Management

This section discusses management theories applied in innovation researches in the business and management and construction management field. A total of eight theories are discussed: the three theories used by Crossan and Apaydin (2010) to organize the determinants of innovation research –the dynamic capabilities (Resource-Based View) the upper echelon, and process theories – and five additional theories which are useful for discussion of the innovation systems framework, namely the neoinstitutional, strategy formation (Mintzberg), positioning school (Porter) and knowledge-based theories.

Two early theories of organizational structure are those of Weber (1947), who describes the characteristics of bureaucracies and Miller et al. (1984), who were concerned with the relationship between structure and performance. Subsequent modern theories that either draw on or oppose these early approaches examine the development of organizational structure and its role in organizational practices and performance (e.g. stages of organizational growth, organizational ecology theory, social network theory, neoinstitutional theory); theories of ownership and the role of management (e.g. shareholder theory and agency theory, stakeholder theory); and theories of strategic management (e.g. Mintzberg's general theory, the positioning school, dynamic capabilities and the resource-based view (RBV) and the knowledge-based theory of the firm). Several of these theories provide insights into the environmental determinant of innovation, as illustrated in Figure 2.5.

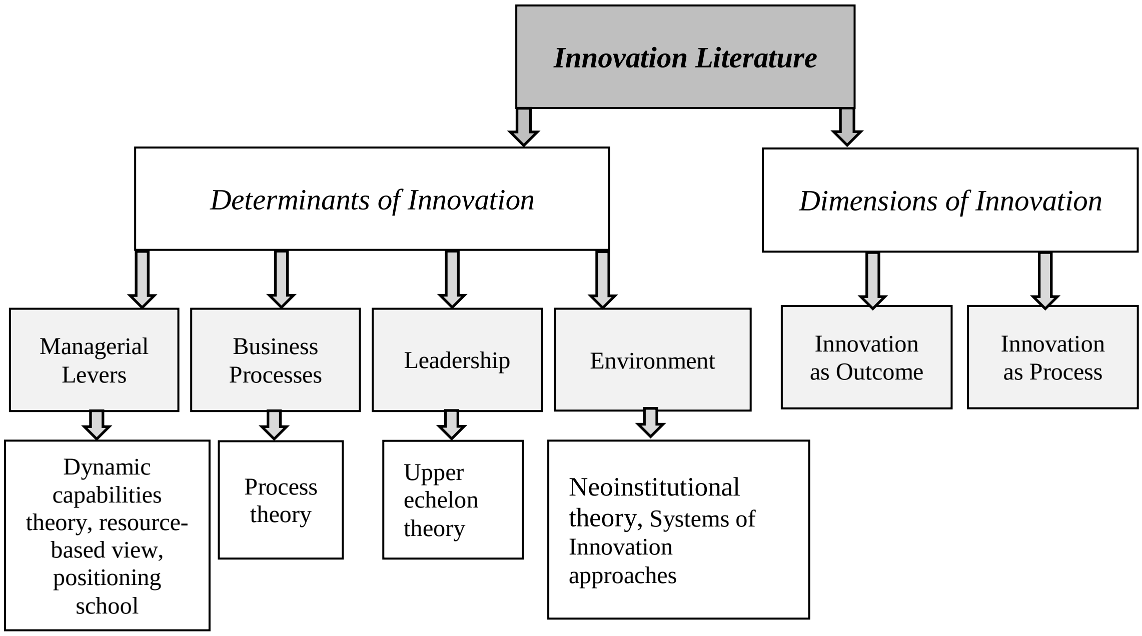

Figure 2.5: Innovation Literature and Innovation Theories

2.3.2.1 Neoinstitutional Theory

In neoinstitutional theory, rational action in organizations is constrained by a number of factors, including existing organizational characteristics (Scott, 2013; Simon, 1955). This view is in contrast to the view of early institutional theorists that managers and other organizational actors act rationally. Thus, institutions are defined more broadly than formal governmental and legal structures and systems.

Neoinstitutional theory, influenced by the sociology, psychology and economics, was proposed by DiMaggio and Powell (1983) as an explanation for organizational structure and behaviour. Behaviour is influenced by the set of organizations that defines the field of operation of an organization, including competitors, customers, suppliers, regulators, and others in the form of regulative systems, normative systems, and cultural-cognitive systems. The effects of institutions are examined in terms of compliance, the basis of order, isomorphic mechanisms, logic, indicators, affect, the basis of legitimacy and symbols, artefacts and other carriers of meaning (Scott, 2013).

2.3.2.2 Mintzberg's General Theory of Strategy Formation

Henry Mintzberg who is the forefather of theories of strategy, views strategy as a pattern of organizational actions, whether planned or emergent, to reach a specified and measurable position, or to achieve a broader vision (Mintzberg, 2007). Mintzberg's general theory of strategy formation includes: the relationships between organizational configuration and strategy process, visioning in entrepreneurial organizations, planning in bureaucracies, learning in adhocracies and venturing in professional organizations, the relationship between strategy process and common stages in organizational growth over time. The common stages in organizational growth comprise visioning "as organizations are created" (p. 340), planning as organizations are developed, learning as organizations mature, and venturing as they are turned around, how these elements relate to strategic management as a human endeavour and the relationships between organizational configuration, organizational growth and strategy. Other strategy theorists are positioning school and resource-based school presented in the next two sections.

2.3.2.3 The Positioning School

The positioning school views strategy as a planned process and the role of management is to set strategic direction for competitive advantage, i.e., best organizational performance requires strategy to be planned rather than emergent. The approach is often considered synonymous with Michael Porter, although its followers do not adopt all his views. Porter (2008) who emphasizes organizational uniqueness, rather than striving to be the best in order to achieve superior performance and competitive advantage (Magretta, 2012). Porter (2008) identifies five structural forces in the industries and sectors in which organizations compete: rivalry amongst competitors, threat of new entrants, threat of substitute products or services, bargaining power of suppliers and buyers and the bargaining power of customers. The approach focuses on clusters of economic activities and competition between actors in industries and not on non-market interactions nor on entities outside the industry, although other researches have added additional forces such as government to the model.

2.3.2.4 The Resource-Based View (RBV)

The theoretical notions of the RBV originated with Penrose (1995), although Barney (1991) and Prahalad and Hamel (1990) developed it extensively in the field of management. Its main notion is that firms can only compete and grow in the long-term by sustaining competitive advantage through on-going development of competence, resources and capabilities; the role of management is to identify and develop these dynamic capabilities. According to this view, competencies, rather than generic strategies, differentiate organizations. Learning theory is linked closely to the RBV, where core competencies are equated with collective learning in the organization

(Prahalad & Hamel, 1990). One stream of the RBV is found in the works of Teece (Teece, 2009; Teece et al., 1997) and Eisenhardt and Martin (2000) on the identification and development of capabilities for long-term growth and performance.

2.3.2.5 Knowledge-Based Theories

Knowledge-based theories of the firm, rooted in Drucker (1969), emphasize knowledge or human capital as the primary source of differentiation and the central factor of production. Two popular approaches are: Nickerson and Zenger's (2004) adaptation of the RBV, based on alignment of boundaries and governance; and Nonaka et al.'s (2008), approach where knowledge is viewed as more than a resource and thus to be managed differently.

2.3.2.6 Upper Echelon Theory

Upper echelon theory (Hambrick & Mason, 1984) explains the association between agents' characteristics and behaviours with organizational outcomes. It suggests that leaders' behaviours are dependent on their values, experiences, and personalities (Hambrick & Mason, 1984). Effective leaders have considerable technical and professional capability and creative abilities, the capability to deal with complicated information and the drive to use these abilities (Mumford et al., 2002). Motivation is dependent on leaders' insights into environmental pressures and opportunities (Sternberg et al., 2003). The make-up and quality of the top management team provides a better account of organizational results than the leader's characteristics alone. The characteristics of leading individuals and top management teams were listed together under Leadership Determinant in Table 2.10.

2.3.2.7 Process Theory

The process approach is rooted in several areas of the social sciences (Crossan & Apaydin, 2010): Marx and Braveman's labour process theory (Knights & Willmott, 1990), process theories of human behaviour and motivation (Adams, 1963; Kahler, 1975; Locke, 1968) and the information processing theory of cognition (Miller, 1956). According to the process theory, similar inputs changed by similar processes produce similar results, with specific recurring or required conditions dictating the nature of the result. Thus, process theorists ascertain the means that direct events to occur under particular conditions or contingencies (Tsoukas, 1989). Patterns of actions are main theoretical constructs (Van de Ven & Poole, 1995). Main processes in innovation include "initiation, portfolio management, development and implementation, project management, and commercialization" (Crossan & Apaydin, 2010, p. 1173).

Summary of Innovation Theories

The management theories reviewed to this point are used in the business and management innovation and construction innovation research to examine determinants and dimensions of organizational innovation. A schematic view of their relationship to one another is provided in Figure 2.6.

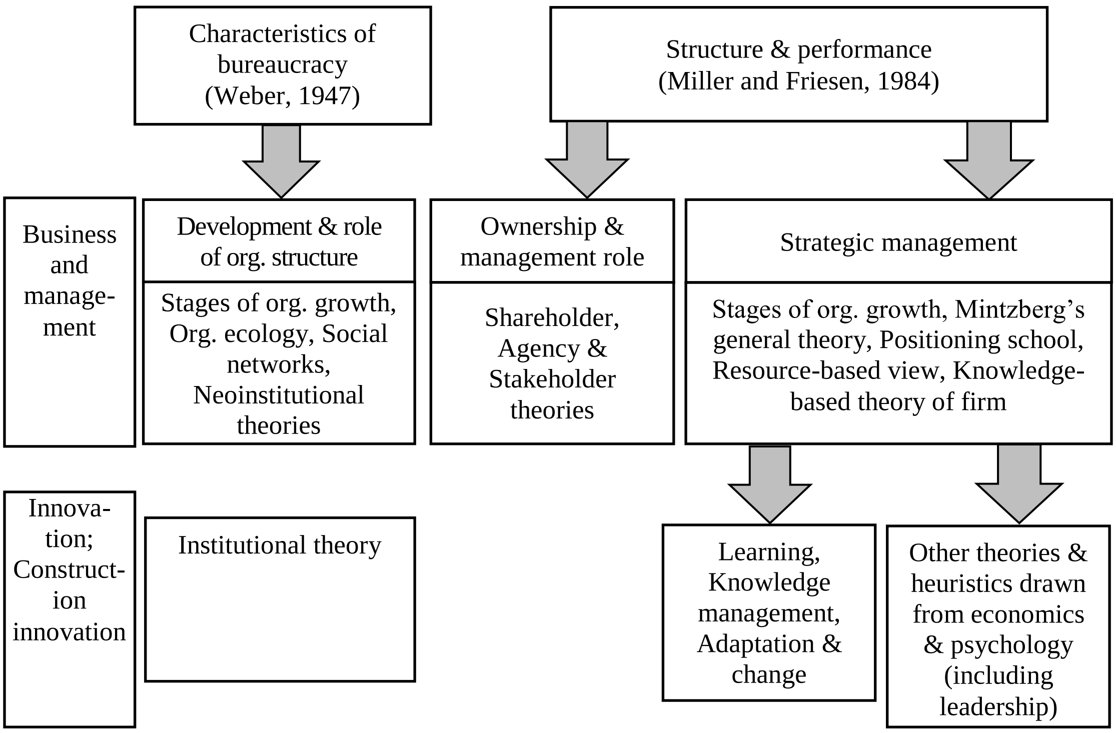

Figure 2.6: Management Theories of Innovation

As Figure 2.6 shows, each of the management theories applied to innovation takes a singular point of view, emphasizing an aspect of organizational environment, growth, structure, ownership, strategy, management or practice, but not examining innovation in a systemic way. A separate stream of theory and research has evolved to consider innovation systemically.

2.3.3 Systems of Innovation Approaches

2.3.3.1 Evolutionary Theory

The national innovation systems perspective originated in the field of economics with two prominent branches of economic theories as its fundamentals (Hauknes & Knell, 2009) namely, the evolutionary theory and institutional theory. The evolutionary view represents a Schumpeterian perspective on economic growth and technological progress. The seminal work of Nelson and Winter (2009, p. 4) provided the groundwork of the evolutionary models.

Evolutionary hypothesizing on economic growth and technological change is the outcome of two criticisms of the traditional neoclassical approach to economic growth (Lundvall, 1998; Mulder et al., 2001). Firstly, the neoclassical approach treats economic growth as "a smooth process involving a continuous tendency to return to an equilibrium state" (Mulder, 2005 p. 25). Secondly, it assumes that technological progress is exogenous, thus neglecting its importance in underpinning irregular economic growth (Mulder et al., 2001). The evolutionary theorists therefore suggested empirical observations on the process of technological progress.

The four main empirical findings of the evolutionary perspective on the sources, procedures, directions, and efforts of technological development are summarized by Woojin and Eunjung (2009, p. 4). First, innovative endeavours are typified by different extent in appropriability and ambiguity about technical and commercial results. Second, technology represents tacit knowledge that is confined and collective (Kogut & Zander, 1992; Nonaka, 1994). Third, innovations are the outcomes of the seeking and learning processes of individuals or organizations, with knowledge building and problem solving activities rooted in organizational or behavioural routines. Fourth, technologies develop along reasonably systematic paths, within the borders of the organizations and technological paradigms, as effects of the first three characteristics.

2.3.3.2 Institutional Theory

Schumpeter (1961) explains capitalism as an evolutionary process of continuous innovation and creative destruction, although growth is propelled by entrepreneurial activity with institutions facilitating economic change. Both new institutional and evolutionary economists agree on the importance of institutions and institutional change for growth. The difference is that, for the new institutional economists, the market is the dominant institution (Coase, 1937; Williamson, 2000) whereas, for evolutionary theorists, the market is determined by the type of activity involved, the location and the timing.

The array of definitions of institutions can be summarized under two main headings: what institutions entail and what they influence. Firstly, institutions entail:

i. “rules of the game”, and “the players”, namely the organizations and their entrepreneurs, “the players” (North, 1997);
ii. how these rules are enforced and how the norms limit the behaviour of the players that institutions (Nelson 2008b), structures and forces that mould and hold in place prevalent behavioural patterns or social technologies (physical technology: activity; social technology: way the rules are structured, coordinated and delivered) (Nelson, 2008b; Nelson & Sampat, 2001);
iii. established social practices, or “habits of thought”, or a form of organization (Veblen, 1915);

iv. government regulations, property rights and trust relationships supported and sustained by specific socio-cultural and economic groups and intermediary organizations. Government plays mediating role between social groups (Rasiah, 2011).

Secondly, institutional outcomes are seen in the form of social production through various institutions of the market, such as states, regulations and social norms (Buchanan, 1986), technology with importance above socio-cultural institutional development (Ayres, 1952), production allocation and economic development (Rasiah, 2011).

The importance of intermediary organizations in attracting the resources to produce knowledge (a public good) is emphasized by Nelson (2008a, 2008b). Intermediary organizations play an important role in translating rules or institutions for public goods and collective action problems for the use of micro-level agents (Katz, 2000). In the generation and diffusion of innovative technologies, institutions such as government regulation, trust relationships supported by particular socio-cultural and economic groups and in-house command in intermediary organizations (e.g. R&D laboratories), are important. Intermediary organizations such as chambers of commerce, training institutions and R&D laboratories play an important role in resolving collective action problems given the problems of information asymmetries between government and firms (Rasiah, 2011). Rapid growth and structural change require strong support from institutions and intermediary organizations, while a lack of intermediary organizations is characterized by institutional failure (Rasiah, 2011). Intermediary organizations are also called *meso-organizations* where their roles are located at the meso-level between the macro and micro-levels (refer Rasiah, 2011). Hence, intermediary organizations can be defined as organizations that translate rules or institutions for public goods and collective action problems (macro-level) for the use of organizations and individuals, or agents, at the micro-level in an economic system.

The elements of institutional theory that are useful for study of innovation (Figure 2.7) can be broadly summarized as:

i. types, forms and mechanics of institutions;
ii. extent of institutional outcomes such as social production, production allocation, economic development and technology, and socio-cultural institutional development;
iii. two types of supporting institutions: socio-cultural and economic groups, and intermediary organizations; and
iv. government as mediator to the first type of supporting institution's role and as recipient of support from intermediary organizations.

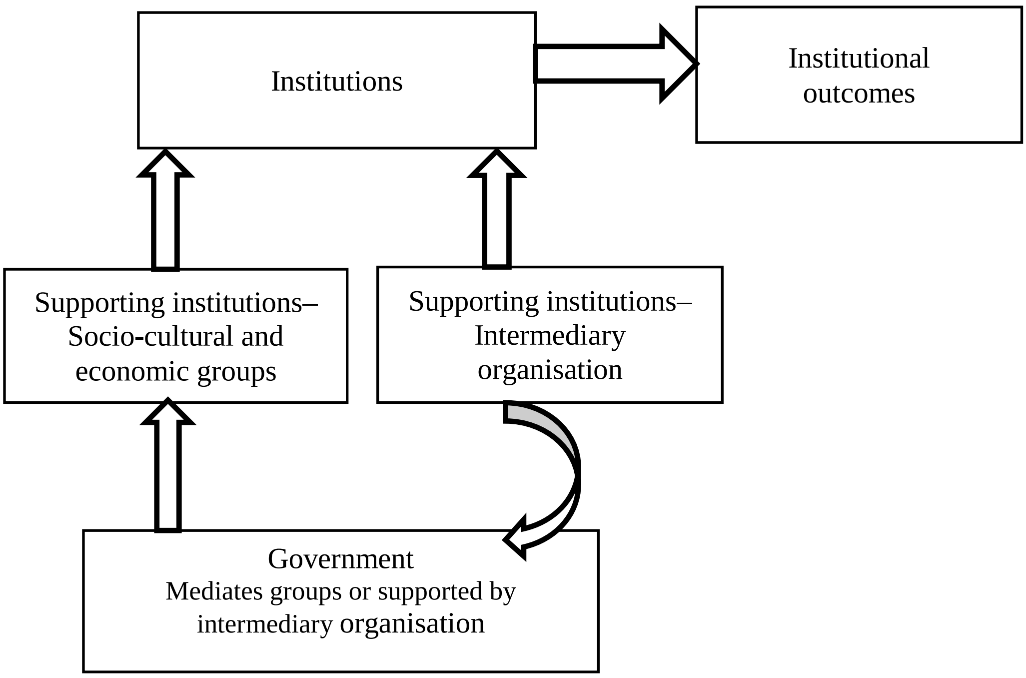

Figure 2.7: Elements of Institutional Theory used to Examine Innovation (Author's Interpretation)

National Systems of Innovation (NSI)

Freeman (Dosi et al., 1988; Freeman, 1995) first distinguished national systems as systems of innovation, a term later used more broadly by Lundvall (2007) and Nelson (1992). The national systems of innovation (NSI), a policy-oriented approach with countries as its unit of analysis, examines why the pattern of innovation (and specialization) differs between countries. The input/output system view is expanded to include not only industries and firms, but also other actors and organizations (primarily in science and technology), government science and technology policies and support for innovation, the extent and organization of R&D within firms, training and education systems and financial institutions (Carlsson et al., 2002; Coombs et al., 2003).

The NSI approach locates institutions and institutional change in the innovation process, as their influence explains how economic transactions and change occur (Nelson, 2008a, 2008b; Nelson & Winter, 2009). It explains variations in innovation capacity and innovation patterns between nations through national institutions and differences in institutional settings which cause performance variations. The strength of the approach is that it depicts national variations in types of specialization and innovativeness which characterize specific national economies at specific times. However, there is little research into the ways the components of systems interrelate or are interdependent. Further, its broad focus that cuts across services and products limits research at the level of specific fields of innovation (Coombs et al., 2003).

Geographical Innovation Systems (Networks and Clusters)

Another system definition is geographical, with focus on (spatial) networks and clusters of production and innovation as represented in Saxenian's (1989) study of the electronics industry in Silicon Valley in California and along Route 128 in Massachusetts. The geographical approach is concerned with variation in culture and competition which cause regional differences in terms of hierarchy and intensity, experimentation, collaboration, and shared learning to bring about variation in the ability to adjust to modifications in technology and markets (Carlsson et al., 2002). In contrast to other systems of innovation literature, this approach concentrates greater on the nature and degree of interfaces between different actors, the role of demand within a cluster, the role of power and power irregularities in interfaces (Storper & Harrison, 1991) and production and innovation (Coombs et al., 2003). As the approach is geographical and primarily spatial, it lacks meticulous comprehension of innovation processes and continuing dynamics.

Regional Innovation Systems

Regional innovation systems (RIS) possess autonomy over the national context (Asheim & Gertler, 2005). Examples of institutions in RIS are professional competencies, shared cultural orientations, trust and collaborative practices, market structures and autonomous regulative institutions (Cooke et al., 1997 cited by Rohracher et al.,2010, p. 5).

Technological Innovation Systems

Two distinct technological systems strands exist (Carlsson & Jacobsson, 1997; Carlsson & Stankiewicz, 1991). One is an extension of the work of sociologists and historians of technology and is not treated by researchers in the systems of innovation field as part of their stream of research. The other, attributed to Carlsson and his colleagues, draws on studies of networks of innovators, especially those of Anderson et al. (1994). Carlsson and Stankiewicz (1991, p.111) define a technological system as “a network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion and utilization of technology”.

In technological systems, innovation processes relate to specific technologies, rather than locations, industries, groups or sectors. Research examines both the role of institutions and the actors and the actor network. Institutional infrastructure refers to the political system, educational system, patent legislation, market organization, capital supply, collective bargaining, industrial and corporate organization, etc. (Rohracher et al., 2010)

International Innovation Systems

The perspectives of economic geography, industrial economics theory have been further expanded to International Innovation Systems (IIS) through the linkages of regional, national and international innovation system in innovation policy (Fromhold-Eisebith, 2007). ISS examines the effects and interactions of international Science and Technology (S&T) on countries and regions with focussed S&T resources (Desai, 2013).

Sectoral Systems of Innovation

The SSI approach was developed, in part, to address limitations in the NSI approach – on the importance of technological basics fundamentals are at least as important as differences in national institutions (Malerba, 2000). Although the SSI is an adaptation of the NSI concept, it originated from earlier notions of families of technologies (Scherer, 1967) and broad configurations of technological activities, including technological regimes and paradigms (Dosi, 1982; Malerba & Nelson, 2008; Pavitt, 1984).This explanation of systems of innovation, containing interacting firms and organizations such as universities and research institutes, is essentially complemented by an evolutionary and competence- or resource-based view of the firm (Knudsen et al., 1996; Penrose, 1995).

The four building blocks of the SSI are a) actors and networks, b) knowledge base and learning processes, c) institutions, and d) demand. These building blocks overlap, as the SSI approach is based on a systemic conception. The building block, *Knowledge Base and Learning*, is built by the *Actors* element of the *Actors and Networks* building block. The *Networks* element connects not only the diverse *Actors* within the *Actors and Networks* building block, but also the *Actors* element to the building block, *Institutions*. Network evaluation suggests that market activities (*Demand*) are not solely economic but also embedded in social norms and *Institutions* which mediate their effects (MacIver, 1957). *Actors* and their behaviours can also be fostered or impeded by *Institutions*. Thus, the SSI is inherently dynamic with reciprocal influence amongst building blocks and on-going creation, diffusion and application of knowledge, which takes place through interactions between the various actors in the innovation system, influenced by surrounding institutions (Malerba & Nelson, 2011). The interactions between the building blocks or components in innovation in industrial sectors derived from Malerba's (2002, 2004, 2006) SSI framework are illustrated in Figure 2.8.

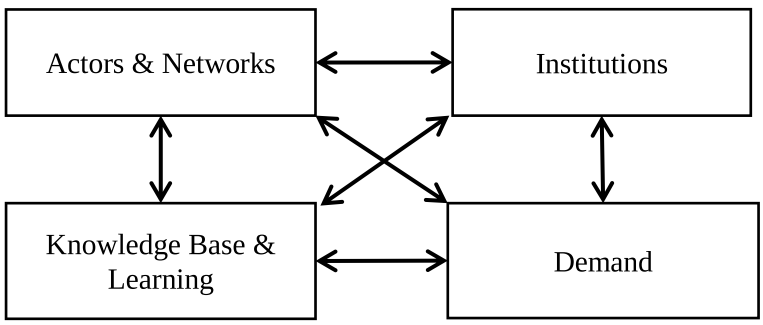

Figure 2.8: Components of the SSI (Author's Interpretation of Malerba, 2002, 2004, 2006)

The following four building blocks of the SSI are defined and explained by Malerba (2002, 2004, 2006). *Actors and Networks* consists of two interlinked elements, namely the *Actors* and *Networks* elements. Actors are a heterogeneous set of agents that includes firms and other actors, comprising: upstream suppliers and systems; users and customers (national and international); universities and public laboratories that have a role in research, human capital formation and innovation; financial organizations, banks and venture capitalists; trade unions; technical associations; and government. The *Actors and Networks* component considers the attributes of these actors in terms of their capabilities and the process of building these capabilities; accumulation and learning processes; competencies, beliefs, expectations and goals; and organizational structure and behaviour and the importance, role and effects of firms and other actors on structure and behaviour.

Networks and flows are critical to generation of innovative ideas (Asheim & Gertler, 2005). Networks encourage knowledge sharing, and the fluency of communication depends on the firms' knowledge bases, structure, and internal mechanisms (Molina, 2011). Examination of the *Networks* component considers the processes of interaction among actors, including communication, exchange, cooperation, competition, and command.

The *Knowledge Base and Learning* processes component is concerned with the technological regime in terms of components and coverage; accessibility and sources of knowledge; protection of innovation; and the firm's capabilities and institutional and cultural context.

Demand examines the heterogeneity of clients, network effects on clients, market segmentation, the type of customer and demand and the role of demand in user-producer relationships.

Institutions, in the SSI framework, concerns the types and objectives of institutions, their effects on actors' interactions and cognition, and the effects of institutions on innovation. Relevant institutions "include norms, rules, laws, standards, informal constraints, conventions, routines, common habits, and established practices":

Agents' cognition, actions, and interactions are formed by the building block institution. Institutions may be formal or informal, may include norms, rules, laws, standards, informal constraints, conventions, routines, common habits, and established practices, etc. They may vary from those that tie or apply enforcements on agents, to ones that are formed by the interaction among agents (such as contracts) (Malerba, 2005, pp. 66-67).

At times, institutions develop or are designed with the objective to stop opportunistic behaviours among competitors (patent protection) or to change the terms of agreements. Institutions also address problems of bureaucracy that may result in loss of income and lack of flexibility (North, 1997). Some institutions are national and shared by all sectors (such as the patent system), while some are peculiar to a sector (e.g., sectoral labour markets or sector-specific financial institutions) (Malerba, 2002, 2004, 2006).

The SSI deliberates on the interactions between organizations and supporting institutions in a sector to understand the sources and patterns of *technological* progress within the sector; this permits comparison across sectors of opportunity and appropriability conditions for innovation. Thus, the SSI is more specific than the NSI in terms of the organizations and institutions discussed and the need to understand interactions and interdependencies amongst them.

As in Porter's analysis, the SSI approach (Breschi et al., 2000; Malerba & Orsenigo, 2001) examines an industry or sector. However, instead of focusing on interdependence within clusters of industries, SSI considers different sectors or industries which operate under different technological regimes with respective opportunity and appropriability conditions, knowledge base and capacity to accumulate technological knowledge (Carlsson et al., 2002). The SSI approach also emphasizes the "creation and selection of diversity amongst firms, where diversity is itself the result of the path-dependent accumulation of firm-specific technological knowledge and expertise" (Malerba, 2004, p. 317). Thus, the creation and accumulation of specific capabilities by innovating firms reinforces the value of their participation in the relationships which constitute the sectoral system (Malerba, 2004, p. 317).

Findings from SSI Research

Malerba's (2004) empirical research on five sectors in advanced countries finds the SSI framework useful for four reasons. Firstly, it provides "descriptive analysis of differences and similarities in the structure, organization and boundaries of different sectors" (Malerba, 2004, p. 465). Secondly, it identifies differences and similarities in the operation, dynamics and transformation of sectors. Thirdly, it identified the factors affecting innovation and the commercial performance and international competitiveness of firms and countries in different sectors (Malerba, 2004, p. 465). In addition, it provides the indications for development of new public policy for these sectors. The five sectors studied were the biotechnology and pharmaceuticals, telecommunications equipment and services, chemicals, software and machine tools sectors. This section discusses the results of Malerba (2004) and others according to the components of the SSI framework. There is a great heterogeneity of actors in most sectors. Co-invention involved suppliers and users, but suppliers proved to be particularly important Malerba (2004). The significance and intricacy of networks varied, depending on the subsector Malerba (2004).

For the knowledge base and learning component, Malerba's (2004) empirical research in advanced countries find that the features and sources of knowledge are important to understand the workings of sectors, as an explanation of: the rate and direction of technological change, organization of innovative and production activities and identification of factors for successful performance. In most sectors, R&D is found to have been increasingly decentralized, externalized and internationalized (Coriat &

Weinstein, 2004). The combination of “a rich, multidisciplinary and multi-source knowledge base and rapid technological change also implied a great heterogeneity of actors in most sectors” (Malerba, 2004, p. 471). Research on the pharmaceutical, telecommunications, software, semiconductor, automobile and agro-alimentary industries identifies the following common knowledge base and learning catch-up variables and mechanisms: the necessity of learning and creation formation of aptitudes of local firms to absorb and adapt foreign knowledge; access to foreign knowledge; and development of skilled labour, especially in knowledge intensive sectors (Malerba & Nelson, 2011). Active government policy is also important to stimulate learning processes and firms’ capability formation.

Universities have an important role in basic research and human capital development, and in some industries (such as biotechnology and software) they are also originators of innovation (Malerba & Nelson, 2011). Financial organizations play different roles, according to the stage of industry cycle. The role of financial organizations varies according to the stage of industry cycle. When an industry advances or large firms are involved, capital limitations are very high and specific financial intermediaries such as venture capitalists play a role (Malerba & Nelson, 2011).

Demand, in the form of users and the consumers, is important: as a key source of the re-delineation of the periphery of a sectoral system; as motivation for innovation; and as a factor shaping innovative and productive activity to propel and shape innovation and productive activities (Malerba & Nelson, 2011). Sectoral innovations have local, national and global dimensions (Malerba & Nelson, 2011).

Additional differences found by Malerba and Nelson (2011) are: industry structure in technological regimes; extent and variety of production and demand characteristics; type and role of demand; research institutions and facilities; type of financing; type of government policies; standards, regulations and norms; and national differences in terms of institutions and government policy. The observed differences between the respective sectors are summarized in Table 2.13.

Table 2.13: Sectoral Differences in SSI Studies

Sector	**Observations**
Biotechnology and pharmaceuticals	Demand and institutions (such as regulations, intellectual property rights and national health systems) affect innovation process.
Telecommunications equipment &services	Innovation is affected by standards, the institutional setting and the process of privatization and liberalization.
Chemicals	Innovation by multinational firms through R&D, economies of scale and scope and the cumulativeness of progress, research and commercialization capabilities.
Software	User-producer interaction, global and local networks of innovation and production. High mobility of highly skilled human capital. Role of university in open-source domain. IPR regimes.
Machine tools	User-producer interactions, local networks or innovators and in-house experienced human capital. Suppliers of components increasingly involved.

Source: Summary of Malerba (2004, p. 466-467)

Empirical researches in developing countries

Empirical researches in developing countries provide insights to this thesis which is conducted in Malaysia, a developing country.

Perini (2009) examines the relationship between knowledge base and innovation activity of the ICT sector in Brazil. He finds that knowledge base influences hierarchy and market, governance mechanisms and inter-organisational channels of knowledge. Mani (2006) maps the sectoral system of innovation of India's pharmaceutical industry in terms of its policy and strategic direction, intellectual property right regime, human resource development, technology generating institutions and its supply chain. Toivanen and Lima-Toivanen (2009) and Toivanen and Toivanen (1957) trace the growth and evolution of the sectoral innovation system of Brazilian pulp and paper industry and find that it is shaped by the needs of the firms, their economic and industrial policies and global advancement. Marques and Oliveira (2009) examine how Brazilian local suppliers maintain themselves in the competitive supplier chain of Embraer, the Brazilian airline company where a few by foreign suppliers dominate. They show that local suppliers strengthen and upgrade their basic technological capabilities to intermediate and advance levels on production processes. The main source of the knowledge is their relationship with Embraer, foreign buyers and research institutions.

In a study on a furniture cluster in Malaysia, Ng and Kanagasundaram (2011) find that linkages and interactions amongst actors in its supply chain are critical to distribute knowledge and innovation. The distinct features of furniture industry are in its main knowledge source and learning and the cooperative spirit, trust and loyalty among the industry players. Ng and Kanagasundaram (2011) find that the main knowledge source in Malaysian furniture industry is from accumulated work experience and knowledge from the founders and their next generation educated locally or abroad. The learning processes are basically in-house and on the job training. Molina (2011) researches on the food processing and mapped the food processing sector in Argentina, Brazil and Chile and finds the need for interacting agents, networks and institutions.

The study by Caniels et al. (2009) examine the role of local skills and clustering of innovative activity in Uruguay's software sector. The growth of the sector is attributed to demand and presence of skilled manpower associated to focus on education by Uruguayan state. The sector is dominated by small and medium sized companies where knowledge is concentrated at the local level. The sector grew over time through intense entrepreneurship spin-offs and labour mobility. Firms learn through internal efforts (R&D) but also access external knowledge and information through networking.

Iizuaka (2009) researches on the salmon farming industry in Chile. He challenges the opinion that `low-tech' sectors – such as food and other natural resource based industries – are not dynamic or innovative for path to development. His study shows that low tech sectors can be innovative through major transformation that requires advance capabilities – in particular by combining existing technological, organisational and market knowledge from different technological domains. In this sector, the innovation process involves wide network extending beyond national boundaries in order to encourage dynamic interactions in aligning the interests of agents. In a study by Lee (2009), he traces the evolution of the ICT sector in Taiwan and finds the dominant role of government in research and the dominance of foreign companies in the sector.

Intarakumnerd and Fujita (2009) examine the evolution of Thai and Vietnamese motorcycle industries in competition with China. They show that SSI and production can evolve differently for the same sector due to differences in absorptive capabilities, strength of linkages and learning. They show Thailand compete better than Vietnam as it possesses longer present and more technologically capable multinationals, local agencies support, research institutes and universities, sophisticate demand condition and more interactions for knowledge transfer.

Kim and Lee (2009) examine the catchup process in Korean machine tools industry and attribute its slow and gradual catchup to serious government efforts to support local companies with foreign ones, certification of product quality by the government.

Common findings of researches

Typically in the SSI researches of advanced and developing countries, the empirical researches employ the four SSI building blocks to identify the sources of innovation and development in different sectors. The common findings of these researches are in the aspects of knowledge base and learning, actors and networks and institutions detailed in the following discussion.

In terms of knowledge base and learning, similar to findings of the empirical researches in advanced countries of Malerba (2004) which was discussed above in the subsection "Findings from SSI Research", knowledge intensive sectors such as software, in Uruguay (Caniels et al., 2009), skills and human capital formation are particularly relevant for growth and knowledge base of a sector. This is because it greatly affects the organisation of innovative activity and the type of networks as in the case of ICT in Taiwan (Lee, 2009). Whereas, Mani (2006)'s study on the Indian pharmaceutical industry shows that R&D and production capabilities are to be integrated for successful innovation as their separation leads to companies' lack of competence in production, causing reliance on external research.

Additionally in the developing countries researches, for example the software sector in Uruguay (Caniels et al., 2009), show that the sectoral system developed because of the presence of skilled workers with good level of education and from the intense entrepreneurship spin-offs and labour mobility over time. Firms' learning occurs through internal efforts (R&D) and access of external knowledge and information through networking while policy does not play any major role in innovation except in human capital formation and providing general infrastructure (Malerba & Mani, 2009).

In the researches on the salmon farming industry in Chile (Iizuaka, 2009) and furniture industry in Malaysia (Ng and Kanagasundaram, 2011), traditional sectors are not found to be necessarily low tech with low knowledge intensity as they often are innovative and use advance and differentiated knowledge.

In terms of actors and networks, the study on software in Uruguay (Caniels et al., 2009) shows that the intense dynamic clustering from vibrant entrepreneurship and intense spin-offs are extremely important for innovation in sectors characterized by small and medium enterprise. Also in developing countries, private sectors are key actors in a SSI, as in the case of the pulp and paper industry in Brazil (Toivanen and Lima-Toivanen, 2009) where entreprenuers and business managers thrive under healthy internationally competitive incentives in the creation and adoption of scientific technological and business innovations. In the study on Malaysia furniture cluster, Ng (2011) and Ng and Kanagasundaram (2011) find that its main innovation actors are from its supply chain consisting manufacturers, buyers, suppliers, and retailers. Linkages and interactions amongst actors are critical to distribute knowledge and innovation. They find that one distinct feature of actor is the cooperative spirit, trust and loyalty among the industry players.

Similar to findings of empirical researches in advanced countries (Malerba, 2004), the type of networks that emerge in innovation processes is strongly associated with the specific knowledge base. The study on ICT in Brazil by Perini (2009) show that understanding of type of knowledge is necessary for understanding the presence of certain types of networks in the development of a sector. Additionally in developing countries, the studies on ICT in Brazil (Perini, 2009) and pulp and paper industry in Brazil (Toivanen & Toivanen, 1957) show that the formation of networks and knowledge systems in developing countries may require complex alignment in a multi-level governance structure, as they include multinational and domestic networks.

In terms of institutions, in developing countries, the study on ICT in Taiwan (Lee, 2009) shows that its SSI are embedded in the NSI and their evolution is both nurtured and hampered by the government. Whereas in terms of public policies, developing countries need to pay attention not only to the positive feedbacks on innovation but also to the barriers from different sectors and their interdependencies on innovation and development. Additionally, the specific institutional frameworks in developing countries allow for organisational learning and decentralized interaction between shareholders with different interests (Malerba & Mani, 2009).

Similar to findings of empirical researches in advanced countries (Malerba, 2004), SSI of developing countries are not confined to national borders but can be global in nature. Intarakumnerd and Fujita (2009) also find that the same sector in different countries may evolve differently. They examine the motorcycle industry in Thailand and Vietnam and find that the sector evolves differently in Thailand and Vietnam when faced with threats and opportunities due to SSI factors differences in absorptive capabilities, strength of linkages and learning.

Limitations of the SSI Framework

One of the strengths of the SSI is its focus on the sectoral origins of new scientific and technological knowledge. On the other hand, Coombs et al. (2003) note that the SSI has limited or no focus on inter-sectoral interactions, demand (even though this is proposed to be a component of the sectoral innovation system) and market (as opposed to technological) knowledge. Other limitations of the SSI include: that sectors are broadly defined, a limitation shared with the NSI; the SSI's limited focus on the processes of innovation and selection of relationships between actors, especially the effects of asymmetrical power relationship on patterns of innovation – and, in broad terms, poor definition of the relationship between the sectoral and national systems of innovation; and SSI researchers' focus on high technology sectors and the lack of research on services and service elements (other than in sectors associated with high technology).

In addition to lack of research in the service sector, there is very little research on the construction sector or other project-based industries using the SSI framework or other systems approaches to innovation (Andersen et al., 2000; Malerba, 2004). These limitations of the SSI framework are summarized in Figure 2.9. Reichstein et al. (2005) calls for more research on the sectoral system of innovation in construction to explore how different components interact with one another (Malerba & Nelson, 2011).

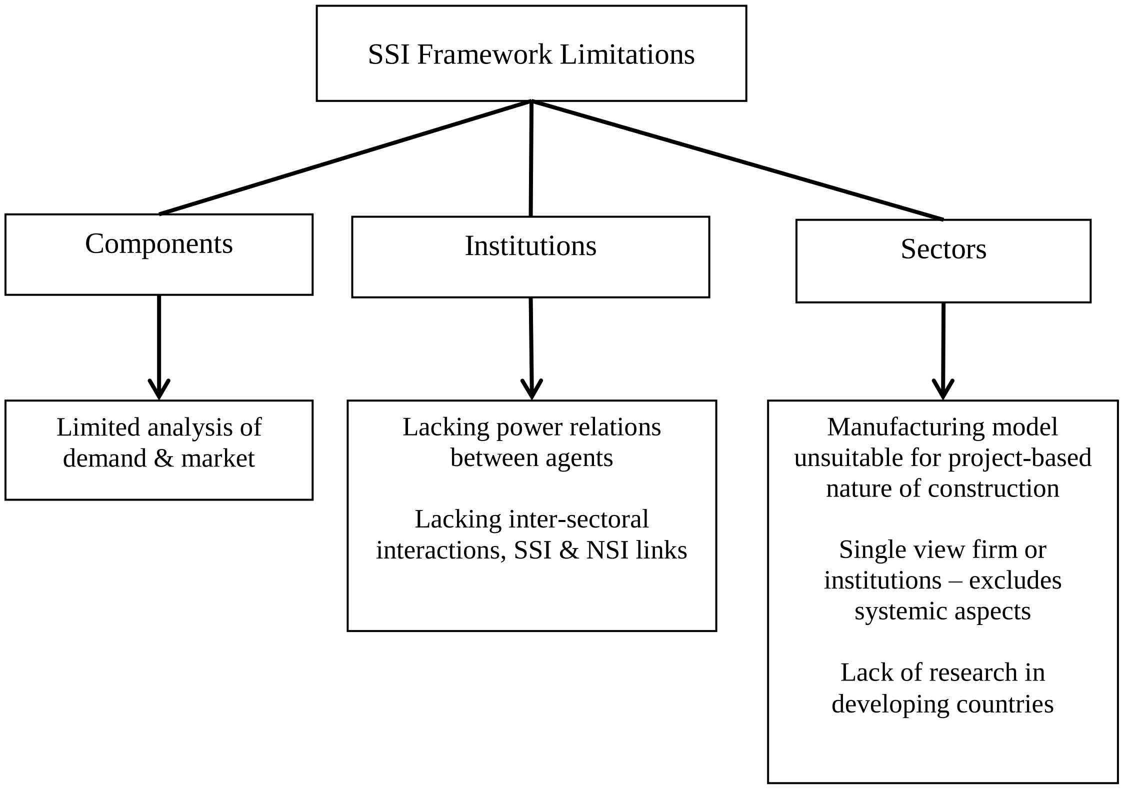

Figure 2.9: Limitations of the SSI framework

Richness and Limitations of Systems of Innovation Approaches

Four different approaches to the study of innovation systems have been reviewed. Their key characteristics are summarized in Table 2.14 and their strengths (richness) and limitations are summarized in Table 2.15.

Table 2.14: Innovation Systems Frameworks and Institutional Components

Approach	Institutional Components	Examples of issues studied
National innovation systems (NSI)	National context	Variations of innovation capacity and patterns between nations
Geographical innovation systems (GIS)	Regional context	Professional competencies, shared cultural orientations, trust and collaborative practices, market structures and autonomous regulative institutions
Technological innovation systems (TIS)	Specific technologies, focusing on role of institutions, actors, actor network	Political system, educational system, patent legislation, market organization, capital supply, collective bargaining, industrial and corporate organization
Sectoral systems of innovation (SSI)	Sectoral differences in structural, organizational, dynamic terms. Both sector and national specific.	Norms, rules, laws, standards, informal constraints, conventions, routines, common habits and established practices.

Source: Summarized from Rohracher et al. (2010)

Table 2.15: Richness and Limitations of Systems Approaches to Innovation

Approach	Richness	Limitations
NSI (Freeman, 1988, Lundvall, 1988, Nelson, 1988)	Countries, institutions	Broad
GIS (Saxenian, 1989, 1994)	Regional infrastructures Structured interactions Suppliers, demand	Lacks meticulous comprehension of innovation processes and continuing dynamics
TIS (Carlsson, 1995, 1997)	Technological, less sectoral	Specific to technologies
SSI (Malerba & Orsenigo, 1990)	Sectors interactions, technological regimes Sectoral knowledge bases	Inter-sectoral interactions, demand, market knowledge, innovation & selection processes, power relations, service sectors

Source: Summarized from Coombs et al. (2003) and Carlsson et al. (2002).

Innovation in the Service Sector (ISS) Framework

Tether and Metcalfe (2004) observe that, although the SSI framework highlights interactions between organizations and institutions, it is concerned with products and outcomes – usually of manufacturing processes – rather than processes. Yet the process dimension is crucial in services and service sectors are usually categorized by process rather than product; examples provided by Tether and Metcalfe include retailing, transportation and financial intermediation. Reichstein et al. (2005) propose that the service industries characteristics of construction to be applied to research on construction innovation that adopts a service industries perspective. The work of Tether and Metcalfe (2004) on innovation in the service industries provides a conceptual framework for such an approach.

Instead of mapping an innovation system onto a precisely defined service sector, Tether and Metcalfe (2004) propose the mapping of systems of innovation that cut across sectors. Using their approach, innovation systems research concerns aspects of innovation rather than all-embracing study of a sector, given the large size, complexity and multi-faceted nature of industry sectors. For instance, Tether and Metcalfe's (2004) study focuses on particular activities within wider activities or sectors, e.g., air traffic control services within airports, the insertion of intra-ocular lens in health services and consumer self-service in supermarkets within retailing. This focus on particular activities permits investigation of interaction and interdependency, classic properties of systems, in studies of innovation in services.

Tether and Metcalfe (2004) note that innovation in services differed from innovation in manufacturing in the following ways:

i. Form of innovation: processes rather than their products; greater inter-relationships between business models, organizational forms, technology and outputs.
ii. *Actors and networks*: the importance of network relationships in services with significant variations over time and or space; and non-market organizations' for example regulation has significant impact.
iii. *Knowledge Base and Learning*:

- Form of knowledge base – market knowledge and procedural knowledge other than technological knowledge (and R&D);
- techniques and procedures other than equipment; and
- learning through experience rather than formal and scientific knowledge.

iv. *Institutions*: process of institutionalization namely the potential conflict in the forming of institutions; and the system of institution especially on how institutions came to be instituted and how institutions influence behaviour.

v. *Demand*: how it is developed, expressed and mediated, thus the importance of market knowledge in the service sector; and the level of interaction and interdependency between service providers and consumers and between service providers and equipment suppliers in the sector.

Because there is no single system of service innovation but, instead, multiple systems or patterns, Tether and Metcalfe (2004) propose that innovations in services are developed around problems (or opportunities) that are framed by a number of contingencies – including the regulatory, cultural and technological context – demand, agents (actors) and incentives (Figure 2.10).

Tether and Metcalfe (2004) further observe that production and innovation activities have been examined mainly in terms of problems of assembling inputs to innovation; reducing risk and uncertainty by creating stable networks; the economies resulting from agglomeration; and the shaping forces of national contexts. Little is known, however, about the economic returns of innovation processes or the distribution of returns to the individual member organizations within the network configuration.

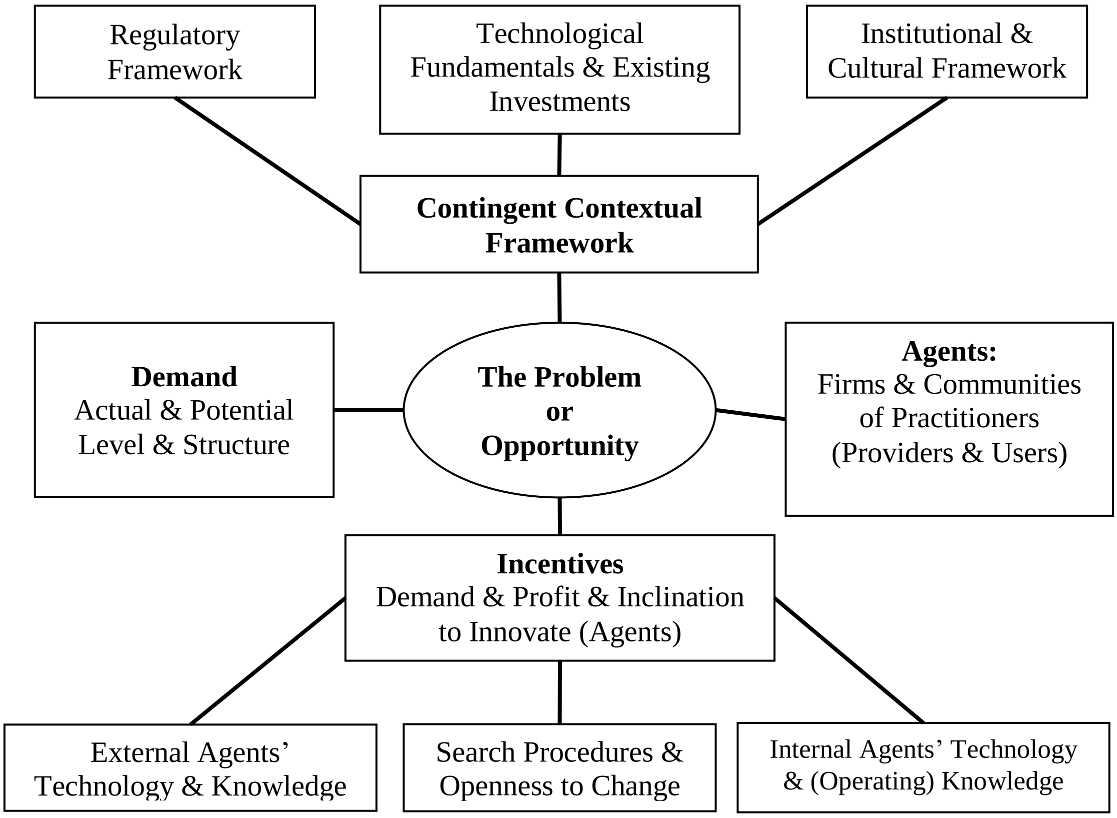

Figure 2.10: Problem-/Opportunity-Centric Innovation (Tether & Metcalfe, 2004)

2.4 Literature Gap

There are four main weaknesses in the construction innovation literature, namely: the adoption of innovation models from other industries; lack of a specific model for construction studies; inaccurate theorizing about construction; and the lack of research on contextual studies in construction work.

The first weakness concerns assumptions about the ability to bring about adoption of innovations in construction (Harty, 2005), the suitability and applicability to construction of innovations originating elsewhere (e.g. Sexton & Barrett, 2003; Winch, 2003), and the need for construction innovation research to understand the characteristics of construction contexts and the differences between them and those of other sectors (Bresnen & Marshall, 2000). As already established, for example, in service innovation research, the patterns and contexts of innovation are markedly different from those of conventional innovation models derived from studies of mass-produced goods; thus, manufacturing models, if applied without modification, are unsuitable, conceptually and in terms of management strategy and practices (Acha et al., 2005; Reichstein et al., 2005; Widén, 2006; Widén, 2010). Similarly, innovation in project-based contexts such as the construction industry, with time pressures that limit the ability to innovate (Gann & Salter, 2000), differs from innovation in traditional manufacturing industries (Reichstein et al., 2008).

The second weakness is the assumption that implementation of innovation in construction occurs in a limited area of interest, typically the firm (Harty, 2005). This is in contrast to the process of construction, which involves diverse actors from separate entities performing complexly-related, but very different activities, which involve different manufacturing, construction and business services industries. This results in a notable gap in the literature, the lack of a specific model of construction innovation.

Associated with this gap are a number of methodological limitations of the construction innovation literature. Although the metrics for assessing the success and impact of an innovation have been identified and discussed in the literature, practical application and especially the validation of these metrics is limited (Gambatese & Hallowell, 2011). Although researchers (Dikmen et al., 2005; Gambatese & Hallowell, 2011) have identified several measures, quantitative research that positively connects specific metrics to innovation is lacking (Gambatese & Hallowell, 2011). Another area suggested for further research is the extent to which innovation brokers are a leading indicator of innovation (Gambatese & Hallowell, 2011) and the impact on innovation of innovation brokers and their involvement at the project level (Winch & Courtney, 2007). Research that examines, in qualitative detail, the processes of implementing innovations within construction has also been found to be lacking (Harty, 2008).

Another gap is seen in the theorizing of construction work, where actual construction activity impedes the appreciation of innovation as well the innovation process itself. The conventional construction management has been faulted as acting as a hindrance to construction innovation (Koskela & Vrijhoef, 2001). For example, Winch (2000) propose that the existing hierarchical structure of management in construction has serious implications for innovation. Winch compared the structure and management of construction firms in Britain and France: the French model of management, which gave more autonomy to employees and provided greater flexibility in role definitions, was more conducive to innovation than the British model.

The fourth weakness is the lack of studies of project-specific factors that affect contextual innovation and co-innovation on construction projects. Damanpour and Gopalakrishnan (2001) find that existing theories and process models of organizational innovation are not supported by empirical studies and, thus, research on inter-organizational relationships, diffuse networks and the relative impacts of project-specific factors is required to produce more accurate models for project-based industries such as construction (Taylor & Levitt, 2004). On the other hand, Gambatese and Hallowell (2011) find only moderate support for the effects of project delivery and contracting methods on innovation and suggest further studies on how these methods can be structured to promote the integration of design and construction expertise on a project and communication among the team members.

2.5 Analytical Framework

This thesis integrates the two frameworks from the Sectoral Systems of Innovation (SSI) tradition to organize the guiding framework to study innovation in the construction sector of Malaysia. Malerba's (2002, 2004, 2006) SSI framework provides four sets of interacting agents and products: *actors and networks, knowledge base and learning, institutions*, and *demand*. Tether and Metcalfe's (2004) application of Malerba's framework to innovation systems in the service sector (ISS) provided additional dimensions namely, the forms of innovation and motivations for innovation in the sector.

Three reasons explain the use of SSI and ISS in this thesis. Firstly, Malerba's themes provide a broad guide to examine construction sector innovation systems without limiting new findings peculiar to the industry. Secondly, these broad themes have been used by Tether & Metcalfe (2004) to examine the service sector and have been proposed for study of the construction sector (Reichstein et al., 2005). Thirdly, as the construction sector has characteristics of both manufacturing and services and innovation in construction is more like innovation in services than in manufacturing, Tether & Metcalfe's (2004) dimensions and variables of service innovation are likely to be applicable to the construction innovation system.

Tether and Metcalfe (2004) suggest the use of problem and opportunity to examine the interactions and interdependencies, patterns of resistance to innovation, patterns of sources of knowledge, balances of dependency and power, and the relations of these characteristics with patterns of activities and innovation. This study examines the motivation for innovation in construction following Tether and Metcalfe's problems or opportunities concept of innovation. This research also examines the *actors'* incentives and rewards from innovation as a form of motivation for innovation in construction.

The relationship between the frameworks developed by Malerba (2002, 2004, 2006), Tether & Metcalfe (2004) and this thesis, in terms of industry type and scope, is depicted in Figure 2.11. Malerba's SSI framework is primarily targeted at the manufacturing sector, while Tether & Metcalfe's framework is used to examine the service sector in advanced economies. The focus of this study is on the construction sector in a developing economy.

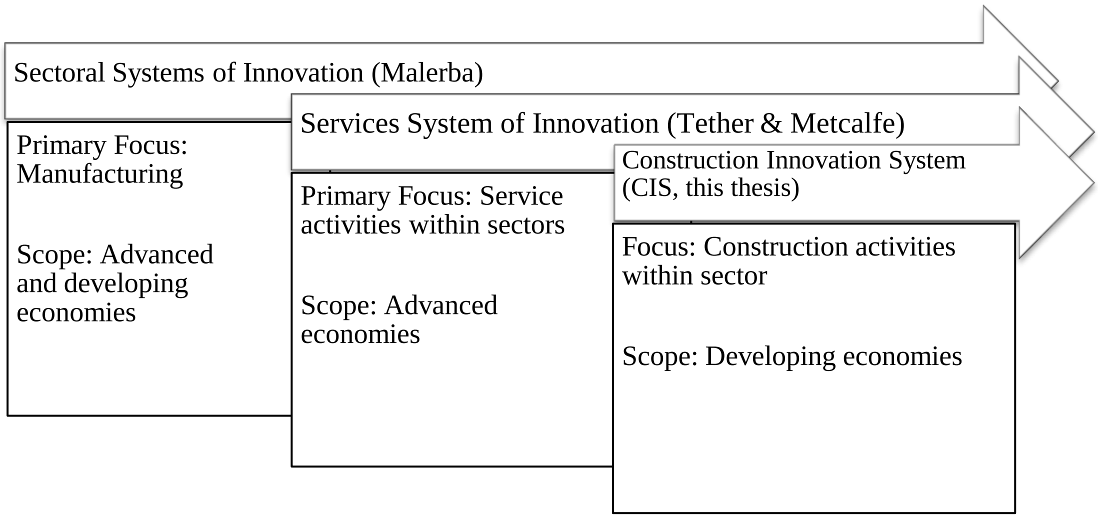

Figure 2.11: Focus and Scope of Existing Approaches and This Study

The components of the integrated framework are summarized in Table 2.16 and Table 2.17. Themes and variables are drawn from the underlying frameworks to study the construction innovation system, as described in Chapter 3.

Table 2.16 Elements of an Integrated Framework for Study of a Construction Innovation System

Component	**Source**
1. Motivation for innovation	T&M = Problem- or opportunity-centric [motivation]
2. Four interacting actors and products	M, T&M
2.1Actors and networks	M, T&M
2.2 Knowledge and learning	M, T&M
2.3 Institutions	M, T&M
2.4 Demand	M, T&M
3. Type of Innovation	T&M

Note: M = Malerba (2002, 2004, 2006). T&M = Tether & Metcalfe (2004).

Table 2.17: Components and Variables in an Integrated Framework for Study of a Construction Innovation System

Component	Variables	Interaction Theme
Actors & Networks - Actors	Types: upstream suppliers' components & systems, users and customers (national and international), universities & public laboratories, financial organizations, banks, venture capitalists, trade unions, technical associations, & government.	
	Capabilities & capabilities building process.	Knowledge Base & Learning
	Accumulation & learning process.	
	Competencies, beliefs, expectations & goals.	
	Organizational structure & behaviour; their importance, role & effects of firms & other actors.	
	Agents' cognition, actions, & interactions formed by institution.	Institutions
Actors & Networks - Networks	Types: communication, exchange, cooperation, competition & command.	
	Connects actors & institutions.	Institutions, Actors
	Encourages knowledge sharing.	
	Fluency of communications dependent on firms' knowledge base, structure, & internal mechanisms.	
Knowledge base & learning	Capabilities & technological regime (C&T): components & coverage.	
	C&T: accessibility & sources knowledge.	all themes
	C&T: the protection of innovation.	
	C&T: institutional & cultural context.	Institutions
	Service characteristics: technique procedure, experience-based (T&M).	
Institutions	Type: formal or informal.	
	Objectives as obstacles, opportunities or outcomes of innovation.	Actors
	National or sectoral.	
	Effects on actors' interactions & cognition.	
	Service characteristics: Process of institutionalisation – potential conflict, system of institution – how instituted & influences behaviour (T&M).	
Demand	Clients' heterogeneity: segmentation & type of customers & demand.	
	Service characteristics: How developed & mediated (T&M).	
	Network effects on clients.	Network
	Role of demand in terms of user-producer relationships.	Actors
Type of Innovation (T&M)	Service characteristics (T&M & extant literature on typology of innovation).	
Motivation for Innovation	Problem & opportunity centric.	

Source: All variables and themes from Malerba (2002, 2004, 2006) unless noted. T&M = Additional variable or theme derived from Tether and Metcalfe's (2004) observations of innovation systems in the service sector.

2.6 Chapter Summary

Existing models of innovation in construction have largely been abstractions, drawn from the field of business, that have dealt with innovation as an outcome or as a process, with strong emphasis on identifying determinants from management theory. In particular, past work on construction has not viewed innovation within a systemic framework. In the absence of studies that examine innovation in the construction sector in depth, this chapter analysed existing systemic and sectoral approaches to innovation as a source of relevant signposts to formulate, inductively, an approach to mapping innovations in the sector.

This thesis has adapted existing sectoral approaches from manufacturing (Malerba, 2002, 2004, 2006) and from services (Tether and Metcalfe, 2004) to construct an exploratory framework to study the nature, type and structure of innovation in the construction sector. Despite its closeness to services, owing to the diverse project-based nature of construction, (which is dominated by a wide range of small firms that function both formally and informally, and a few large, modern firms), and where services and material production overlap with uncertain demand, innovation in construction is unique in its own sense. Hence, this thesis proposes to adapt this alternative framework to study innovation in the construction sector, as explained in the next chapter.

CHAPTER 3

METHODOLOGY

3.1 Introduction

Research methodology refers to the epistemological and ontological assumptions contained in a study's research approach and how these assumptions and approaches are used to design data collection and analysis (Tuchman, 1994). Thus, the research methodology provides the philosophical and conceptual framework that establishes the context of the research (Denzin & Lincoln, 2005; Ponterotto, 2005). This research uses a nested research approach based on Kagioglou et al. (2000).

This chapter presents the methodology used in this research on the innovation system in the construction industry. Sections 3.2, 3.3 and 3.4 present the research philosophy and approach and design. Section 3.5 outlines the procedure for theory development and Section 3.6 describes how the study addresses the issue of trustworthiness, including validity and reliability. The last section summarizes the chapter.

In the nested approach, the research philosophy provides the basis that guides the research approach and the research method for any given study which consists of a selected research design and research techniques (Figure 3.1). It establishes whether the primary role of the research is to test or generate theory. The research method is the specific method selected to test or generate theory, the research design provides a template for how this will be done and research techniques provide the tools and techniques for data collection and analysis. The research approach provides the tools and techniques for data collection and analysis.

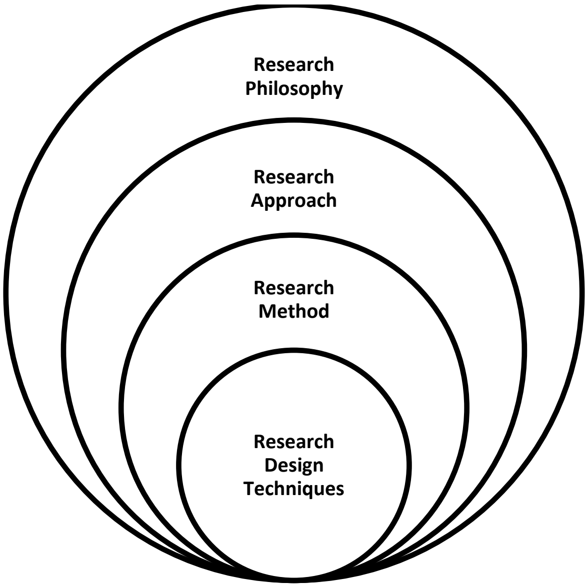

Figure 3.1: Nested Research Methodology (Kagioglou et al., 2000)

3.2 Research Philosophy

This section establishes the philosophical direction of this thesis. Research philosophy refers to the epistemological, ontological and methodological assumptions and undertakings that guide the inquiry in a study, implicitly or explicitly. Research philosophy or paradigms are assumptions or basic belief systems or worldview that defines the nature of the world (Guba & Lincoln, 1994).

The ontological question asks, "What is reality? What is its form and nature, how are they related and how do they work?" The epistemological question asks "What is the truth with respect to how knowledge is accumulated?" and "What is the nature of relationship between the researcher and reality being investigated". The methodological question asks: "How do we examine what is reality?" (Lincoln & Guba, 2000). Due to the nested nature of research methodology (Dempster, 1999) the epistemological question is constrained by the ontological question whereas the methodological question is constrained by the ontological and epistemological questions.

Two opposing philosophical views can be defined by their ontology, epistemology and methodology: positivism and constructivism. Ontologically, positivism is based on the belief that there exists a reality that can be identified through objective, empirical observations. The related postpositivism paradigm holds the less extreme position that, although reality exists, it can only be understood imperfectly due to human intellectual limitations and the complexities of phenomena (Lincoln & Guba, 2000). Positivism and postpositivism share a common goal of explanation that leads to prediction and control of phenomena; their emphasis on cause–effect linkages of phenomena that can be studied, identified, and generalized (Lincoln & Guba, 2000; Ponterotto, 2005).

Constructivists hold a relativist position of multiple, understandable and equally valid realities (Schwandt, 1994) that are constructed in the minds of individuals where meaning is hidden but can be uncovered through reflection (Schwandt, 2000; Sciarra, 1999) and in the researcher's interpretations of conversations, texts and observations. Thus, multiple local and specific formed realities exist. The extreme goal of the constructivist namely the ethnographers is to understand "lived experiences" from the point of view of those who live them day to day (Schwandt, 1994, 2000).

Epistemologically, positivism assumes that it is possible to know exactly what reality is through objective, empirical observation; postpositivism holds that reality can be approximated but never fully known; constructivism views knowledge as jointly created between researcher and participants in the research (Lincoln & Guba, 2000) although, for interpretivists, it is possible to form an understanding of subjective reality through interpretive or hermeneutic analysis of the participant's account of knowledge as long as the researcher acknowledges their role in joint knowledge creation. In its extreme form, the interpretivist approach is criticized for its view that all knowledge assertions have equal status (Järvensivu & Törnroos, 2010).

Methodologically, positivism and postpositivism adopt rule-based protocols, principally those of the scientific method (Hodgson, 2012). Positivism assumes that it is possible to objectively determine the true state and causes of a phenomenon through observation, theorizing and testing of hypotheses. Postpositivism does not accept the assumptions of objectivity, truth and causality, while the scientific method of developing theory and testing hypotheses is still valued as a rigorous approach to understanding phenomena. Constructivism seeks to construct a common construction of individual constructions or a reconstruction of previously held constructions, including that of the researcher (Lincoln & Guba, 2000).

3.2.1 Dominant Paradigm in Construction Management Research

Although the positivist approach using the scientific method has been criticized since Comte and Mill (Johnson & Duberley, 2000) as an inadequate explanation of the subjective human behaviour studied in the social sciences, research in the social sciences and the management disciplines is rooted in the positivist tradition. The positivist paradigm dominated construction management research until the mid-1990s (Seymour & Rooke, 1995).

Dainty's (2008) analysis of the papers and notes published in 2006 in the *Journal of Construction Management and Economics* showed that the construction management field remained strongly positivist and 71% of the studies used quantitative methods. Qualitative studies were strongly reliant on interviews, with three quarters of them employing individual open-ended interviews. Thus, unlike management research in general, the field of construction management seems to be fixed primarily within the positivist convention. Furthermore, construction management research is methodologically conservative: it lacks methodological variety, even in qualitative and interpretative research design (Dainty, 2008). Construction management researchers have persisted with a rationalist approach to theory and method, resulting in greater emphasis on causality than meaning (Seymour et al., 1997).

3.2.2 Evolutionary Economics and the SSI Approach

According to Hodgson (2012), the Sectoral Systems of Innovation (SSI) framework shares four common ontological assumptions with evolutionary economics:

First, reality is a world of change that is qualitative in terms of technology, organizations and structure of the economy, in addition to quantitative change (Schumpeter, 1961). This is in contrast to the equilibrium orientation of mainstream economics, which is less able to accept qualitative change (Klaes, 2004).

Second, important in economic change is the generation of novelty evident in the works of Dosi, Nelson, Winter and Witt. This novelty is important because it propels technological and institutional development, even though the changes and development are not foreseeable (Popper, 1957, as cited by Hodgson, 2012) or unidirectional in time. As a result, evolutionary economics is cautious about the predictions of mainstream economists.

Third, evolutionary economists emphasize the complexity of economic systems, where interactions amongst entities with varied characteristics occur (Hodgson, 2012). These interactions are considered to be non-linear and chaotic. They are further limited by unpredictability and create emergent properties, i.e., novelties. The mixture of novelty and complexity causes many irreversible evolutionary changes.

Fourth, similar to Darwinist beliefs in the emergence of creations without God, evolutionary economics holds that human institutions evolve through individual interactions, without an overall planner or design. Thus, it emphasizes self-organization or the un-designed.

3.2.3 Philosophy of Methodology

Halinen and Törnroos (2005) suggest the existence of a philosophy of moderate constructivism, which defines truth as community-based and derived from empirical data. The moderate constructivism philosophical stance adopted in this thesis can be understood in terms of its ontology, epistemology and methodology.

Ontologically, innovation systems frameworks rooted in evolutionary economics are postpositivist because they assume that, although reality exists, there are limits to how accurately we can know what it is. This is a contingent view of reality, instead of positivism's one single reality or constructivism's multiple realities. The research described in this thesis accepts and adopts this view.

Epistemologically, postpositivists hold modified dualist and objectivist views of truth. This means that reality found through falsification and critical community consensus is probable truth. It also permits local truths through empirical observation and inductive theory generation. However, the understanding of innovation involves in-depth understanding of location in context and specific research of real life, complex, human learning, behaviour and relationships. The subjects being examined are of an unstructured character. This requires an understanding of subjective reality through analysis of human accounts of knowledge. Thus, the epistemology of this research locates it in the constructivist philosophy.

In terms of methodology, this research uses case studies and semi-structured medium-length interviews. The length and structure of the interview protocols are not designed to produce the high researcher-participant contact or in-depth findings of the phenomenological and ethnographic techniques often used as the basis for constructivist interpretation. Therefore, although the findings of this research will include brief quotes from interviewees, the *voice* of the participants will not be presented extensively in contrast to ethnographic studies. Thus, the research methods used in this study are those of moderate constructivism rather than interpretivism.

Based on these arguments, this research adopts the philosophical stance of moderate constructivism similar to the idea of Halinen and Törnroos (2005) moderate constructivism.

3.3 Inductive Approach

The two primary research approaches are the deductive and inductive approaches. In an inductive approach, the researcher begins with data and uses the data to build a theory. In contrast, deductive research begins with theory and uses data to test or extend the theory and/or to understand a phenomenon. This explanation is depicted in Figure 3.2.

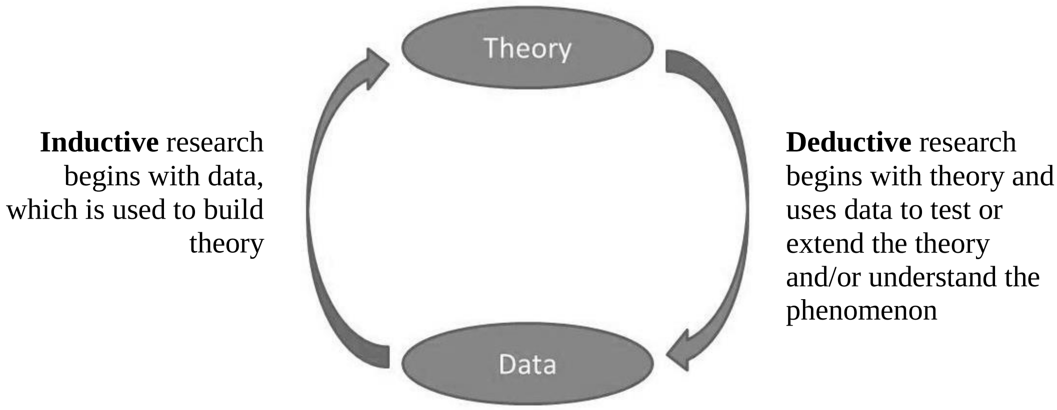

Figure 3.2: Inductive and Deductive Approaches to Research

This research used primarily the inductive research approach with some elements of deduction. The SSI framework has been applied to study five industries in the advanced countries (Malerba, 2004; Malerba & Montobbio, 2004) as well as the furniture industry in Malaysia (Ng & Kanagasundaram, 2011). The broad structure of *Actors and Networks*, *Knowledge Base and Learning*, *Institutions* and *Demand* common to all these industries provided a starting point for the examination of innovation in the construction industry. Innovation Systems in Service (ISS) framework provided two additional high level elements, motivation for innovation and the type of innovation.

From this point of view, the research had a deductive component. Although the broad integrated SSI and ISS structure provided a general guiding framework, it was not applied rigidly, thus new high level elements of the innovation system, as well as new subcategories of each new and existing component were permitted to emerge for the construction industry, if they existed. This approach did not constrain the researcher to explore the nature of innovation in construction, even though the nature of innovation is not included in the broad frameworks of the SSI and ISS. The researcher permitted the characteristics of the construction innovation system to emerge from the interviews and data sources without probing for information about subcategories. Interviewers' transcripts were emailed to interviewees for further clarifications without probing for information on categories and subcategories of the themes and variables of the frameworks.

In the data analysis, the inductive approach was employed by starting with data drawn from interviews, which were then organized logically and systematically to obtain a pattern of emerging themes for innovation in the construction industry. During work on confirmation of the data structure, the researcher used both the inductive and the deductive approaches, i.e., deductive to confirm the high level components, elements and variables from SSI and ISS frameworks, and inductive when new details of the construction innovation system emerged. The analysis and confirmation of data, although interrelated, were conducted separately as confirmation of data required that the analysis be completed first.

Thus, although we commenced the research deductively using an innovation systems framework, data collection and analysis were primarily inductive. The elements of deduction and induction in this research are depicted in Table 3.1. As Keynes (1904) explained, inductive research generally starts from deduction.

Table 3.1: Elements of Induction and Deduction in the Research Process

Elements	Beginning of Interview	During interview	Analysis Process	Confirmation of data
Deduction	Starts with broad themes & elements in mind			High level components & elements from SSI & ISS frameworks
Induction		Allow themes & variables to emerge without probing	Detailed analysis to obtain pattern of emerging themes	New details of construction innovation system emerge

3.3.1 Qualitative Method

Research methods can be broadly divided into quantitative and qualitative methods. This study used a qualitative approach for three reasons. Firstly, the research was exploratory and inductive in nature: to the researcher's knowledge, innovation in the construction industry has not been examined using the SSI and its related frameworks (such as the ISS framework), so the value of SSI theories and frameworks in the construction industry was to be explored. Secondly, understanding the complexity of interactions amongst multi-layered actors in a network requires in-depth study, which is a strength of qualitative methods in contrast to quantitative methods. Thirdly, qualitative reports of findings can be used to reflect informants' perspective of a phenomenon with their perspective incorporated in explaining the context of study (Taylor & Bogdan, 1998).

3.3.2 Case Study Research

A case study is an in-depth description and analysis of a bounded system (Merriam, 2014). A case is a single entity such as a person, a program, a group, or an institution (Merriam, 2014). The purpose of boundaries in a case is to prevent researchers from answering a research question that is too broad or a topic that has too many research objectives (Stake, 1995; Yin, 2014) The ways to bound a case include by definition and context (Miles & Huberman, 1994), time and place (Creswell, 2012) and time and activity (Stake, 1995). The cases in this research are innovative construction firms in Malaysia; they are therefore bounded by innovation as an activity, construction as an industry or sector and Malaysia as the place.

According to Yin (2014) case studies are suitable for *how* and *why* questions, behaviour that cannot be manipulated, contextual conditions and when boundaries between the phenomenon and context are unclear. The case study approach was suitable for this study because two of the research questions asked “How”:

> Research question 2: How do institutions regulate the conduct of actors in the construction innovation system?
>
> Research question 3: How do organizations connect institutions and firms to support innovation in the construction industry?

In addition, the contextual conditions of the firms are relevant to the examination of the knowledge base and learning, in keeping with the project-specific factors of the construction industry.

Case studies can be classified as exploratory, descriptive or explanatory (Yin, 2014). The exploratory case study explores any phenomenon of interest that serves as a point of interest to the researcher; the descriptive case study describes a natural phenomenon; and the explanatory case study examines the data closely at both surface and in-depth levels to explain a phenomenon. This study is of both exploratory and explanatory nature as listed in Table 3.2.

Table 3.2: Nature of Research Questions

Research question		Nature
Research question 1	What are the active components of a construction innovation system?	explanatory
Research question 2	How do institutions regulate the conduct of actors in the construction innovation system?	exploratory
Research question 3	How do organizations connect institutions and firms to support innovation in the construction industry?	exploratory

Case studies can be studied as either a single case or multiple case studies using holistic or embedded design. Multiple case studies are chosen for this research as the phenomenon of study is not a critical, unique, typical or a rare case (Yin, 2014). The strength of multiple case studies is that they enable the researcher to explore the differences within and between cases. Cases are chosen carefully to predict similar results across cases, or to predict contrasting results based on a theory (Yin, 2014). This research uses multiple case studies to compare similarities and differences in the characteristics of the innovation system as experienced by construction firms.

A common criticism of the case study approach is that it lacks rigour and that the views of the investigator may bias the results, thereby causing poor validity or low trustworthiness (Merriam, 2014). Section 3.4 describes the methods and techniques used to overcome this criticism.

3.4 Procedure

This study uses a procedure for building theory from case studies, following Eisenhardt (1989) and Yin (2014). This procedure is appropriate because the guiding framework is an integration of two existing frameworks and an extension into a new research domain, construction innovation systems. The procedure is used to guide the research as well as to address the trustworthiness issues of the study. There are eight steps in the procedure which are explained below.

3.4.1 Step 1: Developing Research Questions and Tentative Concepts

3.4.1.1 Research Questions

In this step, Eisenhardt (1989) proposed that the researcher defines tentative research questions and a possible framework. The former provides a focus for the kind of data to be gathered, whereas the latter helps to shape the initial design of the research and to identify the concepts when they emerge in the study.

Chapter 1 provided the research motivation, the research approach, the significance of the research, and the research questions and objectives. Chapter 2 reviewed the literature related to innovation in construction to develop a guiding framework for the research.

According to Cavana et al. (2001), the research objective of a study determines the unit of analysis, which can be individuals, dyads, groups, organizations or cultures. The main objective of this thesis is to provide an integrated understanding of the characteristics of construction innovation systems to increase the level of innovation in construction firms. Although the main objective is to map the industry, data about the industry is gathered from firms, thus the unit of analysis in this study is the firm.

3.4.1.2 Operationalization of Concepts

The research started with themes and general variables provided by the Malerba (2002, 2004, 2008) and Tether and Metcalfe (2004) frameworks, as articulated in the literature. Each component of the framework was adopted as a high level theme to guide data collection and analysis (see Table 2.16). A list of variables used by SSI and ISS researchers to discuss similarities and differences across sectors and services was also generated (Table 2.17). The themes, and interactions among them, are discussed, with the variables, in Section 2.5, Analytical Framework.

3.4.2 Step 2: Selecting Cases for Study

Four Malaysian construction firms were selected as cases for study using the purposive sampling method. They were drawn following recommendations from the Malaysian Construction Industry Development Board (CIDB), which is the most authoritative body on innovations undertaken in Malaysia's construction firms. Purposive sampling was used so that genuinely innovative construction firms from all four subsectors– infrastructure, commercial building, residential housing and oil and gas – would be included in this exploratory research. Although five firms originally agreed to participate in the research, the oil and gas firm later withdrew due to unforeseen circumstances, leaving four firms in three subsectors: infrastructure, commercial building and residential housing.

Two sets of criteria were used to select the case studies: general criteria established by the researcher and specific criteria suggested by industry experts:

Researcher's criteria.

i. Construction sector

The firms were selected from the construction sector as the research phenomenon is innovation in construction firms.

ii. Innovative firms

We selected innovative firms that "introduce(d) significant improvement in a process, product, or system that is novel to the organization, that may cause individuals to view things differently and results in competitive advantage, increased value for the client or benefit to stockholders" as defined in Chapter 1.

iii. Locally owned

Foreign-owned firms were excluded from this study.

iv. Accessible to the researcher

Case study research requires good collaboration and transparency (Yin, 2014). Therefore, it is important to select firms that showed a high level of interest in participating in the research and were available to participate at the time the study was conducted.

v. Information content

The cases needed to provide enough information about the research phenomenon to permit the researcher to answer the research questions.

Using the above five criteria, the researcher approached two government authorities and four ex-council members of professional associations to recommend innovative firms and obtained a total of 32 recommendations. Interviews with the six industry experts indicated that they had used the criteria listed below.

Industry experts' criteria.

i. Firm size and international involvement

Only large firms were selected, with availability of resources an important characteristic. International involvement was closely linked to firm size because large firms possess sufficient resources to venture abroad.

ii. Nature and extent of innovation

The selected firms were known by industry players to be innovative.

iii. Ownership: government versus private or publicly listed firms

The industry experts did not select any government owned firms. Thirty firms are publicly listed firms and two are privately owned.

We then conducted desktop research followed by a telephone interview with all 32 firms. Thirteen firms were found to be unsuitable because they did not have any substantial innovations. Of the remaining 19 firms, eight advised that they would be unable to participate because they were busy with work commitments. Five of the remaining 11 firms showed a high level of interest in participating in the research and thus were accepted as case studies of this research, with four continuing to completion.

Thus, this thesis reports the findings from four large construction firms in three of the four construction subsectors in Malaysia (Table 3.3). Between them, the four firms were responsible for a total of eight innovations. Two innovations in InnoInfra were more than 10 years old and two innovations in InnoIBS were completed in 2010, whereas all the other three innovations were still on-going during the interviews. The innovation in InnoInfra is 15 years old with on-going improvements was selected because the innovation is a trademark of InnoInfra and is well known in the industry, is a multi-award winning innovation up to the time of the study. InnoIBS advised that their innovation process is similar in almost all cases, so they provided two innovations as examples to explain innovation in the firm.

Table 3.3: The Case Study Firms and Their Innovations

Case Study Firm	**Subsector**	**No. of Inno-vations**	**Innovations**	**Age of Innovation at Interview**
InnoInfra	Civil engineering	1	Joint highway / flood mitigation infrastructure	15 years old, on-going improvements
		1	Connecting highway bridge	10 years old
		1	Public transport infrastructure	On-going
InnoInfo	Building-Commercial	1	Building process information system	On-going
InnoIBS	Building-Commercial	2	Industrialized building system	1 year
InnoWEBS	Residential	1	DIY House consisting of frame, wall, roof systems	On-going

3.4.3 Step 3: Data Collection Methods and Interview Protocols

Information was gathered mainly from face-to-face interviews and, to a lesser extent, from three other sources, namely, secondary desktop research, innovation location visits and interviewee observation. More detail of each method is presented below.

1. Face-to-face interviews

The main purpose of the interviews was to obtain direct responses to the research questions from innovators in the construction industry. Prior to conducting the interviews, we developed semi-structured interview questions and an interview protocol. The interview protocol consisted of a brief description of the research to be explained to the interviewees prior to the interview (Appendix A) and a list of questions to guide the interviewer during the interviews (Appendix B). The list of questions was not provided to the interviewees prior to the interview to ensure that answers were not pre-prepared. As this research used a primarily inductive approach, the initial questions were general in nature, using questions such as "Tell me about the innovation" before moving to specific questions, such as "Please tell me more about the role of the Design and Technical Team that you mentioned earlier" once information about active components of the firm's innovation system emerged (see Appendix I). This approach allowed the themes and variables from the conceptual framework to emerge from the interviewees.

The interviewees were purposefully selected by the researcher and the interviews were arranged by a contact person in the firm. The interviewees consisted of personnel involved in the innovation in the case study firms and were mainly in top management, i.e., the Managing Director, Chief Operating Officer, General Manager and the Heads of Departments of the Design and Technical Team and the Site Team. In one case study (InnoInfo) where the innovation involved actors external to the firm, senior managers from one mechanical and one electrical subcontractor firm were also interviewed.

Four to six semi-structured interviews were undertaken with each firm. A total of 19 interviews were conducted. With the exception of one interview with a project team at InnoInfo, all interviews were conducted on a one-to-one basis. All interviews lasted between one to two and a half hours except for one interview, with InnoInfo's electrical subcontractor, which lasted 45 minutes (Table 3.4). All interviews were audio recorded and fully transcribed, then emailed to the interviewees to confirm the information. A sample corrected transcript is in Appendix C. Clarification and follow-up information was also sought from interviewees from InnoInfra and InnoIBS. Overall, the interview and follow-up process lasted three months, from October 2012 to January 2013.

2. Secondary desktop research

The main purpose of the secondary desktop research was to obtain information about the firm and its innovation profile. The sources of secondary data were mainly the companies' websites and other Internet sources and company annual reports. The companies' websites and other Internet sources provided a profile of the firms. The annual reports provided other information, such as information about InnoInfra's innovations, and innovation about the group of companies associated with InnoIBS and InnoInfo and their activities. The InnoWEBS website and product brochure provided information about InnoWEBS' innovation. For InnoInfo's innovation, the researcher was directed to www.youtube.com to watch a presentation by its Director at an overseas conference. The speech was transcribed and coded to be used as quotes to explain and analyse the innovation in InnoInfo in Chapter 4. InnoInfo also provided a corporate video on its innovation. An InnoIBS interviewee showed to the interviewer company documents in the form of minutes of a quality team meeting.

Table 3.4: Interview Schedule

Case	**Venue**	**Interviewees**	**No. of Inter-views**	**No of Hours**
InnoInfra	Corporate office	(1) Director Corporate Communication	2	3 x 2 = 6
	Café near interviewee's office	(2) Head of Design & Technical (D&T); & Technical Head for one innovation.	1	2
	Café near interviewee's office	(3) Division Leader of a Technical Support Team	1	2.5
InnoInfo	Corporate Office	(1) Chief Operating Officer; & Head of D&T Department	1	2
	Innovation Office	(2) D&T Manager	1	2.5
	Project Office	(3) Innovation Project manager	1	1.5
		(4) Project Team consisting General Manager, the Engineer; Innovation Project manager	1	2
		(5) Mechanical subcontractor; Managing Director & Director	1	2
		(6) Electrical subcontractor Project Manager	1	45 minutes
InnoIBS	Corporate Office	(1) General Manager & Head of D&T & Production	1	1.5
	Site Office	(2) Head of D&T & Production	1	1
	Site Office	(3) Site Manager involved in the PSB innovation	1	2
	Corporate Office	(4) Group Quality Manager	1	2
	Corporate Office	(5) Human Resource Manager	1	1
InnoWEBS	Corporate Office	(1) Managing Director	2	2x2=4
	Production Factory	(2) Head of Production & D&T	1	2.5
	Production Factory	(3) Production Executive	1	1.5
Total			19	36.75

3. Innovation location visits

The main purpose of the location visits was to understand the innovation profile of the firm. Observations were made during visits to view the innovations in location for two case studies, InnoInfo and InnoWEBS, to better understand the mechanics of the innovation. InnoInfo's innovation involved software and was viewed at its construction project office where it was being used. InnoWEBS' innovation was viewed at its production factory; some photographs are provided in Appendix D. No location visits were made for InnoInfra's innovations because two were already implemented and one was a business innovation of which there is no visual evidence. InnoIBS' innovations have also been implemented, but no drawings were shown.

4. Interviewee observation

The main purpose of interviewee observation was to ensure that verbal responses to interview questions were consistent with interviewees' expressions. Interviewee observations were made in the following instances and for their respective purposes:

i. responses related to comments about the effects of actors on leadership, government initiatives and similar issues, as in the case of InnoIBS on the effects of Group culture and InnoInfo on the role of government policies in their innovation; and
ii. responses about the motivation of actors to innovate particularly pertaining to actors' personal motivation to innovate as an interest and as a professional challenge, as in the cases of InnoInfra and InnoWEBS.

An overview of the data sources used and their purpose is provided in Table 3.5.

Table 3.5: Data Sources Used, by Purpose

Research question / other purpose	Interviews	Secondary data	Location visit	Interviewee observation
Firm profile	/	/		
Innovation profile	/	/	/	
Active components of construction innovation system; Interaction among components	/			/
Regulation by institutions	/			/
Connecting organizations	/			/
Motivation for innovation	/			/

3.4.4 Step 4: Reflection on Data Collection

During the process of data collection, i.e., while the interviews were still being conducted, the interviewer transcribed completed interviews to text and reflected on the information gathered. The process of reflection allowed the revision to the interview questions to obtain more informative data. The final set of interview questions appears in Appendix E.

3.4.5 Step 5: Data Analysis

The analysis was an integration of descriptive analysis of the case study firms and the construction industry and thematic analysis of the transcribed interview texts. The descriptive analysis of the case studies refers to information about the firm and the construction industry.

The following steps of the directed approach to thematic analysis, suggested by Hsieh and Shannon (2005), were used:

i. First reading of transcribed text. Firstly, the researcher read the interview transcript and highlighted the text to obtain a first impression of the content. The purpose of this initial reading without coding was to capture all possible occurrences that emerged from the text, recording what the interviewee said (Appendix F).

ii. Secondly, the researcher began to interpret the meaning of what had been said.

iii. Thirdly, the researcher coded the highlighted passages using the conceptual framework developed in Chapter 2 (Tables 2.16 and 2.17). Text that could not be categorized with the initial coding scheme was given a new code. An example appears in Appendix G.

iv. Finally, the researcher described the findings from the analysis in the case studies by answering the research questions according to the existing and new coding and variables (Appendix H). These findings are presented in Chapters 4 and 5.

The researcher initially tested the analyses using both NVivo software and Microsoft Excel and decided on the latter as it provided more flexibility for changes of ideas.

3.4.5.1 Peer Review of Coding

For this research, the researcher employed the peer review of coding, instead of predetermined coding due to the disadvantages of the latter. The disadvantages in the use of predetermined codes are as follows: Firstly, the analysis may have a bias where the evidence may likely be interpreted to be supportive of the conceptual framework. Secondly, interviewees may sense that they need to answer in a certain way to please the interviewer. Thirdly, by using a guiding theory, researchers may forget to account for the contextual aspects of the phenomenon. These limitations are related to neutrality or conformability of trustworthiness, a similar concept to objectivity in positivist research (Guba & Lincoln, 1994).

To overcome the limitations of predetermined coding, a peer review was conducted to increase the accuracy of the categories and to check for bias in the researcher's analysis (Appendix I). The peer review was undertaken by 14 researchers guided by a facilitator, Professor Dr Sharan Merriam, a well-known qualitative researcher. Agreement of peer reviewer and researcher coding was very high. After reflection on the only instance of disagreement, the researcher revised her analysis to exclude a variable which was not derived from the transcribed text but from her own interpretation.

3.4.6 Step 6: Guiding Framework

The initial operationalization of concepts presented in Step 1 (based on the guiding framework developed and presented in Chapter 2, Section 2.5, Analytical Framework), was refined as the interviews and data analysis proceeded.

After conducting and transcribing two interviews at InnoInfra, a modified list of themes and variables was created. The researcher continued to refine and add more variables as the interviews and analyses progressed. Variables that did not emerge from the cases were excluded from the list once analysis was completed. In addition, we made two changes to the list of variables in Table 2.17. Under the *Actors and Networks* component, Competencies, Beliefs, Expectations & Goals was renamed Background, Beliefs & Personal Motivation, and under Motivation for Innovation, a new variable, Actor Attributes, was added.

The themes and variables, as well as interactions between themes, derived from the data analysis are listed in Table 3.6. The final set of themes and variables was used as the conceptual framework for analysis of both the individual case studies presented in Chapter 4 and the cross-case analysis presented in Chapter 5. In both chapters, the analysis is organized by theme (active components of the construction innovation system) and research question. A full list of variables by theme is mapped to the research questions in Table 3.7.

Table 3.6: Final Set of Themes and Variables

Theme	Variables	Interaction Themes
Actors & Networks	Who the actors are, their respective roles & effects	
	Level of interaction	
	Level of interdependence	
	Actors' background, beliefs & personal motivation	
	Actors as source of knowledge base	Knowledge Base & Learning
Knowledge Base & Learning	Type & source of knowledge base	
	Form of R&D	
	Firm capabilities & learning processes	
	Acquisition of knowledge	
	Institutional & cultural context	Actors & Networks, Institutions
	Service characteristics: technique procedure, experience-based	
Institutions	Types	
	Influences, obstacles, factor encouraging innovation	
	Effects on interactions & cognition	Actors & Networks
	Service characteristics: institutionalization process – potential conflict, system of institution – how instituted & influence behaviour	
Demand	Type of customer	
	Role and effects on innovation	
	User-producer relationships	Actors & Networks
	Service characteristics: How developed & mediated	
Type of Innovation	Service characteristics (Extant literature).	
Motivation for Innovation	Problem- & opportunity-centric	
	Actor attributes	

Table 3.7: Variables by Theme, Mapped to Research Questions

Theme	Variables	Research Question
Actors & Networks	Actors	RQ1: Active components
	Types of actor (including non-market organizations – T&M)	
	Actors' roles	
	Actor characteristics:	
	Background.	
	Beliefs.	
	Motivations.	
	Actors' effects.	
	Networks:	
	Level of interaction.	
	Level of interdependence.	
	Forms of networks.	
	Actors & Networks with Knowledge Base & Learning.	RQ1: Active components' interactions
	Actors & Networks with Institutions.	
	Actors & Networks with Demand.	
	Actors' effects as motivation for innovation	
Knowledge Base &Learning	Type of knowledge base.	RQ1: Active components
	Market knowledge & procedural knowledge (T&M), technique procedure, learning through experience (T&M).	
	Source of knowledge base.	
	Knowledge Base and Learning with Actors & Networks.	RQ1: Active components' interactions
	Knowledge Base and Learning with Institutions.	
	Institutional & cultural context (T&M).	
	Knowledge Base and Learning with Demand.	
	Knowledge Base & Learning effects on innovation.	
	External Agent & Technology, Internal Agent & Technology (T&M).	
Institutions	Types and examples of institutional influences.	RQ2: Institutions regulating & RQ3: Organisations that connect
	Types and effects of institutional obstacles.	
	Suggested types of institutions as factors encouraging innovation	
	Institutional effects on interactions (interplay with Actors & Networks).	
	Institutions' effects on Knowledge Base & Learning.	RQ1: Active components' interactions
	Institutions' effects on Demand.	
	Institutions' effects on Innovation.	
	Problem-/Opportunity-centric (T&M)	RQ1: Active components' - Motivation (T&M)
	Type of customer & heterogeneity, how developed, expressed, mediated.	
Demand	Degree of interaction & interdependency between users & suppliers in the service sector (T&M).	RQ1: Active components
	Effects of the role of clients.	
	User-producer relationships.	
	Actors & Networks with Demand.	
	Knowledge Base and Learning with Demand.	RQ1: Active components' interactions
	Institutions' effects on Demand.	
	Demand effects.	
	Type of Innovation.	Profile of Innovation (T&M)

Note: T&M = Variable from Tether and Metcalfe (2004).

3.4.7 Step 7: Enfolding Literature

In this step, the researcher compared the emerging concepts with the literature to investigate the similarities and differences and explain the results. Eisenhardt (1989) provides three important reasons for this step. Firstly, it brings together underlying similarities between the phenomenon and the literature. Secondly, comparison of any conflicting emergent theory with the literature provides deeper insight. Thirdly, linking literature with a limited number of case studies also enhances internal validity and generalizability. The overall result is new emergent theory with stronger internal validity, wider generalizability and higher level of conceptualization.

The cross-case analyses are enfolded with the literature reviewed in Chapter 2 in Section 5.4, Summary and Discussion of Results. The results are compared with the theory and literature of the Sectoral Systems of Innovation (SSI) and Innovation Systems of Service (ISS) frameworks which provided the conceptual framework for this research, as well as with the literature and theories adopted in the more common business and management studies of construction innovation.

3.4.8 Step 8: Reaching Theoretical Generalizations

In this step, the researcher positioned the developed theory into broader theory. Drawing on the comparisons initiated in Section 5.4, the concluding chapter of this thesis, Chapter 6, positions the developed innovation system framework for construction within the SSI and the ISS frameworks, and the wider theoretical frame of the evolutionary theory of innovation as well as the implications of this research's findings. The linking of the developed conceptual model to the existing broader theoretical framework strengthens the internal and external validity of the study.

3.5 Trustworthiness

This study used a procedure for building theory from case studies following Eisenhardt (1989) and Yin (2014) to address the question commonly raised in qualitative research of whether one can trust the findings. This question arises because qualitative research mainly works with small samples, researchers are often directly involved with data sources such as interviewees and can thus might be biased. Further, qualitative studies often do not have hypotheses and hence do not use methods of logic that have traditionally been adopted to warrant research validity.

The two aspects of trustworthiness are validity and reliability. Validity refers to how close findings are to the reality being investigated. Reliability has several components, including *internal validity*, or internal consistency in the information obtained from different sources and in the coding of data from qualitative sources; in this sense, *reliability* refers to the extent that the study can be replicated. Another aspect of reliability in qualitative studies refers to the need to provide a detailed description of the phenomenon so that other researchers can understand it in its context and evaluate the extent to which it can be generalized to their own particular situations. The study addresses validity and reliability through steps 1, 3, 5, 7 and 8 of the procedure in the following ways (summarized in Table 3.8):

i. It addresses internal validity in two ways: by using various sources to gather information, including asking the same questions of different informants (interviewees) in the same firm and fact checking the transcripts in Step 3 and by checking the reliability of coding through comparison with peer reviewer coding in Step 5.

ii. It provides a detailed description of the phenomenon of construction innovation in Malaysia obtained from purposefully selected case study firms that show high level interests in participating in the study (Step 1) as well as a detailed account of the study methods, procedures and reasons for decisions made in carrying out the study (seen particularly in Steps 3,5 and 6)

iii. It addresses external validity in two-ways, namely in Step 7, by comparing findings with extant construction, as well as innovation systems' literature; and in Step 8 by checking the consistency of findings with the conceptual framework and underlying theory.

Table 3.8: Procedural Actions taken to Obtain Trustworthiness

Step	Action	Aspect of Trustworthiness Addressed
Step 1	Purposeful selection of firms for case study	*thick description*: sample of informative innovative firms from various sectors
Step 3	Data Collection Methods: using various information sources, including various informants; transcript confirmation by interviewees	*internal validity*: accuracy of information about components, characteristics, interactions and influences *thick description*
Step 5	Peer review of coding	*internal validity*: consistency of interview coding between the researcher and trained peer reviewers
Step 6	Presentation of individual and cross-case analysis studies	*thick description*
Step 7	Comparing findings with extant construction and innovation systems literature	*external validity*: comparison with findings from other studies and contexts
Step 8	Linking findings to the SSI and ISS frameworks	*external validity*: relationship of CIS model with SSI and SIS frameworks and underlying theory

The researcher also relied on her personal experience of six years in the professional service industry and two and half years in the construction industry to check on the accuracy of information that was provided.

3.6 Chapter Summary

This chapter outlined the key concepts and steps in the formulation of the methodology to map and analyse innovation in the construction sector. The method closely followed the existing approaches used in manufacturing and services. This research subsequently creatively adapted the analytic framework through both initial interviews with construction firms and the researcher's own experience working in the construction industry. Thus, although this research began with the SSI framework of Malerba (2004) (2002, 2004, 2006) as adapted in the Service Innovation Systems framework of Tether and Metcalfe (2004) eventually it adapted the framework to fit the construction sector. The new framework was designed to be open enough to absorb any finding that deviated from the broad general coordinates established in the literature and the general conceptual framework outlined in Chapter 2.

CHAPTER 4

CASE ANALYSIS

4.1 Introduction

This chapter maps and analyses the nature and types of innovation occurring in the four case study firms. Section 4.2 is concerned with InnoInfra, Section 4.3 with InnoInfo, Section 4.4 with InnoIBS and Section 4.5 with InnoWebs. Within each section, the case analysis begins with a short profile of the firm and a description of the firm's innovation(s). Findings related to the three research questions are then presented using the operationalized concepts and themes and variables identified in Chapter 3. Each single case analysis concludes with a discussion of interactions among components of the innovation system. Section 4.6 summarizes the findings of the single case analyses presented in this chapter.

4.2. InnoInfra: Construction Subsector, Civil Engineering

4.2.1 Background

InnoInfra is a Malaysian construction engineering, property development and infrastructure company. The company was incorporated in the mid-1970s and is listed on the main board of Bursa Malaysia since the early 1990s. The company operates as a group of firms whose main projects range from the construction of highways, airport runways, railways, tunnels, water treatment plants and dams to infrastructure privatization and the development of new townships. InnoInfra has positioned itself as the leading expert in rail construction and highways in Malaysia due to its innovative engineering solutions and project management expertise. Its record-breaking engineering milestones include the design and construction of world-renowned highway infrastructure, rail construction and project development for the single largest infrastructure project in Malaysia (TheStarOnline, 2013).

InnoInfra has operations not only in Malaysia, but also in India, Taiwan, Mauritius, Qatar, Bahrain and Vietnam. It enjoys global presence and has won many local and foreign awards in the engineering and property development subsectors for innovation, environmental management, master planning, landscape engineering, health and safety and business and management.

4.2.1.1 Description of Innovations

InnoInfra is well known in the construction industry for a multiple award winning innovation in infrastructure development in Kuala Lumpur, the capital of Malaysia. The problem of flash floods and traffic jam in the city triggered this innovation. While the costs of earlier proposals from other contractors to resolve the flooding problem were too high, InnoInfra's innovative solution was well received. InnoInfra proposed and developed a two in one infrastructure, which resolves the flood problem with a tunnel which is also used for transportation and vehicular traffic. Thus, it undertook "a project that was not deemed feasible and technically possible, and made it commercially feasible and technically possible" (Corporate Director, L117-118). When InnoInfra's top management proposed the two in one infrastructure, the first response from internal staff was that it could not be done. However, a technical solution was found and the project was proposed to and approved by the government. In this case, as in many of its projects, InnoInfra built the infrastructure using existing engineering knowledge, but applied a creative solution to innovatively resolve a difficult problem. The creative approach to the need to connect two development areas resulted in InnoInfra proposing, designing and building a connecting highway by building a bridge over an existing highway.

Traffic congestion in the city triggered a more widespread innovation in transportation infrastructure management. In the absence of a governmental Kuala Lumpur city transport master plan, InnoInfra developed one. InnoInfra referred to this innovation as involving changes to one's mindset because there were no clearly identifiable sequences to follow. The firm studied the transportation infrastructure needs of Kuala Lumpur and benchmarked transportation systems in cities around the world to develop a plan which it proposed to the Malaysian government. Because execution of the plan would require a huge investment, financing considerations were crucial to its acceptance. InnoInfra therefore presented not only the technical framework but also a financing proposal. As a result of the project's implementation, Malaysia's construction industry received a major boost from government investment (Corporate Director, L220-221).

4.2.1.2 Types of innovation

InnoInfra considers innovation to be a radical way of looking at business opportunities, "an innovation of mindset", i.e., doing something that others are not doing and driving the idea to become a reality. Innovation at InnoInfra has three main components: strategic, technical and contractual. Strategically, the firm identifies, initiates, develops, packages, sells and drives proposals for its clients. Although the firm is a contractor, it initiates the projects, employs consultants and develops a comprehensive proposal for clients. This approach contrasts strongly with the norm in the construction industry where contractors neither initiate proposals nor engage clients prior to being hired and clients typically provide the specifications for projects and engage consultants and contractors on the basis of competitive bids or proposals made in response to calls. InnoInfra, on the other hand, will produce the full multi-disciplinary design of the proposed infrastructure in a package that includes project requirements and full costing of development and operation (Corporate Director, L325-328).

InnoInfra acknowledges that innovation in the firm is largely incremental (and thus typical of Schumpeterian Mark 1 systems; Schumpeter, 1961, p. 66) rather than revolutionary. Innovation occurs through the conceptualization and application of existing technology rather than the creation of new technologies. The firm aggressively adapts existing engineering techniques, in some cases deploying existing competencies to use available, but unfamiliar, technologies:

> Technologies that had been around for many years, but not many people may take the effort to investigate how to use this technology. It was also about being daring to use available but unfamiliar technologies. (Corporate Director, L74-75)

InnoInfra's contracts take the form of *build, operate and transfer* and *design and build* contracts which are open enough to permit the firm to innovate by customizing and packaging to the needs of its clients.

4.2.1.3 Motivation for Innovation

InnoInfra is motivated to innovate by both external and internal dynamics.

Problem- and Opportunity-Centric

InnoInfra's motivation to innovate is *problem- and opportunity-centric* for two reasons. Firstly, the firm innovates to address a commercial problem or issue in the industry

> to find better ways of solving business and technical issues (Corporate Director, L370-372)

Such issues include flood and environmental problems, transportation issues and water supply:

> Again, here was a problem [referring to the flood problem in Malaysia] so what could we do? This issue triggered a proposal from us. (Corporate Director, L111-113)

Secondly, innovation is driven by a need for differentiation:

> Innovation in the company is driven by the need to differentiate ourselves in the industry. (Corporate Director, L285-286)

For InnoInfra, differentiation through innovation is a commercial strategy driven by the need to show continuous growth in shareholder value:

> Necessity is the mother of all invention. We innovate because we have to. We need to show continual improvement in our business and grow shareholder value. To grow, we need to secure new projects, and to do so in a competitive and sometimes uncertain market, we need to think of new opportunities using out-of-the-box approaches. (Corporate Director, L387-392)

The dynamics of InnoInfra's problem- and opportunity-centred motivations to innovate are summarized in Figure 4.1.

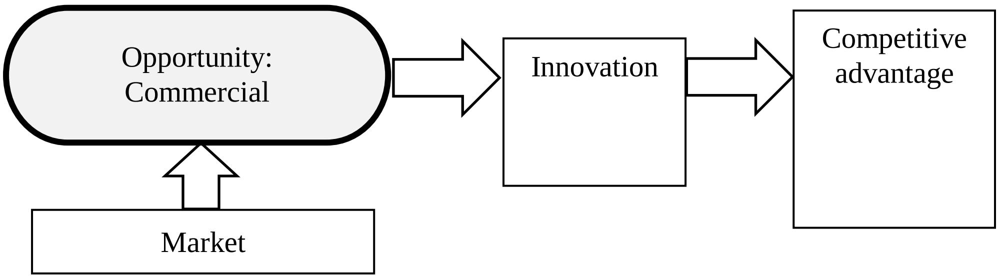

Figure 4.1: Opportunity-Centric Motivation of Firm to Innovate, InnoInfra

Positive Effects of Internal Actors.

InnoInfra also benefits from internal actors' personal motivations to innovate. The Head of the Design and Technical (D&T) Department innovates for two reasons. Firstly, innovation gives him professional satisfaction:

> We always look for things to perfect, to do things better, how to make it … for innovation to happen. One thing is professional satisfaction. (Head D&T, L255-258)

Secondly, innovation challenges him to do things differently, and better:

> We always think, "The conventional way of doing things is like this, can it be done better?" We always challenge ourselves. (Head D&T, L281-282)

4.2.2 Active Components in a Construction Innovation System

This section discusses the active components in a Construction Innovation System (CIS) comprising the four Sectoral Innovation Systems' (SSI) themes namely *Actors and Networks, Knowledge Base and Learning, Institutions* and *Demand.*

4.2.2.1 Actors

Almost 90% of innovations undertaken at InnoInfra are initiated by top management (Head D&T, L241-242). This is because the firm's projects are massive in size and require conceptualization of solutions to complex problems. Senior management is not confident that less senior staff have the experience to address complex issues (Head D&T, L241-244).

In InnoInfra, the innovation process starts with an idea. InnoInfra's top management, led by the Managing Director (MD), identifies a problem to be solved. The first formal meeting involves the MD, the Head of D&T and a few staff from the Technical Support (TS) Team, a sub-division of the D&T Department. The MD states the problem and asks if a technical solution is possible. The initial meetings typically involve brainstorming solutions for an identified problem:

> It is the top management who will actually say there's a problem. Top management will involve a few key people from the functional team. (Head D&T, L104-106)
>
> It is teamwork. Top management sets the direction; every member from a different team will provide the necessary input. (Head D&T, L110-111)
>
> Leadership and direction is very important. I greatly respect our MD because the D&T Department only thinks of the technical part, sometimes not on commercial aspects whether the project is viable or not. (Head D&T, L116-119)

Thus, the role of the MD is not only to initiate the innovation. He also provides leadership and direction and assesses the commercial viability of the innovation project, and these roles are important to the innovation team.

Following the initial meetings, the D&T Department explores the potential for converting the idea into an actual design by conducting a feasibility study using internal and external resources. Resources within the company can come from other departments as well as from within the D&T Department.

The D&T Department has 50 staff. Engineering and technical staff have specialist design and design management knowledge in areas related to InnoInfra's operational departments. They include traffic and transportation planners, civil and structural engineers and geotechnical experts.

InnoInfra equates its D&T Department to an engineering consultancy firm. Most team members are engineers with many years of consultancy experience. This wealth of diverse experience has equipped the team to find technically viable solutions. The D&T Department consists of two divisions, the TS Team and the Design Management (DM) Team. The TS Team is the "think tank" that determines the technical viability of the proposed innovation. The DM Team manages project design once the project has been given the go-ahead and been created by the TS Team (Head D&T, L52-53; L116-119).

Feasibility studies are considered part of company R&D. Within the feasibility study, the TS Team considers matters such as costs of land acquisition, land usage to minimize social impact, environmental impact and project constraints. The TS Team conducts site visits and seeks input from other departments, such as Project Management and Construction.

It also consults externally with local authorities on matters such as their requirements, regulations and laws. When the TS Team does not have the expertise, it engages an external consultant to conduct the feasibility study (Head D&T, L164-168). In the infrastructure project related to water supply (not profiled as an innovation of InnoInfra) for example , InnoInfra drew on the previous work experience of a TS Team member:

> The idea came from one of the team members. He knew that there was a possibility of building infrastructure [A] at location [B] from his experience many years ago in his work with the government. Based on the information from the team member, InnoInfra conducted research on the location recommended by the team member. With the team member's information and with InnoInfra's construction experience, the project was delivered six months ahead of schedule. (Corporate Director, L101 -L102)

The technical solution for the ground-breaking flood mitigation infrastructure innovation came from an external consultant:

> We found from consultants that the solution to this would be… similar to that used in a foreign country location which has been in existence for more than 100 years. (Corporate Director, L155-156)

The external consultants engaged by InnoInfra may be foreign or local specialists. Foreign consultants are engaged when the local industry does not have the information required by the contractor. Because InnoInfra does not have enough staff to work on all detailed design, external consultants work on detailed design and less urgent projects, allowing InnoInfra to work on the main conceptual idea of the innovation (Corporate Director, L294-295).

InnoInfra has developed this type of working relationship with one of its consultants over many years, as captured in the following remark:

> Over the past 20 years we have been working with [X] consultants. Our D&T Team works on the idea and concepts and leaves the details to external consultants because we don't have enough people to do the leg work. For work that has more time we send it to the consultants. (Corporate Director, L294-296)

The early part of the innovation process involves many rounds of meetings, but once the D&T Team has established that the innovation is technically viable, the proposed innovation becomes a confirmed project. Subsequent to the initial meetings, input is sought from other departments as and when required, e.g., input on construction methodology and timeline is obtained from the Project Management Department while commercial information is obtained from the Finance Department.

The detailed design stage of R&D involves preparation of a detailed proposal and evaluation of options. It can last between several months and two years and might involve benchmarking with other countries. Proposal development always involves a few dozen in-house people and may involve many others if external consultants are involved. A complex proposal usually costs many millions of ringgit to develop.

The D&T Department "multitasks", as it is involved in project operations at the same time as it is conducting R&D:

> D&T Department works on a multitasking basis, simultaneously developing proposals and overseeing project operations. Its sees the value in this approach as the involvement in operations enables the team to have a perspective on the implementability of any ideas. (Corporate Director, L166-168)

Another actor in innovation at InnoInfra is the supplier. The flood mitigation innovation of the firm required the development of a new machine. In an example of co-innovation, InnoInfra collaborated with the manufacturer to develop a new machine to build the infrastructure (Corporate Director, L241-42). InnoInfra also works with other institutions such as universities and government authorities (Corporate Director, L342-349).

The actors and their roles in innovation at InnoInfra can be summarized as follows (see Table 4.1). The MD initiates the idea and provides leadership and commercial oversight. The TS Team develops the idea by conducting feasibility studies and developing a detailed proposal with input from the whole D&T Department, input from other departments and often with the help of external consultants. The client is not directly involved (Head D&T, L360-361).

Table 4.1: Actors and Roles, InnoInfra

Actors	**Role**
Managing Director	Initiate idea, Direct, Provide commercial oversight
TS Team	Think tank, Idea development
DM Team	Work on project once idea developed
Other departments	Project Management Department: construction methodology
	Finance Department: Finance
External consultant	Details of idea development
Supplier	Co-innovation
Client	No role

4.2.2.2 Networks

The main actors are the MD and the TS Team. The level of interaction between the two internal actors is high because they are the only actors involved in initiation and initial development of the idea before the establishment of the innovation project. The MD has a strong effect and his key roles in leadership and direction are well respected by the TS Team. InnoInfra is highly dependent on external consultants who play a critical role in detailed design of the innovation. The role of external consultants is acknowledged by the TS Team. The level of interaction between the TS Team and the other departments in the company is also high, and the TS Team attributes its ability to innovate to team work throughout the company:

> It (innovation) is team work. Top management sets direction, every member from a different team will provide the necessary input (Head D&T, L110-111)

> The whole innovation is from the whole group including the Project Management team (Head D&T, L53-54).

Interactions between internal actors and government authorities occur only when government authorities' responses are needed.

4.2.2.3 Knowledge Base and Learning

InnoInfra's knowledge base is drawn from five sources: the experience of its staff, references from past projects, new projects, feasibility studies and external consultants. Learning is mainly on-the-job.

To innovate, InnoInfra takes advantage of the experience of its 50 D&T Department staff and their previous work in consultancy firms:

> The members in the functional team are very experienced people because they are consultants before. From this consultancy experience, we know what is required to make the project happen. (Head D&T, L152-155)

InnoInfra also draws on lessons learnt from past projects, technical publication and seminars, but these sources are considered secondary to *hands on* learning and less effective:

> All these help to a certain extent but I don't think that is how people learn. (Corporate Director, L311-315)

The past projects knowledge base consists of records of projects conducted around the world, including the firm's own past projects as lead or sole contractor or as a subcontractor and sources from the Internet. InnoInfra takes the lessons learnt from every project to subsequent projects ensuring continuous improvement (Head D&T, L170-172). The firm's Data Management System stores proposals, final reports, contracts and designs (Corporate Director, L314-315). It sends staff to attend seminars to be updated on new technology and it subscribes to and circulates professional bulletins on a weekly or monthly basis and extracts relevant information from the Internet (Head D&T, L311-317).

The third source of knowledge base comes from new projects. New projects are considered a primary driver of knowledge as they promote new ideas and provide a platform for information exchange and sharing of ideas. This dynamic source is also considered more effective than formal channels of information exchange, such as dissemination and storage of information, which are static:

> The systems, culture, management process in our company are probably very different. Often when we talk about knowledge, we want to talk about dissemination, storage, etc. Over the years knowledge becomes static when there are no drivers, no change drivers. If there is a change driver, knowledge starts to go around very quickly. Knowledge driver is new projects; the driver is always new projects. Without new projects, things will slow down, ideas will not move, not shared. (Corporate Director, L303-306)

Knowledge obtained from information exchange platforms in the course of work on new projects contributes to this third source. Knowledge can be found in exchanges from external and internal meetings, electronic communication, Internet sources, site visits and tools like engineering designs, pictorial and graphical information, study visits and talks with clients (Corporate Director, L311-e12).

The fourth and fifth sources of knowledge base are feasibility studies and external consultants. These two sources were discussed in the previous section, *Actors and Network*.

Three channels of on-the-job learning are used by InnoInfra: placement, mentoring and management training. Staff may be placed in a project implementation team or in the office of an external consultant (Head D&T, L303-306). Staff placed with external consultants are able to learn more about detailed design enabling them to provide better comments on designs in their future work for InnoInfra (Head D&T, L230-238).

Staff placed in a mentoring program:

> can learn from experienced staff through interacting and watching what others are doing, observing how to solve problems, also learning from solving problems together. (Corporate Director, 317-318)

Staff whose work is mainly technical learn management skills when other staff involve them in meetings with external parties (Head D&T, L217-225). The purpose is to learn how to manage interactions with staff from other departments and deal with clients and government authorities. InnoInfra reinforces this learning through a Key Performance Indicator (KPI):

> For example, in submitting a design, we must get approvals. One of our KPIs for design is it must meet all the project requirements, it must come with approval (Head D&T, L224-25)

InnoInfra considers on-the-job learning more effective than structured training because staff learn from reality, which may be different from what is learnt in the formal environment of structured theoretical learning:

> When a new engineer joins a project, he is given an induction program whereby he is given an overview of a project he will be involved in and assigned specific work tasks. He will go through some structured training. It is nice to follow the theory but theory can be very different from reality. (Corporate Director, L316-321)

The sources of *Knowledge Base and Learning* at InnoInfra are both internal and external (see summary in Table 4.2). Internal sources are the work experience of the firm's staff – both past experience and on-the-job learning, feasibility studies, internal records of the firm's and others' past projects, internal seminars and publications and knowledge and ideas developed in new projects. External consultants act as the primary external knowledge source, both through placements (external on-the-job learning) and the knowledge they use in preparing detailed design. External knowledge sources also include benchmarking, the Internet and external seminars and publications.

Table 4.2: Knowledge Sources and Actors, InnoInfra

Knowledge Source	**Types**
Internal	Work experience
	Feasibility studies conducted
	Documents: past projects, technical publication
	Seminars
	New projects
	New project ideas and records of knowledge exchange
External	Placement in external consultants office
	External consultants detailed work

4.2.2.4 Demand

InnoInfra often innovates by initiating an infrastructure project in a proposal to a future client, i.e., the firm makes a proposal to the client even though the client has not expressed a demand for the infrastructure. For InnoInfra, the client that is not open and rejects innovation, also kills the innovation:

> the mindset of the client which cannot accept things are not done conventionally; hence the client becomes sceptical and dares not try the innovation. (Head D&T, L342-344)

The length of time taken by clients to accept InnoInfra's proposed innovations can also be an impediment:

> Decision making and approvals by the client are among the most difficult. It takes around two years from the initial proposal to project award by the client (Corporate Director, L159-60)

Three factors contribute to the long time between proposal and award. Firstly, many stakeholders are involved and time is needed to align their views. Secondly, the innovation more often than not involves heavy investment. Lastly, clients need to consider complex issues such as environmental and social impact and compliance with laws and regulations.

4.2.3 How Institutions Regulate Actors' Conduct

Institutions act as both positive influences and as impediments to regulate actors' conduct in InnoInfra. This section treats the positive influences before examining the impediments.

4.2.3.1 Positive Institutional Influences

InnoInfra attributes its growth from a subcontractor to a publicly listed main contractor to the firm's entrepreneurship and the Malaysian government's privatization policies:

> A lot of value has been added over the years. We think that has been due to the fact that we look at the business opportunities in radically different ways. We were also helped very much by the wave of privatization that was happening in those days. That opened up a lot opportunities and a lot of companies joined in the band wagon. (Corporate Director, L8-11)

The evolutionary effect is seen in the evolving human resources structure for InnoInfra's D&T Team. As business needs changed a more technical team was needed to create more value-added projects rather than merely construction projects:

> When I first joined, there were only a handful of us … after we got our very first project, that time our technical team was very small, less than 10 people. And from there, we got several projects. It grew from the need to value add from the straightforward projects to construction. It was in the early 90s when we bid for a project, we value added to the project by providing a lot of innovative design and because of that we won the project. The management could see the superior value that we could add to the design. The structure grew and evolved itself, from project needs, to create the projects. (Head D&T, L74-87).

InnoInfra attributes its innovation success to four institutional influences: leadership; a culture of knowledge sharing and innovation with strong human capital in terms of number, experience and expertise; trust and collaborative practices with its external consultants; and collaboration with institutions.

> Leadership is seen in actors at two levels. The role of the MD has already been described. Leadership is also seen in the D&T Department where the two Section (Team) Leaders and the Head of Department deliberately drive a knowledge sharing culture (Head D&T, L273-274).

The culture of knowledge sharing is itself an institutional influence. This includes experience shared by and among expatriates and experienced staff to ensure continued development of knowledge. The drive to share knowledge is considered an important characteristic of professionals and a necessary prior condition for innovation (Head D&T, L275-277). In addition to their direct involvement in driving the culture of knowledge sharing, senior management supports and actively promotes an innovation mindset through on-going investment in learning programs: InnoInfra's Group Vision Statements and Values Statements directly refer to innovation and continuous improvement (Corporate Director, L395-397, L400-401).

The third institutional influence is InnoInfra's human capital. The substantial influence of the large and experienced D&T Department on innovation is particularly evident when innovations draw directly on the previous work experience of a team member, as described in Section 4.2.2, *Actors*. The Corporate Director of InnoInfra is aware that having good technical people who understand engineering problems is an important aspect of the firm's ability to innovate (Corporate Director, L17-18). The firm places strong emphasis on the development of its human capital, as indicated by its efforts and investments in learning and development (see Section 4.2.2, *Knowledge Base and Learning*). These not only develop staff capacity to undertake new projects (Corporate Director, L184) but also instil organizational commitment as part of the firm's staff retention program (Head D&T, L206-207).

The fourth institutional influence, trust and collaborative practices, can be seen in three ways among three groups of actors. Firstly, there is a high level of team work within InnoInfra: the TS Team attributes its ability to innovate to team work across the whole company. Secondly, trust and collaborative practices between the D&T Department and external consultants, developed through many years of working together, are so strong that a consultant's proposed solution to its two-in-one flood and traffic tunnel innovation can be accepted (see Section 4.2.2, *Actors*). Thirdly, InnoInfra will co-innovate with suppliers, as it did when it worked with a manufacturer to develop a new machine in its “two in one” flood mitigation infrastructure innovation see Section 4.2.2, *Actors*).

Another institutional influence is in InnoInfra’s collaboration in its flood mitigation infrastructure innovation, with three institutions namely the universities, training institutions and government agencies. An example of university cooperation is the firm’s cooperation with a European university to test material formulations for the new machine used for innovative infrastructure construction. InnoInfra studied construction skills programs and training institutions in three countries to set up its Plant Operator School (Corporate Director, L344-345). Thirdly, it introduced a construction quality system with the construction authority of a neighbouring country (Corporate Director, L346-347).

4.2.3.2 Institutional Impediments to Innovation

InnoInfra identifies two impediments to innovation: the work and cultural orientation of staff in the form of the mindset of staff, and the Malaysian government rule on the construction industry’s *build* procurement system.

InnoInfra considers the negative mindset of some staff as the main impediment to innovation. *Negative mindset* refers to the thinking that the innovation is not possible because it has not been done before or it is outside the staff member’s comfort zone (Corporate Director, L86-89).

> When top management proposed Innovation [S], the first response was that it is impossible to be done... Unconsciously, we sometimes think that it cannot be done because it had not been done before. (Corporate Director, L114, L150)

InnoInfra overcomes the negative mindset by showing that the innovation can be developed. The top management's role in motivating staff and providing resources for the innovation are important strategies in this regard.

Another institutional impediment is the government's rules for the Malaysian construction industry's *build* procurement system. The need to comply with these rules tends to make both clients and their consultants more conservative and not interested in innovation. This is in contrast with the *design and build* procurement system "which frees owners to think innovatively and to use the best technology" (Head D&T, L294-295).

4.2.4 Overview of Institutional Regulation of Innovation

Institutional regulation of actors' conduct of innovation at InnoInfra is therefore strong and widespread, as can be seen from the summary in Table 4.3. The institutional factor is seen from the impact of InnoInfra MD's entrepreneurship as a form of corporate organization and the Malaysian government privatization policy that contributed to its growth. Institutional influences consisted of leadership as an in-house command, internal team teamwork and the culture of knowledge sharing and innovation as forms of shared cultural orientations, the strengths of its human capital in number, experience and expertise, trust and collaborative practices with its external consultants, collaborative practices with its manufacturers, the role of meso-organizations such as universities, training institutions, government agencies on human capital development. The institutional impediments consist of the work and cultural orientation of staff in the form of the negative mindset of staff and the Malaysian government's rule on the construction industry's *build* procurement system.

Table 4.3: Institutions and Their Role, InnoInfra

Role	**Type of Institutions**	**InnoInfra Examples**
Company Growth	Corporate organization Government policies	Entrepreneurship Privatization policy
Influence	In-house command	Leadership
	Shared cultural orientations	Internal team teamwork; Culture of knowledge sharing and innovation
	Human capital	Strengths of human capital in number, experience and expertise
	Trust and collaborative practices	external consultants
	Collaborative practices	Manufacturers
	Role of meso-organizations on human capital development	Universities, training institutions, government agencies
Impediments	Cultural & work orientations	Negative mindset of staff
	Government rules	*Build* procurement system

4.2.5 How Organizations Connect Institutions and Firms to Support Construction Innovation

No instruments to support construction innovation could be identified in the InnoInfra case. The Head of D&T suggested provision of monetary incentives for innovative companies, e.g., any cost savings from innovation on the awarded build contract sum could be shared between the client and the contractor (Head D&T, L338-341). He also suggested that government policies should facilitate the implementation of new ideas and foster creativity. Appropriate action could take the form of access to capital and revision of laws, regulations and policies that hinder innovation. However, the focus would need to be on the *implementation* of innovation because that is “where the benefits can accrue” (Corporate Director, L371-373).

4.2.6 Interactions in the Construction Innovation System

The innovations developed in InnoInfra are primarily business practices in the form of business strategy and business contracts; technical innovation is limited to creative adaptation and application of known solutions. Ideas for innovations originate with the main actors and are developed with external consultants using the consultants' existing technology; suppliers occasionally participate in co-innovation. As InnoInfra's innovations concern large-scale construction infrastructure, innovation is complex and the innovation cycle is long, taking up to one year. The firm's business evolved from subcontractor to main contractor as the result of an institutional change with the introduction of the Malaysian government's privatization policy, as well as the entrepreneurial leadership of its MD.

The main actors in innovation at InnoInfra are the MD, the D&T Department, other departments involved in planning and construction and external consultants. The level of interaction and interdependence among all these actors is high. Clients are not directly involved in providing input to innovations and are slow to make decisions that involve innovation. InnoInfra's main knowledge source is its main actors, particularly the D&T Department, through the big staff strength and experience and new knowledge gained through the preparation of feasibility studies, and external consultants. Learning is fostered by placing staff in project implementation teams and the offices of external consultants. The company formal training plays a role but informal and practical knowledge are considered more important than formal and theoretical knowledge. New projects are seen to be the driver of knowledge creation and exchange, the opposite of other sectors where the knowledge base acts as a driver to develop new projects.

Institutions regulate actors' conduct in the construction innovation system by acting as influences and impediments to innovation. Positive institutional influences are: in-house command (leadership), shared cultural orientation (internal teamwork; culture of knowledge sharing and innovation; company organization in terms of human capital (number, experience and expertise); trust and collaborative practices (external consultants); collaborative practices with suppliers; and role of meso-organizations - such as universities, training institutions and government agencies – in human capital development. The two impediments are work and cultural orientation in the form of negative staff mindset on innovation and the Malaysian construction industry's build procurement system. Several characteristics of the construction innovation system motivate InnoInfra to innovate. They are identification of a commercial problem or issue that can be solved through innovation; the need to be competitive; and the leadership of actors at two levels, namely the entrepreneurship of the MD, and the drive of the Head of D&T for continuous improvement and professional satisfaction. No instruments support innovation, although instruments that might support future innovation include monetary incentives for companies which innovate and government policies to facilitate new ideas and foster creativity.

Interactions between the active components of the SSI in InnoInfra's construction innovation system can be seen in several forms. The main source of knowledge base comes from two actors (channels), the D&T Department and external consultants. The D&T Department is important because of its size, expertise, multi-disciplinary nature and function as the group which conducts feasibility studies, a form of R&D for the company. Thus, it is the source of technical knowledge for innovation while other actors mainly provide applicable or functional knowledge such as project management and costing.

The interactions between actors and networks and institutions are seen in the different types of institutions which affect innovation at InnoInfra. Firstly, the MD especially his entrepreneurship skills and government policies drove company growth. Secondly, institutions in the form of in-house command, shared cultural orientation, professional competencies, trust and collaborative practices enable innovation. InnoInfra's collaborations with meso-organizations – universities, training institutions and government agencies – both contribute technical expertise and develop the firm's own human capital. On the other hand, the negative mindset of staff toward innovation and government's procurement system regulations act as institutional impediments and there are no government policies or incentives to encourage innovation. The active components of the SSI and motivators for innovation in InnoInfra are summarized in Table 4.4. The interactions amongst the components and motivators are represented graphically in Figure 4.2.

Table 4.4: Active System Components and Motivators of Innovation, InnoInfra

	Component	**Findings**
1	Type of Innovation	Business practices in form of business strategy and business contract; occasionally technical
2	Actors and Networks	MD, D&T Department, other departments, external consultants High level of interaction between all actors High level of interdependence between main actors
3a	Knowledge Source	Staff experience, feasibility studies, external consultants, past projects
3b	Learning	Placement of staff in project implementation teams, in the offices of external consultants and through the mentoring program.
4	Institutions	Influence: shared cultural orientation, *human capital,* trust and collaborative practices, collaborative practices, role of meso-organizations on human capital Impediments: Work & cultural orientations, government rules
5	Client	Not directly involved
6	Motivators for Innovation	Solutions to a commercial problem or issue; for competitiveness; positive effects of actors

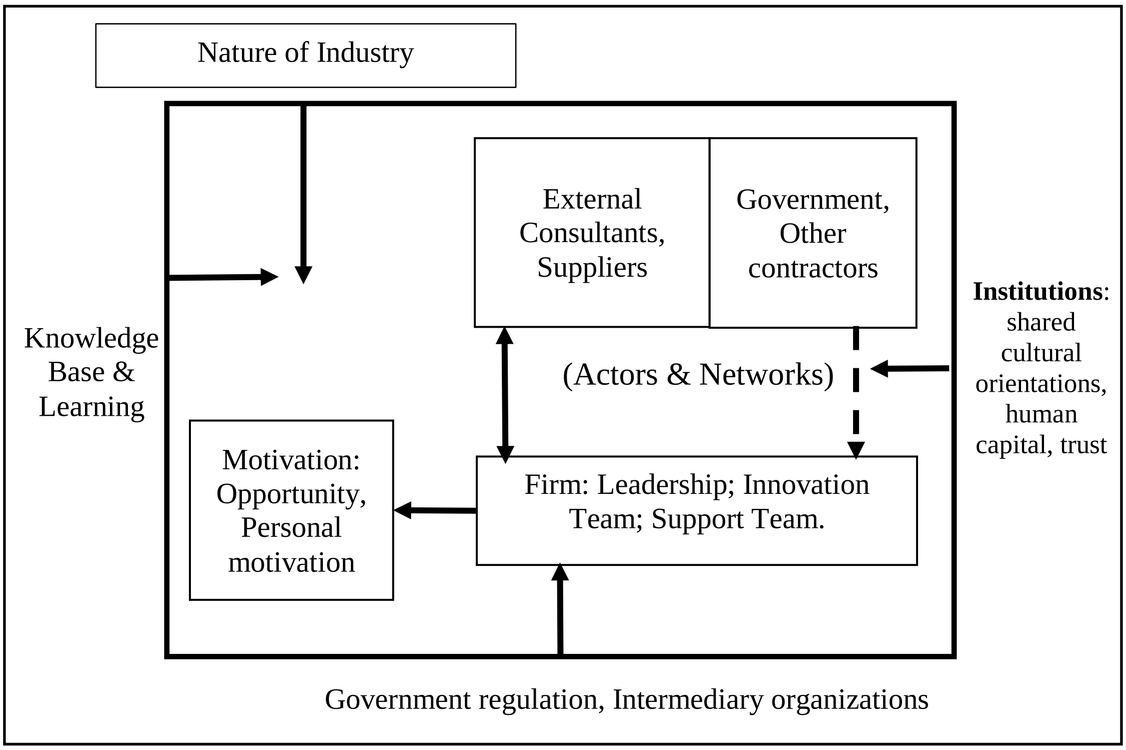

Figure 4.2: Interaction between Active System Components and Motivators, InnoInfra

4.3 InnoInfo: Construction Sub-Sector, Building Commercial

4.3.1 Background

InnoInfo is a civil engineering and building construction company. Its construction projects are large-scale and located across the globe from Malaysia to Singapore, China, India, United Arab Emirates and Trinidad and Tobago in the Caribbean. Its parent company is a publicly listed company with an annual turnover exceeding USD1.8 billion with a global presence in countries all over the world. The core business of the holding company is property and construction, but its diverse businesses are in several industries including property development and investment, building materials, trading, manufacturing, quarrying, leisure, hospitality and entertainment, healthcare and higher education. It has land assets located in diverse geographies in Malaysia, Singapore, China, India and Australia. InnoInfo delivers about 30% of the Group's development projects.

The actors involved in innovation at InnoInfo are summarized in the partial organization chart provided in Figure 4.3.

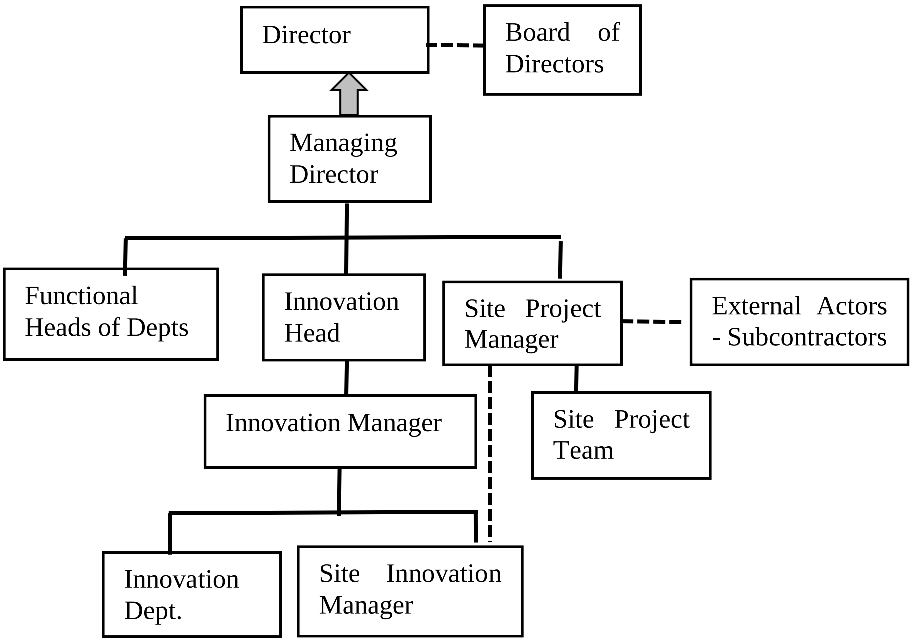

Figure 4.3: Organizational Chart of Actors in Innovation, InnoInfo

4.3.1.1 Description of Innovation

InnoInfo's innovation is an integrated collaborative building modelling and project management platform. It is a *5D system*, which combines software tools for building modelling with tools for project management through all stages of the project. The purpose of the innovation is to streamline the entire construction project lifecycle for construction project implementation (Innovation Head, L96-99).

The innovative platform is a software system comprising third, fourth and fifth dimension software tools. The third dimension (3D) enables digital modelling so that architectural, structural, mechanical, electrical and plumbing consultants can identify design clashes and improve design coordination. The fourth dimension (4D), time, provides a master development programme, assessment of constructability input through construction simulation, time-progress monitoring and field implementation and monitoring. The fifth dimension of cost provides a view of overall costs for the purpose of cost control. The features of the 5D system enable progress and performance management against time and cost, provide early identification of potential problems and conflicts and improve coordination and working relationships with subcontractors.

4.3.1.2 Origin of Innovation

InnoInfo's innovation was borrowed and adapted from other sectors to meet the firm's project objectives. The 3D software tool for building modelling was originally developed to improve information exchanges between stakeholders and allow scenario simulation and analysis at an early stage in the design process. InnoInfo took an existing software tool and customized it to its own company processes. Customization is required because each company has its own processes, even though they may use the same tool:

> You will not find two organizations implementing the software tool the same way. The tools may be the same. If you want to implement a software tool, there are bound to be company processes which need customization. (Innovation Head, L52-54)

> [The adopting firm] does not need the original technology but just needs to know how to apply it to meet its needs. (Innovation Head, L108-109)

In the construction industry, the building modelling tool was prevalent among architects after being developed by an Israeli architect to build his own house. His tool eventually evolved into software that was bought by a software firm. The software is used in the US and Europe. It is less popular in Australia but its usage is increasing in Hong Kong, with China catching up and the Singapore government making it mandatory in 2013. Even though the usage already quite widespread in the global construction industry, it was less common in Malaysia. Nonetheless, InnoInfo decided to adopt the tool after a foreign contractor presented it to its Group Chairman:

> an idea using an advanced software for them to visualize [the idea]. (Director, L199)

The software had its origins in the product life cycle management (PLM) systems used in the automobiles, electronics, and manufacturing industries. PLM systems coordinate the entire process and the multiple actors involved in these industries through a centralized information database (Innovation Manager, L20-27). The innovative design and development of the 5D system commenced in 2010, with design substantially complete and development on-going at the time of interview (Innovation Head, L85).

4.3.1.3 Motivation for Innovation

InnoInfo is motivated to innovate to address commercial problems and due to the positive effects on its main actors, as discussed in this section.

Problem-Centric Motivation for Innovation

InnoInfo innovates to gain competitive advantage because the firm is not otherwise differentiated in the construction industry, which is seen to have a fragmented supply chain:

> Why do we need to innovate software [A]? Because we don't have obvious competitive advantage and we are not differentiated. We are so fragmented, our supply chain is different. (Innovation Manager, L35-37)

In the past, members of InnoInfo's workforce, in common with the workforce of the construction industry as a whole, did not require professional qualifications. Its low level of human capital meant that InnoInfo's staff did not always take a professional approach to problem solving and was not sufficiently competitive. The firm was not able to attract new talent:

> The older generation of construction workers does not need qualifications and bangs tables [is less professional] in their work – this needs to change. Using IT is not to impress talents but overall in an industry we must be more competitive. (Innovation Manager, L66-68)

The innovation, which provides competitive advantage to InnoInfo, will enable the industry to remunerate talent. This will then attract talent to join the company, an important factor in ensuring its competitive advantage. Overall, according to the Innovation Manager, the construction industry has not been able to attract talent due to its negative image of being “dirty, dangerous and difficult” as well as the less than professional behaviour of older generation construction workers. He expects the innovation to provide a more positive branding of the industry which will, in turn, enable InnoInfra to attract higher calibre human capital to the company.

Productivity

InnoInfra is also motivated to innovate to improve productivity in order to address four problems. The first is the lack of timely information, which inhibits informed decisions and thus leads to additional costs and delays:

> decisions are often compromised and lead to some 10-20% time and cost overruns. (Director, L46-47)

The second problem is a lack of collaboration and coordination amongst stakeholders at the early stage of construction when the ability to control costs is higher and the costs of design changes are lower. The lack of alignment amongst stakeholders further compounds the problem (Director, L53-58). Thirdly, inefficient information exchanges between parties in construction projects that are in 2D or hardcopy formats cause rework and risk loss of accuracy (Director, L58-63, Innovation Head, L16-17). Fourthly, existing work tools and processes are unable to meet the needs of increasingly complex work and compressed time schedules as well as pressures to lower costs and increase productivity (Director, L50-53).

The main cause of these problems is the fragmented nature of the industry. Fragmentation is seen in the involvement of many players in any project:

> easily, there can be 100 people [with] different roles and responsibilities without alignment [and] conflicts of interests. (Innovation Manager, L118-120)

> Clients can be one time off to own certain facility [i.e., once only or regular clients]. Consultants that advise developers generally want to make monies, want to finish the job within their budget, specifications and time frame. We (contractors) want things fast. Consultants charge based on the time in designing [and have] no motivation to minimize design time. Subcontractor scope is smaller and they are specialists. All players' motivations are different. Their motivation is still time and cost. The different role and responsibilities tend to make them draw a line, e.g., this is my liability then this is my problem. (Innovation Manager, L102-104; L108-114)

The four problems are seen to cause inefficiency and ineffectiveness in the construction industry:

> We are not effective (Innovation Manager, L100-101) [and] have the lowest productivity compared to manufacturing. (Innovation Manager, L41-42)

InnoInfo was thus motivated to develop the 5D innovation to achieve high productivity, like the manufacturing sector where PLM originated:

> Manufacturing high productivity as model PLM is the way to go (best possible solution) that we think manufacturing has high productivity and construction has the lowest productivity so we want to relook and ask why it is that way for us. (Innovation Manager, L40-41)

InnoInfo's motivation to improve productivity is linked to its motivation to obtain competitive advantage. This is because low productivity further affects competitive advantage and branding:

> Maybe, at the end of the day, your gains are in terms of your branding and in terms of your differentiating between your competitors. When we were in Abu Dhabi, we were asked can you do [X]. We went home two years without any answers. But today we can answer; we are not the experts but we are able to deliver something. (Innovation Head, L223-226)

The interaction between the problems caused by the nature of construction industry and InnoInfra's motivation to innovate is summarized in Figure 4.4.

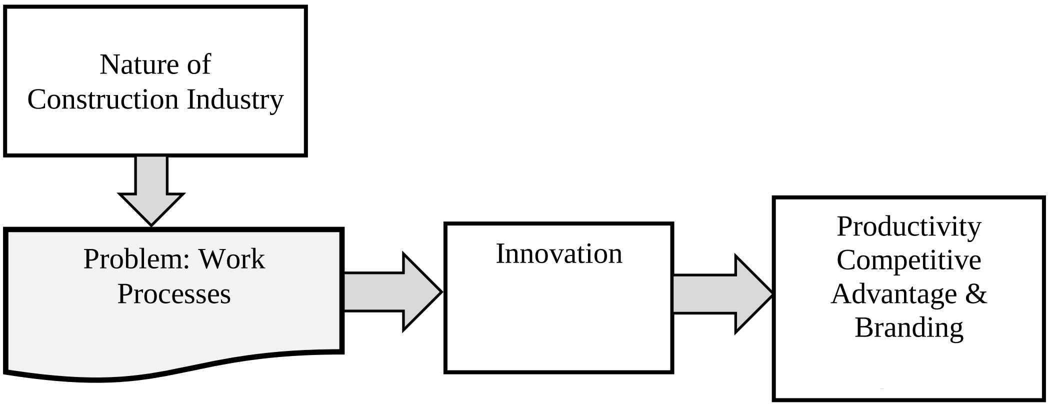

Figure 4.4: Motivation of Firm to Innovate, InnoInfo

Positive effects of actors and networks

InnoInfo's third motivation to innovate is drawn from the positive effects of its actors in the form of the high level of commitment of its top management. In InnoInfo, the existence of a visionary and committed top management drives innovation. Innovation is driven from the top by the Director, through his vision for a virtual construction system, with the support of the company's Board of Directors:

> He had always had dream of having something like virtual construction to be implemented. (Innovation Manager, L206-207)

The Director is a believer in information technology who has experience in customization. He strategized to keep R&D alive in the company by creating a R&D team. He also sits in the Board of Directors and garners their support. The support of the Board of Directors is evident from their allocation of resources to the innovation. This evidence of support was echoed by the Mechanical subcontractors:

> More importantly the developer is committed because the innovation costs lots of money. (Mechanical Subcontractor, L6-8)

and the Site Team:

> The resources are not cheap, so the management itself will have to be committed, willing to spend much money on R&D. (Site Project Team Member, L83-84)

Board support is important, not only because the R&D of innovation involves a lot of money, but also because there is negative return in the first few years:

> If at company level you are making RM[XXX] million and RM[X-X] million is in R&D, the question mark is that are we spending the right way. But in technology advancement, the first few years are always negative not positive. (Innovation Head, L221-223)

The top down vision serves as an important motivation for InnoInfo:

> You really have got to have top down vision, and enforcement mandatory all the way from the top. (Innovation Head, L45-46, 48-50)

4.3.2 Active Components in a Construction Innovation System

This section discusses the active components in a Construction Innovation System (CIS) comprising the four SSI themes namely *Actors and Networks, Knowledge Base and Learning*, *Institutions* and *Demand.*

4.3.2.1 Actors

The main actors in innovation at InnoInfo are the firm's Director and its innovation team. Three other actors are top management in the form of the Board of Directors, the internal and external users of the innovation and the client. The internal users are other departments in the company. The external users are the external consultants and the subcontractors who use the innovation. The client is InnoInfo's parent company, which is indirectly involved in the innovation. The roles of these actors are discussed in this section.

A foreign contractor introduced the innovation to InnoInfo's parent company top management attended by the top management of InnoInfo, the Director and an Information Technology (IT) Manager. The Director, as a believer and experience in technology development, had long dreamt of implementing virtual construction. Both the Director and the IT Manager had previously worked together on the development of a new software for the company. With his beliefs, experience and vision, the Director seized the opportunity to innovate when presented with the innovative idea by the foreign contractor. He initiated the innovation with the IT Manager, who later became the Innovation Manager. Despite prior restructuring in InnoInfo, the Director had the foresight to continue with R&D in the company, and this later translated into an Innovation Department with full-time R&D staff, an integral part of the innovation:

> The Director said that since IT staff had been transferred to IT shared services their roles had changed; shared services are not motivated to do. He had always thought that there's so much innovation of R&D that we should be looking at it as a company. (Innovation Manager, L217-218; L220-221)

The innovation then had to be approved by InnoInfra's Board of Directors as it involved investments which are "heavy, long-term and … continuous" (Innovation Head, L71-72). InnoInfo's top management believes that quick buy-in is an important factor in ensuring the success of the innovation because of the need for substantial resources and investment:

> If the company does not have buy-in from the top, the whole thing may not work. To work on something like this, you have to put in the resources, much money, investments and hiring of so many people. (Innovation Head, L71-72)

After the initial development of the idea by the Director and the Innovation Manager, a Design and Technical (D&T) Team consisting of the Head of D&T and two D&T professionals were nominated to develop the innovation. The Head of D&T was later appointed the Innovation Head and the D&T professionals absorbed into the Innovation Team. The D&T was chosen as the Design and Technical staff would be the first users of the innovation. At this stage of development, the Innovation Manager provided a breadth of knowledge and experience while the D&T Team worked on the details of the innovation and provided ideas from the users' perspective. An example of the difference in roles is that the Innovation Manager conducted R&D on available software tools, consultants and directions in the market whereas the D&T Team tested, adopted, customized and provided feedback on the tools.

In the first year of the innovation process, staff from other departments worked on the innovation on a part-time basis, juggling the innovation work with their own work. By the time of interview, three years into innovation, the Innovation Department comprised a team of 30 young individuals with design and field experience ranging, inter alia, from 3D modelling in all major trades to project planning, quantity surveying and IT development (Innovation Head, L210-212). This Innovation Department worked full-time on developing the innovation and on implementation and user training:

> what we should and how should we do it, how do we train people to use it. (Innovation Head, L92-5)

The Innovation Department is led by the Innovation Manager, under the supervision of an Innovation Project Leader.

Internal and external users receive training to use the innovative software. The nature of the training is personal and intensive. For example, the mechanical subcontractor places a staff member in InnoInfo's office to learn the full operation of the software by learning from "hand-holding" (Mechanical Subcontractor, L190-195). A lot of meetings are held with the subcontractors in the project site office to obtain users' input to the innovation (Mechanical Subcontractor, L200-201). InnoInfo emphasized the importance of collaboration with external users to make the innovation work because different external users look at different aspects of construction:

> Architecture, for example, only models finishes not the concrete element, e.g., for table you will have lamination, only architecture will not model what's below the lamination, whereas the structural and mechanical electrical and planning will look within and below the lamination. This means the three trades are looking at different things. Without collaboration, it won't work. (Site Innovation Manager, L22-26)

In the development stage, at the time of interview, InnoInfo suffered from buy-in issues from various actors: internal staff and external consultants from the architectural and structural disciplines. The only external parties involved are participating mechanical and electrical subcontractors:

> in the contract, they are supposed to build 3D, but they can't do it yet so we are guiding them. (Site Innovation Manager, L47-49)

External consultants were expected to work along with the Innovation Department to develop the building model for the innovation (Site Project Manager, L60-61). However, they did not collaborate for two reasons: firstly, the work is considered additional to the project contract and, secondly, the external architectural consultants faced time limitations:

> Because of this additional work and this work is not spelt out in the contract for the consultants. We invited the consultants of the three trades to provide the 3D drawings but because the consultants have other projects, not enough time and there is no additional fee, they declined to collaborate. Only the mechanical and electrical subcontractors are involved (Site Innovation Manager, L30-33).

In summary, the actors in InnoInfo's innovation began with the Director, who initiated the innovation with the Innovation Manager and the firm's Board of Directors, which made the decision to invest in and allocate resources to the innovation. The idea of the Director and the Innovation Manager was further developed by key people in the Innovation Department, drawn initially from the Design and Technical Department and led by the Head of Design and Technical. This initial small part-time team evolved into a substantial workforce of 30 full-time staff. The internal users consist of the project site office and other departments including the Design & Technical Department and the external users consist of subcontractors that play the role of testing the applicability of the innovation. The external construction consultants and architects, did not participate in the innovation. InnoInfo sourced software from software providers but did not engage a technology solution provider or consultant for this innovation. The actors and their roles are summarized in Table 4.5.

Table 4.5: Actors and Roles, InnoInfo

Actors	**Role**
Director	Initiate idea, strategize R&D
Top management	Allocation of resources
Innovation Department	Idea development
Project site office	Application as internal users
Other departments	Application as internal users
Subcontractors	Application as external users
Client	Applicability of innovation
Software providers	Provide software

4.3.2.2 Networks

The level of interaction between the main actors, the Director and the initial Team members consisting the Head of D&T Dept. and two D&T professionals (before it became Innovation Department) was particularly high because the Director and the Innovation Manager were the only actors involved at the initiation and initial development stages of the innovation. The strong support of top management and the existence of a dedicated R&D team are considered two of the critical success factors for innovation at InnoInfra:

> We work hand-in-hand with the management and [have a] dedicated team. (Innovation Head, L87-89)

The level of interaction between the Innovation Department and internal departments and participating external subcontractors is high because innovation is deemed to require the efforts of all actors:

> No point having very strong say from the management "I want to do" and the executors don't want to move. It won't move as well. (Innovation Head, L59-62)

Collaboration with external users is important because external users provide input on different aspects of construction. Thus, time and effort are spent on human capital development initiatives (detailed under *Knowledge Base and Learning*) to improve the collaboration with both internal and external users.

4.3.2.3 Knowledge Base and Learning

The three main sources of InnoInfo's knowledge base are the experiences of the Director and the Innovation Manager, the R&D conducted by the Innovation Department and the practical experiences of the internal and external users of the innovation. Learning comes from the firm's human capital development initiatives for its internal and external users.

Both the Director and the Innovation Manager had experience implementing a new information system geared towards the manufacturing industry in the 1990s; extensive customization was needed to meet the firm's requirements (Director, L189-192). The Director had the foresight to continue with R&D in the company and this later translated into R&D becoming an integral part of InnoInfo's innovation capacity. The Innovation Manager started the R&D for the innovation from scratch without relying on any external consultant. Instead, she conducted her own research:

> with information obtained from conferences, talking to people, and site visits in Norway and Germany and the US. (Innovation Manager, L60-62)

InnoInfo conducts R&D for three reasons. Firstly, when the innovation is something that no-one in the company has experience of; secondly, when it does not have an external party guiding them in the innovation. Thirdly, R&D is needed for testing the innovation:

> In our company, R&D means no-one of us has dealt with this before. Nobody is holding our hands to do it, so we would like to test it, like to do some R&D. (Innovation Head, L90-92)

At the time of interview, InnoInfo's Innovation Department had 30 full-time multidisciplinary R&D staff and had conducted in excess of 600 training man-days and invested several RM million in computer hardware and software (Director, L215-216).

R&D is conducted in a structured and focused way compared to the as-needs basis of the past (Innovation Head, L97-98). R&D work was initially trial and error with the

R&D team "knocking into a lot of walls" (Innovation Head, L90). InnoInfo still considers its knowledge base to be very fragmented and in the process of being built from the innovation. It sees this new knowledge base as eventually being its competitive advantage (Innovation Manager, L151-155). The firm's vision is to eventually have standardization of models for its building work (Innovation Head, L132-133).

Knowledge sources at InnoInfo are summarized in Table 4.6.

Table 4.6: Knowledge Sources and Actors, InnoInfo

Source Type	Actor	Knowledge from
Internal	Director & Innovation Manager	Previous innovation experience
	D&T Team	R&D
	Internal users	Practical experience
External	External users	Practical experience

4.3.2.4 Demand

InnoInfo is both the contractor and the client for its innovation, in the sense that the innovation will be used by InnoInfo to manage its own construction work (including development construction for its parent company). This results in ready client acceptance and InnoInfo acknowledges that it is able to implement its innovation because it is both the contractor and the client (Site Project Manager, L57-58). The company nonetheless plays an important but indirect client role in accepting the innovation: after development work is completed, InnoInfo engages specialists to audit the innovation to ensure that the software and methods conform to best practice. The innovation is then implemented by involving users from other departments and external subcontractors.

4.3.2.5 Institutions

In terms of the firm's context, InnoInfra's innovation needs to be customized and integrated into company processes, which are best understood by the company itself:

> We have work processes which others may not be practicing. So it depends on our R&D to ensure what is applicable to us (Innovation Manager, L194-195).

> Our people know our processes best. Internally, we have to customize and integrate ourselves. (Innovation Manager, L173-174)

The innovation process comprises research, integration to company processes, testing and user training:

> We research, integrate and test, make sure it is properly implemented, end users get properly trained. (Innovation Manager, L175-176)

Innovation caused changes in InnoInfo as well as in its electrical subcontractor company's organization. InnoInfo changed work processes, usage of human capital and knowledge base. In terms of work processes, InnoInfo faced "a lot of firefighting prior to the innovation "as there was no initial planning involved" (Innovation Manager, L145-148). With the innovation, there is

> streamlining of work with external consultants [and] subcontractors resulting in less firefighting, reduction in unnecessary work and improved productivity. (Innovation Manager, L150-151)

Productivity at InnoInfo has improved because experienced staff that were used to "fire fight" can now be "leveraged" to do more productive work (Innovation Manager, L181-183). Thus the changes in work processes from the innovation translated into a change in the usage of human capital, resulting in higher productivity.

The new work processes have also brought about an improvement in the firm's knowledge base. Prior to the innovation, the knowledge base was fragmented and referred to old work processes. With the innovation, a new and organized knowledge base of new work processes is being created.

The business processes of clients also change as a result of implementing the innovation. Quicker revenue generation is expected from planning, analysis and simulation at the early stages of project development, which reduces time lag between feasibility and execution. (Director, L111-112)

The software enables "forecasting of cash flow with higher accuracy", thus reducing project financing costs for clients (Director, L111-119).

The innovation improves quality control for subcontractors, improving productivity:

> The innovation allows for problems to be resolved at an early stage of project development as well as better quality control, resulting in higher work productivity (Mechanical Subcontractor, L107-110).

It also develops the subcontractors' knowledge base and human capital:

> The training of [our] human capital in the innovation systems develops [our] staff in terms of equipping them with knowledge [and] building their creativity, resulting in more efficiency and higher quality of work. (Mechanical Subcontractor, L169-170)

Ultimately, these two aspects are expected to result in positive branding to the subcontractor's customers:

> When I present to my customers in 3D drawings, I will impress them. (Mechanical Subcontractor, L128-129)

The case of InnoInfo shows the importance of institutions in explaining organizational changes in both the company and a subcontractor firm.

4.3.3 How Institutions Regulate Actors' Conduct

4.3.3.1 Positive Institutional Influences

InnoInfo attributed its innovation success to four institutional influences, namely leadership, trust and collaborative practices with its internal team and subcontractors, its research and development effort and financing.

The institutional factor, leadership, is evident in InnoInfo with the Director having a large effect through his vision for the innovation and as its initiator and supporter. His leadership is further strengthened by his personal characteristic as a believer in technology, which kept R&D alive in the company. His beliefs, abilities and strategy for the company played an integral part in the innovation.

The institutional factor, trust and collaborative practices with the firm's internal team and external subcontractors, is seen from InnoInfo's emphasis on the importance of collaboration with external users because different users look at different aspects of construction. Much of the firm's time and effort are spent on initiatives to improve collaboration with internal and external users.

Another institutional factor is the company's organizational structure, specifically its Innovation Department, consisting of a large (30 people) dedicated, multidisciplinary, full-time R&D team with design and field experience, which is uncommon in the construction industry. The strength of InnoInfo's knowledge base is derived from its R&D team and the practical experiences of its internal and external users.

The institutional factor, finance, is seen especially in financing of human capital development initiatives for internal and external users as well as for staff recruitment, training and retention programs (Director, L294-296; Innovation Head, L199-211) and investments in hardware and software.

4.3.3.2 Impediments to Innovation

The three main impediments to innovation in InnoInfo are also institutional in nature. They are the negative mindsets of staff and external parties due to old work and industry practices and industry fragmentation, lack of human capital able to use the innovation and technology interoperability.

The main impediment is the mindset of staff and external parties. InnoInfo states its greatest challenge as:

> instilling a change in attitude to remove the old way of working to the new one, where [InnoInfo] spends 80% of its time and effort on driving a paradigm shift in mindset through extensive restructuring of business processes, organization alignment as well as human capital training and development. (Director, L284-287)

The Innovation Manager said "problem solving, people and processes" is her daily work (L403). This impediment reduced "buy-in" to the innovation (Innovation Manager, L276) and hindered implementation:

> No point having very strong say from the management "I want to do" and the executers don't want to move. It won't move as well. [This is because the success of innovation involves] both parties in tandem with innovations and technology. (Innovation Head, L60-62)

An example of the old mindset is where external consultants in the construction industry in Malaysia sees the software innovation as a "documentation tool" as compared to consultants in western countries who sees its value in terms of a tool for discussion, coordination and problem solving (Innovation Manager, L380-382). This mindset of using the software as a documentation or processing tool:

> causes users to be mechanical and not creative to innovate design and to make the whole design efficient through the tool. (Innovation Manager, L390-401)

The non-creative usage further causes users to underutilize the extensive tools of the innovation:

> You got to couple your creative, your design knowledge and tools to reap the benefits. Metaphorically you don't want an aircraft which is constantly running on the runway without taking off. You have a powerful thing but you must drive or operate it in a right way, or else it is an aircraft which is running on the runway like a car. (Innovation Manager, L390-401)

InnoInfo defines *buy-in* as:

> resource commitment, in terms of putting in time to join in our meetings, to provide input, amount of resources and the quality of staff input. (Innovation Manager, L306-307, L310-311)

The buy-in issue comes from both internal and external implementers. Internal implementers consist of other departments in the company, for example the Project and Contracts Departments. External implementers consist of external consultants and subcontractors. These users have three functions in different stages of the innovation. At the innovation development stage, the initial members of the Innovation Team sought their input and feedback on the innovation (Innovation Manager, L315-316). The external consultants would have played a crucial role at the innovation development stage in terms of providing a model for conversion from the old to the new software usage. The innovation requires the participation of external consultants from the architectural and mechanical and electrical disciplines. The electrical and mechanical subcontractors are involved in the innovation. The architects are reluctant to participate at least partly because of the nature of the construction industry where the professional service fees of consultants such as architects are fixed by regulatory boards:

> for professional service consultants, no matter how fast the project is, there is no change in their fees, it is a lump sum (Mechanical Subcontractor, L69-71).

Due to the non-involvement of consultant architects, staff from InnoInfo's D&T Department built the model (Site Innovation Manager, L30).

One of InnoInfo's initiatives to overcome the mindset impediment is human capital training and development. InnoInfo trains the electrical and mechanical subcontractors who are users of the innovation. The subcontractors attribute the success of innovation at InnoInfo to two factors. One is the firm's attitude:

> [InnoInfo] always challenge themselves to come out with quality products [like its innovation] (Mechanical Subcontractor, L228-229)

Secondly, instead of the electrical subcontractors and the mechanical subcontractors developing the detailed designs for InnoInfo, InnoInfo developed them:

> They [Innoinfo] help us a lot; they [Innoinfo] have a strong engineering team to support, to come up with the detailed drawings. (Mechanical Subcontractor, L188-190)

Another of InnoInfo’s initiatives to overcome a non-innovative mindset is a series of meetings held at its office with the electrical and mechanical subcontractors to identify any work “clashes” between the subcontractors before construction. The meeting is deemed by the mechanical subcontractors as improving the mindset of the parties so they can see the value of the innovation:

> So the mentality is improved for those who are in the meetings, those who are not involved, they can’t see. In the beginning, the engineers’ meetings were quite rigid, but after a period they see the value of the innovation. Do you prefer to solve the problems in the meetings or go to the site to solve the problems? (Mechanical Subcontractor, L220-224)

Another reason for the non-involvement of external parties in the innovation is the fragmentation of players in the construction industry. This fragmentation causes the players to have a mentality of self-benefit and self-protection. To resolve this impediment, InnoInfo proposed:

> the introduction of a new business model, consisting of an incentive and reward system to be shared across the stakeholders at the outset through a formal contractual framework. (Director, L152-157)

Likewise, sharing of profits should also occur between InnoInfo, the contractor, and its client, i.e., the developer. InnoInfo is looking at rewards from its client as its innovation provides savings to clients in terms of shorter construction time:

> If I am doing our innovation with the developer, how do I benefit you and me? In fact now we are talking to the developer how we share the gains. You gain in time do I get incentives rewards all these things? (Innovation Head, L200, L203-205)

Another aspect related to mindset is having human capital that possesses the right mindset. Training as well as usage of the new software used in the innovation required more time and thus human capital with a positive attitude to innovation. A positive attitude was associated with quicker learning:

> The mindset has to be right. When you love it more however you will learn faster. The heart and mind is very important. (Mechanical Subcontractor, L196-200)

The second impediment is an extension of this point: lack of human capital trained in the types of software used in the innovation. The innovation requires human capital that is competent in using the types of software used in the innovative system. However, such human capital is rare in the Malaysian market as graduates are trained by universities on the old and not new software (Mechanical Subcontractor, L79-83). The mechanical subcontractor highlighted the critical need for universities to produce graduates who are competent in using the new software (Mechanical Subcontractor, L235, L241-243, 252). InnoInfo addresses this issue through changes in its recruitment, training and retention programs (Director, L294-6; Innovation Head, L199-211), supported by heavy investment in its human capital:

> Our investment in the human capital, we invest over and above the software. There's quite heavy investment in human capital. (Innovation Head, L75-77)

The company also has plans to jointly develop the needed human capital by associating its training program with institutions of higher learning and professional bodies.

The third main impediment is a technical impediment in terms of the state of the technology of the innovation relative to the existing technology in the construction industry in Malaysia. InnoInfo innovated on its own, without engaging any external solution provider, with

> all R&D, sourcing of hardware and software technology, training and human capital development conducted in house. (Innovation Manager, L288-290)

InnoInfo faced two related challenges. Firstly, there was a lack of interoperability between the innovative software and existing software, as there was no single software on the market that could cater for the multidisciplinary needs of the construction industry. This caused loss of data and information making collaboration between parties difficult (Director, L303-306). Secondly, software vendors emphasized design and preconstruction visualization and did not fully tap the potential of a 5D project life cycle at the time the innovation was developed (Director, L319-322).

In addition to the three main impediments, two other impediments act as barriers to innovation. The first is the nature of the construction industry in Malaysia, which still relies on less advanced software for information exchange:

> External impediments remain equally challenging due to the nature of our industry in Malaysia. The local construction industry still predominantly relies on 2D for their exchange of information. (Director, L308-310)

The second is a lack of government support in enforcing the implementation of innovation in the construction industry (Director, L310-311; Innovation Manager, L405-408).

4.3.4 How Organizations Connect Institutions and Firms to Support Construction Innovation

The main innovation support noted by InnoInfo is institutional in nature, i.e., the role of government and other institutions. For InnoInfo, the government should play an important role in encouraging innovation. Without such support, the firm's innovation cannot be successfully implemented:

> Externally [the most important factor that will encourage innovation], I will say, the government, if government does not do anything, nothing will move. (Innovation Head, L228-229)

Another supportive role of the government would be to enforce regulatory or mandatory adoption of software tools in the categories of InnoInfo's innovation in the construction industry:

> by starting with the professionals, followed by the contractors, and lastly the suppliers (supply chain), as well as usage by the Government, as an example to others. (Innovation Head, L140-143)

The Building Construction Authority (BCA) of Singapore's mandatory requirement for professionals and contractors to use similar software is quoted as an example (Innovation Head, L55-58).

Other organizations that could play a role in connecting firms to support InnoInfra's innovation are professional bodies which can play a role in human capital development and academic institutions which have a role in research and development programs (Director, L342) as well as human capital development through education and training (Director, L344-345).

4.3.5 Overview of Institutions and Their Roles in Innovation in InnoInfo

The types of institutions and their roles in innovation in InnoInfo are summarized in Table 4.7.

Table 4.7: Institutions and Their Role, InnoInfo

Role	**Institutions**	**InnoInfo Examples**
Organization Changes	Explains organization changes	InnoInfo & its subcontractors
Influence	In-house command	Leadership
	Shared cultural orientation	Internal teamwork
	Company organization & knowledge base strength	Full-time R&D team, Knowledge base strength from R&D team, Practical experience of internal & external users
	Trust and collaborative practices	Subcontractors
	Human capital	Strengths of human capital in number, experience, expertise
	Finance	Financing of innovation
Meso-Organizations	Human capital development	Professional bodies
	Research and development programs	Academic institutions
Obstacles	Educational	Non-innovative mindset
	Work and industry practices, Industry structure	Negative mindset of staff and external parties, Old work and industry practices, Industry fragmentation
	Human capital	Lack of suitably trained human capital.
	State of technology	Low technology interoperability
Supporting Institutions	Work and industry practices, Industry structure	Old work and industry practices and industry fragmentation
	Government regulation	Mandatory requirement for industry adoption of software of the class of the innovation

4.3.6 Interactions in the Construction Innovation System

All in all, the characteristics and their interactions and how they motivate innovation in InnoInfo are as follows. Innovation in InnoInfo involved the purchase, customization and integration of software. The company developed the innovation in-house, with little external support, thus the innovation cycle time was longer than if external IT consultants had been involved, i.e., three years.

InnoInfo is motivated to innovate for two main reasons: competitive advantage and top management commitment. Innovation resulted in organizational changes in

InnoInfo and its electrical subcontractor. The changes in InnoInfo were in aspects of work processes, usage of human capital and in its knowledge base. The changes for the subcontractor were in improvement of productivity and development of knowledge base and human capital, both resulting in positive branding to customers.

The main actors in innovation at InnoInfo are the company Director, Board of Directors, and the initial members of the Innovation Team in collaboration with internal and external users. The level of interaction between all these actors is high as is the level of interdependence between them, in terms of innovation success. InnoInfo's client (its parent company, which is a property developer) was not directly involved in providing input to the innovation but accepted the innovation as the owner of InnoInfo.

InnoInfo's sources of knowledge for innovation are mainly from a subset of the main actors in innovation. The main knowledge sources are the Director's and the Innovation Manager's innovation and work experience; and research and development and human capital development initiatives with internal and external users of the innovation. No external consultants were directly involved in providing knowledge for the innovation. Although R&D was initially a part-time activity, the initial Innovation Team developed into a fully-fledged full-time Innovation Department acting as a significant knowledge source.

Both positive institutional influences and institutional impediments regulated the actors' conduct in innovation at InnoInfo. Positive institutional influences were: in-house command (leadership), shared cultural orientations (internal team teamwork*)*, company organization, human capital (full-time R&D team, strong knowledge base from R&D team and the practical experiences of internal and external users of the innovation), trust and collaborative practices (subcontractors). The institutional impediments were: educational (non-innovative mindset, lack of up-to-date IT education and training), work and industry practices (negative mindset of staff and external parties due to old work practices) and industry structure (industry fragmentation) and the state of technology which is not interoperability. InnoInfo's innovation would be supported by an institutional instrument in the form of government regulation mandate the use of innovation that InnoInfo has developed.

In short, the active components and motivators for innovation in InnoInfo can be summarized as per Table 4.8.

Table 4.8: Active System Components and Motivators of Innovation, InnoInfo

Component	**Findings**
Type of Innovation	Adaptation of existing software
Actors and Network	Director, Board of Directors, initial Innovation Team collaboration with internal and external users
	High level of interaction between all actors
	High level of interdependence between main actors
Knowledge Source	Director and Innovation Manager experience, Research and development, Human capital development initiatives (training)
Institutions	Positive influences: In-house command, Shared cultural orientation, Organization & Strong knowledge base, Trust and collaborative practices, Human capital (firm), Role of meso-organizations in human capital development &R&D program
	Institutional impediments: Work and industry practices, Industry structure, Human capital (industry), State of technology
	Supporting instruments supporting: Work and industry practices, Industry structure, Government regulation
Client	Not directly involved; ready acceptance of innovation through structural role
Motivators for Innovation	Solve problems to improve productivity for competitive advantage; Top management commitment

The interaction between the active components and motivators of innovation is summarized in Figure 4.5.

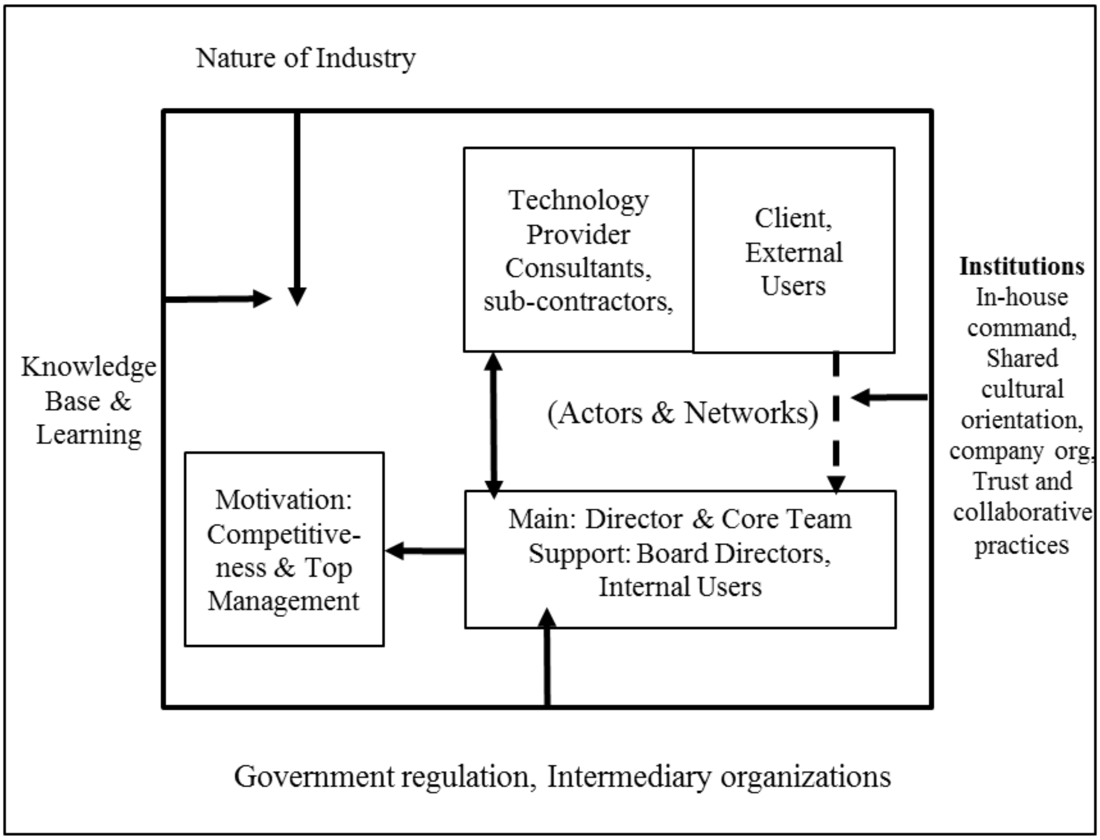

Figure 4.5: Interaction between Active System Components and Motivators, InnoInfo

4.4 InnoIBS: Construction Sub-Sector, Building Commercial and Residential

4.4.1 Background

InnoIBS is a specialist contractor for the construction of buildings using precast technology and associated works. As described by the Manager of the Technical and Design (T&D) Department, it is both a precast manufacturing company and a building contractor, in a single entity (Manager T&D, L25-30). It is an integrated industrialized building system (IBS) firm which designs, supplies and constructs, using precast materials, components for multi-storey residential units and commercial developments.

Precast components are produced in precast concrete at the precast plant and transported to the construction site to be erected onto floor slabs by crane. The advantages of the precast method are that it shortens the construction period and requires less labour compared to the conventional method. Over almost 30 years, InnoIBS has built more than 35,000 prefabricated residential units. It leverages its partnership with one of the top precast builder in Japan in engineering, research and development. A General Manager manages the company, which comprises four operational departments and four construction-related departments.

InnoIBS is the recipient of awards from the CIDB, the Malaysian Occupational Safety and Health Professionals' Association (MOSHPA) and Malaysia's Social Security Organization (SOCSO), an agency of the Ministry of Human Resource. InnoIBS is a Class A contractor registered with the Pusat Khidmat Kontraktor (PKK) as well as a registered CIDB Grade 7 contractor.

InnoIBS' holding company is a publicly listed company in Malaysia, which began as a construction firm in the 1970s and later refocused into property development as its primary business. The holding company's other businesses now comprise construction, infrastructure, wood-based manufacturing and trading and its projects range from landed properties to high-rise condominiums and commercial centres in several countries, including Malaysia, Singapore, Vietnam and China. It has won multiple awards in master planning and ecological development.

4.4.1.1 Description of Innovation

Although InnoIBS has developed other innovations, this case study focuses on two of its technical innovations, the Precast Shell Beam (PSB) and the Reinforced Slab Strip (RSS) because all InnoIBS innovations follow similar processes:

> Even though product is different, all our innovations involve more or less the same processes. (Manager T&D, L221-222)

The Precast Shell Beam (PSB) is a shell, or frame, that is prefabricated off-site instead of fabricated on site. This shell differs from the full or half section beams produced by the industry. InnoIBS developed PSB for two reasons, to solve a technical problem and to meet the safety demands of a foreign client.

Technically, InnoIBS developed the PSB because in one particular project the design of a certain area consisted of just beams, without a slab, and the Site Team requested a solution:

> Technically, how to support the Site Team. (Manager T&D, L221-222)

The nature of a beam is to support the floor slab. Without a slab, there is no facility to place or support the beam. Hence, a shell was created to support the beam.

In describing the need for the innovation, InnoIBS' Site Manager referred to the high safety standards demanded by the client in one of its projects managed by a foreign company (Site Manager, L3-5). In the absence of the PSB, InnoIBS would have had to resort to a conventional method that requires many workers to work from a great height on scaffolding, using plywood and other materials and fabricating the beam. By prefabricating the PSB off-site, InnoIBS eliminated fabrication from height on site, improving site occupational safety.

Another benefit of PSB is that it saves time; large beams take a long time to be produced on site. Hence PSB provided the dual advantage of addressing the high safety requirements of the client and expediting construction time:

> It is for safety and to expedite time. (Site Manager, L12-13)… [The safety issue is one of reasons that] sparks the innovation" (Site Manager, L21-22).

The second innovation considered in this case study is the Reinforced Slab Strip (RSS), a support that does away with a separate beam by being concealed within the slab. This is an advance in the design of precast components. With the use of RSS, a job requires fewer beams, translating to less labour, cost savings and more efficient design. These benefits fit in with the role and responsibility of the T&D Team, which is to provide technical support and know-how to the Site Team to improve the efficiency of construction.

InnoIBS categorizes innovation in the firm as modification and refinement to something that is already in the market,

> not something new. (Manager T&D, L18)

Nonetheless, some development work is needed to modify what is in the market to suit the firm's needs. InnoInfo also engages external consultants, and some trial and error is also involved:

> It does not mean that every time, whatever we propose, it can work. (Manager T&D, L38-40)

4.4.1.2 Motivation for Innovation

Problem-and opportunity-centric

InnoIBS' motivation to innovate is problem-centric. Firstly, it innovates because innovation that simplifies construction work saves time, which translates to cost savings, increased efficiency and productivity, which ultimately provide increased competitiveness:

> This is the message from our General Manager, as the head of the company, he must always make sure that there is efficiency and productivity – these two things must always be there or else we can't compete outside. (Manager T&D, L192-193)

The motivation for innovation is to overcome the problems of inefficiency and low productivity:

> For us, innovation is to overcome problems. It's all problem solving and firefighting or so called innovation because we have to deliver the end product. (Site Manager, L296-297)

Another driver for innovation is the project-based nature of industry, which often imposes time constraints. (Site Manager, L73-77)

Client Demand

InnoIBS also innovates in response to client demand, as when its foreign client's demands for high safety standards caused it to develop the RSS (Site Manager, L6-7, L10-11, L81-86). The motivation was to overcome challenges for safety in construction (Site Manager, L105-106).

InnoIBS' business model does not, however, encourage large-scale innovation because the company does not market its products; rather the focus of the construction industry is to obtain projects to survive (Manager T&D, L260-262). The interaction between the nature of the construction industry and the resulting problems that motivate InnoIBS to innovate is illustrated in Figure 4.6.

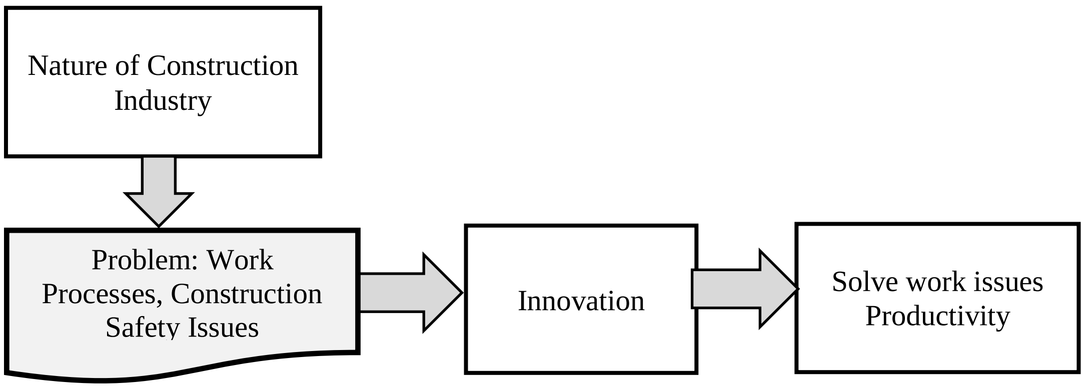

Figure 4.6: Motivation of Firm to Innovate, InnoIBS

4.4.2 Active Components in a Construction Innovation System

This section discusses the active components in a Construction Innovation System (CIS) comprising the four Sectoral Innovation Systems' (SSI) themes namely *Actors and Networks, Knowledge Base and Learning, Institutions* and *Demand.*

4.4.2.1 Actors

The main actors in innovation at InnoIBS are its Quality Team, the Group of companies of which it forms a part and the T&D Department. The other actors are the Site Team, the Production Team, InnoIBS management and external consultants. All actors' roles are discussed in this section, except for the Group, which is discussed in the following section on How Institutions Regulate Actors' Conduct.

PSB Innovation

The innovation process for PSB began when InnoIBS' Site Manager brought the safety issue to the firm's monthly Quality Team meeting, called the Centre of Excellence (COE) meeting. The Site Team was working on the project and knew that there would be a safety issue. The Site Manager was involved in discussion at the COE to brainstorm a possible solution to the issue:

> The Site Team is doing the job so we know there will be issues if we use this method. So we brainstorm to come up with an alternative method. (Site Manager, L21)

After the COE meeting, the Head of the T&D and Production Team and the T&D Manager brought the problem back to the T&D Department because it involved detailed work (Manager T&D, L73-75). The T&D Department sought the advice of its external consultant, and discussed the solution at a COE meeting. It then checked with the Site Team to see whether the proposed solution was practical or feasible:

> Project Managers organize site activities so they will know whether it is feasible or practical. (Manager T&D, L100-101)

Subsequently, the T&D Department provided shop drawings for the Production Team, which produced the mould at its factory and sent the PSB innovation to the Site Team for installation on site.

In InnoIBS, the role of the T&D Department is to render technical support to other departments, e.g., the Production and Construction Departments, for construction-related work or to resolve their problems. The T&D Department is a technical team and a reference point for other departments or teams, such as the Site Team, which faced safety issues in the PSB innovation. The T&D Department considers itself "the knowledge centre of the company":

> In our company, we have a technical team which is basically the knowledge centre of the company. (Manager T&D, L10)

The T&D Department plays a "How to", i.e., developmental, role (Manager T&D, L63). In InnoIBS, the Head of T&D is also the Head of Production, because the work of the T&D Department and the Production Department are closely related.

The Site Team's role in the company is construction on the project site. The Site Team's role in the PSB innovation was to provide feedback on the feasibility and practicality of implementation of the PSB (Manager T&D, L252-L253). However, its role as an implementer is not a fixed role, as the Site Manager is also part of the COE that brainstormed the solution for the safety issue. Thus, the Site Team can also play a role in the initial development of innovation. Both the Site Team and the T&D Department played a role in the initial development of the PSB innovation because each of them provided input into different aspects of the solution. Both were able to detect the issues at hand in different ways. The Site Team provided input because they were "doing the job" whereas the T&D Department was "looking at the drawings". The difference was that the Site Team, which was "facing the problem initiated the change" (Site Manager, L22-24) and the T&D Department developed the idea in detail, because this is the Department's function:

> When we discuss this problem, I didn't tell him specifically I need shell beam, I told him the issue we were facing. (Site Manager, L32-33)

Nonetheless, the Site Team also innovates on site to resolve other construction problems. The Site Manager explained the multiple roles he plays:

> It is hard to pinpoint a category or a specific role I play in innovation because I appear in a few categories, whether in initiating ideas, implementing, etc. (Site Manager, L1-2)

To develop a solution for the Site Team's problem, the T&D Department searched the Web for solutions offered by other precast companies. After finding a probable solution from the Web, the T&D Department sought the advice of its external consultant. The external consultant is a separate entity which InnoIBS engages on a project-by-project basis. Although the T&D Department had the basic knowledge, it sought their consultant's advice because, in InnoInfo's business model, detailed design and calculation are outsourced:

> We outsource because this is our business model, another company's business model may be different. (Manager T&D, L49-51)

The construction industry, in general, as InnoInfo with the PSB innovation, revolves around structural calculations:

> For the construction industry, everything involves structural calculations. (Manager T&D, L48-49)

Although the T&D Department found the solution to the safety problem, the details of the PSB are a trade secret which involves structural design and would be unlikely to be found on the Web (Manager T&D, L44-47, L48-49). In the PSB innovation, therefore, the external consultant's role was to provide details of the structural design, its calculations and how the T&D Department should go about making the innovation work.

In general, the time taken to search for solutions depends on the urgency of solving the problem, but the problems are normally urgent, so InnoIBS has to develop solutions quickly – in about one to two weeks in the case of PSB.

RSS Innovation

The RSS innovation idea came from a T&D Department member when the T&D Department was reviewing the original drawings from a client's consultants. The T&D Department member saw that some of the beams could be eliminated and the design could be further enhanced and improved. The T&D Manager had seen a design without beams before (Manager T&D, L141-142).

However, the T&D Department did not have any idea how to do it, so it checked with its external consultant for advice (Manager T&D, L123-124). The client's consultants, whom the client relies on, accepted the innovation with no additional input as InnoIBS demonstrated with calculations that the innovation could work, and gave sufficient information. Thereafter, the T&D Department discussed with the Site Team how to install the innovation. The T&D Department started developing the idea earlier, but because the Site Team did not implement it right away, it had more time to deliberate on the idea. The whole development process took three months.

The actors involved in the RSS innovation are almost the same as those involved in the PSB innovation. The only difference is that the PSB was initiated by the Site Team because it faced the problem and the initial idea development started at COE, whereas the RSS innovation was initiated by the T&D Department and the initial idea came from a T&D team member.

Actors' Roles

The roles played by the actors in innovation at InnoIBS are outlined more generally in this section. The source of ideas may come from any actor, including the Site Team, the Production Department or a Quantity Surveyor, although it is mainly the T&D Department that develops the idea (Manager T&D, L303-306) with the advice of its external consultant, who works on details of the innovation. Thereafter, the Production Team produces the mould at its factory and the Site Team tests its applicability. Thus, although each actor has a specific role in the company, in innovation the actors can play several different roles. Also, each Department has to play its part to make an innovation work (Manager T&D, L154-157).

The COE meeting is an activity initiated in the year 2012 at the Group level for companies owned by the Group to improve product quality, productivity and efficiency; an aspect of innovation is included in the COE initiative (Manager T&D, L274-277). COE meetings are held for 2-3 hours once a month and attended by the company's top management. In InnoIBS, the attendees are the General Manager, the Assistant General Manager, the Head of T&D & Production, the T&D Manager, different Site Managers at different meetings (depending on whether the issues relate to a particular project or site) and the firm's Quantity Surveyor. These staff were selected by the General Manager because their functions relate to product quality, productivity and efficiency. The purpose of the meetings is to discuss, seek feedback and provide suggestions on how to improve product quality, productivity and efficiency, including through innovation. However, if the matter is urgent, the T&D Department will look for solutions and not wait for the COE, which is held only once a month. The COE plays an important role in almost all InnoIBS innovation:

> I would say that the team that has really come with innovation, it is our Centre of Excellence (COE) monthly group, because our innovation cannot really just rely on the T&D Department. (Manager T&D, L153-156)

Although the Site Team plays the role of testing the applicability of innovations, it also initiates and develops innovation on site. For example, the Site Manager has had to develop an edge protection quickly at the construction site to prevent workers from falling off the building:

> So we do an edge protection that enables us to solve the issue efficiently and as fast as possible. (Site Manager, L81-82)

This situation is considered firefighting, and arises due to differences between what is designed on paper and actual site conditions. In this case, the Site Team had to resolve the problem quickly by coming up with a solution (Site Manager, L73-77).

The General Manager plays the role of advising on the feasibility of ideas, provides suggestions in the COE meetings and approves high cost innovation, although not all matters require his approval (Manager T&D, L88-91). The Quantity Surveyor, also part of the Quality Team, provides input on costing (Manager T&D, L225). The firm's manufacturing arm, the Production Department, produces the innovation. The main clients of InnoIBS are companies in its own Group. The client is either indirectly involved or not involved in innovation. The role of each actor in innovation in InnoIBS is summarized in Table 4.9.

Table 4.9: Actors and Roles, InnoIBS

Actors	Role
Centre of Excellence (COE)	Initiate idea, Feedback, Networking
T&D Department	Idea development
Parent Group	Inculcate innovative culture
Production Department (manufacturing arm)	Production of innovation
Site Team	Test applicability, Initiate and develop innovation
Other departments	Quantity Surveyor: Costing
External consultant	Detailed structural design and calculations
Client	No direct role

4.4.3.2 Networks

A key factor in working with different actors in innovation is good communication:

> This close communication is very important. (Manager T&D, L214)

Good communication avoids misunderstanding the intention of the communicator and inefficiency or error:

> They might misunderstand your intention and also they might not be able to do the things well. (Manager T&D, L208-209)

The T&D Manager and Site Manager communicate on innovations when the Site Manager seeks clarification of aspects of the innovation they do not understand (Manager T&D, L211-212). Such verbal communication occurs as and when required.

The T&D Manager also visits the site to look at actual problems and get a better understanding of them when the matter at hand is urgent and "difficult to imagine":

> Sometimes work cannot wait. On and off we go to site visit to see the problems they have. Sometimes problems they have are difficult to imagine (Manager T&D, L197-199)

Additionally, the T&D Department checks if the Site Team faces problems and attends Site Team meetings with clients and consultants on site (Manager T&D, L212-213). Good communication is supported by good relationships between the T&D Manager and the Site Team who have been working together in the company for several years:

> We have a good relationship as I know the Site Team quite well and they also know me quite well as I have been working here some years. (Manager T&D, L215-216)

The Site Manager also has open, direct and two-way communication with InnoIBS' external consultant:

> Whenever I need information, I will call our external consultants directly. Communication is open and they are engaged by us to help us on technical issues that we face… I will go directly to the external consultants to update them or get more information. When the external consultant needs information, he will also call me directly. (Site Manager, L59-61)

This quote emphasizes the importance of good communication with the firm's external consultant, again in terms of open, direct and two-way communication.

The importance of collaboration is seen with the multidisciplinary Quality Team, structured to consist of staff selected to provide external networking. The level of interaction between internal members of InnoIBS is high through the COE. The level of interdependence between internal members is also high through the COE as well through its structured and focused function on quality.

4.4.3.3 Knowledge Base and Learning

Knowledge in InnoIBS is derived from two sources. The first is an internal source which comprises the experiences and knowledge of its internal teams and senior management. The knowledge comes from both basic training and practical knowledge. Another important internal source of knowledge is the COE meeting. The second source of InnoIBS' knowledge base is external and consists of other precast companies, the firm's external consultant, site visits and study trips.

The T&D Department was able to find the solution for its PSB innovation from other precast companies through the Internet for two reasons. First, the team draws from its years of experience in the industry:

> We roughly know what it is already, how it works because we have been in the industry for such a long time. (Manager T&D, L35-36)

This experience is evidenced by the composition of the T&D Department: all of its eight team members had between 5 and 10 years of experience at the time of the case study, with the Head of the Department having 40 years' experience (Manager T&D, L159-160). Secondly, the fundamental engineering knowledge is the same across the construction industry, so the team is able to draw from its existing knowledge:

> In the construction industry, the basics are the same, as the core thing is always there. The difference is in the system or packaging. (Manager T&D, L36-38)

Thus, internally, InnoIBS obtained knowledge for the PSB innovation from two sources: tacit knowledge from team members' experience and their existing professional knowledge.

On the hand, the RSS innovation was derived only from the "basics" of engineering; the knowledge source was mainly derived from the T&D Department members' core experiences. *Core experiences* refer to

> something we used/have come across, our experiences… Last time, for a certain project, I used this before…it is from the engineer's knowledge. (Manager, T&D, L149-150)

This core experience is the norm in construction industry:

> That's why for construction industry, that's always the case, this is from our knowledge. (Manager T&D, L151)

InnoIBS does not have a team of full-time dedicated R&D staff and each staff member involved in innovation has their daily work to do in their respective team (Manager T&D, L230). Feasibility studies are considered to contribute to R&D in InnoIBS. External knowledge for the PSB came from the consultants who worked on the details. Thereafter the Site Team's practical knowledge was used to test the applicability of the design on site.

An important source of knowledge in InnoIBS is its Quality Team, the COE meeting. The COE meeting is likened to an R&D Department because of its aim:

> to innovate and improve our construction methods for efficiency and better product quality. (Site Manager, L158-159)

It is considered a good platform for two reasons. Firstly, it enables COE members to start an idea, to get the idea going and to solicit feedback. Secondly, this is possible because its membership consists of people of different levels, background, disciplines and experiences who have travelled to or worked in different locations or who have different contacts.

InnoIBS' knowledge source also consists of site visits, study trips and basic training. The General Manager organizes site visits and study trips to broaden the staff's knowledge. Even at the Group level, the top management encourages site visits which are organized on an ad-hoc basis; study trips are organized on a yearly basis. The Group also encourages staff training (Group Quality Manager, L157-161).

In terms of knowledge management, InnoIBS maintains a data and knowledge management system. This knowledge base consists of proposals, final reports, contracts and designs and is accessible from the Internet, although accessibility to the knowledge is limited to the T&D Department. The institutional and cultural context of the firm's knowledge base is discussed after a brief consideration of *Demand*.

4.4.3.4 Demand

The clients of InnoIBS are mainly companies in its own Group. Although they are from the same Group, the same quality of work is expected for the Group as for other clients (Manager T&D, L238-241). The client's role in innovation is usually indirect because of the construction industry practice of setting a short time for project completion and setting the demands for things to be done in a certain way (Manager T&D, L244; Site Manager, L243-244). The firm's client or the clients' consultants are often not involved or "way out of the picture", as in the RSS innovation:

> They only check on the progress of the construction. Input from consultants is limited to the normal work. (Manager T&D, L222-225)

In the RSS case, the client did not provide any input to the innovation and it was relatively easy to obtain their approval. This is because the RSS was not entirely new and was being used elsewhere. Approval is easy to obtain, especially if InnoIBS is able to justify its innovation with calculations and provide sufficient information to the clients' structural engineering consultants (Manager T&D, L128-133). The non-involvement or indirect role of clients is explained by the characteristics of construction clients that:

> bring problems and ask for solutions [from the contractors]; and don't share solutions [with the contractors] (Site Manager, L107–110).

4.4.3 How Institutions Regulate Actors' Conduct

4.4.3.1 Positive Institutional Influences

The two positive institutional influences in InnoIBS are shared cultural orientations in its parent Group and internal team and trust and collaborative practices with its external consultants. The main institutional influence in InnoIBS is its shared cultural orientation through the culture which its parent Group instils in all its subsidiaries. The Group has instilled its continuous improvement culture, which includes innovation, in InnoIBS through innovation-related activities and performance measurement. This section discusses the impact and critical success factors of three of the Group's activities, the Product Quality Forum (PQF) and Ideas Campaigns and a performance benchmark tool called the Key Performance Indicator (KPI) tool.

The holding company of InnoIBS initiates and organizes a product quality forum called the PQF for its subsidiaries on a half yearly basis. The purpose is to instil a continuous improvement culture in staff in all subsidiaries:

> With PQF, staff have a mind to continuously improve ways of doing things. (Group Quality Manager, L10-11, L14-15, L103-104)

PQF solicits new ideas on quality from Group subsidiaries. Ideas about efficiency and productivity are included, but PQF does not only focus on innovation. InnoIBS views the Group as its client that promotes an innovation culture to them:

> I see the group as the client to promote innovation culture amongst our company and other business units. (Site Manager, L186-187)

Representatives of subsidiaries present their new ideas at this forum to the Group top management, which consists of the Group Chairman and 40 other senior managers, for their approval. PQF is held at a large scale on a Group level and the management of InnoIBS rotates its middle and top management level staff to attend. Once an idea initiated at the PQF is accepted, it is adopted by other business units. For example, PQF initiated the COE monthly meetings.

PQF also impacts innovation because subsidiaries:

> find ways to improve your product quality and to do this you have to innovate. (Site Manager, L178)

At the Group level, PQF has had far-reaching impact that produces ground-breaking services and products (Group Quality Manager, L119-120), including:

> For example, our new [*Y*] tag came from the PQF. It became a very important development philosophy and also good branding for our Group. We became the first Property Developer that provides [Service X] to our purchasers. This idea came from PQF. (Group Quality Manager, L120-125)

The PQF initiative has been around for more than 10 years, with changes in structure and type of activities (Group Quality Manager, L62-66). To the Group, although it ranks highly in the market, it has not achieved its aim to build a continuous improvement culture and their journey continues (Group Quality Manager, L115-117).

Another activity the Group organizes is the Ideas Campaigns. This purpose of this activity is to provide a platform for staff at all levels in the subsidiaries to contribute to ideas on specific topics. It aims at building a culture of continuous improvement:

> The intention is continuous improvement, to build a culture or mindset that looks for improvement at all times. (Group Quality Manager, L23-24)

Ideas Campaigns are held one to two times per year. The assessors evaluate ideas contributed during the campaign and winners are given due recognition. In InnoIBS, this activity indicates to staff an

> open culture of soliciting ideas, i.e., culture of sharing, not rejecting, and encourage voicing ideas, welcome ideas. (Site Manager, L191-192)

The Group uses a performance measurement approach called Key Performance Indicators (KPI) in its subsidiaries. The KPIs impose targets on sales, timeliness and completion of projects as performance measures for salary increments and bonuses. In addition to these KPIs, the Group also allocates a common KPI to the subsidiary as a whole for new ideas that are originated and implemented by staff:

> KPI is imposed on the business unit level which means that for that particular business unit you have to achieve this or all your business unit staff will be affected. For InnoIBS, we all share a common KPI … it involves increments and bonus payments. (Manager T&D, L180-1. 182-5)

The two critical success factors in InnoIBS' Group journey toward instilling continuous improvement are top management commitment and the linking of innovation efforts to performance measurement. Top management's commitment is shown from their involvement in almost all aspects of continuous improvement. Firstly, the activities are initiated by top management and implemented by the Group's Quality Unit. For example, even the specific topics of the PQF may be initiated by top management (Group Quality Manager, L53-58). Secondly, the Chairman and 40 senior management personnel attend the half yearly event. The presence of top management is considered a strong push as it indicates to staff that their ideas are important. This indication is powerful as it acts as a form of recognition. Group management commitment during the PQF is considered important:

> If at the GPQF [Group PQF], staff need to come up with new ideas but the ideas are not presented to top management, it does not work because the staff may think I have some new ideas and I just present to middle management and my ideas don't matter. This is a strong, good push factor. (Group Quality Manager, L27-33)

In addition, top management approve staff members' ideas at PQF and this is supplemented, again, with rewards and recognition of the staff concerned.

Top management are also involved in tracking the progress of implementation of the new ideas generated at PQF:

> Other than presenting the status of the previous ideas at GPQF, bosses will also ask the Business Unit's Head at various meetings. The tracking of the progress of

> these ideas is done by top management, GPQF and the Group Quality Management Unit. (Group Quality Manager, L52-54)

Fifthly, the commitment of the top management can be seen in the resources that are allocated to manage the initiatives. The Group-level Quality Unit is responsible for Quality initiatives. It initiates, develops and implements quality programs, evaluates and tracks implementation of subsidiaries' new ideas and measures quality programs with formal tools such as documentation and audits (Group Quality Manager, L105-106, L143-144, L230-231, L138-139).

The second critical success factor is the link of the quality initiative to performance measurement. The quality initiative is tied to staff performance measurement as a KPI. And this KPI translates to staff members' salary bonuses and increments:

> If they come out with new ideas, it ties to their salary bonuses and increment. (Group Quality Manager, L25-26)

To summarize: in InnoIBS, the Group inculcates a continuous improvement culture where innovation is an inclusive aspect through the three activities and a performance benchmark. The impact is visible through the Group's ground-breaking services and products, which are well known in the market. The two critical success factors are top management commitment and the link to performance measurement. The COE meeting, a product of the PQF, is an integral part of innovation activities in InnoIBS in terms of idea generation, feedback and networking and as a source of knowledge. The shared Group cultural orientation toward continuous improvement is translated into teamwork in InnoIBS' COE Quality Team, which owes its existence to the Group. The level of interaction in the COE is high, with its focused quality function, of which innovation is an aspect. In addition to the COE, there is strong interdependence between the T&D Department, and the Site Team and Production Department for innovation in InnoIBS.

Another positive institutional influence is the firm's high level of trust and collaboration with its external consultant. InnoIBS emphasizes the importance of good communication with its external consultant, in terms of open, direct and two-way communication.

4.4.3.2 Barriers Impeding Innovation

In InnoIBS, the three main impediments to innovation are a culture that discourages innovation, the mindset of staff who are not open to ideas, the build procurement system and government policy on IBS. The first impediment is indirectly linked to the institutions component of the innovation system whereas the third and fourth impediments, highlighted respectively by InnoInfra and InnoInfo, are institutional in nature.

Although there is a strong Group continuous improvement culture, there is also a perception that some managers in InnoIBS are closed to ideas and discourage sharing by not listening to ideas brought to them. This more closed culture is linked to the nature of construction industry:

> Boss is right, shoots ideas. (Site Manager, L283-284)
>
> [The] fast track environment of construction with tight deadlines causes middle management to be under pressure and tense, which does not encourage sharing of ideas. (Site Manager, L285)

A second impediment is the mindset of staff who are not open to new ideas:

> Problem is human-related, the technical problems are very easy to solve. (Site Manager, L302-303)

Thirdly is the institutional factor, the government rules in the existing build procurement system, an impediment because

> they have the design in place, the end result required is as per the design. (Site Manager, L312-314)

Fourthly, is that the Malaysian government policy on IBS is seen to be too weak. InnoIBS would like to see a more aggressive policy driving client adoption of IBS. They cite the rules of Singapore's BCA on the adoption of IBS as an example of supportive government regulation (Site Manager, L315-316).

The institutional factors observed and their impact on innovation in InnoIBS are summarized in Table 4.10.

Table 4.10: Institutions and Their Role, InnoIBS

Role	**Institutions**	**InnoInfo Examples**
Positive Influences	Shared cultural orientations	Group culture, Internal teamwork (COE and main internal actors)
	Organizational structure	COE
	Trust and collaborative practices	Main internal actors and external consultant
Impediments	Industry practices	Culture that discourages innovation
	Government rules	Build procurement system
	Government policy	Lack of IBS policy

4.4.4 Interactions in the Construction Innovation System

The active components of the construction innovation system, the interactions among them and the motivations of innovation in InnoIBS are summarized in this section. The type of innovation at InnoIBS is modification and refinement of existing technology. The firm's innovation ideas originate from the main actors and are developed with external consultants using existing technology. The innovation cycle time may take only a few weeks if improvement is of high urgency.

The main actors in innovation at InnoIBS are the COE meeting, the T&D Department, the external consultant and the Site Team. Network and collaboration are important and the level of interaction between all actors is high. Interdependence between main actors is high.

InnoIBS' clients may play no role in innovation that improves quality, efficiency or productivity for continuous improvement. When clients play a role in innovation, it is indirect, motivating innovation with demand for things to be done in a certain way e.g. demands for higher safety standards.

The three main knowledge sources for innovation in InnoIBS are the T&D Department, who develops the innovation; the external consultant who provides the details; and the Site Team who tests its applicability. The knowledge of the T&D Department may be derived from the team's core experiences and basic knowledge or from external sources such as other precast companies. Another important source of knowledge in InnoIBS is its Quality Team in the form of the COE meeting with its multidisciplinary members. The interaction between knowledge source and actors is summarized in Table 4.11.

Table 4.11: Knowledge Sources and Actors, InnoIBS

Source	**Actors**
Internal	T&D Department Site Team COE Meeting
External	External consultant Site and study visits Other precast companies (new ideas)

The institutional influences on innovation at InnoIBS are: shared cultural orientation (Group culture, internal team teamwork – COE and departments involved in innovation) and trust and collaborative practices (external consultant). Institutional impediments are: industry practices (culture that discourages innovation due to industry practices) and government rules (the build procurement system). The nature of the construction industry, particularly the focus on rapid construction time, discourages a culture of listening and sharing ideas important for innovation to occur. A change in government policy to encourage IBS would provide institutional encouragement for innovation.

InnoIBS is motivated to innovate for two main reasons: to solve problems (problem-centric, e.g., safety issue) and to improve productivity and efficiency for competitiveness. A summary of the active components and motivators for innovation in InnoIBS appears in Table 4.12.

Table 4.12: Active System Components and Motivators of Innovation, InnoIBS

Component	**Findings**
Type of Innovation	Modification and refinement of existing technology
Actors and Network	COE meeting, T&D Department external consultant, the Site Team. Network and collaboration important. High level of interaction between all actors, High level of interdependence between main actors.
Knowledge Base	T&D Department, Site Team, COE meeting, External consultant, Site visits, Other precast companies.
Learning	Study visits
Client	Not directly involved, can motivate innovation with demands for higher safety standards
Positive Institutional Influences	Shared cultural orientations (Group culture, Internal teamwork – COE and main departments, Trust and collaborative practices with external consultants.
Institutional impediments	Industry practices (culture that discourages innovation due to industry practices), Government rules (build procurement system).
Institutional support	Government policy (IBS policy).
Motivators for Innovation	Problem-centric, Improve productivity and efficiency for competitiveness.

The interaction between the active components and motivators in InnoIBS are summarized in Figure 4.7.

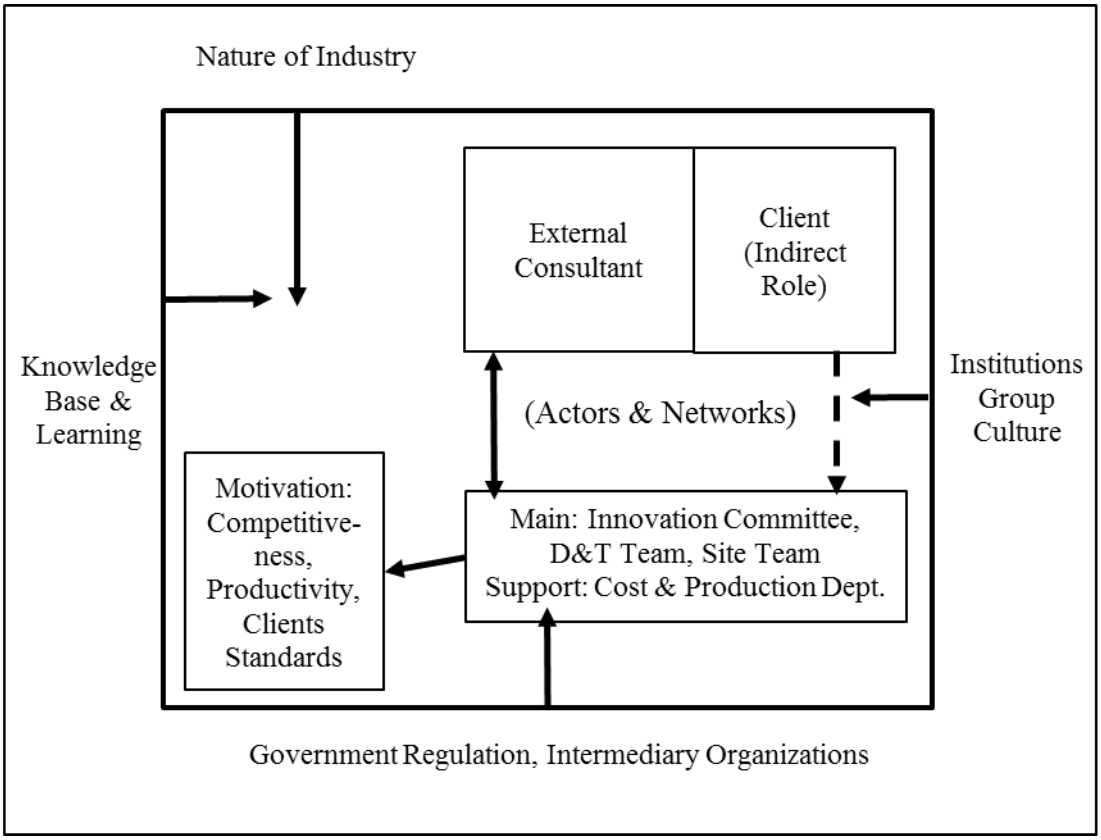

Figure 4.7: Interaction between Active System Components and Motivators, InnoIBS

4.5 InnoWEBS: Construction Sub-Sector, Building Residential

4.5.1 Background

InnoWEBS is a Bumiputera (native Malaysian) owned company that was incorporated in the late 1990s. Since then, it has established itself in water-related projects such as flood management and mitigation, river works, river rehabilitation, urban drainage, water supply and dam construction. The Managing Director (MD), who is also the owner, manages the company which consists of a manufacturing arm and a construction arm. The manufacturing arm was established to produce square steel brackets, a component of the firm's innovation. InnoWEBS is a registered Grade 7 company with the CIDB and a Class A PKK Bumiputera company. The company also has a subsidiary which provides mapping services.

4.5.1.1 Description of Innovation

The innovation is an extension of IBS in Malaysia. With IBS, prefabricated materials are transported by lorry from factories to construction sites. The prefabricated materials are heavy, so require a crane to lift them. This requirement gave the MD of InnoWEBS the idea to create "something lighter" in terms of materials (Managing Director, L10-12, L18-20).

The innovation is a system consisting of prefabricated parts that make a complete house: steel frames, floor system, roof thrust and wall system. The system replaces the conventional method of building houses that use brick, slabs, complete columns and piling. The steel frames are made of higher strength and thinner steel than material that uses concrete in construction, and achieves lightness with high strength to sustain even earthquakes.

The market in Europe and Australia, as well Malaysia, was mainly using *C-channel* metal shapes, but InnoWEBS' steel frames are rectangular (or *tabular*), which makes them more reliable than C channels (Production Executive, L25-27). Although other companies in Malaysia had attempted to develop light weight steel system previously, their ideas were not realized. The other companies focuses were also on a different part of the building, the roof.

InnoWEBS' innovation is the realization of the MD's vision to make the building of houses easy to understand and user friendly through a *do-it-yourself* (DIY) tool kit that is sold at hardware stores (HPDT, L1-6), like IKEA's easy to assemble concept:

> We also aspire to be like IKEA where we provide the drawing and you can fix the house yourself. (Managing Director, L152-154)

The innovation is adapted from a technology developed by a Professor from a University in China. The innovation originated from the UK, Europe and Australia and China had learnt and modified it (HPDT, L47-53). The Professor showed the MD and his team how to design buildings that can survive large earthquakes using tabular shaped steel frames. Tabular shaped frames are stronger than C-channel metal shapes because

> C-channel is very flimsy. If you don't handle it in a proper manner, it will be subjected to twisting, etc. (Managing Director, L136-138)

InnoWEBS purchased the design and technology, including production machines for the steel frames. The reason InnoWEBS purchased the innovation is because the firm did not want to spend time developing the innovation:

> from scratch, to think of each and every part of the innovation. (Managing Director, L79-80)

Although InnoWEBS started with the design from China, it then modified the design to suit the demands of users from Malaysia and other countries. Since the purchase of the technology and its modification, InnoWEBS has developed three main products, consisting of the prefabricated steel frame, floor and wall. It has also established a new manufacturing arm that produces the prefabricated steel frame.

Modification of an existing design, in this case the Chinese Professor's original innovation, is considered normal in engineering, where an existing design can be tweaked to become a new innovation (Managing Director, L70-72). The CIDB has approved InnoWEBS' innovation system as suitable meeting the requirements of a building product (Managing Director, L30-33).

4.5.1.2 Motivation for Innovation

InnoWEBS is motivated to innovate for two main reasons: to address a commercial problem or issue – in this case, competitiveness and to obtain revenue for the company; and due to of positive effects of its main actors.

Problem- and Opportunity-Centric

The innovation provided a platform for the MD to learn something new, i.e., it provided the “excitement of knowing”:

> It is the excitement of knowing, but also we know we can make money. It is the combination of these two factors. At the end of it, it is about monies. We know that if we can capture that knowledge: first is what knowledge can do; two is that we need to recoup for monies spend to commercialize. (Managing Director, L165-167)

Thus, the learning is obtained with the MD’s prior knowledge that it will also provide competitive advantage by giving InnoWEBS a niche:

> enter the market and be one of the competitors... and make it as our niche market [as well as providing a new business opportunity]. (Managing Director, L7-9)

This niche will recoup the expenditure in the innovation and ultimately bring revenue to the company:

> We believe that we can enter the market with this innovation and get back our monies. We believe in the returns. (Managing Director, L128-129)

The new business opportunity is the venture of InnoWEBS into manufacturing in the future which is expected to provide more business opportunities than construction:

> We want to be the manufacturer one day. We hope we will be the manufacturer and let someone else be the contractor. Now, the manufacturing part is still under the same entity although we have a different group of people working there (HPDT, L136-138).

The interaction between the market and the commercial opportunity that motivates InnoWEBS to innovate is summarized in Figure 4.8.

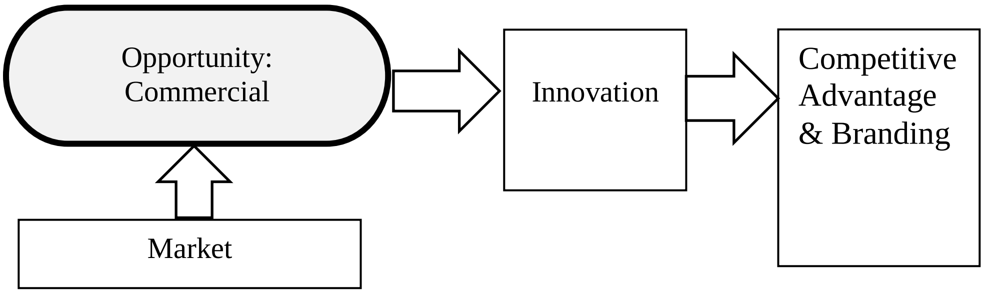

Figure 4.8: Motivation of Firm to Innovate, InnoWEBS

Positive Effects of Actors and Networks.

Another reason that InnoWEBS is motivated to innovate is the personal motivation and training of the innovator. The MD appreciates knowledge (Managing Director, L162-163), enjoys the excitement of knowing (Managing Director, L165) and understands that the skills obtained from his PhD education enabled him to innovate. Likewise, the Head of Production, Design and Technical (HPDT) innovates because he enjoys innovating, it is one of his interests and he sees the result for end users:

> [I like] things that are different, simple yet serving the purposes, easy for end users to use and they can enjoy it. (HPDT, L244-246)

4.5.2 Active Components in a Construction Innovation System

This section discusses the active components in a Construction Innovation System (CIS) comprising the four Sectoral Innovation Systems' (SSI) themes namely *Actors and Networks, Knowledge Base and Learning, Institutions* and *Demand.*

4.5.2.1 Actors and Networks

InnoWEBS' MD discovered the rectangular steel frames while he was searching for another innovation. He met the Chinese Professor who invited him to China to look at the other innovation and discovered the innovation by the same Professor while he was there. Although the frames were used to design buildings to withstand earthquakes in China, the MD and two of his two staff, the HPDT and the Production Executive (PE), looked into the suitability of the steel frames for design of Malaysian buildings. Once a solution was found, InnoWEBS bought machines that produce the steel frames from the manufacturers in China.

In addition to paying for the production machines, InnoIBS also paid considerably so that the Chinese inventors, who are known to be protective of their inventions, were willing to part with their technology:

> These monies are for them to part with their knowledge and security because they are secretive; with payment they allow access to their knowledge. (Managing Director, L116-117)

InnoWEBS acknowledges that the price of knowledge is high, but recognizes that monies have to be paid to obtain the required knowledge:

> We know the price is expensive but you have got to pay for the knowledge (Managing Director, L117-118). All in, it is about RM[X] million we have spent. (Managing Director, L138-139)

The knowledge transfer consisted of training in China and visits by the Chinese Professor to InnoWEBS' production factory. Two of InnoWEBS' staff spent one month in China to learn how to produce the tabular steel frames. The HPDT learnt the design and theoretical aspects of it from the Professor and the PE learnt how to produce it at the factory (Production Executive, L37-38). The rationale of involving only the MD and two other staff in the innovation was because it costs money to learn (Managing Director, L150-152) i.e., to train staff in the innovation.

Training on the theoretical aspects consisted of several one-to-one informal learning sessions with the Professor and visits by the Professor to Malaysia to check the quality of the end product that was produced by InnoWEBS. The content of the theoretical sessions addressed steel and the behaviour of metals under stress (Managing Director, L103-105).

Training on the practical aspects included installation of the frames, assignments to check staff members' understanding and site visits to:

> different Chinese building sites to observe, on the engineering design and the calculations. (Managing Director, L92-93; HPDT, L64-65; L67-69)

The MD and the PE were also included in the site visits to China. Although the theoretical knowledge flow was initially mainly one-way from the Professor to the staff, the Professor also learnt from the staff, as Malaysian building materials use British codes whereas the Chinese are uses Chinese codes (Managing Director, L110-112).

This two-way knowledge exchange is another reason InnoWEBS was able to get the Professor to part with his knowledge; other than receiving considerable amount of monies from InnoWEBS, the Professor also benefitted from knowledge transfer from InnoWEBS to him:

> In a way he learnt from us; that's why he agreed to teach us, because there is something in exchange from us to them. (Managing Director, L110-112)

The two-way knowledge exchange was even more evident when the:

> Chinese technology provider visited us and when they started to use our modified design. (Managing Director, L45-46)

The PE learnt two aspects of production of the steel frames. The first was operationalization of two machines and how to use the machines to produce the components from raw material (Production Executive, L39-59). One machine produces the steel tubes and the second machine, the stamping machine, produces connectors. The second aspect was management of the production factory, including management of factory workers.

The staff learnt to operate the steel tubes machine only by observation, without any hands on learning, because:

> they can't stop operating the machines which were [in the process of] producing … [and also because] the communication between us and the China people are limited as the translations of communication are average. (PE, L58-59)

On the other hand, for the stamping machine, the PE learnt hands on because:

[there was] an instructor to teach, show and monitor us. (PE, L53)

The Chinese instructors were workers in the Chinese factory. The PE learnt the two machines in one month, spending two weeks on each machine. Only a limited amount of knowledge was transferred due to the short duration of training, limitations in linguistic translations and the limitation of the trainers' time because:

> the production people in China were busy with their production. (PE, L47)

Changes in InnoWEBS as a result of the innovation can be seen in company structure, work processes and knowledge base. These changes occurred with the establishment of its production arm, which did not exist prior to the innovation. Following training, the HPDT conducted research by gathering information from his friends to establish a factory to house the production machines purchased from China, and recruited staff for InnoWEBS operations (HPDT, L185-187). The new work processes required to operationalize the factory took one year to be established:

> Even in filling of documents we learnt how to set up filling, how to manage the incoming and outgoing sales and purchases. (HPDT, L194-195)

Prior to the innovation, the firm had no knowledge of production, so it had to start from scratch. The building of its knowledge base was slow:

> our learning was slow, bit by bit because we started from scratch. All of us had zero knowledge so we learnt. (Managing Director, L189, L198-199)

The main actors in InnoWEBS are the MD, the HPDT and the PE. The other actors are the other two members of the Design Team and Technical Team that support the HPDT.

As already noted, the thinking behind the innovation came from the MD's dream of DIY house building:

> The thinking behind the innovation all comes from me but the hard part of coming up with the innovation comes from my staff. (Managing Director, L158-160)

the MD discovered the technology, purchased it and provided the commercial direction for innovation to his staff. His two other staff being engineers focused on problems in the differences between the Chinese using American and Chinese codes and the Malaysians using British codes, so they could not initially see the commercial value of the technology. The MD therefore directed his staff to replace the American and Chinese codes with British codes:

> I am the one giving the direction to my team. We sit down and discuss but I have got to tune them on the monetary part because engineers only talk about standards. Once anything is outside the standards, their thinking stops**.** Business-wise you have got to think about the monies so you got to take away the standards. (Managing Director, L141-144)

The HPDT and the PE both trained in China and worked on developing the innovation. The HPDT is responsible for both design and production in the company. On the design side, he has one engineer and one draftsman to support him. On the production side, he has the PE to assist him. He asks the MD for advice and ideas:

> [Once the HPDT] thinks of an idea, he discusses it with the team members from the two divisions and seeks the MD's ideas. (HPDT, L137-139)

In addition to these roles, one other important aspect of the main actors i.e., the MD and HPDT, is their experience, training and motivation. In terms of experience, both of them have an engineering background. The MD has 30 years of industry experience and the HPDT has experience from four different industries comprising consultancy, contracting, fabrication and oil and gas, which allow him to draw different functions from each industry and provide him a wider picture or "work boundary" when he innovates:

> My experiences [learning] are from four different industries that help me as an innovator. If you a consultant only, you are selling a story, you can't materialize them. The contractor does not care about design, they will just do whatever you give them, they don't care whether the engineering is correct or wrong. Fabricators are the same – whatever contractors ask them to fabricate, they will

> ask for drawing to follow it. All of them only think up to where their work boundary is. (HPDT, L219-229)

His educational background in engineering and his work experience helped the HPDT to understand the innovation from the Chinese Professor easily. Also he deemed the innovation as normal:

> It is also easy as I am engineer I can understand what he (Chinese Professor) teaches; also because the innovation is not something difficult it was something normal which is tweaked then it became an innovation. (HPDT, 70-72)

The MD also has experiences in innovating as he has a few other innovations. He has a PhD which he said:

> [trained his] mind where knowledge is no longer a barrier (Managing Director, L174-177) [and made him] very rational – it trains you to stand up on what you believe. (Managing Director, L179)

In terms of motivation, both the MD and HPDT indicated their interests in innovating and the benefits that innovation brings them personally. The MD innovates because he appreciates knowledge (Managing Director, L162-163) and the feelings of excitement in knowing (Managing Director, L165). Likewise, the HPDT said that he innovates

> because he enjoys innovating, he likes things that are different, simple yet serving the purposes, easy for end users to use and they can enjoy. (HPDT, L244-246)

Another aspect of the actors in InnoWEBS is the management priority of the MD. For the MD, the way to ensure the best use of resource is for the firm's staff to focus on daily work and not on innovation. Thus, the MD does not encourage InnoWEBS' staff to focus on being innovative. The staff may innovate but their priority is their work:

> I don't really encourage my staff to be innovative because, at the end of the day, I have got to make money, so they must help me make money. To make money, it is by the way of best use of resources. But if they want to innovate, why not. But if I give them something to do, I want them to finish on time to deliver. (Managing Director, L194-195)

In terms of the *Actors and Networks* variables, InnoWEBS' innovation can be summarized as follows. InnoWEBS innovation involves the purchase of technology from a technology provider, a foreign university. The main actors are the MD who initiated the innovation and the HPDT and PE who modified and implemented the innovation. The innovation also involved market research on consumers and construction players' needs. The firm's manufacturing arm, the Production Department plays the role of producing the innovation. Innovation in InnoWEBS does not involve many actors because of the MD's strategy of not involving other departments due to other work priorities. The role of each actor is summarized in Table 4.13.

Table 4.13: Actors and Roles, InnoWEBS

Actors	**Role**
Managing Director	Initiate Idea & allocation of Resources
D&T Department	Idea development
Production Department (Manufacturing Arm)	Machinery development
Technology Provider	Transfer of technology

4.5.2.2 Knowledge Base and Learning

The three main sources of knowledge base in InnoWEBS are: research and development; the educational background, work experience and training obtained by the main internal actors (the MD, the HPDT and the PE) from the technology provider; and the technology provider, the Chinese Professor. R&D in InnoWEBS concerned on the material codes for the tabular steel frame, building finishes and the production machines.

InnoWEBS used the structure that was developed by the Chinese and only changed the codes for the tabular steel frame from Chinese and American codes to the British codes required by the Malaysian authorities. However, as a wall system with a hollow sound was not acceptable to Malaysian consumers, InnoWEBS had to change it to brick, which is preferred by the consumers, and had to produce it quickly:

> They like brick in whatever construction. But how to produce something quickly using bricks? (HPDT, L73-75, L83-84)

R&D on the wall system consisted of technical development and market research. The HPDT conducted market research by meeting contractors and consumers (end users) in villages and in the city (HPDT, L96-98). On the technical side, he researched the type of materials to be used in terms of two factors:

> [the strength of the] material and reasonable price that will not burden the consumers. (HPDT, L99-101)

The strength of material was tested using bending or tension tests which were conducted at SIRIM laboratories for a fee following SIRIM standards (HPDT, L101-103, L109-110).

The production factory produces the tabular steel frames and the connectors from raw material and sheet coil from galvanized iron. The production of the tabular steel frames and the connectors come in different sizes according to the D&T Team's design for different projects.

InnoWEBS made three modifications to the production machines purchased from China (Production Executive, L60-67). Firstly, he and his team changed the manual function of the stamping machine to automatic by obtaining new parts from the market. Secondly, they changed the heavier air drills used for assembly to lighter ones. To obtain a lighter drill, the PE drew on his existing knowledge to source drills from a few suppliers and tested their suitability by way of trial and error until a suitable drill was found (Production Executive, L80-85). Thirdly, they improvised the water flow of the steel tubes production machines to ensure that the water did not wet the floor. The PE used his technical (engineering related) knowledge to redirect the flow of water from higher to lower levels and his instincts, which he described as common sense to design the piping to channel the water. He and his team took two weeks to analyse and resolve the problem. The PE and his team members discussed these solutions and proposed them to the MD for agreement.

The experience, training and educational background of the MD and the HPDT were discussed in the previous section. Similarly, the sources of the PE's knowledge consist of his technical (engineering-related) knowledge and his intuition.

Another important source of knowledge is the Chinese Professor, who is the technology provider. He imparted technical knowledge on the innovation in terms of theory related to engineering and the practical aspects of setting up the production factory. The theoretical aspect was imparted through classroom training and construction site visits as well as information about production of the tabular brackets. The practical aspects including installation of the frames, assignments to check on staff members' understanding, site visits and assistance with setting up InnoWEBS' production arm. Knowledge transfer was a two-way in which InnoWEBS learnt from the Chinese Professor and his team and what the Chinese Professor learnt from InnoWEBS.

InnoWEBS does not have a team of full-time R&D staff. Its R&D consists of technical and market research.

4.5.2.3 Demand

InnoWEBS' clients are consumers: house buyers, architects and contractors. These clients played a direct role in the innovation, providing input on their preferred material and acceptable costs. The consumers became an impediment to innovation as they were attached to conventional methods and focused on costs. The effects of InnoWEBS' consumers on innovation are discussed in the following section.

4.5.4 How Institutions Regulate Actors' Conduct

4.5.4.1 Positive Institutional Influences

Three positive institutional influences on InnoWEBS are associated with finance, establishment of industry standards (for certification of its innovation components), and R&D facilities (testing laboratories). Firstly, in terms of finance, InnoWEBS paid a relatively large sum of money for access to the knowledge of the innovation, including staff training; purchase of machinery; and development costs.

Secondly, certification institutions are less involved in the initiation and development stage but at the marketing stage when the market asks for the certification of the innovation. Upon request, InnoWEBS submitted its innovation for certification to the CIDB, a meso-organization that is charged by the government to register and regulate the industry:

> The institutions were not involved until we started to market and people say they want some certification then we submit to CIDB. (Managing Director, L97-98)

CIDB certification reduces the market's caution toward the innovation because it certifies the quality of the innovation and indicates that an authority in the construction industry accepts it:

> Institution is involved in sort of certification on the suitability of the system because we bring in a different product, so people are cautious. They need an organization to run tests to say that, in their authority, it's suitable and follows the accepted codes. (Managing Director, L99-100)

Thirdly, to conduct technical research on the innovation, involving the testing of material strength using bending and tension tests, InnoWEBS involved another meso-organization, SIRIM, which provides laboratory facilities at a fee and tested that the components of InnoWEBS' innovation adhered to SIRIM standards (HPDT, L101-103, L109-110).

4.5.4.2 Barriers Impeding Innovation

InnoWEBS identified three main institutional impediments to innovation. The first is the market, which was reluctant to accept the innovation and which focuses on costs. A second impediment is the focus of professional engineers on career advancement, which discourages them from innovating. An associated impediment is the education system which directs professional engineers toward careers rather than innovation.

The market is accustomed to the conventional way of construction using bricks and does not encourage innovation that uses steel and new technology:

> Market is used to see the conventional way of construction; now you tell them you are using steel, they don't accept the innovation and discourage the innovation. (Managing Director, L217-222)

InnoWEBS' MD sees this as the result of failure to understand the technology:

> They don't understand technology. They don't want the technology; they just want to stick to the old technology. (HPDT, L232-234)

For example, the Asian house buyer market perceives dry walls as weaker and providing less privacy than brick walls, so they rejected the InnoWEBS innovation. This is in comparison with western clients who can accept the dry wall.

> Customers assume that if, when you knock on the walls there are hollow sounds and echoes, the houses are not strong; if the sound is packed, it is strong. The western clients can accept the dry wall, but Asians cannot accept it – quoting not providing privacy as an issue. People have all sorts of perceptions. (HPDT, L25-27, L29-31)

Also the mindset of the market is one that focuses on costs. The market is willing to use a new innovation only if it does not cost more than a conventional construction. Once InnoWEBS reduced its product pricing, the market started using its innovation systems. In the words of the MD, the basic requirement of the customers is:

> It won't cost more to use our system compared to the conventional way of building houses today. (Managing Director, L217-222)

This first impediment can be explained in part by the cultural and technological orientation of the market and in part by the nature of the industry, which focuses on costs.

The MD believes that professional engineers (human capital) in Malaysia are discouraged from innovation and learning something outside their field because innovation is perceived as not contributing to their careers. He sees this as a fault of the local education system's focus on career path:

> Also to recruit people to learn something which they are not used to is difficult in Malaysia because people are also thinking of their career. We cannot get someone to do something which they think they can't make a career from. (Managing Director, L152-155)

The MD provided an example of two staff who learnt the innovation technology but left the company because they were unsure whether their experience could contribute to their career given the uncertain market response to the innovation. The MD believes that there is a perception that, if one is an innovator, one cannot be a professional engineer:

> If they start to be like me [an innovator], it will not make them professional engineers, and some people may only want to be want to be engineers. (Managing Director, L201-203)

Institutions and their roles in InnoWEBS are summarized in Table 4.14.

Table 4.14: Institutions and Their Roles, InnoWEBS

Role	Type of Institution	InnoWEBS Examples
Positive influences	Finance	Financing of innovation
	Industry standards by meso-organization	Certification of the components of its innovation
	R&D facilities by meso-organization	Testing laboratories
Impediments	Cultural and technological orientation	Market which does not accept the innovation and which focuses on costs
	Education system	Focuses on career path & discourages innovation
Potential new influences	Monetary	Monetary incentives
	Marketing entities	Market the innovation
	R&D facilities by meso-organization	Research facilities for innovation activities
	Innovation centres	Innovation centres to nurture innovative activities

4.5.5 How Organizations Connect Institutions and Firms to Support Construction Innovation

4.5.5.1 Institutions Supporting Innovation

InnoWEBS proposed four ways for government to encourage innovation by acting as an institutional mediator: by providing monetary incentives for innovation; by establishing business entities, consisting of both academics and industry representatives as at the Chinese partner university, to market innovations; by providing research facilities for innovation activities; and by establishing innovation centres.

Providing monetary incentives to encourage innovators is expected to be especially effective in Asian contexts because Asians are deemed to be materialistic:

> Asian thinking is money, money, money. (Managing Director, L206, L224-226)

Establishment of business entities to market innovations is also considered important. In the Chinese technology provider university's business entity, the academics are able to develop an innovation at the university's laboratory and market the product outside the university (HPDT, L128-132; Managing Director, L50-55).

Also, the function of innovation is in line with the university's function to think, to learn and to store knowledge. By contrast, Malaysian universities are different entities, separated from the private sector, causing academics to be absorbed in their own research. Although universities are allocated funds for research, the research does not often match the needs of the industry.

Thirdly, the research facilities for innovation activities in Malaysia are limited, both in terms of being owned by government agencies and by being limited in their research functions:

> For example, in Malaysia, Construction Research Institute of Malaysia (**CREAM**) a subsidiary of the CIDB, which is government agency, is unable to conduct testing on earthquakes. Comparatively, the University in China that developed the innovation has three avenues and is able to conduct more varieties of testing: their own internal company lab – small machines to test like what we do in SIRIM; the lab in University; and testing for withstanding of fire – they use certified laboratories by ILAC. These are laboratories owned by China and certified by an international body. (HPDT, L111-125)
>
> Malaysian laboratories that are endorsed by the universities are also small in size. (HPDT, L132)

Therefore, meso-organizations need to play roles such as providing bigger and multiple types of testing laboratories. Another suggestion to encourage innovation is for the government to establish centres that encourage people to think freely to nurture innovative (HPDT, L267-270).

4.5.6 Interactions in Construction Innovation System

In sum, the active components of the InnoWEBS' construction innovation system, their interactions and how they motivate innovation in InnoWEBS are as follows. The type of innovation is an adaptation of a technology developed externally by a Chinese Professor. The innovation cycle was short as the technology provider did the main development work. Changes in InnoWEBS from the innovation are seen in aspects of its business structure and its knowledge base.

In terms of actors, the main influences are the MD who drove the innovation and the HPDT who developed the innovation. Another critical influence are the consumers who are directly involved in providing input to the innovation.

The top management and innovation team members' experience comes mainly from their previous innovation and work experience. Both the MD and HPDT spoke of their personal motivation in terms of their interest in innovating and the benefits that innovation brings to them personally. Innovation in InnoWEBS does not involve many actors due to the isolation of innovation work to selected individuals, as prioritized by the MD. The level of interaction between the actors participating in innovation is high and the level of interdependence between the main actors is also high.

The three main sources of knowledge base in InnoWEBS are its research and development; the educational background, work experience and training of the MD, the HPDT and the PE; and the technology provider (the Chinese Professor). The technology provider provided theoretical and practical knowledge through classroom training, site visits, observations and hands on training. Although InnoWEBS purchased the technology, it was modified to suit its needs and their technology provider later learnt the modifications from InnoWEBS. The R&D for InnoWEBS' innovation concerned the material codes for the tabular steel frame, the building finishes and the production machines.

InnoWEBS' main channel for learning is its technology provider. The learning, training and transfer of technology came with a substantial amount of investment by InnoWEBS. The type of knowledge source is summarized in Table 4.15.

Table 4.15: Knowledge Sources and Actors, InnoWEBS

Knowledge Source	Actor	Types
External	Technology provider	Technical & manufacturing
Internal	Managing Director	Previous innovation experience
		Industry experience
		PhD, education background
	Head of Production, Design and Technical	Experience from four industries
		Engineering knowledge
		Technical
		Market research
	Production executive	Intuition and basic engineering
	Users (market research)	Preferences, perception, experience

The main positive institutional influence on innovation in InnoWEBS is finance, in terms of financing of the innovation for technology transfer, including training. Meso-organizations support technology transfer by providing R&D facilities such as testing laboratories and providing industry standards for certification of the firm's innovative components.

The main institutional impediment is an educational system that does not create an innovative mindset and focuses on career path, thus discouraging innovation. Another impediment is the mindset of the market which focuses on costs and is attached to conventional methods and lacks an understanding of technology.

Institutional improvements that would encourage innovation, according to InnoWEBS, are: for government to encourage innovation by playing the mediating role for institutional influences by providing monetary incentives, establishing innovation centres and joint university-industry business entities that would market the innovation. Different meso-organizations could play roles such as providing bigger and multiple types of testing laboratories.

InnoWEBS is motivated to innovate for two main reasons: for competitiveness and to obtain revenue for the company; and due to the personal motivation of the innovator, the MD.

The active components and motivators for innovation in InnoIBS are summarized in Table 4.16.

Table 4.16: Active System Components and Motivators of Innovation, InnoWEBS

Component	**Findings**
Type of Innovation	Adaptation of a technology developed by technology provider
Actors and Network	MD as driver, HPDT Manager developer, consumers provide input
Knowledge Source	Research and development; MD, HPDT & PE and technology provider
Learning	From technology provider consisting classroom training, site visits, observations and hands on training.
Institution Influence	Finance and R&D facilities of R&D facilities *meso*-organization
Client	Directly involved by providing input to innovation, act as impediments to innovation negative mindsets
Institution Impediments	Educational system does not create an innovative mindset and mindset of the market
Institutional encouragement	Government support in providing monetary incentives, establishing innovation centres and establishing a business entity that markets the innovation.
Motivators for Innovation	Opportunity-centric and positive effects of actors

The interaction between the active components and motivators of innovation is summarized in Figure 4.9.

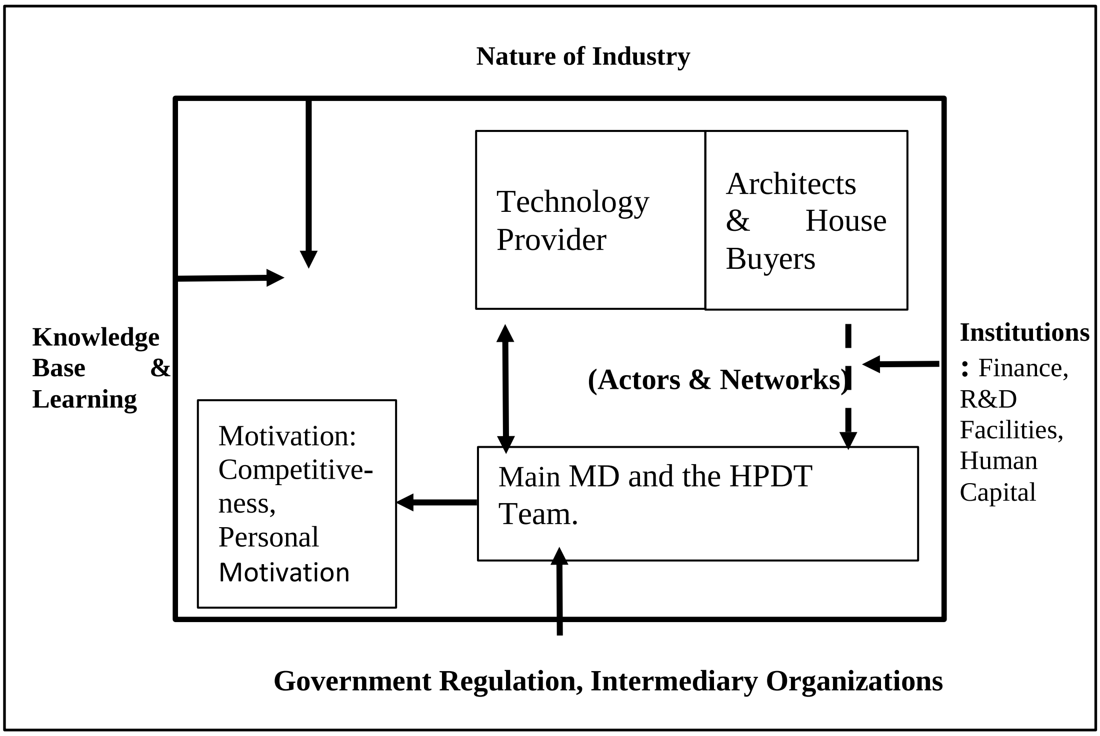

Figure 4.9: Interaction between Active System Components and Motivators, InnoWEBS

4.6 Chapter Conclusion

This chapter presented analysed four case studies of innovation in construction firms. It can be seen that all four firms participate strongly in innovation with the focus on conceptualization and execution dominated by adaptations of engineering systems borrowed from other sectors. Thus, despite the massive (or *mega*) nature of projects undertaken by construction firms, innovations in the sector are dominated by incremental innovation typifying Schumpeterian Mark 1 systems (Schumpeter, 1961, p. 66). The next chapter will present a cross-case analysis of the findings.

CHAPTER 5

CROSS-CASE ANALYSIS

5.1 Introduction

Chapter 4 identified the types of innovation and the nature, structure and relationships between active components in the construction innovation systems of four firms in Malaysia. This chapter provides a comparative analysis of innovation in the four construction firms, guided by the conceptual framework developed in Chapters 2 and 3. The main body of this chapter is structured according to the three research questions presented in Chapter 1: Section 5.2 identifies the active components in a construction innovation system (CIS); Section 5.3 describes how institutions regulate actors in the Malaysian CIS and discusses the roles that organizations institutions currently play, and could play in an improved CIS, as connectors between institutions and firms in the CIS. Motivation for innovation in the construction industry is considered as a separate topic in Section 5.4.

5.2 Active Components in a Construction Innovation System

The characteristics of the active innovation system components in the four case studies are compared in this section using the variables in the conceptual framework developed for the study.

5.2.1 Actors and Networks

Before considering the background, beliefs and motivations of the main actors in the innovations described in the cases, we define the types of actor involved in innovation in the construction industry and their roles. Common characteristics of the networks amongst actors in innovation in the construction industry are then revealed in terms of the relationships, interaction and interdependence amongst the actors and the nature of the networks involved in innovation.

Multiple actors, both internal and external to the lead construction firms, play main and supporting roles in innovation (Table 5.1). Two groups of internal actors that play a main role are: Top management (Board of Directors, Managing Director, CEO, Director); and Innovation Department, Committees or Individuals. The external actors that play a main role are engineering design consultants and technology providers.

Actors that play a supporting role can provide either direct support or indirect support for innovation. Direct support, particularly in the form of testing if an innovation can be implemented, is provided by internal users of the innovation, such as the site, project and construction teams or by external users, such as subcontractors, architects and home buyers. Indirect support is provided by internal actors that play functional roles, such as the firm's Finance Department or cost personnel.

Table 5.1: Types of Actor in the Construction Innovation System

Actor Type	**Internal to Innovating Firm**		**External to Firm**
Main	Top Management	Board of Directors, MD, CEO, Director	
	Others	Design & Technical unit, Innovation unit, Innovation committees, Selected individuals	Design consultants, Technology providers
Support	Internal users	Site team, Project construction team	External users: Subcontractors
			Consumers: House buyers, Architects
Indirect support	Functional units	Finance Department, Cost personnel	

The role of internal actors in innovation, in most cases, corresponds with the firm's organizational structure (Table 5.2). The main actors are the top management and the firm's Design & Technical (D&T) unit or innovation team. Support is provided by the internal groups that use the innovation, i.e., the site, project or construction groups. Additional support roles are played by functional areas such as production and cost planning.

Table 5.2: Roles of Internal Actors in Innovation

Type of Actor (Internal)		**Organizational Role**	**Role in Innovation**
Main	Board of Directors, MD, CEO, Director	Direction, Leadership, Managing resources	Leadership, Initiation of innovation, Approving resource allocation
	D&T unit, innovation committee, selected individuals	Design and technical matters, R&D	Innovation development R&D, Initiation of innovation
Support	Site project construction teams department	Testing and application of construction methods	Applicability of innovation
	Production department	Manufacture of innovation	Manufacture of innovation
	Finance Department or costing personnel	Cost planning	Cost planning

Two important roles of top management are to initiate the idea of innovation and to allocate resources. The D&T unit develops the innovation with the support of the external consultants or solution providers. However, in construction, the role of initiation of innovation is not only carried out by the firm's top management but also by its innovation team, committees or individuals involved in innovation. Thus, while the innovation function exists formally, with responsibilities assigned to specific components of the organizational structure, it also exists in informal structures where staff initiates innovation, as in InnoIBS and InnoWEBS. These joint roles are highlighted in Table 5.3.

Table 5.3: Joint Innovation Roles of Main Internal Actors

Role	Main actors	Case Studies
Initiation of idea	MD, CEO, Director, D&T unit, Innovation committees	All
Development of idea	D&T unit Head of Production and Design & Technical; Production executive	All
Resource allocation	Board of Directors	InnoInfra, InnoInfo

External actors include design consultants, who provide details on idea development (InnoInfra and InnoIBS), and technology providers who supply technology and learn from the contractor how to modify it (InnoInfo and InnoWEBS). External users consist of subcontractors and consumers who test the applicability of the innovations. At InnoWEBS, the foreign technology provider provided technology transfer. InnoInfra co-innovated with one of its suppliers on the development of a new machine. External users consisted of subcontractors and consumers who tested the applicability of the innovations. These roles are summarized in Table 5.4 and Figure 5.1.

Table 5.4: Roles of External Actors in Construction Innovation

Role	Actors
Details for idea development, Detailed design	Design consultants
Supply technology, Learn to modify existing technology	Technology providers
Co-innovation	Suppliers
Test Innovation	External users: Subcontractors
	Consumers: House buyers, Architects

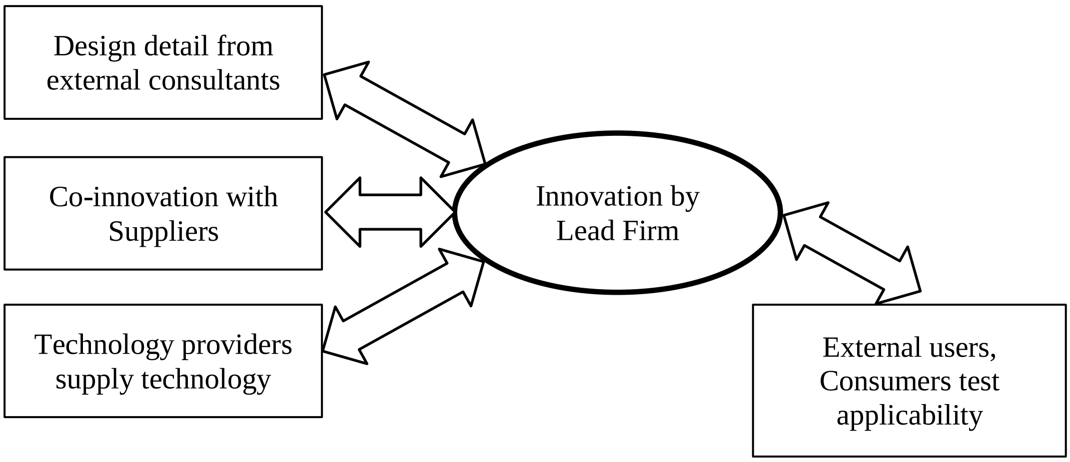

Figure 5.1: The Role of External Actors in Construction Innovation

5.2.1.1 Actors' Background, Beliefs and Motivations

The background and personal motivation of the main actors play an important role in innovation in construction (Table 5.5). InnoInfo is motivated by a visionary and committed top management in the Director and Board of Directors. The Director drives the innovation through his vision for virtual construction, his personal belief in technology and his experience in customization of technology. He also strategized to keep R&D alive in the company by creating an R&D team. InnoWEBS is motivated to innovate due to the personal motivation of its top management, the MD, and the HPDT, the two main actors of its innovation. Its MD's personal motivation is "the excitement of knowing from innovating", likewise the Head of Production, Design & Technical (HPDT) innovates:

> because I enjoy innovating as it is my interests and I see the result for end users: likes things that are different, simple yet serving the purposes, easy for end users to use and they can enjoy (HPDT, L244-6).

InnoInfra is motivated to innovate due to the personal motivation of its D&T team members to "obtain professional satisfaction to perfect and improve things". The innovation initiators and developers in all three case studies except InnoInfra had prior experience in innovating. In summary the personal motivation of the main actors is indicated by their interests in innovating and experiencing personal satisfaction professional satisfaction and challenge from innovation and prior experience in innovating.

Table 5.5: Actors' Background, Beliefs and Motivation

Case	Actor	Background, Beliefs, Motivation
InnoInfra	Head of D&T Department	Professional satisfaction & challenge in improving things
InnoInfo	Director, Innovation Manager	Vision for innovation & believer in technology (Director), prior experiences in innovation (Director & Innovation Manager).
InnoWEBS	MD & HPDT	Interests in innovating & personal satisfaction, prior experiences in innovation.
InnoIBS	HPDT, D&T Manager	Prior experiences in innovation (HPDT), ability to innovate (D&T Manager)

5.2.1.2 Actors' Effects on Innovation

The actors may have either effects positive or negative effects on innovation. Positive effects were observed where top management provided leadership, direction and showed commitment to the innovation. The Board of Director's support for innovation is evident through allocation of resources in terms of investments in technology, human capital allocation in R&D, human capital development and collaboration initiatives with its external users. This support is important because the R&D of innovation involves a lot of monies with negative returns in the first few years. InnoIBS is motivated to innovate because of its Group top management's commitment in almost all aspects of its improvement journey and enforcement of innovation through performance measurement. InnoInfra is motivated to innovate because of its Managing Director who provides leadership in identifying a commercial opportunity and driving the innovation.

On the other hand, negative effects were observed in the form of user non-participation (InnoInfo) and the negative mindset of staff (InnoInfo), users (InnoInfo & InnoIBS) clients (InnoInfra) and customers (InnoWEBS). Actors' effects are summarized in Table 5.6.

Table 5.6: Actors' Effects on Innovation

Effects	**Actors**	**Case studies where observed**
Positive	Top management: Leadership, direction, commitment	All
	Board of Directors: allocating finance	InnoInfra, InnoInfo
	Innovation or D&T unit: Commitment	All
	Support users through human capital development	InnoInfo
	User participation	InnoInfo
Negative	Non-participation of users	InnoInfo
	Negative mindset of internal and external users	InnoInfo, InnoIBS
	Negative mindset of staff and clients	InnoInfra
	Negative mindset of customers	InnoWEBS

5.2.1.3 Networks

Because innovation requires input from all actors, a high level of interaction and interdependence amongst actors exists. This is particularly seen amongst the main internal actors.

In all cases except InnoWEBS, the innovation required the effort of all internal actors. Thus, a high level of interaction and dependence exists particularly amongst the main internal actors. Innovation in InnoWEBS did not involve all actors due to the allocation of innovation work only to selected individuals as prioritized by the MD.

Interactions with external actors are facilitated through networks by cooperation and collaboration. For example, InnoInfo emphasized the importance of collaboration with internal and external users because both groups look at different aspects of construction, thus it focuses on initiatives such as training and meetings to strengthen collaboration. The Quality Team at InnoIBS is structured so that it consists of selected, multidisciplinary staff that provide external networking for site visits.

Factors that provide good cooperation and collaboration are: a long working relationship, good communication and the provision of monetary incentives. For example, InnoInfra has more than twenty years of working relationship with one of its consultants. InnoIBS emphasized the importance of good communication with its external consultants. InnoInfo suggested the sharing of profits from innovation with its clients.

A particular form of collaboration in InnoInfra is its co-innovation with its manufacturer to formulate the new machine used in one of its infrastructure innovations. Other forms of collaboration in InnoInfra are human capital development through research and training with meso-organizations such as university and training institutions and the development of standards with government agencies. Another form of collaboration is mutual learning between the contractor and technology providers. Although both InnoInfo and InnoWEBS purchased the technology or software that formed the basis of their innovations, they both modified it to suit their needs and their technology or software providers later learnt these modifications from them. Hence, the technology/software providers of InnoInfo and InnoWEBS also learnt from them. The observed *Networks* characteristics are summarized in Table 5.7.

Table 5.7: Networks Characteristics

Element	**Characteristics**	
Interaction		High interaction, especially amongst internal and external users
Interdependence		High interdependence: amongst internal actors, with external consultants
Forms	a.	Interaction amongst all actors, external user participation important
	b.	Types of collaboration with suppliers: co-innovation; collaboration with institutions, universities, professional bodies and industry standards organization(s) for human capital development, standards development
	c.	Factors for good collaboration: long working relationship, good communication, monetary incentives.

5.2.2 Knowledge Base and Learning

The characteristics of the knowledge base and learning involved in innovation in the four case studies are compared in this section using the variables in the conceptual framework: the source and type of knowledge base and learning.

The source and type of knowledge base at each case study firm is compared in Table 5.8. Both internal and external sources of knowledge were observed.

Table 5.8: Type of Knowledge Base and Knowledge Source

Knowledge Source	**Type of Knowledge Base**	**Cases**			
		Infra	Info	IBS	WEBS
Internal	Feasibility studies or R&D	X	X	X	X
	Site and study visits	X	X	X	X
	Practical experience of internal users	X	X	X	X
	Work experience of innovation team	X		X	X
	Innovation experience of top management		X		X
	References: Past projects, seminars, technical publication	X		X	
External	External consultants' detailed work	X		X	
	Practical experience of external users		X		

In all cases, the knowledge base was built from feasibility studies or R&D conducted by the firm's D&T Dept. or innovation team. With the exception of InnoInfo, innovation work was also undertaken by selected individuals as part of their technical work, rather than on a full-time basis, and with the help of external consultants or a technology provider. In the construction industry, where R&D work is rare and even more rare is staff that work full-time on R&D work, InnoInfo has a team of 30 staff working on its innovation. InnoInfo's Innovation Manager started the R&D work from scratch without relying on any external consultant, and most of the company's staff initially worked part-time on R&D before the innovation team became a full-fledged full-time Innovation Department.

Local and international site and study visits, organized by the contractor or technology provider (InnoWEBS) also acted as a source of knowledge base. In the case of InnoIBS, the Quality Team's network enabled access to site visits. Another source of knowledge base came from the practical experience of internal users of the innovation and the previous innovation and work experience of the innovation team and the firm's top management.

References from past projects, seminars and technical publications also provided a source of knowledge base, although practical learning and experience is considered a more effective source (InnoInfra, InnoIBS). In InnoInfra, knowledge from new projects is seen as the driver to create and exchange knowledge, and not the reverse, where knowledge base as the driver to create new projects. Formal knowledge management in the form of database exists in almost all case firms (except in InnoWEBS) although it is in a fragmented form.

In short, the knowledge in construction firms is both of the practical and the theoretical types, although the former is seen to be more effective. Feasibility studies, a form of R&D, are conducted part-time by the D&T unit or innovation team. New projects are seen as the driver of knowledge and not the reverse. The observed *Knowledge Base and Learning* characteristics are summarized in Table 5.9.

Table 5.9: Knowledge Base and Learning Characteristics

Characteristics		Explanation		
A.	Type and source of knowledge base	1	Top management, D&T Dept. & Innovation team	
			External consultants & Technology Solution provider	
			Internal, external users	
		2	Internal: Formal, informal, practical experience (site, study visits)	
			Innovation experience of top management/ Innovation team	
		3	Feasibility studies as a type of R&D	
			a	No formal R&D; No full-time R&D staff except in InnoInfo
			b	Innovation cycle: Depending on own development or purchase, urgency, complexity; 1 week to 2 years
		4	Informal and practical knowledge more important than formal and theoretical knowledge	
		5	New projects as driver of knowledge creation & exchange; not knowledge base as driver of new projects	
		6	On-the-job learning more effective than structured training	
		7	Fragmented knowledge base	
B.	Learning	1	On-the-job learning more effective than structured training	
		2	References from past projects, seminars and technical publications	

5.2.3 Demand

The characteristics of the demand involved in innovation in the four case studies are compared in this section using the variables in the conceptual framework. The type of customers and their heterogeneity, their role and effects on innovation; and the user-producer relationships in the innovations described in the cases are discussed in this subsection.

5.2.3.1 Customers and Heterogeneity

Construction firms' customers are known as *clients*. The type of client depends on the construction subsector of the firm, although most big construction firms belong to a combination of subsectors. Government is usually the client for infrastructure innovation (civil engineering subsector), consumers or building owners for the building and residential subsector and house buyers or architects for the residential subsector. In this study, the clients were the Malaysian government (InnoInfra); the developer where the case study firm (contractor) and developer belonged to the same parent company (InnoInfo, InnoIBS); and the consumers of innovation, house buyers, architects and contractors (InnoWEBS).

5.2.3.2 Clients' Roles and Effects

There are three types of client role in innovation. The first is an indirect role where the client provides no input to the innovation. This typically occurs when construction clients "bring problems and ask for solutions [from the contractors]; as well as the known fact that construction clients rarely share solutions" (InnoIBS Site Manager, L107–110).

The second type of client role is also indirect. In this role, the client motivates innovation by demanding things to be done in a certain way, e.g., demands for higher safety standards as well as in setting a short time for project completion. This latter reason is institutional in nature as the construction industry environment is known to be one that is "fast track environment with tight deadlines" (Site Manager, L285).

In the third type of client role, the client provides direct input to innovation. In InnoWEBS, consumers play a direct role, providing input to innovation on their preferred materials and costs.

Clients can either motivate or present barriers to innovation. In InnoWEBS, consumers became an obstacle to innovation because their mindset was attached to conventional methods and focused on costs. On the other hand, in InnoIBS, client demands for higher safety standards positively motivated innovation. In InnoInfra, the greater length of time taken by clients to make decisions about innovation is due to the complexity of issues needed to be considered and the fact that many stakeholders are involved.

5.2.3.3 User-Producer Relationships

Another aspect of demand is the user-producer relationship. This is seen in co-innovation between contractor and manufacturer, where the former assumes the role of the client and the latter as the producer. In InnoInfra, co-innovation occurred with the manufacturer to formulate a new machine that is used in one of its ground-breaking infrastructure innovation.

A summary of the observed *Demand* characteristics is provided in Table 5.10.

Table 5.10: Demand Characteristics

Characteristics	**Explanation**
Customers and heterogeneity	Type of client reflects construction subsector: government for infrastructure (civil engineering), contractor and developer belonged to the same parent company (commercial property), house buyers, architects and contractors residential property.
Role and effects on innovation	Indirect role by providing no input to the innovation, demanding for higher safety standards & in setting a short time for project completion
	Act as barrier when attached to conventional methods and focused on costs or greater length of time taken by clients in decision making on innovation
User-producer relationships	Co-innovation of contractor with manufacturer to formulate something new

5.2.4 Interactions between Components of the CIS

The interactions between components of the CIS that emerged from this research are summarized in Table 5.11. In addition to the observed interactions between the *Knowledge Base and Learning* and *Actors and Networks* components, there was weak interaction between *Demand* and the other components.

Table 5.11: Interaction between Components of the Construction Innovation System

Component	No.	Interaction Component	Nature of Interaction
Actors and Networks	1	Knowledge base	Actor as source of knowledge; Distinct knowledge base characteristics of main actors: Multi-disciplinarity of expert areas, combination of functional departments; Experience from different construction-related industries
	2	Institutions	Group culture as reinforcement
			Development of human capital
			Nature of construction industry as obstacle
Knowledge Base and Learning	1	Institutions	Finance for human capital development
			Culture of knowledge sharing
			Group culture indirectly builds information database

5.2.4.1 Interactions between Actors and Networks and Other Components

As already noted, the main internal actors are the knowledge source for construction innovation. External consultants and technology providers act as external knowledge sources. The *Actors and Networks* component interacts with *Institutions* of culture, human capital and nature of construction industry.

5.2.4.2 Interactions between Knowledge Base and Institutions

Interaction between knowledge base and institutions was seen in three forms. First, the use of finance for transfer of technology, including training (InnoWEBS), for human capital development of internal staff (InnoInfra and InnoInfo) and for human capital development of external users (InnoIBS). Secondly, the culture of knowledge sharing, evident where it is driven by section heads in InnoInfra’s D&T Department and by top management in InnoInfo; the Innovation Committee in InnoIBS, is institutional in form because each subsidiary establishes a Group Quality that indirectly builds a database. Thirdly, informal knowledge base and learning is believed to be more effective in construction due to the (institutional) nature of the industry.

5.2.4.3 Interaction between Demand and Institutions

The demand component is evident only in InnoWEBS. Nonetheless, the absence as well as the presence of demand effects has an effect on innovation in the construction sector. *Demand* interacts with *Knowledge Base and Learning* in the form of the use of feedback from consumers to the innovation in both InnoWEBS and InnoIBS to have a positive effect on innovation. *Demand* interacts with *Institutions* because of several aspects of the nature of the industry (discussed in the following section as Institutional Barriers to Innovation).

5.3 Institutional Regulation of Actor Conduct

This section compares how institutions regulate the conduct of actors in the four case studies. Institutional theory was used to categorize the types and examples of institutional influences into six categories: in-house command, shared cultural orientations, trust and collaborative practices, company organizations, professional competencies and finance and intermediary organizations, or *meso-organizations*, supporting institutional influences. The types and examples of institutions as influences on innovation in the construction industry are presented first, using institutional theory, before revealing the effects of institutions as influences and obstacles to innovation**.**

5.3.1 Positive Institutional Influences

5.3.1.1 In-house Command

In-house command comes in the form of leadership by top and senior management. Top management leadership is seen in the form of initiating, leading and making quick decisions about resource allocation for innovation. Top management in the case studies consisted of Managing Directors (InnoInfra, InnoWEBS), a Director (InnoInfo), Chief Operating Officer (InnoInfo), Chairman and General Manager (InnoIBS). Leadership by senior management (heads of sections in D&T units) was seen in the form of leading knowledge sharing in innovation. Leaders positively influenced other actors in innovation.

5.3.1.2 Shared Cultural Orientation

Three types of shared cultural orientation were observed in the study: internal departmental teamwork (all case firms), a culture of knowledge sharing (InnoInfra, InnoIBS) and innovation culture (InnoIBS). Internal teamwork occurred among the top management, innovation teams, internal users and functional teams. Teamwork is crucial due to the multidisciplinary nature of construction industry, which requires the effort of the all departments in the company even though formal roles may vary. A culture of knowledge sharing is important because knowledge from a variety of team members acts as an important source of knowledge for innovation. The knowledge sharing culture is strengthened if it is driven by top management and senior staff and a group culture as in InnoInfra and InnoIBS. In InnoIBS, innovation culture is a group culture driven by its top and senior management and reinforced with incentives and rewards to encourage and nurture an innovation mindset.

5.3.1.3 Trust and Collaborative Practices

Trust and collaborative practices come in two forms. The first form is seen where the all case firms (except InnoWEBS) form collaborations with external parties involved in the innovation namely the external consultants and subcontractors. This practice is facilitated by good communication and long term working relationships, innovating firm commitment and sharing of monetary incentives.

The second form is one where the case firm (InnoInfra) collaborates formally with external parties not involved in the innovation. This can be seen in InnoInfra's co-innovation with manufacturers, collaboration with meso-organizations such as universities and training institutions to develop or deliver human capital development programs and collaboration with government agencies on development of industry standards.

5.3.1.4 Changes in Organizational Structure

The organizational structure of both construction firms and the sub-contractors involved in the innovations changed as the result of innovation in the case study firms. For the case firms (InnoInfo & InnoWEBS), innovation resulted in streamlined work processes and improved productivity and human capital, and created an organized knowledge base and quicker revenue generation. For the subcontractors (InnoInfo), the innovation improved productivity and developed knowledge base and human capital. In InnoInfra, an evolutionary effect was observed in the evolution of the technical team's human resource structure in response to changes in business needs: a more technical team was needed to create more value-added projects. In InnoWEBS, innovation created a new organizational structure with the addition of a manufacturing arm and associated work practices.

5.3.1.5 Finance

Finance provided resources for innovation in terms of technology purchase, human capital development, innovation development work, buy-in initiatives including training for human capital development of internal staff and external users (InnoWEBS, InnoInfo). The summary of institutions influencing innovation is contained in Table 5.12, at the end of the section on Organizational Connectors and Institutions Supporting Innovation.

5.3.2 Institutional Barriers to Innovation

5.3.2.1 Education and Human Capital

The case study informants believe that human capital acts as a barrier to innovation in three ways. First, there is a lack of human capital trained to use innovations because users are not trained in the technology (InnoInfo). Secondly, the education system does not create an innovative mindset and the engineering profession is focused on career path (InnoWEBS). Thirdly, staff have a negative mindset that innovation is not possible because it is has not been done before or because they find it challenging (InnoInfra, InnoInfo).

5.3.2.2 The Nature of the Construction Industry and its Practices

The "fast-track environment with tight deadlines" (Site Manager, L285) nature of the construction industry discourages the culture of listening and sharing ideas that is important for innovation to occur (InnoInfo). Three additional aspects of the industry act as barriers to innovation: a market that conforms to conventional methods, e.g., through reliance on less advanced software (InnoInfo); poor understanding on technology (InnoWEBS); and a mindset that focuses on costs (InnoWEBS). The fragmented nature of the construction sector causes the industry players to have a mentality of self-benefit and self-protection which leads them to be reluctant to participate in innovation (InnoInfo).

The *build* procurement system used in Malaysia provides little room for innovation because causes clients and their consultants to be more conservative and not innovate because the contractors are required to construct from what has already being designed (InnoInfra, InnoIBS). This is in contrast with the *design and build* procurement system which allows contractors to think innovatively and in using the best technology (InnoInfra). Additionally, the existing practice whereby the professional service consultant fee is fixed by the regulatory board causes reluctance to participate in innovation as participation is factored into the schedule of fixed fees (InnoInfo).

Another institutional impediment is the state of technology in the construction industry where software innovations are not interoperable with existing technology, as in the case of InnoInfo. The institutions and organizations impeding innovation are summarized in Table 5.12.

5.4 Organizational Connectors and Institutions Supporting Innovation

Participants in the four cases proposed two overlapping ways in which institutions might encourage innovation: improvements to government rules and policies and enhancement of the roles played by mediating organizations. It was suggested that government play a mediating role, providing monetary incentives for innovation, establishing centres like those in the USA to nurture new ideas and foster creativity and establishing a marketing entity consisting of both academicians and industry representatives as per the example of the University of China (InnoWEBS). A need for government support to enforce and drive implementation of innovation was also expressed, and Singapore's Building Construction Authority (BCA), a meso-organization, was proposed as an exemplar in enforcing mandatory requirements for professionals and contractors to use an innovation (InnoInfo). Mediating organizations, such as universities and shared R&D facilities and joint marketing entities, could also act as meso-organizations providing research facilities, testing laboratories providing industry standards for certification of innovation components and marketing (InnoWEBS). The summary of institutions supporting innovation is in Table 5.12.

Table 5.12: Institutions and Organizations Influencing and Impeding Innovation

Institutional Influences	**Cases**
In-house command: Leadership	InnoInfra, InnoInfo
Shared cultural orientations: Internal team teamwork	InnoInfra, InnoInfo, InnoIBS
Shared cultural orientations: Culture of knowledge sharing and innovation, Culture of innovation	InnoInfra InnoIBS
Trust and collaborative practices: External consultants	InnoInfra, InnoIBS
Trust and collaborative practices: Subcontractors	InnoInfo
Collaborative practices: Manufacturers, universities, training institutions and government agencies	InnoInfra
Professional competencies: Experience, expertise, R&D staff	All
Finance: Financing of innovation	InnoWEBS
Industry standards by meso-organization: Certification of innovation components	InnoWEBS
R&D facilities by meso-organization: Testing laboratories	InnoWEBS
Institutional Barriers	
Government rules: Build procurement system	InnoInfra, InnoIBS
Education system and human capital: Lack of trained human capital, Non-innovative mindset; Negative mindset: Cannot be done because has not been done before, focus on career path	InnoInfra, InnoInfo InnoInfo, InnoWEBS
Industry practices: Time stretched; Cost-focused	InnoIBS, InnoWEBS
Work and industry practices, Industry structure: Outdated work and industry practices and industry fragmentation	InnoInfo
Cultural and technological orientation: Market that does not accept innovation	InnoWEBS
State of technology: Technology interoperability	InnoInfo
Proposals for further Institutional Support	
Government rules: Monetary incentives	InnoInfra, InnoWEBS
Government policies: For new ideas and to foster creativity	InnoInfra, InnoWEBS
Government regulation: Regulatory or mandatory requirements	InnoInfo, InnoIBS
R&D facilities from meso-organizations: Research facilities	InnoWEBS
Marketing entities: Market the innovation	

5.5 Summary and Discussion of Results

5.5.1 Form of Innovation

Two sources of innovations were observed in this research: in the first, the innovation idea originated from the construction firm (InnoInfra and InnoIBS); in the second, the construction firm purchased the technology or solution for the innovation and customized it (InnoInfo and InnoWEBS) (Table 5.13). In the first type of innovation, the main actors initiated the idea then developed the innovation with external consultants. In the second, the construction firms customized the technology, either according to company processes company (InnoInfo) or market needs (InnoWEBS). The size of the internal development team can be big or small and the development work in most cases is conducted as part of the team's work except for InnoInfo that has a full-time R&D team. The extent of initial investments in technology and subsequent customization of the technology varied, from the case of InnoInfo where it involved a sizeable full-time R&D staff for a period of three years to the case of InnoWEBS, where it involved an initial investment in technology of RM8million without extensive R&D following the purchase.

Table 5.13: Source and Type of Innovation in Case Study Firms

Firm and Innovation	Source of Innovation	Type of Innovation
InnoInfra: Highway (2), Transportation	Contractor-led	Big internal design team, Business practice
InnoIBS: IBS related innovation	Contractor-led	Smaller internal design team, Construction process & product
InnoWEBS: DIY house consisting frame, wall, roof systems	Technology provider, some customization	Smaller internal design team, Construction process & product
InnoInfo: Information on building process	Solution provider, heavy customization by own full-time R&D staff	Organizational & business process

Both contractor-led and externally provided innovations used existing solutions with incremental changes in technology. Thus, the innovations were imitations or adoptions of existing innovations with customization to suit the processes of the company and market needs. Using Bougrain's (2006) typology (Table 2.3), this approach would locate construction firms most nearly in the *supplier-dominated* category, which has the characteristics of: process type of innovation, little R&D and suppliers as source of innovation, than any other, but this is not an accurate representation of the source of innovation in all the studied cases. Contractor leadership was a key feature of innovation in two case study firms, namely in InnoInfra and InnoInfo. Thus, in construction, not all innovations can be deemed supplier-dominated. Further, in the two case studies involving a technology or solution provider, InnoInfo undertook extensive customization with a full-time team of R&D staff and without the support of external solution providers.

The observed innovations consisted of innovations in business practices, in the form of business strategy and business contracts (InnoInfra); organizational processes (InnoInfo); and both construction process and product characteristics (InnoIBS and InnoWEBS). The product innovations were similar to those found in manufacturing while the process innovations were similar to those found in service sector systems of innovation. The observed innovation in business models and organizational forms was not foreshadowed by the literature on innovation in the construction industry and in construction compared to manufacturing and services reviewed in Chapter 2.

In all case studies, innovation was based on the usage of existing technologies. This is similar to the service sector, where innovation rarely involves intellectual property rights but uses existing solutions with incremental change and little technological content. Innovation in the construction industry is therefore also similar to the innovation in the service sector in that the non-technological is linked to technological innovation (Tether & Howells, 2007) through increased business and technological inter-relationships. The large amount of simultaneous process and product innovation in the construction case studies also differentiates innovation in construction from innovation in the manufacturing sector which is product focused as pointed out by the OECD (1997).

R&D in the construction firms existed in a different form to the formal conventional R&D of firms with full-time staff and access to testing laboratories.

Except for one case study (InnoInfo), development of the innovations occurred as part of the firms' technical work on feasibility studies rather than as a permanent, full-time function. InnoInfo, on the other hand, has a sizeable full-time team that permits the company to conduct R&D full-time without calling on external consultants to customize the software also due to the fact that InnoInfo believe that they understand their business processes better.

The length of the innovation cycle time in the case study firms depended on three factors: the complexity of the innovation, whether the innovation is developed in-house or externally and the urgency of the innovation. Where the innovation was more complex, as in the case of infrastructure innovation at InnoInfra, the innovation cycle time was longer, taking up to two years. Where, the contractor developed the innovation in-house, with little external support, the innovation cycle time was longer, e.g. three years in the case of InnoInfo. Where the technology was purchased from a technology provider (InnoWEBS), the innovation cycle was short as the main development work had been completed by other parties. Where the innovation was required urgently (InnoIBS), the innovation cycle time took only a few weeks. Thus, a greater variation in innovation cycle times was seen amongst the construction firms than in either the manufacturing and service sectors, as foreshadowed in the literature reviewed in Chapter 2.

5.5.2 Motivation for Innovation

This thesis finds two main motivations for innovation in the construction sector. The first motivation arises from problems and opportunities when the firm innovates to solve a problem or to seize a business opportunity in the market (all case firms). The second type of motivation is due to positive effects of actors and networks, particularly top management commitment (all case firms), and the personal motivation of innovators (except InnoIBS), as discussed in Section 5.2. Motivations for innovation in the CIS are summarized in Table 5.14.

Table 5.14: Motivation for Case Study Firms to Innovate, Compared With Extant Literature

Aspect of Motivation	Details	Sources
Problem- and opportunity- centric	Firm seeks competitive advantage–reputation, work processes & ability to attract new employees	Slaughter (1998) This thesis
	Firm seeks to improve project performance	Toole (1998) This thesis
Positive effects of *Actors and Networks*	Client or demand pull and technology push are both relevant	Arditi et al. (1997), Bossink (2004), Tatum (1989) This thesis
Indirect	Demand pull has stronger effect than technology push	Gann (2000) This thesis

5.5.2.1 Problem- and Opportunity-Centric

Both problem- and opportunity-centric motivations were observed in the case study firms. This finding is in line with the innovation in service sectors framework of Tether and Metcalfe (2004); Slaughter's (1998) findings that innovation can lead to competitive advantage through improved firm reputation, easier work processes and improved ability to attract new employees; and Toole's (1998) observation that performance of the final structure or system improvements as a result of construction innovation.

The problems that motivated innovation were observed in the form of work processes. InnoInfo was motivated to innovate because it faced ineffective work processes and the inability of the existing tools to meet challenging construction demands. In turn, the firm was ineffective and productivity was low through uninformed decisions, time and cost overruns, inability to control costs, the need for rework and the risk of losing accuracy. One cause of these problems is the fragmented nature of the construction industry, which results in low productivity and affects competitive advantage, brand and ability to attract talent. InnoIBS faced problems in design and construction methods. It innovated because the innovation simplified construction work to save time, which resulted in cost savings and increased efficiency and productivity. This ultimately increased competitiveness. Like InnoInfra, efficiency and productivity were the main goals of InnoWEBS' innovation.

Motivation is opportunity-centric when firms seize commercial opportunity. InnoWEBS and InnoInfra were motivated to innovate to provide a solution to issues faced by the market. InnoInfra's ability to solve construction-related environmental issues enabled it to differentiate itself, providing competitive advantage. InnoWEBS innovated with light weight IBS component materials to provide an alternative to heavier materials that required transport by crane; the innovation gave the firm a niche to enter into IBS component manufacturing, providing greater business opportunities compared to construction. The operation of problem- and opportunity-based motivations for innovation in the case study firms is illustrated in Figure 5.2.

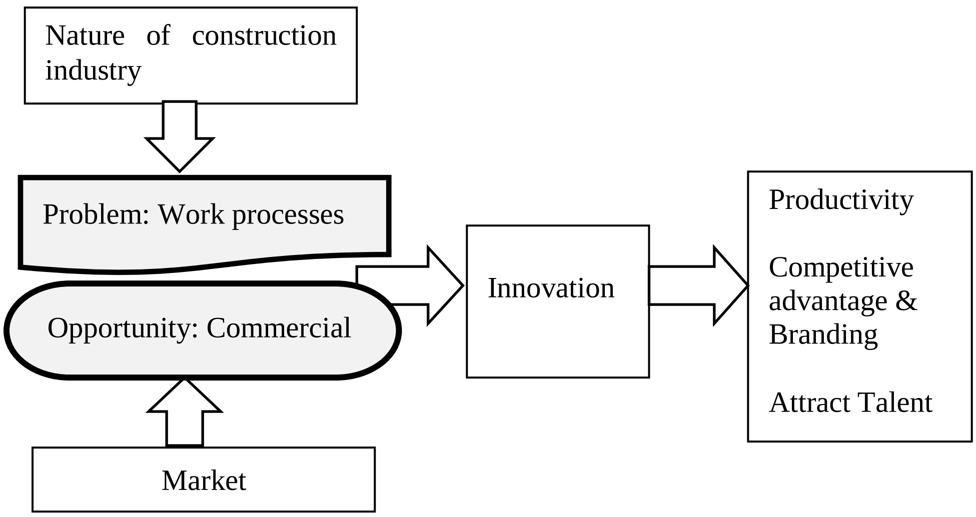

Figure 5.2: Problem- and Opportunity-Based Motivations of Case Study Firms to Innovate

5.5.2.2 Positive Effects of Actors

In addition to their institutional role in innovation (summarized in Section 5.3 under In-house Command), internal actors had positive effects in two-ways, through top management commitment and through the personal motivation of the innovation leaders. As discussed in Section 5.2, top management commitment was shown in all cases through leadership, belief and interest in the firms' innovation, allocation of finance and other resource, initiation of programs, management's active participation in innovation activities and, enforcement through rewards and recognition. This concurs with the existing literature on capability push in the form of leadership in construction innovation. However, contrary to Gann's (2000) observation that demand pull was stronger than capability push in construction, clients played only an indirect role in the case study firms. In line with the leadership determinant literature, the leaders in the case study firms acted as champions for the innovations and were personally motivated to innovate, points that will be taken up in the next section.

5.5.3 RQ1: What are the Active Components in a Construction Innovation System?

The service sector extension of the Sectoral Innovation Systems (SSI) framework used in this study provides a useful structure for discussion of the Construction Innovation Systems (CIS) components observed in the case study firms.

5.5.3.1 Actors and Networks

Actors

In the *Actors and Networks* theme, the conceptual framework guided discussion of the type of actors and their roles, their background, personal motivation and effects; the level of interaction, level of interdependence and type of network, and actors as a knowledge source. The results are summarized and compared to the literature here.

The research found that innovation champions played the determinant leadership role in initiating and developing the innovation in all the case study firms. This finding concurs with the leadership determinant literature on the role of leaders as champions of construction innovation and their positive attributes and support role of upper management (Table 5.15). Innovation leaders possess attributes such as belief and interests in the innovation, as reported in the extant literature. Additionally, we identified two other attributes of leaders. First, leaders have vision and act as entrepreneurs, as in the case of InnoInfra where the MD is greatly respected by the Innovation Team (Head D&T, InnoInfra, L116-119). This is in line with prior business and management research that found that innovation leaders have a long-term and holistic view of the innovation process (Toole et al., 2013). Similarly, in developing country research with the SSI, the software sector in Uruguay was found to have developed because of intense entrepreneurship, and entrepreneurs and business managers in the private sector are key actors in the creation and adoption of scientific technological and business innovations in the pulp and paper industry in Brazil (Malerba & Mani, 2009). Secondly, leaders are interested in innovation and the experience of innovating, as in the InnoInfo and InnoWEBS cases.

Table 5.15: Leadership Determinants – Roles and Positive Attributes of Leaders

Determinant–Leadership	**This thesis**	**Extant Literature** [a]	**Sources**
Role: CEO, Company personnel	Initiator, developer, champion, entrepreneur	Champion, entrepreneur, etc.	Tatum (1986a, 1986b, 1991), Slaughter (1993, 1998), Winch, (1998), Schein (1999), Barlow, (2000), Gambatese & Hallowell (2011), Bossink (2004). Mitropoulos & Tatum (2000), Ling (2003), Koebel et al., (2004). This thesis
Role: Top management team	Top management team: Support	Support	Gambatese & Hallowell (2011) This thesis
Attributes	Visionary, entrepreneurial, Takes long-term, holistic view of innovation process	Takes long-term, holistic view	Toole (2013) This thesis
	Belief & interests in innovation Interests in innovating & experiences, personal and professional satisfaction and challenge from innovating	Strategic clarity & consistency	Laborde & Sanvido (1994), Ling (2003)
		Power & technical competence	Nam and Tatum (1997)
		Motivated leader	Koebel et al. (2004) This thesis

Source: a. Summarized from Toole et al. (2013), Gambatese & Hallowell (2011) and Blayse and Manley (2004).

The research also identified three additional aspects of actors. First, in addition to top management, the main innovation developers were the firm's innovation unit and external consultants. Secondly, the distinct characteristics the firm's innovation department are its multidisciplinary characteristics with respect to expert areas and departmental functions. Similarly, the presence of skilled workers with good level education contributed to development of the software sector in Uruguay (Malerba & Mani, 2009). Thirdly, the actions of actors have both negative and positive effects on innovation: positive if they drive, participate or show commitment to the innovation; negative effects in the form of non-participation and negative mindset of staff, users and clients.

Networks

In all cases except one, innovation was a team effort of top management, the innovation team and all internal departments. Because construction involved multiple actors, high levels of interaction and dependency existed amongst the main internal actors and between these actors and the main external actor, the external consultant or the technology provider. Factors that provided good cooperation and collaboration were: long working relationships, good communication and provision of monetary incentives through the sharing of profits from innovation. These findings are in line with the following observations of the extant literature (Table 5.16). First, the purpose of the network is collaboration for information exchange and building of trust. Secondly, the network involves both internal and external parties. Thirdly, communication is important for the innovation to be implemented efficiently and effectively and for long term relationships between actors.

Three new aspects of *Networks* in the CIS that emerged from the case studies. First, the high levels of interdependence observed between innovation initiator and developer, and between the developer and internal users and developer and external solution providers and external users. Secondly, other forms of enablers of good networks include provision of monetary incentives and human capital development initiatives. Thirdly, interactions between *Networks* and *Institutions* play an important role in the CIS, as discussed in the separate section on institutional influences in regulating of actors.

Table 5.16: Networks in the Case Study Firms Compared to the Extant Literature

Thesis Finding	Extant Literature	Sources
Concur	Significant effects	Blayse & Manley (2004), Dulaimi et al. (2002), Dulaimi et al., (2005) This thesis
Concur	Purpose : collaboration & trust	Bossink (2004), Gann and Salter (2000), Hartmann et al. (2007), Ling (2003), Ling, This thesis
Concur	Collaboration for information flows	Anderson & Manseau (1999), Anderson & Schaan (2001), Barrett et al. (2008), Cleff & Rudolph-Cleff (2001), Manley (2005), , Manley &McFallan (2006), Miozzo & Dewick (2004), Reichstein et al., (2005) This thesis
Concur	Involves both internal and external parties	Bossink (2004) This thesis
Concur	Linkages within organizations & between organization	Bossink (2004), Gann (2000), Ling, (2003), Ling et al. (2007) This thesis
Concur	Importance of communication	Blayse and Manley (2004), Dulaimi, Ling et al. (2002) This thesis
High levels of interdependence: innovation initiator & developer; developer & internal users; developer & external solution providers & external users.		This thesis
Forms enablers of good network: monetary incentives, human capital development initiatives.		
Interactions between the "Network" and "Institutions" themes		

5.5.3.2 Knowledge Base and Learning

Knowledge Base and Learning was studied with respect to the type and source of knowledge base and learning processes, and institutional and cultural context. The results concur with the following five findings in extant literature:

i. importance of absorptive knowledge transfer;

ii. organizational learning in the form of exchange and transfer of knowledge;

iii. codified knowledge is also limited due to the project-based nature of construction;

iv. practical learning and experience is more effective than formal courses; and

v. knowledge management is in a fragmented form.

Similarly, SSI research in the software sector in Uruguay showed that skills and human capital formation are particularly important for growth and, in Brazil, that the knowledge base of a sector greatly affects the organization of innovative activity and the type of network (Malerba & Mani, 2009).

Additionally, we found the following (Table 5.17):

i. The two types of knowledge base and learning observed in the case study firms were: feasibility studies, a form of R&D conducted part-time as part of the innovation team's technical work assisted by its external consultants; and site and study visits, practical experience of internal users, work experience of the internal main actors and references from past projects.

ii. Significantly, projects are a driver for creation and exchange of knowledge in new projects, rather than knowledge base being the driver of new projects.

iii. The informal form of knowledge base and learning is more effective in construction, and this is associated with the nature of the industry, an interaction between the *Institutions* and *Knowledge Base and Learning* components of the construction innovation system. The *Knowledge Base and Learning* and *Institutions* components also interact in the use of finance for transfer of technology and in encouragement of the culture of knowledge sharing. The experience, expertise and background of the main actors are the source of knowledge base, showing the interaction between the *Actors and Networks* and *Knowledge Base and Learning* components.

The importance of actors and networks in knowledge base and learning in the construction firms concurs with earlier SSI in developing country research:

i. the software sector in Uruguay, where firms' learning occurs through access to external knowledge and information through networking;
ii. the ICT industry in Brazil (Perrini, 2009) where skills and human capital formation are important for growth and the knowledge base of the sector greatly affects the organization of innovative activity and the type of networks; and
iii. the Malaysian furniture cluster, where linkages and interactions amongst actors are critical to the distribution of knowledge and innovation (Ng & Kanagasundaram, 2011).

Similar to the findings of empirical research in advanced countries, the type of networks that emerge in innovation processes in developing countries are strongly associated with the specific knowledge base (Malerba & Mani, 2009). In studying the ICT sector in Brazil, Perini (2009) showed that understanding of type of knowledge is necessary for understanding why networks of certain types are present in the development of a sector.

Our finding that the construction industry focuses on the informal form of knowledge base and learning and prefers part-time to full-time R&D contrasts with the findings for other industries in developing countries. In the case of the Indian pharmaceutical industry, Mani (2006) showed that R&D and production capabilities have to be integrated for successful innovation, as their separation leads to companies without competence in production, or reliance on external research without any internal capability. Similarly, in the software sector in Uruguay, firms' learning occurred through internal R&D efforts (Malerba & Mani, 2009). Nonetheless, in three of our cases, innovation was conducted only as part of the development team's work. The size of the internal development team varied across the cases, either big or small.

Table 5.17: Knowledge Base and Learning Compared to the Extant Literature

<table>
<tr><th>Thesis Finding</th><th>Extant Literature</th><th>Sources</th></tr>
<tr><td>Concur</td><td>Absorptive capacity & knowledge codification</td><td>Gann (2001)</td></tr>
<tr><td>Concur</td><td>Organizational learning & knowledge management</td><td>Laborde & Sanvido (1994), Miozzo & Dewick (2002), Sexton & Barrett (2003), Blayse & Manley, (2004), Harty (2005)</td></tr>
<tr><td colspan="2">New projects as driver to create and exchange knowledge, not knowledge base as driver for new projects</td><td rowspan="3">This thesis</td></tr>
<tr><td colspan="2">Feasibility studies considered part of R&D</td></tr>
<tr><td colspan="2">Interaction of institutions & knowledge base and learning themes; actors & network and knowledge base & learning</td></tr>
</table>

5.5.3.3 Demand

We observed two types of client roles in innovation: clients that play indirect roles, as they do not provide input to innovation, and client that provide direct input to innovation. The extant literature points to clients that provide a direct input to innovation (Gann, 2000 cited in Ling, 2003) as the main motivators of innovation in construction, whereas we found that the type of client and their role in innovation is dependent on the construction subsector: in the infrastructure subsector, the client does not play any role in innovation whereas in the residential subsector the client is found to be a motivator of innovation. A third type of client role, observed in the construction innovation literature (Blayse & Manley, 2004; Dulaimi et al., 2002; Dulaimi et al., 2005) but only in one innovative case study firm (InnoWEBS) we studied, is the client that impedes innovation when they have a mindset fixed on a conventional method and focused on costs. This type of client is seen in studies that find that clients act as obstacles with respect to decisions for timely collaboration amongst actors (Blayse & Manley, 2004; Dulaimi et al., 2002; Dulaimi et al., 2005) and demand is a greater impediment than the availability of technologies to innovation by service firms (Tether & Howells, 2007).

5.5.4 RQ2: How do Institutions Regulate the Conduct of Actors in the Construction Innovation System?

A wide range of types and influences of institutions in construction innovation were identified in the case studies. They were discussed in detail in Section 5.3 and summarized in Table 5.14. In this section, we note similarities between the institutions observed in the Malaysian construction industry and those observed in other studies. Institutions regulate the conduct of actors in the construction innovation system by acting as positive influences or impediments. In terms of positive influences, our findings concur with three aspects of the extant literature on three aspects, namely, culture, collaboration and the role of external institutions in the forms of the following (Table 5.18). First, a culture that enables innovation and employees' ability to balance efficiency and being open to changes, such as openness to new ideas and on-going dialogue and accepting conflict. Secondly, collaboration with other industry players and the role of innovation brokers' – such as professional institutions, universities and other tertiary institutions, construction research bodies, and individual academics and researchers – as facilitators of cooperation and knowledge growth and as producers and/or repositories of knowledge, to disseminate knowledge and to evaluate competing technologies. Thirdly, the role of external institutions in relation to regulations.

Table 5.18: Institutions in Construction Innovation Compared to the Extant Literature

Thesis Finding	Extant Literature	Sources
Culture		
	Openness to new ideas & on-going dialogue	Barlow (2000), Blayse & Manley (2004), Dulaimi et al. (2002), Ling et al. (2007), Love et al. (2002), Manley & McFallan (2006)
	Accepting conflicts, Communication	Gambatese & Hallowell (2011), Martins & Terblanche (2003)
	Employees' ability to balance efficiency with being open to changes	Sexton & Barrett (2003)
	Recognize innovation is not limited to R&D	Toole et al. (2013)
Collaboration		
	Role of innovation brokers	Davidson (2001), Gann (2001), , Manseau (2003), Winch (1998)
External sources –Institutional support		
	government regulatory policies, capabilities of regulators, enforcement methods	Dubois & Gadde (2002), Gann et al., (1998), Gann & Salter (2000)

The importance of trust and collaborative practices between innovative firms, external firms and other organizations, and collaborative practices with intermediary organizations, also concurs with similar findings in the Malaysian furniture sector. Ng and Kanagasundaram (2011) found that one distinct feature of actors is the cooperative spirit, trust and loyalty among the industry players.

In addition, our finding that meso-organizations mediate institutions with respect to providing industry standards and R&D facilities in construction concurs with SSI studies in developing countries that found that specific institutional frameworks in developing countries allow for organizational learning and decentralized interaction between shareholders with different interests (Malerba & Mani, 2009) and that collaboration on external training for innovation and formal relationships with knowledge institutions –such as universities and consulting firms and other providers of scientific and technical support – favoured innovation (Laursen & Foss, 2003).

Our observation that the Malaysian construction industry practice with regard to adoption of the build procurement system discourages innovation concurs with extant literature on impediments to construction innovation with respect to procurement and contracting strategies of that cause fragmented and disjointed design and construction process (Slaughter, 1998; Gann, 2000; Harty, 2005; Manley & McFallan, 2006) and the selection of contractors based on low bids (Miozzo & Dewick, 2002). The non-innovative and negative mindset of clients caused by the time sensitive, cost-focused nature of the industry, along with a lack of technology interoperability, concurs with extant literature on the impediments of technological, financial and employee resistance to risks (Mitropoulos & Tatum, 1999). Additionally, we found one other barrier to construction innovation, namely the lack of trained human capital.

5.5.5 RQ3: How do Organizations Connect Institutions and Firms to Support Innovation in the Construction Industry?

With respect to encouragement of construction innovation, we found that government plays a supportive role, especially through government regulation for adoption of innovations. The firms would like to see the government's role extended to support innovation by encouraging innovation through monetary incentives and setting policies to encourage new ideas and foster creativity. Generally, however, SSI studies in developing countries have found that policy does not play a major role in innovation, except in human capital formation and providing general infrastructure (Malerba & Mani, 2009).

5.6 Chapter Summary

This chapter analysed the findings across the four cases according to the three research questions. The system of innovation approach allowed this study to examine construction innovation in an integrated way by mapping the characteristics of the institutions, actors and organizations, and the relationships between them. We compared the findings of this study with extant empirical studies and listed the additional findings of the study. The next chapter will present the conclusions of this thesis.

CHAPTER 6

CONCLUSION

6.1 Introduction

The main objective of the work described in this thesis was to provide a profound understanding of the characteristics of the construction innovation system to increase the level of innovation in construction firms. In order to achieve this, a research methodology was developed to produce a mapping of a construction innovation system in terms of its characteristics and their interactions and how these characteristics and their interactions influence, hinder and motivate innovation in construction. The mapping of a construction innovation system that has been achieved provides new knowledge that will help policy makers and the owners and managers of construction firms to increase innovation in construction. By adopting a service sector adaptation of the Sectoral Innovation Systems (SSI) framework, we used a systemic model of innovation to explain how innovation occurs in the construction industry through a complex interplay of interactions, taking account of the specific project-based nature of the industry and the specific processes within it.

This chapter presents the conclusions of the study in three sections. Following this introduction, Section 6.2 provides the synthesis of the findings by mapping the characteristics of the construction innovation system. Section 6.3 discusses the implications for theory, management practice and policy, and Section 6.4 acknowledges the limitations of this study and provides recommendations for future research before a final note in Section 6.5.

6.2 The Construction Innovation System

The construction innovation system has both unique characteristics and characteristics that are shared with other sectoral systems of innovation. By taking a service sector point of view, it has been possible to identify these characteristics as well as characteristics of the form of innovation in the construction industry and construction firms' motivation to innovate. The construction innovation system (CIS) is represented in Figure 6.1 and described in this section.

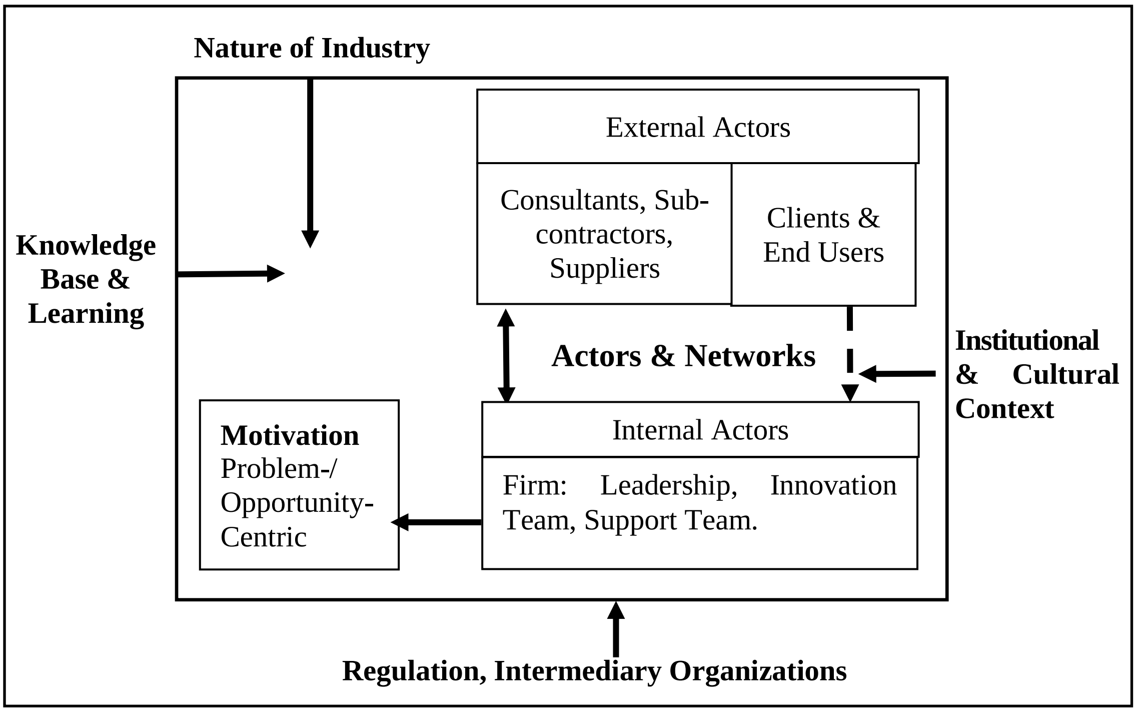

Figure 6.1: The Construction Innovation System

6.2.1 Forms of Innovation in Construction

Innovation in construction is largely incremental and not revolutionary, thus typifying Schumpeterian Mark 1 systems (Schumpeter, 1961, p. 66). The innovations themselves are imitations or adoptions of innovations from other sources, with contractor-led innovations quite common, in addition to customization of supplier-dominated innovation as seen in other sectors. As observed by Tether and Howells (2007), innovation in construction is similar to innovation in the service sector, consisting of business practices, organizational processes, construction processes and products.

Several types of product innovations in the construction sector also share similarities with manufacturing products, such as the use of modular components in industrialized building systems (IBS), where components are prefabricated in factory conditions. The sources and types of innovation observed in the case study firms are summarized in Table 6.1.

Table 6.1: Source and Type of Innovation in Case Study Construction Firms

Source of Innovation	Type of Innovation
Contractor-led	Business practices Construction process & product
External provider	Organizational process (heavy customization) Construction process & product (some customization)

Innovation in the construction industry has similar characteristics to innovation in the service sector where the non-technological is linked to the technological (Tether & Howells, 2007). Business, organizational and other forms of non-technological innovation are important in construction, where process innovation occurs simultaneously with product innovation. This is in contrast to innovation in the manufacturing sector which is product focused (OECD, 1997).

The size of the internal innovation development team can be big or small, and full-time R&D team appears to be rare. The length of innovation cycle time depends on three factors, namely, the complexity of the innovation, whether the innovation is developed in-house or externally and the urgency of the innovation. The characteristics of innovation in construction as compared to manufacturing and services are summarized in Table 6.2 using Tether and Howells' (2007) framework.

Table 6.2: Characteristics of Construction Innovation Compared With Manufacturing and Services

Construction characteristic	Manufacturing (M) & Services (S) characteristic
Intellectual Property Rights: None	M: Patents S: Copyright
Technology orientation: Problem-opportunity-centric	M: Technology push (led) S: Technology pull: Consumer / client led
Research: Developed with external consultants; Sourced externally	M: In-house S: Mainly sourced externally
Innovation cycle times: Depends on complexity, urgency and whether developed in-house or externally	M: Short S: Long (except for computer services)
Product characteristics: Both tangible and intangible constructed at locations	M: Tangible, easy to store S: Intangible, difficult to store

Source: Extended by the author to the construction sector, from selected elements of Tether and Howells (2007)

6.2.2 Motivation to Innovate: Problem-and Opportunity-Centric

Construction firms might innovate for problem-centric or opportunity-centric reasons, as do firms in the service sector. Actors have a positive effect on innovation through top management commitment, the leadership behaviours and attributes of innovation champions and the personal motivations of the innovators. Thus, the capability push of leaders has a strong effect on construction innovation. Clients played only indirect roles and demand pull was not apparent in the construction subsectors we studied in Malaysia, contrary to the propositions made by Gann (2000). Motivation to innovate in the construction sector is summarized in Table 6.3.

Table 6.3: Motivation for Construction Firms to Innovate

Characteristic	Detail
Problem- and opportunity- centric	Firm seeks competitive advantage–reputation, work processes & ability to attract new employees
	Firm seeks to improve project performance
Positive effects of *Actors and Networks*	Client or demand pull and technology push are both relevant
	Leaders' capabilities and formal and informal roles are strong determinants
	Leaders' personal motivations are a strong determinant
Indirect	Firm capability push has a stronger effect than demand pull [a]

Note. [a] Previous research found that demand pull had a stronger effect than demand pull (Gann, 2000).

6.2.3 The Active Components of the Construction Innovation System (CIS)

6.2.3.1 Actors and Networks

Innovation in construction is an internal and external team effort with actors playing specific roles through their participation or non-participation. As in other sectors, leadership is a strong determinant of innovation, with the top management team playing a strong role and senior managers and technical leaders playing the role of champions, using power and competence to drive innovation. Additionally, as already noted, the motivation of leaders with vision and entrepreneurship skills and interests in innovating and learning from their experiences and gaining personal and professional satisfaction and challenge gave an important push to innovation. The characteristics of innovation leaders are summarized in Table 6.4.

The main innovation developers in the construction innovation system are top management and individual leaders. Other main actors consist of the innovation unit, and external consultants and technology providers. The distinct characteristics of the firm's innovation unit are its multidisciplinary characteristics with respect to expert areas and departmental functions.

Table 6.4: Characteristics of Leaders in Construction Innovation

Characteristic	Detail
Role	Top management team: Resource support Individuals: Initiator*, Developer*, Champion
Attributes	Power & technical competence
	Long-term strategic vision, holistic view
	Belief and interest in motivation
	Personal motivation to innovate, innovation a challenge*
	Innovation gives personal and professional satisfaction*

Note. * New finding from this thesis.

The actions of actors have both positive and negative effects on innovation, the former if they drive, participate or show commitment in the innovation. The latter occurs in the form of non-participation and negative mindset of staff, users and clients.

6.2.3.2 Networks

Because construction involves multiple actors, innovation in construction is a team effort that requires high levels of interaction and dependency. Other network enablers are monetary incentives and human capital development initiatives. The latter is consistent with the extant literature on network enablers, such long working relationships and open communication.

6.2.3.3 Knowledge Base and Learning

The *Knowledge Base and Learning* component of the CIS is similar to that of other sectors, in several ways. Organizational learning occurs through exchange and transfer of knowledge and the institutional and cultural contexts can enable or impede learning and knowledge accumulation. The knowledge base is limited by absorptive capacity.

In contrast to the manufacturing sector, informal forms of knowledge base and learning are considered more effective than codified knowledge and formal learning programs. Knowledge codification is limited, with fragmented knowledge management, partly due to the project-based nature of construction, and practical learning and on-the-job experience are valued. The creation and exchange of knowledge is not a driver of new projects, but rather new projects are a driver of knowledge creation and exchange, e.g., through feasibility studies which may be considered part of R&D.

The capabilities and competencies of external consultants and technology providers are important knowledge sources, along with those of internal actors. Knowledge transfer is two-way, from technology providers to the construction firm and from the construction firm to technology providers.

The role of actors as a source of the knowledge base confirms the interaction between the *Actors and Networks,* and *Knowledge Base and Learning* components of the CIS. The *Knowledge Base and Learning* component also interacts with institutions in the encouragement of the culture of knowledge sharing and in the financing for technology transfer. The elements of the *Knowledge Base and Learning* component of the CIS are summarized in Table 6.5.

Table 6.5: Knowledge Base and Learning Elements, Construction Innovation System

Knowledge Base and Learning Elements
Informal learning more effective Knowledge codification limited Institutional and cultural contexts as learning enablers Past experiences valued Absorptive capacity important Knowledge management fragmented
New projects drive knowledge creation and exchange, not knowledge base as driver of new projects Feasibility studies are part of R&D
Two-way knowledge exchange with external providers
Interaction of Actors & Networks with Knowledge Base and Learning Interaction of Institutions with Knowledge Base and Learning

6.2.3.4 Demand

Clients can provide direct input to innovation, indirectly motivate innovation or impede innovation in the construction sector. The type of client and their role in innovation is dependent on the subsector. In the infrastructure subsector, the client plays no direct role in innovation, and typically has a mindset fixed on conventional methods, focused on costs and slow to make decisions; this cultural and industry practice shows the interaction of the institutional theme with demand. In Malaysia, the infrastructure subsector requires contractors only to respond to client demands, limiting opportunities for innovation. In the residential subsector, on the other hand, clients motivate innovation by providing feedback on the innovation.

6.2.4 Institutional Regulation of the Conduct of Actors in the CIS

Institutions regulate actors' conduct in the CIS in eight ways: through leadership by top management as in-house command, shared cultural orientations in the forms of internal teamwork and a culture of knowledge sharing and innovation, trust and collaborative practices, collaborative practices, the firm's human capital structure, finances and the role of meso-organizations as intermediary organizations to institutions (Table 6.6).

Table 6.6: Institutions in Construction Innovation

Institution Categories	**Elements**
In-house command	Leadership
Shared cultural orientations	Internal team teamwork; Openness to new ideas & on-going dialogue, accepting conflicts, communication; Employees' ability to balance efficiency with being open to changes; Recognize innovation is not limited to R&D;
Trust and collaborative practices	External consultants, subcontractors
Collaborative practices	Manufacturers, universities, training institutions and government agencies
Firms human capital & finance	Human capital structure
Finance	Finances for innovation
External sources–Institutional support	Government regulatory policies, capabilities of regulators, enforcement methods
Intermediary organizations	Industry standards on innovation, R&D facilities laboratories

Institutions that impede innovation include the absence of or opposite of positive institutional influences on innovation, e.g., the lack of human capital for innovation and a lack of openness to or a non-innovative and negative mindset amongst clients. The nature of the industry, in terms of its tight focus on time and costs, and lack of technology interoperability, impedes innovation, along with certain industry practices, particularly the build procurement system.

6.2.5 Organizational Connectors between Institutions and Firms

In Malaysia, the meso-organizations that play the most important roles in the CIS are those that provide industry standards and R&D facilities for innovation. The government does not play a main role in construction innovation, but more of a supporting role by encouraging innovation. The case studies suggested some additional possible roles for government, by way of providing monetary incentives for innovation, setting policies to encourage new ideas and foster creativity and setting policies related to human capital and adoption of innovations.

6.3 Implications

The understanding of the construction innovation system developed in this thesis has implications for theory, for management and for policy. The implications are discussed in this section.

6.3.1 Implications for Theory

This thesis makes four main theoretical contributions. First, it has established the specific contours of innovation in construction by identifying the construction sector's own characteristics and showing that they most resemble those of the service industries, and by providing a mapping or topography of innovation in construction (Figure 6.1), which has not previously been done.

Secondly, rather than limiting the conceptual modelling and analysis to a single view, this study examined jointly and systemically the forces affecting innovation in construction firms. In so doing, we used an evolutionary approach to capture the qualitative nature of institutions, innovation and organizations in the construction industry as well as extending the SSI framework used by other sectors to the construction sector.

Thirdly, given the paucity of studies on innovation in construction firms in developing countries, this study has added to that field. Indeed, further studies of this sort can be conducted using the findings and methods of this research.

Through these theoretical contributions, this thesis addressed the SSI limitations of lack of focus on demand theme as well as lack of researches in construction sector.

The mapping of the construction innovation system also substantiates the evolutionary argument that innovation dynamism is industry or sector, timing and location dependent (Nelson, 2008; Rasiah, 2011). In the usual way inductive research is carried out, drawing on paths established by deductive research, we followed the approach to identifying and mapping the active components in innovation systems used in the manufacturing and service sectors. The tools, characteristics and paths identified in these sectors were valuable. However, the evidence that emerged from their application enabled the mapping of an innovation system that is different to those of both manufacturing and services and unique to the construction sector.

6.3.2 Implications for Management Practice

This thesis makes four managerial contributions. First, findings show a non-linear sequential pattern of innovation. Innovation in construction consists of a combination of strategic, organizational and technological aspects due to the needs and resources available. This implies that firms need to consider the interrelatedness of these aspects of innovation to enable innovation success.

Secondly, innovation in developing countries has previously been found to be heavily influenced by government (Zheng, 2014). The findings of this research suggest otherwise. Innovation in construction is found to be more internally driven by main actors consisting of top management which provides leadership and commitment in initiating, leading and making quick decisions in allocating resources for innovation and development work by innovation teams supported by external consultants or technology provider.

Thirdly, the shared cultural orientation demonstrated in internal teamwork amongst members of the top management team, innovation teams, internal users and functional teams is critical for innovation. Equally important is trust and collaboration with external consultants, technology providers and external users, facilitated by good working relationship and communication, commitment from the innovating firm. Firms might also consider collaborations in terms of co-innovation with suppliers. We observed the importance of institutional factors internal to the firm such as good relationships amongst main actors as well as the institution of the firm’s internal culture. Government and intermediary organizations do not play a main role in innovation, but important supporting roles; they establish and maintain institutional factors external to the firm that encourage and enable innovation in terms of financing, research facilities, human capital development, regulation and development of industry standards. Financing is important for the purchase of technology and operating technology and in human capital development initiatives including buy-in from internal and external collaborators.

Fourthly, the inherent capability of main actors, including external consultants and technology providers, in terms of knowledge base and learning is very important. Firms might also strategize innovation teams to be multidisciplinary in terms of multiple expert areas, functionality and industry experiences.

Fourthly, innovation means creativity, which is more likely to occur in environments conducive for creativity, thus the institution, culture, driven by top management and linked to work performance, is an important condition for innovation.

6.3.3 Implications for Policy

The policy strategies and implications identified by this research concern human capital development and the roles of government and intermediary organizations.

6.3.3.1 Human Capital Development

The capabilities and professional competencies of the innovating team are important influences on innovation in construction. Two aspects of human capital act as an impediment to innovation: a non-innovative mindset of staff that reject innovation, and the lack of human capital able to use an innovation. Negative mindset also applies to those construction industry professionals who do not participate in innovation due to a perception that it does not advance their careers.

The implication is for policy makers to investigate how the education system may be structured to include the building of an innovation mindset for workers in the construction sector as well as a supply of construction professionals equipped with the skills that are required by the construction industry. Education of construction professionals would involve educational institutions, such as universities, and professional institutions, and might focus, in the first instance on software-related innovation. The informal form of R&D in construction implies that policy makers need to account for this activity into national statistics as well in policy making.

6.3.3.2 Role of Government and Intermediary Organizations

Government's role in innovation is also important in terms of establishing rules, regulations and policies that encourage innovation, providing financial incentives and recognizing innovative capabilities, increasing the capability of meso-organizations and encouraging network development and learning through collaboration amongst industry players. There is also a need for intermediary government agencies to enforce and drive the implementation of innovations. The role played by the Building Construction Authority in Singapore, which enforced mandatory requirements on professionals and contractors to use IBS, is an example. Government may also act as an institutional influence by providing monetary incentives for innovation and establishing centres to nurture new ideas and foster creativity.

Heavy investments in technology purchase and development and in human capital development of internal staff and external users are required to further construction innovation in Malaysia, as observed both in this research and in the Ministry of Science, Technology and Innovation (MOSTI) study (Thiruchelvam et al., 2013). However, contrary to these findings, the range of fiscal and financing incentives and schemes available for supporting innovation in Malaysia has been reported to be notably deficient in management and design, and rationalization of these schemes to avoid duplications has been recommended (Thiruchelvam et al., 2013).

In terms of knowledge content, performance of the enabling factors of knowledge content, especially human capabilities, is still low and knowledge generation is typically low. The policy implication is for government to increase the capability of construction firms by recognizing their innovative capabilities through: promotion of innovative firms for business opportunities, providing incentivized capabilities programs in specialized areas for innovation and providing opportunities for contractors to implement their innovations in government projects. In addition to encouraging firms to innovate by recognizing their capability and addressing the marketing of innovation, these initiatives will also alter mindset of a market that does not accept innovation.

The example of the Chinese university, with its superior R&D facilities and role in marketing of innovation, compared to the university and SIRIM test laboratories in Malaysia, was provided by one case study firm to highlight the important role of the meso-organizations in innovation. Bureaucracy and lack of industry-relevant R&D are cited as the main reasons that firms are deterred from collaborating with research institutes and universities (Chandran et al., 2008; Rasiah & Chandran, 2009) even though, in recent years, several initiatives have been made by government research institutions (GRIs) and universities to enhance linkages. Other related areas of weakness include: a) the absence of a dedicated institution entrusted with the transfer of industrial technology to industry, as well as mechanisms to enhance the absorptive capabilities of firms; b) weak diffusion of science, technology and innovation efforts; and c) concerns about the effectiveness of education investments in producing competent students, as well as the issue of brain drain (Thiruchelvam et al., 2013). A policy implication is the need to increase the capability as well as to strengthen the role of meso-organizations in innovation in Malaysia.

The nature of the construction industry acts as a barrier to innovation. The industry is fragmented, projects are time-critical and cost-focused, and conventional methods are preferred or imposed by lack of technological interoperability. A policy implication is the need to encourage network development and learning through collaboration amongst actors in innovation. Government can provide incentives to programs that facilitate firms' collaboration with external actors and intermediary organizations. In Malaysia, the intermediary organization, CIDB, can act as a centre for innovation network collaboration as well as a facilitator of technology transfer and sharing of technical expertise that drives innovation.

Overall, institutions act as important positive influences on and impediments to innovation in the construction industry. Thus, an important policy implication is the need for government and intermediary organizations to understand the forms of institutions that influence construction innovation, along with their roles as enablers and obstacles, so that the forms of institutions are properly strategized to increase the level of innovation in construction.

6.4 Limitations and Recommendations for Future Research

The qualitative nature of this research constrains generalization of the results beyond the construction industry in Malaysia. Nonetheless, as the construction faces similar challenges worldwide, the findings of this research may apply more generally. Specifically, the findings should be applicable to construction industries in developing countries that share similarities with the Malaysian construction sector. As the conclusions are limited by data from four case studies, future qualitative and quantitative research might further test the external validity of the understanding of the CIS presented here.

The research has been conducted in large construction firms where greater resources make innovation more possible than in smaller firms. Future research could explore if similar findings emerge in medium-sized and foreign-owned construction firms, to enhance reliability.

As this research is exploratory in nature, it covers a wide range of construction innovation, consisting of adoption, integration, production of something new and significant improvements in product, process and practice (Anderson & Schaan, 2001). Future researchers might examine only new innovation and specifically technological innovation as well as failed innovation attempts to enhance research reliability.

The focus of this thesis was on the determinants and not the process of innovation in construction hence did not emphasize on information on when innovative ideas were conceived, projects were launched, critical junctures/learning events were overcome and innovations were commercialised". Future research could examine the roles of SSI components and their interplays at those points in time.

The thesis used the integrated framework of SSI and Innovation Systems of Service. Future researchers might examine innovation in construction using the SSI with National Innovation Systems and International Innovation Systems frameworks to examine the linkages between these frameworks.

6.5 Final Remarks

This research began with the objective of providing an integrated understanding of the characteristics of a construction innovation system to increase the level of innovation in construction firms. It adopted the service sector adaptation of the SSI framework to explain how the complex interplay of interactions and the project-based nature as well as the specific processes of construction influence construction innovation. The research questions asked what are the active components of a construction innovation system; how do institutions regulate the conduct of actors in the construction; and how do organizations connect institutions and firms to support innovation in the construction industry? The research began with broad themes and variables from the service sector adaptation of the SSI framework and developed variables specific to the construction industry. It answered the three research questions to produce a mapping of a construction innovation system in terms of the characteristics and their interactions; and how these characteristics and their interactions influence, hinder and motivate innovation in construction. The mapping of a construction innovation system provides new knowledge that will help policy makers and the owners and managers of construction firms to increase innovation in construction. Theoretically, this research extends the service sector adaptation of the SSI framework by developing a Construction Innovation System (CIS) framework as well as providing an integrated understanding on the characteristics of a construction innovation system to address the limitations of extant literature which is manufacturing based and single view focused.

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APPENDIX

Appendix A: Interview Protocol

Information	**Details**
On studies	PhD at University Malaya
PhD Title	Innovation in Construction
Focus of Study	How and why innovation occurs across construction sub sectors
Selection of Cases	Recommendation by industry experts
Brief on interview	Who to be interviewed: within the firm, external to firm Selection of Innovation
Innovation location visit	Sightings of innovation, documentation.
Permission	Permission on: -recordings, transcripts of interviews -use of excerpts in thesis & publications in journals

Appendix B: Initial Interview Questions

Q 1.1: Describe briefly a few innovations of your firm in terms of: 1.1.1 Type of innovation 1.1.2 Their impact 1.1.3 Required human resource, processes (machinery, materials, processes), product development capability
Q 2.1: Describe in detail one or two of the innovation(s) you mentioned above in terms of: 2.2.1 How (process) the innovation occurred 2.2.2 Who (internally & externally) were involved 2.2.3 Criteria in selecting partner(s) for innovation **Part 3: Knowledge**
Q 3.1: How are ideas generated in your company?
Q 3.2 How is knowledge kept and used?
Q 3.3 Type of information flow and how it flow internally
Q 3.4 Type of information flow and how it flow externally. Q.3.5 Extent to which your company make use of customers, competitors, suppliers as a source of information.
Part 4: Contractor's perception of network of firms
Q 4.1: Is your company currently participating in an industry network of firms and institutions that shares knowledge and new technologies?
Q 4.2: Do you see the formation of industrial network important for your company to cultivate a higher level of technological capability? (Why?)
Part 5: Major obstacles for you to innovate
5.1 What are the major obstacles for your business to innovate? 5.2 What can the government do to increase level of construction innovation?
Part 6: Factors that induce investment in innovation Q6.1 What were the sources of innovations expenditure? Q6.2 What kind of investments in innovation has your company made? Q6.3 What are the factors that induce your company to invest in innovation? Q6.4 Is the level of profit a contributory factor to your company's level of investment in R&D?

Note: Questions highlighted in grey were deleted after the first interview.

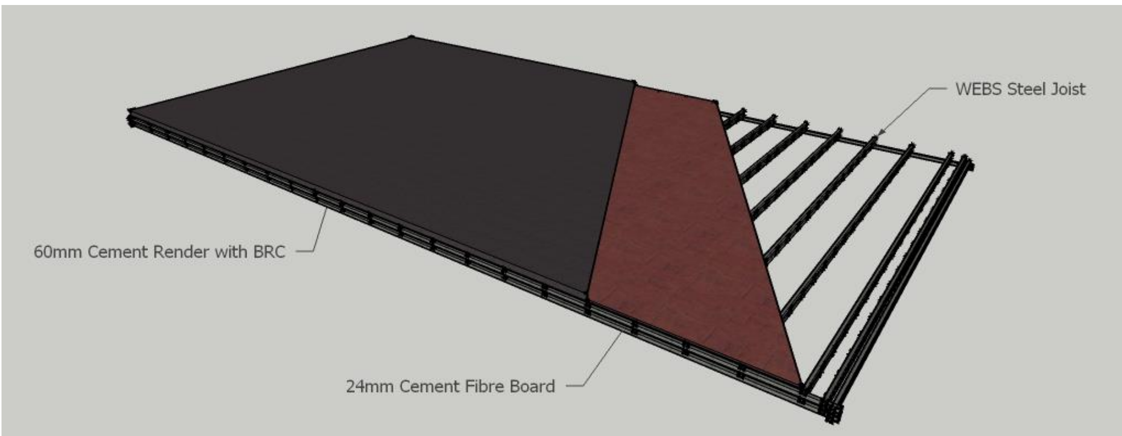
Appendix C: Excerpt from Interviewee Fact Check

QUESTION: Can you elaborate your statement "testing with suppliers". We do it jointly because manufacturers of products ~~they~~ as they are in control of their own manufacturing processes and products which we are not privy to. ~~so~~ For instance we tell them we want some steel materials of certain size, strength, finishes then we send them for testing. We may send to commercial labs for testing- for once-off tests but if we need to monitor the performance of the material continuously, we may purchase the test equipment ourselves for testing ~~– simple testing of strength~~. It is difficult to do everything in house because some of it requires very specialized equipment which ~~are out there and~~ we don't use ~~it~~ frequently. We drive the research testing to the point where we are satisfied with the results ~~then we say ok~~.

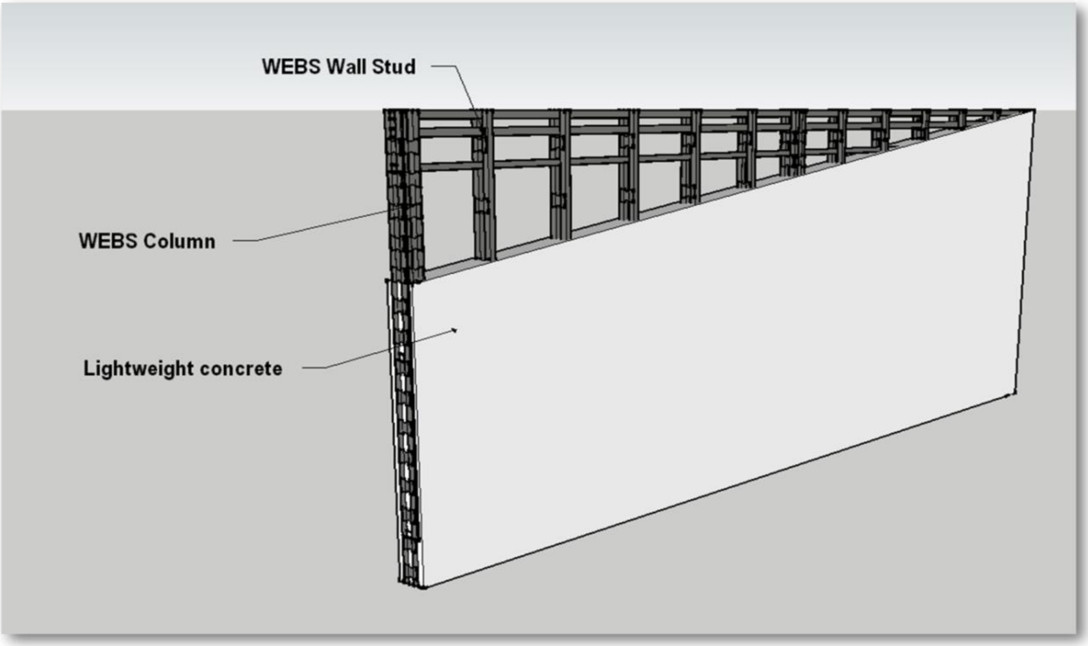
~~In engineering terms we call it mixed design. For example, c~~Concrete is of a standard formula or mix-design most of the time ~~it is ok for our usage~~. ~~It's like baking a cake sometimes baking standard recipe is ok most times but sometimes people need gluten free cakes.~~ Sometimes certain environment may require ~~need certain designs~~different concrete mixes so we have to change the mix-designs. ~~The scale of construction is so big scale that we don't it like labs. Sometimes we need to do in a field and need equipments. Before we~~

Appendix D: InnoWEBS' Innovations

InnoWEBS Floor System



InnoWEBS Wall System



Appendix E: Revised Semi-Structured Interview Questions

A.	**Profile Firm**
	Brief information on company **Description of Innovation –** What is it for, Who is it for, Users
B.	**Before Innovation**
	How things were done before the innovation? Challenges
C.	**Initiation & Implementation of Innovation**
	Who was involved? Reasons for Innovation How was it developed Challenges
D.	**General Question followed by emerging themes**
	Actor Top Management & other actors role Importance of innovation vs. other aspects of business What were important aspects to make it successful? Network & Collaboration Knowledge systems – Learning Institutions
E.	**Others**
	Differences after innovation Difficulties face, how to overcome barriers overcome? About other actors, organizations, institutions in Innovation

Appendix F: First Reading of Transcribed Text before Data Analysis

Category	Subcategory	Thoughts	Quotes	Lines
ACTOR	Actor :Development of idea : Design and Technical Team	Actor :Development of idea : Design and Technical Team	Actor :Development of idea : Design and Technical Team After that we start out with the Design and Technical Team. Mr K is the Head of Technical Team; he got in the Head of Architecture and another engineer	239-40
ACTOR	Actor :Initiation of idea: Board Director & Specialist Staff	Actor :Initiation of idea: Board Director & Specialist Staff	Actor :Initiation of idea: Director & Staff To initially start off the idea there was just Director and I.	238-9
ACTOR	Actor: Role of Contractors - implementor - don't have to innovate	the contractors are the executor and they don't have to innovate	Architect take lead and then clients get contractor to build – the contractors are the executor and they don't have to innovate We are not effective and are fragmented.	96-7, 100-1
ACTOR	Actor: Solution provider: foreign -	Opportunity - push factor ? US InnoInfo contractor	A US InnoInfo contractor came to us	45
CHANGES	After innovation less firefighting.	After innovation less firefighting, improves productivity	After innovation less firefighting. reduces the work and improves productivity	150-151
MANUFACT-URING	Aim of innovation: Manufacturing as model	Manufacturing high productivity as model	high productivity PLM is the way to go that we think manufacturing has high productivity and construction has the lowest productivity so we want to relook and ask why it's that way for us	40-41
CHANGES	Before innovation: Coordination Issues	Before innovation: Coordination Issues firefighting no planning, confirmation	Before innovation: Coordination Issues Before innovation there's a lot of firefighting with no upfront planning and confirmation	145 -148
CHANGES	Competitiveness from innovation Knowledge Base	Eventually our master library be our competitive advantage as well.	Competitiveness from Knowledge Base Eventually this will be our competitive advantage as well.	155
DESCRIPT-ION	Description of innovation	see excerpts	Description of innovation- History of innovation	20 -27

Category	Subcategory	Thoughts	Quotes	Lines
DESCRIPTION	Description of innovation: Differences of 3D conventional vs. 3D innovation	see excerpts	Description of innovation: Differences of 3D conventional vs. 3D information on quality, specifications, materials	6-7
FRAGMENT-ATION	Fragmentation refers to All players' motivation is different. Want to finish the job within their budget, specifications and time frame.	All players' motivation is different. Want to finish the job within their budget, specifications and time frame.	Fragmentation refers to the roles and responsibilities of all parties. Clients can be one time off to own certain facility. consultants advice developers generally want to make monies. want to finish the job within their budget, specifications and time frame. We want things fast. consultants charge based on the time in designing, no motivation to minimize design time. Sub-contractor scope is smaller and they are specialist. All players' motivation is different. Their motivation is still time and cost. The role and responsibilities tend to draw a line e.g. this is my liability then this is my problem.	102-4; L108-114
FRAGMENT-ATION	Fragmented Nature of Industry Definition	different players (clients, etc) different finished product, procurement system	Fragmented Nature of Industry Definition -- different players (clients, etc) different finished product, procurement system	92-95
FRAGMENT-ATION	Fragmented Nature of Industry:different roles and responsibilities, alignment of interests Definition	different roles and responsibilities, alignment of interests	Innovation involves many people and there can easily be 100 people with different roles and responsibilities, alignment of interests is not there, there are lots of documentation to say this is your problem and not my problem	118-120
FRAGMENT-ATION	Impact of Industry Fragmentation: Ineffectiveness	We are not effective and are fragmented.	Impact of Industry Fragmentation: Ineffectiveness We are not effective and are fragmented.	
CHANGES	Impact: productivity: human capital improvements	Impact: productivity: human capital improvements	Impact: human capital improvements In the olden days we can use an experienced staff and throw away all coordination work. But	181-3

Category	Subcategory	Thoughts	Quotes	Lines
			in actual fact we can leverage on him to do bigger scales of work.	
CHANGES	Knowledge Base before innovation	Only experience eyes can use 2D for drawings.	Knowledge Base before innovation last time only experience eyes can use 2D for drawings.	155-6
KNOWLEDGE	Knowledge base: R&D fr Scratch – Conferences (Institutions), innovation site visits (foreign countries) Network. R&D	own R&D from conferences, talking to people & site visits to Norway, Germany, US	Knowledge base – institutions, network. R&D I started my own R&D from scratch, I started with information obtained from conferences, talking to people & site visits We visited Norway and Germany. In US, we met architects and talked to them.	60-62
KNOWLEDGE	Knowledge Base: Tacit Knowledge (talking to people): hard to codify, remains an type of knowledge	experiences where you simply talk to people – it's very hard to codify; tacit knowledge will always be there	Knowledge Base: Tacit Knowledge: hard to codify there are experiences where you simply talk to people – it's very hard to codify and it stays with you. We will maximize the codified knowledge but tacit knowledge will always be there.	166-8
KNOWLEDGE-FRAG	Knowledge Base: very fragmented	our files were very fragmented	Knowledge Base building our master library our files were very fragmented	151-3
KNOWLEDGE	Knowledge Base: R&D: Internally done : we know best	we have to customize and integrate ourselves	Knowledge Base: R&D: Internally done Our people know our processes best Internally we have to customize and integrate ourselves. We research, integrate and test make sure it's properly implemented, end users gets properly trained	173-6
KNOWLEDGE	Knowledge management: RnD: Definition	should be looking at RnD as a company	He had always thought that there's so much innovation of R&D that we should be looking at as a company	220-221
MOTIVATION	Motivation for implementing innovation is different	Different motivation in innovation - what benefits each party will get	Motivation for implementing innovation is different In innovation implementation, different stakeholders and different parties depends on benefits they are going to get	138-140

Category	Subcategory	Thoughts	Quotes	Lines
MOTIVATION	Motivation of innovation: Better Human Capital: change image of industry	change image of industry appeal to younger generation attract talents to construction	Motivation of innovation: Better Human Capital: change image of industry appeal to the younger generation attract talents to construction	63-66
MOTIVATION	Motivation of innovation: growth of industry: Better Human Capital	Better human capital to increase competitiveness	remunerate talents: increase competitiveness	67-9
MOTIVATION	Motivation of Original innovation: Differentiation of small consultants	innovation in US by small consultants: to differentiate themselves.	Motivation of innovation: innovation in US by small consultants: to differentiate themselves. Because the smaller firms use innovation, the bigger firms start to wake up	57-60
MOTIVATION	Motivation: attract talents	attract talents: branding	Motivation: attract talents: branding	67-8
MOTIVATION	Motivation: Problem-centric	Motivation: Problem-centric - Address industry fragmentation	Motivation: Problem-centric - Address industry fragmentation We are very fragmented so at least with our innovation, we get to coordinate at design and planning stage.	87-9
COMPETITIVE ADV	Need for innovation: Nature of Industry – Fragmentation – Need for competitive advantage,	Need for competitive advantage emulate & innovate fr manufacturing	Need for innovation: Nature of Industry – Fragmentation – Need for competitive advantage, not differentiated. Eventually we want the value and Product Life Cycle Management (PLM) can give us the big picture – we want to emulate and innovate from	35-38
MANUFACT-URING	Origin of innovation - manufacturing	see excerpts	Origin of innovation fr automobiles, electronics, and manufacturing is called Product Life Cycle Management (PLM)	9-10
TRIGGER innovation	Triggers for innovation – Leadership – believer in technology	Triggers for innovation – Leadership – believer in technology	Triggers for innovation – Leadership – believer in technology our Director is a believer in technology	197
TRIGGER innovation	Triggers for innovation – Leadership – Experience in other innovation (ERP)	Triggers for innovation – Leadership – Experience in other innovation (ERP)	We started implementing our ERP systems in the 90s	201-2

Category	Subcategory	Thoughts	Quotes	Lines
TRIGGER innovation	Triggers for innovation – Leadership –Strategy – keeping R&D alive	Triggers for innovation – Leadership – Strategy – keeping R&D alive	Triggers for innovation – Leadership –Strategy – keeping R&D alive our Director said that since IT staff has been transferred to IT shared services they roles have changed shared services are not motivated to do. He had always thought that there's so much innovation of R&D that we should be looking at as a company He had always thought that there's so much innovation of R&D that we should be looking at as a company R&D.	217-8; L220-221
TRIGGER innovation	Triggers for innovation – Leadership –Vision (Virtual Construction)	Triggers for innovation – Leadership –Vision (Virtual Construction)	Triggers for innovation – Leadership –Vision He had always had dream of having something virtual construction to be implemented.	L206-7
TYPE	Type Innovation: Customization of innovation: Different company processes	Customization of innovation becos different company processes	Type Innovation: Customization of innovation - You will not find two organization implementing innovation the same way. Tools maybe the same. If you want to implement this innovation, there is bound to be company processes which need customization	L52-4
TYPE	Type of Innovation: process improvement	Type of Innovation: process improvements	Type of Innovation: process improvement Like process improvement, it's more intensive now although we have existing business process improvements.	L176-7
MOTIVATION	Why innovated by own firm? Practise on own process; what's applicable to us	Innovate because different processes	Why innovated by own firm? we have work processes which others may not be practicing. So it depends on our R&D to ensure what is applicable to us	L194-5

Appendix G: Sample of Coded Passages

Theme	Coding 1	Coding 2	Coding 3	Interpret-ation	Quotes	Lines
ACTOR	ActFirRol	ActFirRolTop		Actor :Development of idea : Design and Technical Team	Actor :Development of idea : Design and Technical Team After that we start out with the Design and Technical Team. Mr K is the Head of Technical Team; he got in the Head of Architecture and another engineer	239-40
ACTOR	ActFirRol	ActFirRolTop		Actor :Initiation of idea: Board Director & Specialist Staff	Actor :Initiation of idea: Director & Staff To initially start off the idea there was just our Director and I.	238-9
ACTOR	NatIndCon	NatindNE	NatIndFra	The contractors are the executor and they don't have to innovate ; We are not effective and are fragmented.	Architect take lead and then clients get contractor to build - the contractors are the executor and they don't have to innovate We are not effective and are fragmented.	96-7, 100-1
ACTOR	OthActSP			Other Actor: Solution provider: foreign - our contractor Opportunity - push factor ? US our contractor	A US theme park contractor came to us	45
CHANGES	InvImp			after Innovation less firefighting, improves productivity	After Innovation less firefighting. reduces the work and improves productivity	L150-151
MANUFACT-URING	MfInvL1	MfInvL2	ManMod	Aim of innovation; Manufacturing high productivity as model	high productivity PLM is the way to go that we think manufacturing has high productivity and construction has the lowest productivity so we want to relook and ask why it's that way for us	L40-41
CHANGES	InvImp			Before Innovation: Coordination Issues firefighting no planning, confirmation	Before Innovation: Coordination Issues Before innovation there's a lot of firefighting with no upfront planning and confirmation	L145 - 148
CHANGES	MfInvL1	MfInvL2	KnwDev	Eventually our master library be our competitive advantage as well.	Competitiveness from Knowledge Base Eventually this will be our competitive advantage as well.	L155

Theme	Coding 1	Coding 2	Coding 3	Interpret-ation	Quotes	Lines
DESCRIPTION	DesInv			Description of innovation	Description of innovation- History of innovation	L20 - 27
DESCRIPTION	DesInv			Description of innovation	Description of innovation: Differences of 3D conventional vs. 3D innovation information on quality, specifications, materials	L6-7
FRAGMENT-ATION	NatIndFra			Fragmentation refers to All players' motivation is different. Want to finish the job within their budget, specifications and time frame.	Fragmentation refers to the roles and responsibilities of all parties. Clients can be one time off to own certain facility. Consultants advice, developers generally want to make monies. Want to finish the job within their budget, specifications and time frame. We want things fast. Consultants charge based on the time in designing, no motivation to minimize design time. Sub-contractor scope is smaller and they are specialist. All players' motivation is different. Their motivation is still time and cost. The role and responsibilities tend to draw a line e.g. this is my liability then this is my problem.	102-4; 108-114
FRAGMENT-ATION	NatIndFra			Fragmented Nature of Industry Definition	Fragmented Nature of Industry Definition -- different players (clients, etc) different finished product, procurement system	92-95
FRAGMENT-ATION	NatIndFra			Fragmented Nature of Industry: different roles and responsibilities, alignment of interests Definition	innovation involves many people and there can easily be 100 people with different roles and responsibilities, alignment of interests is not there, there are lots of documentation to say this is your problem and not my problem	118-120

Theme	Coding 1	Coding 2	Coding 3	Interpret-ation	Quotes	Lines
FRAGMENT-ATION	NatindNE	NatIndFra		Impact of Industry Fragmentation: Ineffectiveness	Impact of Industry Fragmentation: Ineffectiveness We are not effective and are fragmented.	
CHANGES	InvImp	HCPro		Impact: productivity: human capital improvements	Impact: human capital improvements In the olden days we can use an experienced staff and throw away all coordination work. But in actual fact we can leverage on him to do bigger scales of work.	181-3
CHANGES		HCPro	KnwDev	Knowledge Base before Innovation	Knowledge Base before Innovation last time only experience eyes can use 2D for drawings.	155-6
KNOWLEDGE	KnwSou	InsRnDTyp		Knowledge base: R&D fr Scratch – Conferences (Institutions), innovation site visits (foreign countries) Network. R&D	Knowledge base – institutions, network. R&D I started my own R&D from scratch, I started with information obtained from conferences, talking to people & site visits_We visited Norway and Germany. In US, we met architects and talked to them.	60-62
KNOWLEDGE	Knwexp			Knowledge Base: Tacit Knowledge (talking to people): hard to codify, remains an type of knowledge	Knowledge Base: Tacit Knowledge: hard to codify there are experiences where you simply talk to people – it's very hard to codify and it stays with you. We will maximize the codified knowledge but tacit knowledge will always be there.	166-8
KNOWLEDGE-FRAG	KnwFra	KnwCod		Our Knowledge Base: very fragmented	Knowledge Base building our master library our files were very fragmented	151-3
KNOWLEDGE	InsRnDTyp			Knowledge Base: R&D: Internally done : we know best	Knowledge Base: R&D: Internally done Our people know our processes best Internally we have to customize and integrate ourselves. We research, integrate and test make sure it's properly implemented, end users gets properly trained	173-6

Theme	Coding 1	Coding 2	Coding 3	Interpret-ation	Quotes	Lines
KNOWLEDGE	InsRnDPri	ActFirRolTop		RnD as a company	He had always thought that there's so much innovation of R&D that we should be looking at as a company	220-221
MOTIVATION	MfInv			Different motivation in innovation - what benefits each party will get	Motivation for implementing innovation is different In innovation implementation, different stakeholders and different parties depends on benefits they are going to get	138-140
MOTIVATION	MfInv	HCBT		Motivation of innovation: Better Human Capital: change image of industry	Motivation of innovation: Better Human Capital: change image of industry appeal to the younger generation attract talents to construction	63-66
MOTIVATION	MfInvL1	MfInvL2		Motivation of innovation Better human capital to increase competitiveness	remunerate talents: increase competitiveness	67-9
MOTIVATION	MfInv			Motivation of Original innovation: in US - Differentiation of small consultants	Motivation of innovation: in US by small consultants: to differentiate themselves. Because the smaller firms use innovation, the bigger firms start to wake up	57-60
MOTIVATION	MfInv	HCBT		Motivation: attract talents: branding	Motivation: attract talents: branding	67-8
MOTIVATION	MfInv	NatIndFra		Motivation: Problem-centric - Address industry fragmentation	Motivation: Problem-centric - Address industry fragmentation We are very fragmented so at least with VDC, we get to coordinate at design and planning stage.	87-9
COMPETITIVE ADV	MfInvL1	MfInvL2		Need for competitive advantage emulate & innovate for manufacturing	Need for innovation: Nature of Industry – Fragmentation – Need for competitive advantage, not differentiated. Eventually we want the value and Product Life Cycle Management (PLM) can give us the big picture – we want to emulate and innovate	35-38

Theme	Coding 1	Coding 2	Coding 3	Interpret-ation	Quotes	Lines
					from	
MANUFACT-URING	OriInv	ManMod		Origin of innovation - manufacturing	Origin of innovation fr automobiles, electronics, and manufacturing is called Product Life Cycle Management (PLM)	9-10
TRIGGER INV	FacEncInv	TopMgtChr		Triggers for innovation – Leadership – believer in technology	Triggers for innovation – Leadership – believer in technology [CEO] is a believer in technology	197
TRIGGER INV	FacEncInv	TopMgtChr		Triggers for innovation – Leadership – Experience in other innovation (ERP)	We started implementing our ERP systems in the 90s	201-2
TRIGGER INV	FacEncInv	TopMgtChr		Triggers for innovation – Leadership – Strategy – keeping R&D alive	Triggers for innovation – Leadership –Strategy – keeping R&D alive our Director Tan said that since IT staff has been transferred to IT shared services they roles have changed shared services are not motivated to do. He had always thought that there's so much innovation of R&D that we should be looking at as a company He had always thought that there's so much innovation of R&D that we should be looking at as a company R&D.	217-8; 220-221
TRIGGER INV	FacEncInv	TopMgtChr		Triggers for innovation – Leadership – Vision (Virtual Construction)	Triggers for innovation – Leadership –Vision He had always had dream of having something virtual construction to be implemented.	206-7
TYPE	TypInv			Type Innovation: Customization of innovation: Different company processes	Type Innovation: Customization of innovation - You will not find two organization implementing innovation the same	52-4

Theme	Coding 1	Coding 2	Coding 3	Interpret-ation	Quotes	Lines
					way. Tools maybe the same. If you want to implement innovation, there is bound to be company processes which need customization	
TYPE	TypInv			Type of Innovation: process improvements	Type of Innovation: process improvement Like process improvement, it's more intensive now although we have existing business process improvements.	176-7
MOTIVATION	InsRnDTyp			Innovate because different processes Practise on own process; what's applicable to us	Why innovated by own firm? We have work processes which others may not be practicing. So it depends on our R&D to ensure what is applicable to us	194-5

Appendix H: Final Set of Codes

Code	Theme	Category : Subcategory	Definition
ActFirCom	Actor-Network	Innovating Firm : Composition	Composition of innovating firm.
ActFirRol	Actor-Network	Innovating Firm : Role	Role of innovating Firm.
ActFirRolTop	Actor-Network	Innovating Firm : Role Top Management	Role Top Management of innovating Firm.
OthActImp	Actor-Network	Other Actor :Importance & Effects	Other actor their importance & effects.
OthActRol	Actor-Network	Other Actor : Role	Other actor's role.
OthActEC	Actor-Network	Other Actor: Role External Consultants	Role of external consultants.
OthActRolLab	Actor-Network	Other Actor: Role RnD Laboratories	Role of R&D Laboratories.
OthActSup	Actor-Network	Other Actor: Role Suppliers	Role of suppliers.
OthActSP	Actor-Network	Other Actor: Solution Provider	Solution provider.
BarPro	Institution	Barrier Procurement	Procurement systems as barrier.
BarCliGov	Institution	Barrier: Client (Government)	Client (Government) as barrier.
BarCulLea	Institution	Barrier: Culture & Leadership	Culture & Leadership as barrier.
BarHumRel	Institution	Barrier: Human Related	Human related barriers.
BarMin	Institution	Barrier: Mindset	Mindset as barrier.
BarMinOve	Institution	Barrier: Mindset: Overcome	Overcome mindset barrier.
BarNatfInd	Institution	Barrier: Nature of Industry	Nature of Industry as barrier.
BizStra	NEW	Business strategy	Innovation as a business strategy.
CliInvTyp	Demand	Client Innovation Type	Client type of innovation.
CliCon	Demand	Client Own Consultant	Clients own consultant.
CliRol	Demand	Client Role	Client's role.
CliTyp	Demand	Client Type	Type of client.
DesInv	Profile	Description of Innovation	Description of innovation.
Ent	Actor-Network	Entrepreneurship	Entrepreneurship in innovation.
FacEncInv	Institution	Factors Encouraging Innovation	Factors encouraging Innovation.
FacEncInvHC	Institution	Factors Encouraging Inv – Human Capital	Human capital as factor encouraging innovation.
FacEncInvLC	Institution	Factors Encouraging Inv – Leadership & Culture	Leadership and culture as factor encouraging innovation.
FacEncInvPS	Institution	Factors Encouraging Inv – Professional Satisfaction	Professional satisfaction as factor encouraging innovation.
FacEncInvSV	Institution	Factors Encouraging Inv – Shareholders value	Shareholders value as factor encouraging innovation.
FinInv	Institution	Finance for Innovation	Finance for innovation.
HCMul	Knowledge	Human Capital – Multitasking	Multitasking work.
HCRes	Knowledge	Human Capital – Responsibilities in Accumulating Knowledge	Human Capital responsibilities in accumulating knowledge.
HCNo	Knowledge	Human Capital Numbers	Human capital in terms of numbers.
HCRet	Knowledge	Human Capital Retaining	Retaining human capital.
HCBT	Knowledge	Human Capital: Better Talent	Obtaining better talent.

Code	Theme	Category : Subcategory	Definition
HCEvo	Knowledge	Human Capital: Evo	Evolution of human capital.
HCExp	Knowledge	Human Capital: Experience	Human capital in terms of experience.
HCMul	Knowledge	Human Capital: Multidisciplinary	Human Capital in terms of multidisciplinary.
HCPro	Knowledge	Human Capital: Productivity	Human Capital in terms of productivity.
InvCha	Change	Innovation & Changes	Changes as a result of innovation.
InvChaMea	Change	Innovation & Changes Measurement	Changes measurement as a result of innovation.
InvImp	Change	Innovation Impact	Impact of innovation.
InvTopBot	Actor-Network	Innovation: Involve top to bottom (team effort)	Innovation involve top to bottom (team effort).
InvTop	Actor-Network	Innovation: Top Management Initiation	Innovation as a top management initiation.
InsCulConImp	Institution	Institution: Culture of Continuous Improvement	Culture of Continuous Improvement as institution.
InsUnitAct	Institution	Institution (Innovation Unit): Activities	Innovation Unit activities as a form of institution.
InsUnitEvo	Institution	Institution (Innovation Unit): Evolvement	Innovation Unit evolvement.
InsInvUnitTop	Institution	Institution (Innovation Unit): Top Management Initiation	Innovation Unit as a form of top management initiation.
InsPerf	Institution	Institution (Performance)	KPI to track innovation performance.
InsRnR	Institution	Institution (Performance)	Recognition and reward as a form of institution.
InsCul	Institution	Institution Culture	Culture as a form of institution.
CulConImp	Institution	Institution Culture of Importance	Importance of culture as a form of institution.
InsCulGrp	Institution	Institution Culture Group	Group culture as a form of institution.
InsCulGrpObj	Institution	Institution Culture Group Objective	Group culture objective as a form of institution.
InsEva	Institution	Institution Evaluation	Innovation evaluation as a form of institution.
InsFin	Institution	Institution Finance	Finance of innovation as a form of institution.
InsActRoleQua	Institution	Institution Innovation Activities: Role of Quality Unit	Role of Quality Unit as a form of institution.
InsActRoleTop	Institution	Institution Innovation Activities: Role of Top Management	Role of top management as a form of institution.
InsRnDAct	Institution	Institution RnD Actor	R&D as a form of institution.
InsRnDActFir	Institution	Institution RnD Actor Firm	R&D Actor Firm as a form of institution.
InsRnDIde	Institution	Institution RnD Ideas	R&D Ideas as a form of institution.
InsRnDLck	Institution	Institution RnD Lack	R&D Lack as a form of institution.
InsRnDMtg	Institution	Institution RnD Meeting	R&D Meeting as a form of institution.
InsRnDNT	Institution	Institution RnD No dedicated team	R&D No dedicated team.
InsRnDPri	Institution	Institution RnD Priority	R&D as priority as a form of institution.
InsRnDRol	Institution	Institution RnD Role	Role of R&D as a form of institution.
InsRnDTyp	Institution	Institution RnD Type	Type of R&D as a form of institution.
InsTraQua	Institution	Institution Tracking by Quality Unit	Quality Unit performance tracking as

Code	Theme	Category : Subcategory	Definition
			a form of institution.
InsTraMgt	Institution	Institution Tracking by top management	Top management performance tracking as a form of institution.
InvPro	Process	Innovation Process	Innovation process.
InvProT	Process	Innovation Process: Length of Time	Innovation process in terms of length of time.
InvProTy	Process	Innovation Process: Type of Innovation	Innovation process as type of innovation.
InvInvCul	Institution	Investment in Innovation – Culture	Investment in innovation in the form of culture building as a form of institution.
InvInvHC	Institution	Investment in Innovation – Human Capital	Investment in innovation in the form of human capital as a form of institution.
InvInvRes	Institution	Investment in Innovation – Resources	Investment in innovation in the form of resources as a form of institution.
KnwAcc	Knowledge	Knowledge: Accessibility	Knowledge in terms of accessibility.
KnwComCov	Knowledge	Knowledge : Components, Coverage	Knowledge in terms of components, coverage.
KnwDev	Knowledge	Knowledge : Development:	Knowledge in terms of development.
KnwMgt	Knowledge	Knowledge : Management	Knowledge in terms of management.
KnwSou	Knowledge	Knowledge : Source	Knowledge in terms of source.
KnwSouExp	Knowledge	Knowledge : Source: Experience	Knowledge in terms of source (experience).
KnwSouFre	Knowledge	Knowledge : Source: Frequency	Knowledge in terms of source (frequency).
KnwTyp	Knowledge	Knowledge : Type	Knowledge in terms of type.
KnwCro	Knowledge	Knowledge Cross functional	Knowledge in terms of being cross functional.
KnwDri	Knowledge	Knowledge driver is new projects	Knowledge driver is new projects.
KnwExc	Knowledge	Knowledge Exchange	Knowledge exchange.
LeaNet	Knowledge	Knowledge Exchange Link Network Learning – Interactions	Knowledge exchange as network of learning.
KnwImp	Knowledge	Knowledge Importance	Importance of knowledge.
KnwFra	Knowledge	Knowledge Nature of Industry Fragmented	Fragmented nature of knowledge in industry.
KnwObj	Knowledge	Knowledge Objectives	Objectives of knowledge.
KnwSha	Knowledge	Knowledge sharing	Knowledge sharing.
KnwCod	Knowledge	Knowledge: Codified	Codified knowledge.
LInsPerftop	Link	Link Institution (Performance) & top management	Link between institution (performance) and top management.
LeaNet	Link	Link Network Learning – Interactions	Link between network and knowledge.
LTopMgtFin	Link	Link Top Management Finance	Link between top management and finance.
LTopMgtKnw	Link	Link Top Management Knowledge	Link between top management and knowledge.
LCliRolStr	Link	Link:Client Role Strategy	Link between client and role of strategy.
LInsAct	Link	Link: Institution Actor	Link between institution and actor.
LInsKnw	Link	Link: Institution Knowledge	Link institution and knowledge.
LKnwIns	Link	Link: Knowledge Institution	Link between Knowledge and Institution.

Code	Theme	Category : Subcategory	Definition
LBizStrInv	Link	Links: Institutions (Biz Strategy) vs. Inv	Links between institutions (Biz Strategy) and innovation.
LNetKnw	Link	Link: Network Knowledge	Link between network and knowledge.
ManMod	Manufact-uring	Manufacturing as Model	Manufacturing as model for construction industry.
MfInv	Motivation	Motivation Inv	Motivation of innovation.
NatCon	Institution	Nature Construction	Nature of construction as a form of institution.
NatConInvMul	Institution	Nature Construction Innovation (Multiactors)	Nature of construction innovation (Multi actors) as a form of institution.
NatConInvT	Institution	Nature Construction Innovation (Time)	Nature of construction innovation (Time) as a form of institution.
NatConInvOTG	Institution	Nature Construction Innovation On the ground	Nature of construction innovation (On the ground) as a form of institution.
NatIndAPD	Institution	Nature Industry all projects different	Nature of industry (all projects different) as a form of institution.
NatIndCli	Institution	Nature Industry Clients	Nature of industry (type of clients) as a form of institution.
NatIndCon	Institution	Nature Industry Contractor Executor	Nature of industry (contractor as executor) as a form of institution.
NatIndFra	Institution	Nature Industry fragmentation	Nature of industry fragmentation as a form of institution.
NatindNE	Institution	Nature Industry not effective	Nature of industry (not effective) a form of institution.
NatCOnInvAppSui	Institution	Nature of Con Inv Applicability Suitability	Nature of construction innovation applicability and suitability as a form of institution.
NetActFir	Network	Network Actor Firm	Network between actors within firm.
NetCha	Network	Network Characteristics	Network characteristics.
NetCoInv	Network	Network Co-innovation: contractor–institution, supplier	Network as in co-innovation between contractor and supplier.
NetDef	Network	Network Definition	Network's definition.
NetImp	Network	Network Importance	Network importance.
NetNat	Network	Network Nature	Network's nature.
NetOthAct	Network	Network Other Actor	Network between firm and other actors outside firm.
NetOthActIns	Network	Network Other Actor – Institutions	between firm and other actors outside firm i.e. institutions.
NetRel	Network	Network Relationship	Relationship between actors in network.
NetObj	Network	Network Objective	Network's objective.
OriInv	Profile	Origin of Inv	Origin of Innovation.
TecExi	Profile	technology; existing technology	Existing technology.
TopCul	Actor-Network	Top Management & Culture	Top Management and culture.
TopMgtEng	Actor-Network	Top Management & staff engagement	Top Management and staff engagement.
TopMgtChr	Actor-Network	Top Management Characteristics	Top management's characteristics.

Appendix I: Materials Used in Peer Review of Coding

I.1 Peer Review Context

Data Analysis workshop, 18th November, 2013 held in Universiti Kebangsaan Malaysia by Prof. Dr. Sharan Merriam.

Fourteen qualitative researchers guided by Prof. Dr. Merriam analysed one interview in a two hour workshop session to answer the research question: "What is/are the motivations for innovation in the firm?

I.2 Materials Provided to Peer Reviewers

Company:	CASE STUDY 3	Date: 09.01.2013
Interviewee:	Innovation Project Manager, Ms L	Duration of Interview: 2 hours
Venue:	Innovation Project Manager's Office	Copy : Excerpts, Course notes

Researcher: Please share what motivated your company to innovate XYZ?

Ms. LEL: In US, the innovation of XYZ is more prevalent amongst the smaller consultants because they want to differentiate themselves. When the construction giants are differentiating themselves, the smaller ones start to use XYZ to differentiate themselves. Because the smaller firms use XYZ, the bigger firms start to wake up. Productivity translates to bottom line. Also construction being dirty, risky and dusty – how would it appeal to the younger generation. A mechanical engineer has a choice of working in manufacturing, consultancy, construction – how to attract talents to construction becomes difficult. The older generation of construction doesn't need qualification and bangs table (less professional) in their work – this needs to change. Using XYZ is not impress talents but overall in an industry we must be more competitive. Only if we are more competitive then we can remunerate them, they take pride in their jobs then the whole industry can grow. If you talk to local university admission unit, they say that the civil engineering courses are not so appealing to students. We are even talking about getting the `cream' but just getting people to join the course. When we started XYZ, the industry started to know, i.e., when we brand CASE 3, it attract some of the very good candidates. At least, they have a choice to use XYZ other than being in the hot sun doing engineering work. We don't mean with XYZ quality issues will be sorted out, it comes back to our culture whether we are particular about quality about culture in the site/project implementation. And also we know our industry supply chain – foreign labour is doing the work – these are not skilled -- they may be farmers who become construction workers.

Researcher: How were things done before your company has XYZ?

Ms. LEL: Manufacturing is very advanced, has high productivity, clean environment and advance tools. Construction is less advanced because each product is different and the processes are redundant and the players always changes e.g. different clients. Panel consultants may be the same. Engaging of consultants is mainly through open bidding. It's very fragmented and things are done ad-hocly. There are different procurement system - `build' or `design and build'. The conventional way where the client appoints the architect take lead and then clients get contractor to build - the contractors are the executor and they don't have to innovate. If drawings are wrong, we hack it and redo and are entitled to claims. In Design and Build, then the contractor is accountable for overall design but for contractor the more inefficiency exists the better it is for them "to claim" monies. Contractors are not motivated to innovate at all these loop holes. We are not effective and are fragmented.

Researcher: Please explain what you mean by the construction industry being fragmented?

Ms. LEL: Fragmentation refers to the roles and responsibilities of all parties. Clients can be one time off to own certain facility. Regular developers selling house are different from those selling shopping malls. These developers generally want to make monies. Then there are the consultants that are needed for design input and professional liability.

They charge based on the time they use in designing – more time spent more charges. Percentage of contract sum is the architect fees and design time. There is no motivation to minimize design time. Contractors want to finish the job within their budget, specifications and time frame. We want things fast. All players' motivation is different. Sub-contractor scope is smaller and they are specialist. Their motivation is still time and cost. The role and responsibilities tend to draw a line e.g. this is my liability then this is my problem. Even in the implementation of XYZ – the coordination, planning and logistics, costs – motivation for implementing XYZ is different. For consultants, their motivation is that they want to change the way of designing and they don't feel the benefits of XYZ. In XYZ implementation, different stakeholders and different parties depends on benefits they are going to get.

Researcher: How were things done before your company has XYZ?

Ms. LEL: Before XYZ there's a lot of firefighting with no upfront planning and confirmation. When you actually have drawings and start to coordinate almost reaching the execution part already but now it's different. The price to pay is that we have to involve a lot more people and involve them earlier at the upfront. And towards the tail end, during execution onsite, the engineers have been cut down less firefighting. It "reduces the work and improves productivity.

In terms of cost estimations we are also building our master library. Through the years, we have files but they are very fragmented – they are here and there –but now we are consolidating them into a Master Library and data. Eventually this will be our competitive advantage as well.

At the end of the day, it's to ensure things are structured and in a systematic form. But still it cannot eliminate tacit knowledge. For example, I am involved in kicking out this project, the process of pushing change management, there are experiences where you simply talk to people – it's very hard to codify and it stays with you. We need to form a system and eventually a community of ecosystem to support it. We will maximize the codified knowledge but tacit knowledge will always be there. It’s more versus less.

XYZ, we are doing R&D is in progress and is consolidating. Our R&D is not dealing with programming or equipment but integrating where we know our business processes best where we can’t outsource.

Our company productivity can be improved through managed processes – products are being reached because depends on the contract, the design part are mainly driven by clients’ expectations and what architects have come out with on designs. So what can be managed to make business more productive is how to manage the processes. In the olden days we can use an experienced staff and throw away all coordination work. But in actual fact we can leverage on him to do bigger scales of work. This is how we also do in human capital improvements.

Researcher: What are the factors that triggered the innovation of XYZ?

Ms. LEL: A foreign consultant approached us. Our Director is a believer in technology. Even 20 years ago in the 1990’s we were the first in using X. Back in the 90’s he already understand that in order for us to scale up because we were small then. He has always been thinking about being more productive. It’s in his blood not because XYZ we suddenly get excited. He has always been a believer in technology. He had always had dream of having something like XYZ to be implemented. He told us a story long ago where by the Japanese already uses part of XYZ. During X, we have a 10-20 people kind of set-up and eventually when X matured staff was all seconded to our shared services. Our Director said the shared services is more to service and performing general tasks so somehow the R&D initiative died off. He had always thought that there’s so much innovation of R&D that we should be looking at as a company but there’s not much now. Staffs that were previously doing R&D when they were transferred their roles and responsibilities change because they are serving wider base customers of our sisters companies. R&D is so company specific that he would think that it should be coming from a business unit. Our Director asked me to sit in the meeting and meet the foreign background because of my expertise related to XYZ. We got to start from the Design and Technical team. To initially start off the idea there was just our Director and I. After that we start out with the Design and Technical Team. It's natural that XYZ software that the users will start off with the Design and Technical team but we actually roll out to the planning Dept. and QS Dept.

Researcher: Please describe how the innovation was developed.

Ms. LEL: I have more breadth of the innovation whereas the Design and Technical team (DTT) have the details. I will start off with the R&D and preempt them on the tools, consultants or what's on in the market, and the directions of the market. the Design and Technical team start with the adoption or testing first depends on situations and tools. After that they test run and implement it. They are giving ideas from the users' perspective. We actually give DTT the ideas on their new ways of doing things but as they move on, as they start using it, they start giving ideas and customize. I source for the stuffs and then I send to the users (DTT) to test suitability. Whenever I propose a new way, DTT will give back ideas and customize. That was the initial stage. So after doing R&D for a while we call in the specialists to audit whether we are doing in a very traditional way using XYZ tools or it's a best practice that they had experienced before. So it got to go through a different life stage where after a while you got to do things differently to check our own team's work. We need feedback whether we are on the right track. Then we roll out to the other Departments. During the first one year, we didn't have full-time staffs working on XYZ from other Departments. Like others, we also suffer from buy-in issues. Now we have full-time staffs from other Departments working on it. We were fortunate that top management didn't take a long time to believe in in it. If the company does not have buy-in from the top, the whole thing may not work. To work on something like this, you have to put on the resources, much money and investments and you have to hire so many people, I would say it's a work of "Faith".

Researcher: What are the challenges that your company face in innovating XYZ?

Some software is not matured. Some software is harder to use then others. It's not so straight forward. Mainly the issues were "buy-in" and technical. The "buy-in" as change management is in place – we are not suffering from it anyway now. The technical issues were also take time to resolve but it comes from vendor side and we have to provide feedback. Again it depends on how important is CASE 3 to the vendor.

Researcher: Tell me more about the issue of buy-in.

Change management refers to management got to put emphasis on it, have to put investments in it, give training. To get buy- How do you know whether this dept. Head has got buy-in or not? You got to see the amount of resources that he put in and the quality of staff he put in. Let's say they give the most lousy staff then you know this Department Head don't really believe in it. If they give you the brightest talent and top talent round and they dedicate them and commit them to the road map and assignments that we request then you have the "buy-in". Through the process, we have seen that in terms of resource commitment, in terms of putting in time to join in our meetings, to provide input. We involve internal staff, consultants and at the project level we also have sub-contractors.

We have to get their ideas for XYZ but because consultants tend to be smaller set-up, they don't have manpower to do R&D. So a lot of times they are actually under our guidance where we teach them this is the way to do it, we give them templates to start off with. Their role is passive. At the earlier stage the consultants are more actively involved, sub-contractors, sub-contractors at the downstream so their involvement is at the later stage. The level of details between them is different. M&E Consultants are more on schematic designs. Actually we help these consultants and sub-contractors more. This is because you have to see the motivation. Our motivation is to save costs and to be productive. Consultants' motivation – it involves so much work and you are not the only client for me. To them, they are a small set-up, the way they see R&D, way to justify costs is also different. But they do get involved. We have internal buy-in now so the challenge is still how to enlarge this influence, the external people which is more tough as it involve conflict of interests. At least internally, we are still under the strong "leadership of command" everyone will be in line. When you do "change management", you are bound to meet people with different motivations – the more friendly or less friendly ones because of top management you can bull doze through them. The company has to move together, we are as strong as the weakest link.