MODELLING INNOVATION PERFORMANCE OF TURKISH CONSTRUCTION COMPANIES

by

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B.S., Civil Engineering, Yıldız Technical University, 2009

Submitted to the Institute for Graduate Studies in
Science and Engineering in partial fulfillment of
the requirements for the degree of
Master of Science

Graduate Program in Civil Engineering

Boğaziçi University

2014

MODELLING INNOVATION PERFORMANCE OF TURKISH CONSTRUCTION COMPANIES

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DATE OF APPROVAL: 04.04.2014

ACKNOWLEDGEMENTS

I am grateful to my thesis advisor Assoc. Prof. Beliz Özorhon Orakçal who is captivating, honest and the true embodiment of a mentor. I would like to thank her for her guidance, support and patience. Her expertise in project management and innovation in construction improved my research skills and prepared me for challenges.

I wish to express my sincere thanks to all company members who have participated questionnaire survey for their positive approach and considerable help that have made this study to reach its objective.

I would also like to thank my family who have believed in me in the way to achieve this study for their sincere and continuous support.

It should also be noted that this thesis is produced based on the research project funded by Boğaziçi University Research Fund (BAP) under the grant number 7085.

ABSTRACT

MODELLING INNOVATION PERFORMANCE OF TURKISH CONSTRUCTION COMPANIES

The construction industry has always been high importance of the national economy. Due to increasing pressures from clients to improve quality, reduce costs and speed up construction processes, innovation can be a key source of competitive advantage for construction companies. On the other hand, construction industry has also long been criticised for exhibiting low rates of innovative activity and its unwillingness to innovate. Construction is a project based and fragmented industry, the patterns of construction innovation are different from the other industries and much of the innovation co-developed at the project level and remains hidden. An appropriate innovation performance measurement system is needed to better understand of the actual level of innovation in construction. The major aim of this research is to develop a comprehensive model which aims at assessing the innovation performance in construction at the project level. In order to achieve this, an extensive literature survey was conducted to find the most appropriate components of innovation including the drivers, enablers, barriers, inputs, benefits and impacts. Then, the interrelationships between those components were identified and the proposed model was tested based on data collected from the Turkish construction companies. The validity of the model was tested by statistical analyses using structural equation modelling (SEM). Findings of the study suggest that drivers and enablers have a highly positive effect on inputs. In addition, inputs have positive affect on benefits and impacts. It is interesting that since the drivers and enablers have a high positive impact on the inputs, the effect of the barriers has become negligible. Proposal of such a framework has considerable contributions to measure the innovation capabilities of companies in Turkish construction industry. This model aims to help companies to be aware of the innovation performance of their company and decide on long-term strategies accordingly.

ÖZET

TÜRK İNŞAAT FİRMALARININ İNOVASYON PERFORMANSININ MODELLENMESİ

İnşaat sektörü, ulusların ekonomisinde her zaman büyük bir öneme sahip olmuştur. İnşaat projelerinde, işverenin proje kalitesinin artırılması, maliyetlerin azaltılması ve süreçlerin hızlandırılması için yaptığı baskılar, inovasyonu inşaat firmalarının rekabetçi avantajı için en önemli kaynaklardan biri haline getirmiştir. Diğer yandan inşaat sektörü düşük inovasyon kapasitesi ve inovasyona karşı ilgisizliğinden dolayı eleştirilmiştir. İnşaat sektörünün kendine özgü; proje odaklı, parçalanmış yapıya sahip olmasından dolayı inşaat sektöründeki inovasyon diğer sektörlerden farklı olarak proje düzeyinde ve farkına varılmadan gerçekleşir. İnşaat sektöründeki inovasyonun düzeyini daha iyi anlamak için, uygun bir inovasyon performans ölçüt sistemi gereklidir. Bu çalışmanın amacı, inşaat sektöründe proje düzeyinde inovasyonun değerlendirilmesi için uygun bir inovasyon performans ölçüm modeli geliştirmektir. Bu modeli oluşturacak en uygun parametreler olan "itici güçler", "katalizörler", "engeller", "girdiler", "faydalar" ve "etkiler" i belirlemek için, detaylı bir literatür araştırması yapılmıştır. Daha sonra bu parametreler arasındaki ilişkiler belirlenmiştir ve önerilen model Türk inşaat sektöründe yapılan anket çalışmasından toplanan veriler ile test edilmiştir. Oluşturulan modelin geçerliliği Yapısal Eşitlik Modeli kullanılarak test edilmiştir. Bu araştırmanın sonucunda, itici güçlerin ve katalizörlerin inovasyon girdileri üzerinde önemli derecede olumlu bir etkisi olduğu, ayrıca inovasyon girdilerinin de proje düzeyindeki faydalara ve firma düzeyindeki etkilere önemli derece olumlu katkı sağladığı bulunmuştur. İtici güçlerin ve katalizörlerin inovasyon girdilerine olumlu yönde yaptığı yüksek etki nedeniyle, engellerin inovasyon girdilerine olumsuz yönde yapacağı düşünülen etkilerin herhangi bir önemi olmadığı bulunmuştur. Önerilen bu modelin, Türk inşaat sektöründeki firmaların inovasyon kapasitelerinin ölçülmesinde katkı sağlaması beklenmektedir. Bu model firmaların kendi inovasyon kapasitelerinin farkına varmaları ve uzun dönem iş stratejilerinin belirlenmesinde göz önünde bulundurulmasını hedeflemektedir.

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LIST OF ACRONYMS / ABBREVIATIONS

3D	Three Dimensional
4D	Four Dimensional
ADF	Asymptotically Distribution Free
AGFI	Adjusted Goodness of Fit Index
BIM	Building Information Modelling
CAD	Computer-Aided Design
CBPP	Construction Best Practice Programme
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
CIC	Computer Integrated Construction
CoCoPS	Component Configuration of Prefabricated Structures
CSR	Corporate Social Responsibility
DTI	Department of Trade and Industry
dof	Degree of Freedom
ECI	Early Contractor Involvement

EIS	European Innovation Scoreboard
EIS	European Innovation Scoreboard
ERP	Enterprise Resource Planning
EU	Europe Union
FTE	Full Time Equivalent
GFI	Goodness of Fit Index
GIS	Geographic Information Systems
GLM	General Linear Model
GLS	Generalized Least Squares
GPS	Global Positioning System
GPS	Global Positioning Systems
GRI	Global Reporting Initiative
ICT	Information and Communication Technologies
IIRC	International Integrated Reporting Committee
IT	Information Technology
ITC	Information Technology in Construction
IVC	Innovation Value Chain

KN	Knowledge Management
LEED	Leadership in Energy and Environmental Design
M4I	Movement for Innovation
ML	Maximum Likelihood
MMC	Modern Methods of Construction
NESTA	National Endowment for Science, Technology and the Arts
NFI	Normed Fit Index
NIS	National Innovation System
NIS	National Innovation System
NNFI	Non-Normed Fit Index
OECD	Organization for Economic Co-Operation and Development
R&D	Research and Development
RF	Radio Frequency
RFI	Request for Information
RFID	Radio Frequency Identification
RFQ	Request for Quotation
RIS	Regional Innovation System

RMSEA	Root Mean Square Error of Approximation
SCM	Supply Chain Management
SEM	Structural Equation Model
SME	Small – Medium Enterprise
SR	Sustainability Reporting
TCA	Turkish Contractors Association
TCEA	Turkish Construction Employers Association
TSLS	Two Stage Least Squares
UK	United Kingdom
USA	United States of America
USD	United Stated Dollar
USGBC	United Stated Green Building Council
UWB	Ultra Wide Board
VDC	Virtual Design and Construction
WLS	Weighted Least Squares
WPMS	Web-Based Project Management
WPMS	Web-Based Project Management Systems

1. INTRODUCTION

Introduction chapter of the thesis includes background of the research, problem determination, problem statement, related studies, aim and objectives of the research, research method, scope and limitations and organization of the thesis.

1.1. Background of the Research

The importance of innovation in construction has been widely advanced. Innovation can be a key source of competitive advantage for construction companies, offering the means through which a firm can achieve a client's objectives in a specific project or its own objectives over a range of projects (Slaughter, 2000). Innovation also enables firms to successfully contend with major changes occurring in the industry. These changes include increasingly competitive and global markets, demand shifts, and client expectations for capital and operating costs to fall (Seaden and Manseau, 2001). Slaughter (1993) suggests that innovation has always occurred in construction and Seaden and Manseau (2001) assert that in most countries there are construction companies that have been able to achieve superior market positions through innovative practices. However, despite these indications there is great concern regarding innovation in the construction industry. The general rate of innovation in construction is argued to be low in comparison to other industries and this low rate has been advanced as the major explanation for poor industry performance in terms of productivity and quality (Winch, 1998; Gann, 2000; Koskela & Vrijhoef, 2001). The low rate of innovation in the industry has made innovation in construction a compelling research topic.

1.2. Problem Determination

Innovation is a key driver of economic growth. It is widely accepted that innovation is a prerequisite to any competitive advantage. Innovation provides benefit to an individual, an organisation or wider society (West and Farr, 1990) and is directly linked to the economic development of any country (Seaden *et al*., 2003). From a construction industry perspective it is widely believed that due to the continuously changing conditions, construction

innovation may become a fourth performance dimension in the future in addition added to the traditional dimensions of cost, quality and time (Newton, 1999). Innovative thinking has become essential for construction organisations because of increasing pressures from clients to improve quality, reduce costs and speed up construction processes (Gann, 2000).

Considering this fact, it is important for the construction organisations to innovate in order to take advantage of changes in market economy, build long-term relationships with clients, increase organisational motivation and make improvements to the systems and processes. A successful innovation performance management process which can be implemented through a comprehensive performance measurement system is a way for organizations to see their status in the business environment and therefore make appropriate strategic decisions. Therefore, a comprehensive innovation performance measurement system measures is needed for construction industry.

1.3. Problem Statement

The majority of the current literature on innovation concentrates on manufacturing industries, while innovation theories have not been investigated empirically in the construction industry.

This research is based on the definition of appropriate innovation performance measures and investigation of determinants influencing the innovation in construction industry. Review of literature suggests that only an adequate combination of criteria allows assessing the multidimensionality of performance, which requires a better understanding of the links between its different dimensions.

In this respect, a complete and valid innovation performance measure should be constructed; direct and indirect impact of factors on innovation performance in construction need to be explored.

1.4. Related Studies

A major difficulty in evaluating the innovation performance in construction is caused by the confusion associated with the definition of performance and how performance should be measured.

Innovation in construction research has gradually increased and reached the point where a multitude of construction innovation books have been produced including Gann (2000), Seaden and Manseau (2001), Jones and Saad (2003), and Miozzo and Dewick (2004). In addition, two international construction journals published special issues on innovation, Construction Management and Economics and Engineering on September, 2003, Construction and Architectural Management on May, 2004 (Dickenson *et al*., 2005).

There are many studies that investigated innovation in construction. According to Dickenson *et al*. (2005) at the individual level (e.g. Nam and Tatum, 1997), project (e.g. Ling, 2003; Ozorhon, 2009a, b), firm (e.g. Sexton and Barrett, 2003a; Ozorhon, 2010), client (e.g. Ozaki, 2003; Ozorhon, 2013a, b), product (e.g. Burford and Smith, 1999), and industry/national (e.g. Pries and Janszen, 1995). Construction innovation at more than one level of analysis (e.g. Winch, 1998; Gann and Salter, 2000; Blayse and Manley, 2004; Bossink, 2004; Ozorhon *et al*., 2009; Ozorhon, 2013a, b). Only a small minority of the research articles have considered innovation at a specific stage of the project lifecycle or from the point of view of the project lifecycle in general. Salter and Gann (2003) and Salter and Torbett (2003) have considered the design stage of construction, working closely with major design firms. Elsewhere, Sidwell *et al*. (2001), Kumaraswany and Dulaimi (2001) have considered the preparation stage of construction. Ozorhon *et al*. (2009b) investigated in detail the particular ways in which innovation occurs throughout the lifecycle of a construction project and the dynamics between project and firm level innovation.

The assessment of the performance of an innovation in construction is complex and requires a structured, systematic, and comprehensive approach. There are studies which propose several performance measures for innovation in construction (e.g., Slaughter, 2000; Ling, 2003; Sexton and Barrett, 2003b; Dikmen *et al*., 2005; Yitmen, 2007; Ozorhon *et al*., 2009; 2010; Ozorhon, 2013a, b).

1.5. Aim and Objectives of the Research

The major aim of this research is to construct an innovation performance measurement model which has the ability to assess the innovation performance both in project and corporate level in construction industry. In order to achieve this, the most appropriate innovation performance measures as well as the innovation performance indicators will be determined, and validity of the measures and the relationships between them will be justified. The validity of the model will be tested by statistical analyses using structural equation modelling (SEM) based on data collected through a questionnaire study. Proposal of such a framework has considerable contributions to measure the innovation capabilities of companies in construction industry. It will provide a multiple faceted innovation performance measurement system with determined measures and indicators valid for most situations in a construction project and a company. This model aims to help companies to be aware of the innovation performance of their company and decide on long-term strategies accordingly.

In this respect, following are the objectives of this research:

- Determination of the measures and determinants of innovation performance as explained within the construction innovation literature,
- Development of an innovation framework specific for the construction industry,
- Analysis of the whole model and exploration of the inter-relationships between model parameters,

1.6. Research Method

A questionnaire survey is administered to construction companies established in Turkey. A questionnaire consisting of questions about innovation performance measures and indicators was designed to analyse their influence on project and company level in construction industry. The data collected from respondents were analysed using structural

equation modelling (SEM) technique. By using SEM, validity of the hypothetical relationships and the proposed measures were tested.

1.7. Scope and Limitations

The limitations related to the research mainly based on the data collection process. Data were collected from medium to large size construction companies established in Turkey. Although most of the respondent companies work internationally, measures were determined according to their availability in Turkish construction industry since respondents were Turkish companies. Rating levels of some the measures as well as the relations between them would be somehow different if the questionnaire was administered in a different country.

Since the data reflects the experiences of Turkish companies and the markets they operated in, the model may not be applicable to all construction companies; other models for companies from different countries may be developed and different results may be obtained. However, conducting such a survey was not included within the scope of this thesis.

1.8. Organization of Thesis

The thesis is comprised of seven chapters.

In the first chapter, introductory information has been given related to the background of the research as well as the definition of the problem, objectives and limitations. In the second and third chapters of this study, in-depth literature review on innovation, innovation measurement and innovation performance issues in general and in construction industry was given respectively. In the fourth chapter research methodology and proposed model was presented as well as the determined measures and the indicators. The questionnaire that is prepared for data collection is depicted. In the following fifth chapter, descriptive statistics of the collected data were given and a comprehensive statistical analysis of the proposed model was explained in detail in line with a review of the Structural Equation Modelling (SEM). SEM is proposed as the statistical analysis method using which the hypotheses

regarding the interrelations between the attributes of the model and their influence on innovation performance are tested. In the sixth chapter, determinants of innovation performance were discussed. Finally, the conclusions of the research were elaborated and some recommendations are provided for the construction companies in the seventh chapter.

2. INNOVATION IN CONSTRUCTION

Innovation is not a new phenomenon. It is as old as man-kind itself. There seems to be something inherently "human" about the tendency to think about new and better ways of doing things and to try them out in practice (Fagerberg *et al*., 2004). Research on the role of innovation in economic and social change has proliferated in recent years, particularly within the social sciences, and with a bent towards cross-disciplinarily (Fagerberg *et al.*, 2004).

Innovation has long been recognized as one of the key factors contributing to national economic growth, competitiveness, and higher living standards, and has recently been at the heart of the knowledge-based economy (OECD, 2005; EC, 2010).

Ozorhon *et al*. (2009d) regarded innovation as development of new products/services /technologies/strategies or the implementation of new processes (adoption) or the continuous improvement within the organizations. Innovation can be technological and/or non-technological. Innovative activities and effects of innovation depend extensively on the why innovation takes place (drivers) and who innovates (actors) as well as the external environment the innovation takes place.

Innovation success is the degree to which value is created for customers through enterprises that transform new knowledge and technologies into profitable products and services for national and global markets. A high rate of innovation in turn contributes to more market creation, economic growth, job creation, wealth and a higher standard of living (21st Century Working Group, National Innovation Initiative, 2004).

2.1. Innovation in Research and Practice

2.1.1. Definition of Innovation

There is not a single and complete definition of innovation since it is a complex phenomenon with a wide range of inputs and outputs. In broad terms, it may be defined as the creation and adoption of new knowledge to improve the value of products, processes,

and services (Ozorhon *et al*., 2009a). In the UK, the Department of Trade and Industry (DTI) states that innovation is "the successful exploitation of new ideas" and that "it is the key business process to compete effectively in the increasingly competitive global environment" (DTI, 2007).

OECD (2005) explains innovation as "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations". Schumpeter (1911) defines innovation as "the commercial or industrial application of something new – a new product, process or method of production: a new market or sources of supply: a new form of commercial business or financial organization". Innovation can also be defined as "the adoption of an idea or behaviour, whether a system, policy, program, device, process, product or service, that is new to the adopting organization" (Damanpour, 1992).

The other definitions of the innovation are:

- Innovation is the intersection of invention and insight leading the creation of social and economic value (Innovate America Report, Council on Competitiveness, 2004).

- Innovation – the blend of invention, insight and entrepreneurship that launches growth industries generates new value and creates high value jobs (Ahead of the Curve, The Business Council of New York State, Inc., 2006).

- The design, invention, development and/or implementation of new or altered products, services, processes, systems, organizational models for the purpose of creating new value for customers and financial returns for the firm (Measuring Innovation in the 21st Century Economy Advisory Committee, Department of Commerce, Federal Register Notice, April 13, 2007).

- The creation and commercialisation of new knowledge is a final and crucial source of dynamic improvements in productivity. For advanced economies, innovation is a

matter of pushing the world frontier of knowledge. For developing countries technology assimilation is the central challenge (Porter and Ketel, 2003).

2.1.2. Role of Innovation in Economy

Joseph Schumpeter (1934) developed an original approach, focusing on the role of innovation in economic and social change. Economic development, in his view, had to be seen as a process of qualitative change, driven by innovation, taking place in historical time. As examples of innovation, he mentioned new products, new methods of production, new sources of supply, the exploitation of new markets, and new ways to organize business. He defined innovation as "new combinations" of existing resources. This combinatory activity is labelled "the entrepreneurial function" (to be fulfilled by "entrepreneurs"), to which he attached much importance. One main reason for the important role played by entrepreneurs for successful innovation was the prevalence of inertia, or "resistance to new ways" as he phrased it, at all levels of society that entrepreneurs had to fight in order to succeed in their aims. In his early work, which is sometimes called "Schumpeter Mark I", Schumpeter focused mostly on individual entrepreneurs. However, in later works he also emphasized the importance of innovation in large firms (so-called "Schumpeter Mark II"), and pointed to historically oriented, qualitative research (case studies) as the way forward for research in this area (Swedberg, 1991; Shionoya, 1997; Fagerberg, 2004).

The function of innovation is to introduce novelty (variety) into the economic sphere. Should the stream of novelty (innovation) dry up, the economy will settle into a "stationary state" with little or no growth (Metcalfe, 1998). Hence, innovation is crucial for long-term economic growth.

Innovation is a powerful explanatory factor behind differences in performance between firms, regions, and countries. Firms that succeed in innovation prosper, at the expense of their less able competitors. Innovative countries and regions have higher productivity and income than the less innovative ones. Countries or regions that wish to catch up with the innovation leaders face the challenge of increasing their own innovation activity (and "absorptive capacity") towards leader levels (Fagerberg and Godinho, 2004).

"Innovation Nation" White Paper (DIUS, 2008) presents a broad vision of innovation and its importance not only to manufacturing but also for services, the creative industries, the public sector and the third sector. The White Paper explicitly recognise the importance of forms of innovation beyond the invention of new (technological) products and points out the "changing face of innovation" that includes services, business processes and models, marketing and enabling technologies.

2.1.3. Types of Innovation

Innovations may also be classified according to "type". Schumpeter (1934) distinguished between five different types: new products, new methods of production, new sources of supply, the exploitation of new markets, and new ways to organize business.

According to the UK's DTI (2007), innovation can take several forms. Including; product innovation (changes in the products/services) which an organisation offers; process innovation (changes in the ways in which they are created and delivered); position innovation (changes in the context in which the products/services are introduced); paradigm innovation (changes in the underlying mental models which frame what the organisation does).

The terms "product innovation" and "process innovation" have been used to characterize the occurrence of new or improved goods and services, and improvements in the ways to produce these good and services, respectively. The argument for focusing particularly on the distinction between product and process innovation often rests on the assumption that their economic and social impact may differ. For instance, while the introduction of new products is commonly assumed to have a clear, positive effect on growth of income and employment, it has been argued that process innovation, due to its cost-cutting nature, may have a more ambiguous effect (Edquist *et al*., 2001).

Phillips (1997) distinguishes between technological innovation and non-technological (including organisational and marketing) innovation. Technological innovations comprise implemented technologically new products and processes and significant technological improvements in products and processes**.** Organisational innovation in the firm includes

significant changes in organisational structures; the implementation of advanced management techniques; and the implementation of new or substantially changed corporate strategic orientations. Marketing innovation, on the other hand, is the implementation of a new marketing method involving significant changes in product, price, and promotion strategy (OECD and Eurostat, 2005). Whether technical or not, innovation is complex, non-linear and dynamic and so there is not a single and complete definition or classification of innovation (Aouad *et al*., 2010).

Edquist *et al*. (2001) have suggested dividing the category of process innovation into "technological process innovations" and "organizational process innovations" the former related to new types of machinery, and the latter to new ways to organize work. However, organizational innovations are not limited to new ways to organize the process of production within a given firm (Chandler, 1990).

2.1.4. Novelty of Innovation

An important distinction is normally made between invention and innovation. Invention is the first occurrence of an idea for a new product or process, while innovation is the first attempt to carry it out into practice (Fagerberg *et al.*, 2004).

While inventions may be carried out anywhere, for example in universities, innovations occur mostly in firms, though they may also occur in other types of organizations. To be able to turn an invention into an innovation, a firm normally needs to combine several different types of knowledge, capabilities, skills, and resources. For instance, the firm may require production knowledge, skills and facilities, market knowledge, a well functioning distribution system, sufficient financial resources, and so on. It follows that the role of the innovator, the person or organizational unit responsible for combining the factors necessary may be quite different from that of the inventor (Fagerberg, 2004).

To explore the differences in the innovation process for innovations associated with different degrees of novelty (Freeman and Soete, 1997). A variety of empirical studies has shown that the level of novelty of an innovation strongly influences the factors that shape

innovative performance (Garcia and Calantone, 2002). Taxonomies of novelty of innovation span from radical and truly revolutionary to the incremental (Henderson and Clark, 1990; Freeman and Soete, 1997; Tidd *et al*., 2000). From this perspective, continuous improvements of the type referred to above are often characterized as "incremental" or "marginal" innovations, as opposed to "radical" innovations (such as the introduction of a totally new type of machinery) or "technological revolutions" (consisting of a cluster of innovations that together may have a very far-reaching impact). Schumpeter (1934) focused in particular on the latter two categories, which he believed to be of greater importance. It is a widely held view, however, that the cumulative impact of incremental innovations is just as great (if not greater), and that to ignore these leads to a biased view of long run economic and social change (Lundvall *et al*., 1992). Moreover, the realization of the economic benefits from "radical" innovations requires a series of incremental improvements. Arguably, the bulk of economic benefits come from incremental innovations and improvements (Fagerberg *et al.*, 2004).

Radical innovations seem to offer the greatest opportunity for performance differences (Marsili and Salter, 2005). Tushman and Anderson (1986) classify radical innovation in terms of "competence-enhancing" or "competence-destroying", reflecting the different ways novel innovations alter patterns of industrial competition among firms working within the industry (Tushman and Anderson, 1986; Anderson and Tushman, 1990). To achieve radical innovation, firms often need to make a considerable investment in R&D and the chances of success are lower as the rewards are great. In contrast, incremental innovation is more common and the reward is smaller. It requires less effort and its performance implications appear to be more modest (Marsili and Salter, 2005).

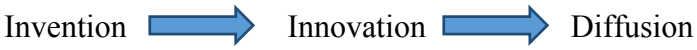
2.1.5. Linear Model of Innovation

The importance of an understanding of innovation as a process is that it shapes the way in which we try and manage it. This understanding has changed a great deal over time. Early models saw innovation as a linear sequence of functional activities. Either new opportunities arising out of research gave rise to applications and refinements which eventually found their way to the marketplace (technology push), or else the market signalled needs for something

new which then drew out new solutions to the problem (need pull, where necessity becomes the mother of invention) (Tidd *et al*., 2004).

The limitations of such an approach are clear; in practice, innovation is a coupling and matching process, where interaction is the critical element. Sometimes the "push" will dominate, sometimes the "pull", but successful innovation requires an interaction between the two (Tidd *et al*., 2004). One of the first (theoretical) frameworks developed for historically understanding science and technology and its relation to the economy has been the "linear model of innovation". The model postulates that innovation starts with basic research, then adds applied research and development, and ends with production and diffusion (Godin, 2005):

Basic Research → Applied Research → Development → Production and Diffusion



It priorities scientific research as the basis of innovation, and plays down the role of later players in the innovation process.

Two versions of the linear model of innovation are often presented:

(i) "Technology Push" model

(ii) "Market Pull" model.

In the period 1950s – mid 1960s the industrial innovation process was generally perceived as a linear progression from scientific discovery, through technological development in firms, to the market place (Rothwell, 1994). The stages of the "Technology Push" model are:

Basic science → Design and Engineering → Manufacturing → Marketing → Sales

In the period mid 1960s – early 1970s emerges the second-generation innovation model, referred to as the "market pull" model of innovation. According to this simple sequential model, the market was the source of new ideas for directing R&D, which had a reactive role in the process. The stages of the "market pull" model are:

Market need → Development → Manufacturing → Sales

The linear models of innovation supported numerous criticisms concerning the linearity of the models. These models ignore the many feedbacks and loops that occur between the different "stages" of the process. Shortcomings and failures that occur at various stages may lead to a reconsideration of earlier steps and this may result in an innovation (Godin, 2006).

Rothwell (1992) provided a useful historical perspective on innovation management, suggesting that our appreciation of the nature of the innovation process has evolved from simple linear models (characteristic of the 1960s) to increasingly complex interactive models (Table 2.1). His "fifth-generation innovation" concept sees innovation as a multi-actor process, which requires high levels of integration at both intra- and inter-firm levels, and which is increasingly facilitated by IT-based networking (Tidd *et al*., 2005).

Table 2.1. Rothwell's five generations of innovation models (Rothwell, 1992).

Generation	**Key features**
First and second	Simple linear models – need pull, technology push
Third	Coupling model, recognizing interaction between different elements and feedback loops between them
Fourth	Parallel model, integration within the firm, upstream with key suppliers and downstream with demanding and active customers, emphasis on linkages and alliances
Fifth	Systems integration and extensive networking, flexible and customized response, continuous innovation

2.1.6. Closed and Open Innovation.

Open innovation (Chesbrough, 2003) describes an innovation paradigm shift from a closed to an open model. Open innovation has taken on greater saliency in light of the debate about globalization and the potential for the R&D function itself to become outsourced. Figure 2.1 shows a representation of the innovation process under the "closed innovation" model. Here, research projects are launched from the science and technology base of the firm. They progress through the process, and some of the projects are stopped, while others are selected for further work. A subset of these are chosen to go through to the market. This process is termed a "closed" process because projects can only enter in one way, at the beginning, and can only exit in one way, by going into the market (Chesbrough, 2006).

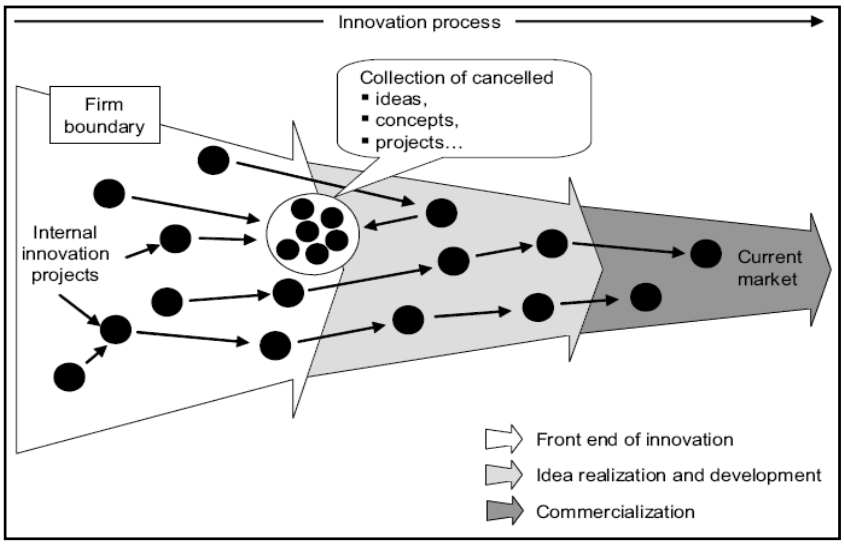


Figure 2.1. Closed innovation (Chesbrough, 2003).

The Open innovation paradigm can be understood as the antithesis of the traditional vertical integration model where internal research and development (R&D) activities lead to internally developed products that are then distributed by the firm. Open innovation is the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation, respectively (Chesbrough, 2006). Open innovation is a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as they look to advance their technology. Open innovation processes combine internal and external ideas into

architectures and systems. They utilize business models to define the requirements for these architectures and systems. The business model utilizes both external and internal ideas to create value, while defining internal mechanisms to claim some portion of that value. Open innovation assumes that internal ideas can also be taken to market through external channels, outside the current businesses of the firm, to generate additional value (Chesbrough, 2006).

Figure 2.2 shows a representation of an open innovation model. Here, projects can be launched from either internal or external technology sources, and new technology can enter into the process at various stages. In addition, projects can go to market in many ways as well, such as throughout licensing or a spin-off venture company, in addition to going to market through the company's own marketing and sales channels. This model is labelled "open" because there are many ways for ideas to flow into the process, and many ways for it to flow out into the market (Chesbrough, 2006).

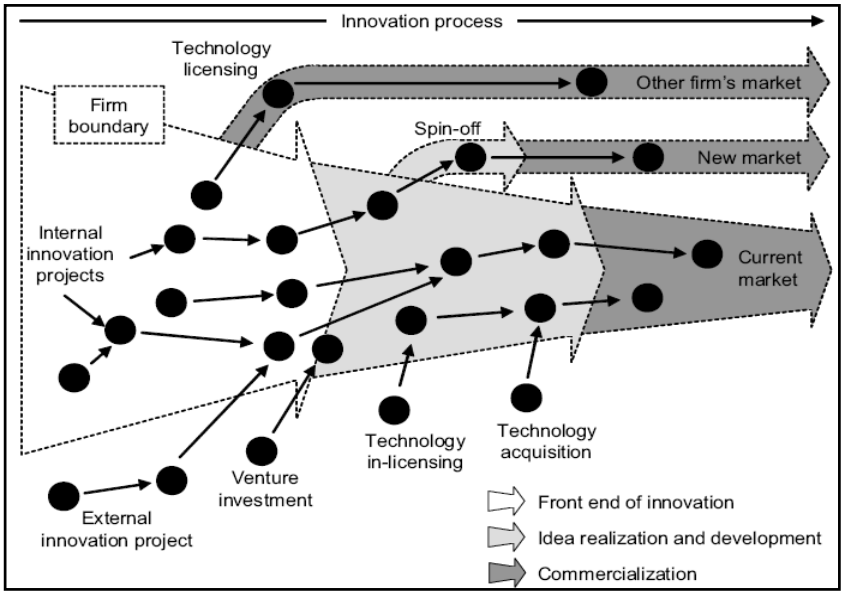


Figure 2.2. Open innovation (Chesbrough, 2003).

2.1.7. Diffusion of Innovation

The diffusion of innovation is defined as "the process by which an innovation is communicated through certain channels over time among the members of a social system" and "the process in which participants create and share information with one another in order

to reach a mutual understanding" (Rogers, 2003). Most of the research on innovation diffusion are based on Rogers' (2003) diffusion theory and mainly investigate the diffusion rate of different type of innovations within an industry.

A great deal of research has been conducted to try to identify what factors affect the rate and extent of adoption of an innovation by the markets. A number of characteristics of an innovation have been found to affect diffusion including relative advantage; compatibility; complexity; trialability; and observability. As Roger (2003) defines, relative advantage is the degree to which an innovation is perceived to be better than the product it supersedes, or competing products; compatibility is the degree to which an innovation is perceived to be consistent with the existing values, experience and needs of potential adopters; complexity is the degree to which an innovation is perceived to be difficult to understand or use; trialability is the degree to which an innovation can be experimented with on a limited basis; and observability is the degree to which the results of an innovation are visible to others (Tidd, 2006).

An innovation diffusion model in its simplest form focuses on describing and explaining the adoption process as a process of innovation diffusion at the aggregate level. The main objective of innovation diffusion models is to explain or predict rates and patterns of innovation adoption over time and/or space (Mahajan *et al*., 1990). Using innovation diffusion models such as those used by Mansfield, 1961; Coleman *et al*., 1966; and Bass, 1969 present a number of advantages (Goldenberg *et al*., 2001). First, they provide a relatively easy and efficient way to look at the entire social system and interpret its behaviour. Second, they are parsimonious yet based on a rich and empirically grounded theory. Finally, they can use any social setting that is of interest to decision makers (Kale and Arditi, 2010).

Innovation diffusion models build on well-established theories in sociology, psychology, and communications. They adopt a simple conceptual framework for understanding the diffusion of the innovation process.

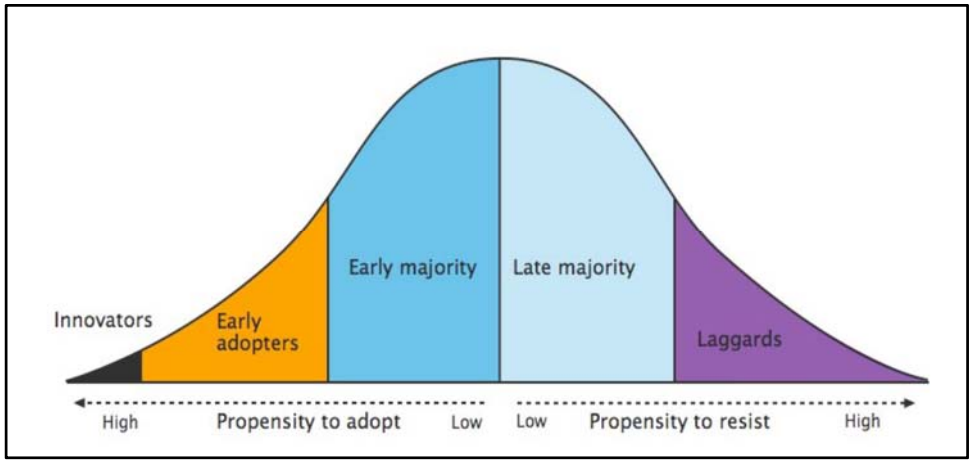


Figure 2.3. Diffusion of innovation (Rogers, 2003).

Research on diffusion attempts to identify what influences the rate of adoption of an innovation. The diffusion of an innovation is typically described by an S-shaped (logistic) curve. Initially, the rate of adoption is low, and adoption is confined to so-called "innovators". Next to adopt are the "early adopters", then the "late majority", and finally the curve tails off as only the "laggards" remain. Such taxonomies are fine with the benefit of hindsight, but provide little guidance for future patterns of adoption (Tidd, 2006). Figure 2.3 shows diffusion of innovation. Each group has its own "personality", at least as far as its attitude to a particular innovation goes. It's best to think of the membership of each segment as static. Innovations spread when they evolve to meet the needs of successive segments (Robinson, 2009).

2.2. Systems of Innovation

A central finding in the innovation literature is that a firm does not innovate in isolation, but depends on extensive interaction with its environment. Various concepts have been introduced to enhance our understanding of this phenomenon, most of them including the terms "system" or "network". Some of these, such as the concept of a "national system of innovation," have become popular among policy makers, who have been constrained in their ability to act by lack of a sufficiently developed framework for the design and evaluation of policy (Fagerberg, 2004).

According to innovation system theory, innovation and technology development are results of a complex set of relationships among actors in the system, which includes enterprises, universities and research institutes. The concept of the innovation system stresses that the flows of technology and information among people, enterprises and institutions are key to the innovative process. It contains the interaction between the actors who are needed in order to turn an idea into a process, product or service on the market (OECD, 1997).

Innovation at a firm or project level is strongly influenced by the external business environment. Understanding this environment and its influence on innovation has been a key concern of policy makers. To this end, the concept of an "innovation system" first appeared in the beginning of the 1990s (Lundvall, 1992; Nelson, 1993) and is now widely used (Breschi and Lissoni, 2001; Cooke, 2001; Carlsson, 2004; Iammarino, 2005). The systems of innovation approach (Edquist, 1997) argues that innovation should be seen as an evolutionary, non-linear, and interactive process, requiring intensive communication and collaboration between different actors. Howells (1999) identifies at least four overlaid innovation systems – sub-regional, regional, national, and international level. The links between sub-regional, regional, national, and international systems of innovations imply that analysis should include actors and institutions at all four levels.

It is now widely acknowledged that companies can no longer afford to rely entirely on their own ideas to advance their business. Relationships and knowledge flows are important for innovation at all levels of economic activity, including internationally, nationally, inter-sectorally, sectorally, inter-firm, intra-firm, inter-project, and intra-project (Manley, 2008a). The traditional, internally focused model for innovation is being replaced by an open innovation system (Chesbrough, 2003), with the aim of strategically leveraging both internal and external sources of ideas (Swan *et al.*, 2009) that enables knowledge exchange with a range of partners at regional, national and international levels. This overall and constantly evolving landscape is characterised as an innovation eco-system that involves the complex inter-linkages amongst the variety of participants (including individuals, companies, and universities) in an innovation economy.

The competitiveness of firms inevitably depends on national and regional systems of innovation, which in turn depend on government policy. For example, the level of business-funded R&D is influenced by national policies such as competition and macroeconomics, and also by the behaviour of national institutions such as agencies funding basic research, banks and stock markets, and systems of corporate governance (Pavitt and Patel, 1999).

2.2.1. National Systems of Innovation

Initially, the concept of innovation system was applied to the national level (Lundvall, 1992; Nelson, 1993; Niosi *et al*., 1993; OECD, 1999). The national systems of innovation (NSI) studies innovative firms in the context of the external institutions, government policies, competitors, suppliers, customers, value systems, and social and cultural practices that affect their operation (OECD, 2005).

The notion of the NSI (Freeman, 1987; Lundvall, 1992; Nelson, 1993) expresses the importance of establishing links between the various networks related to innovation in increasing the innovation capability at the national level (Aouad *et al*., 2010).

Main actors of national innovation systems are (Na *et al.,* 2006):

- Governments which are making and implementing policies,
- Companies in all sectors,
- Companies which serve as a bridge between governments and companies, universities and research institutions,
- Universities,
- Patent offices, research centres, technology transfer units, education centres, techno parks.

National innovation system is a network which is established from these players. This network helps producing, distributing and using information and technology. Degree of social benefits, speed and success of innovation depends on strong interactions between institutions and how dynamic of network. Government policies aims strengthen linkages between actors. These policies should be accept that innovation is not just related to science and R&D, it is related all other policies. Consequently, innovation policies, associated with economy, industry, education, competition, science and technology, environment policies, and it stays core of all of these policies.

Now aware of the importance of innovation, all countries' national policies focus on innovation. In these countries, macro-level economic discussions have been replaced by discussion of national policy. In the light of these policies, providing incentives for innovation and creation of suitable environment is one of the most important tasks of governments.

An effective national innovation policy, the shaping and regulation of all these elements while providing a supportive framework for innovation aims to respond to the needs of all firms regardless of sector and their size.

2.2.2. Regional Systems of Innovation

The regional innovation system (RIS) approach (Autio, 1998; Braczyk *et al*., 1998; Cooke *et al*., 2000) provides a higher level of resolution that enables a differentiated approach. The RIS approach focuses on the firms, clusters, and institutions of an innovation system, to the interdependencies within the region and links to higher spatial levels.

Regional innovation policies should eliminate the disadvantages of a region than others have, attracts innovation bases companies and skilled manpower, enhance competitiveness of existing companies. Physical capital, social capital, human capital and financial capital must be invested for development of a region, increasing competitiveness and raise of life standards depending on innovation. The presence and the effective use of these factors brings regional productivity, employment and high life standards together (Cooke *et al*., 2000).

All the stakeholders in the region play very important active role design and implementation of regional innovation policy which is a very important tool for the elimination of regional differential. Policies should be design particularly to meet the needs of companies which are in the region and planned to be invited. Another important point is that close contact, cooperation and communication with the regional policy makers (Autio, 1998).

2.3. Innovation in Construction

The construction industry has always been among the driving forces of the economy. However, it has also been criticized for its lack of efficiency and unwillingness to innovate in comparison to other industries (Egan, 1998).

Early research focus on innovation in construction can be traced back to seminal work by Bowley (1960; 1966) however, innovation in construction received scant attention from researchers for many years after this, seldom being studied with the same thoroughness as in sectors such as aerospace, telecommunications and biotechnology (Manseau, 1998). Over the last decade research has gradually increased and reached the point where a multitude of construction innovation books have been produced including Gann (2000), Seaden and Manseau (2001b), Jones and Saad (2003), and Miozzo and Dewick (2004).

Winch (2003) argues that when attempting to understand whether construction is performing worse (or better) in a technological sense than other industries, it is important to reflect upon differences in the way the construction process is organized. He suggests that using national account statistics and productivity comparisons between construction and manufacturing can be potentially misleading. Using the Porter (1985) framework, Winch (2003) argues that every industry is part of a larger innovation system with linkages between different value chains of the system. It is important to avoid false comparisons that encompass different parts of different value chains. Construction in the national accounts covers manufacturing, distribution and installation activities. Yet, it does not include the design component of the value chain, where most of the product and process development activity takes place. In order to deal with this problem it is necessary to have a broad definition of construction that incorporates the design element within it.

In comparison to other sectors, construction is usually classified as a traditional or low-technology sector with low levels of expenditure on activities associated with innovation, such as research and development (R&D) (OECD, 2000; Seaden and Manseau, 2001).

Slaughter (1993) suggests that innovation has always occurred in construction and Seaden and Manseau (2001) assert that in most countries there are construction companies that have been able to achieve superior market positions through innovative practices. However, despite these indications there is great concern regarding innovation in the construction industry. The construction industry is widely perceived as being among the less innovative sectors.

The Organization for Economic Co-operation and Development (OECD) argues that in aggregate, the construction sector is characterized by low barriers to entry, limited international competition, low quality, fierce price based competition and poor rates of successful project completion. The main drivers of technological change in the industry are seen to be new components introduced by suppliers to the industry. It appears that many construction firms are in a vicious cycle of low performance, anaemic levels of profitability, limited investment, and poor organizational capabilities (OECD, 2000).

The importance of innovation in construction has been widely advanced. (Dickenson *et al*., 2005). Innovation can be a key source of competitive advantage for construction companies, offering the means through which a firm can achieve a client's objectives in a specific project, or its own objectives over a range of projects (Slaughter, 2000). Innovation also enables firms to successfully contend with major changes occurring in the industry. These changes include increasingly competitive and global markets, demand shifts, and client expectations for capital and operating costs to fall (Seaden and Manseau, 2001a).

2.3.1. Characteristics of Construction Innovation

In many studies of innovation, construction is seen as a low performing sector, exhibiting low rates of innovative activity (Bowley, 1960, 1966; OECD, 2000). Nam and Tatum (1988) compare the characteristics of constructed products with those of manufacturing, arguing that five specific differences limit the development of construction

technology, these being: immobility, complexity, durability, costliness and high degree of social responsibility. They cite these characteristics as creating the conditions for production processes that result in a 'locked system' in which innovation, or in their words, 'changing the status quo' becomes difficult. Developing these concepts and linking them to other contemporary studies, Reichstein (2005) identify six factors that shape the nature of innovation in construction.

The first factor relates to the "*liability of projects"* and is based on the fact that construction is largely a project based activity with temporary coalitions of different organizations that come together to attempt to achieve a task over a specific period (Gann and Salter, 2000). The temporary nature of organizational factors makes the transfer of lessons from one project to another problematic given that teams often disband at the end of projects. The episodic nature of activities limits opportunity for the development of 'economies of repeatability' (Davies and Brady, 2000). There is a tendency to re-invent processes on each new project and some of the detailed technical activities performed on one project may be difficult or impossible to transfer to new projects.

Secondly, construction often involves high levels of in-situ production, relating to the immobility of the product described by Nam and Tatum (1988). This factor can be seen as the "*liability of immobility"*. Final production takes place at the point of consumption, or use of a building. Producing on-site limits opportunity to develop the routines associated with highly productive manufacturing industries. It also opens the construction processes to many uncertainties not faced in the controlled environment of a factory. The use of modular components in many parts of the construction process provides an opportunity to raise the share of construction output created in factory conditions, especially in markets such as housing (Gibb, 2001; Venables *et al*., 2004).

Thirdly, demand usually depends upon fixed capital investment decisions, often involving several stakeholders, taking time and creating a degree of market complexity not found in many manufacturing or service sectors. This factor could be called the *"liability of uncertain demand"*. In construction projects, clients or customers often play a significant role in shaping design and production processes used in the creation of the final products.

Many projects involve the creation of highly bespoke products, focused on meeting the requirements of individual customers and mediated by exigencies of local circumstances. In parts of the sector, architects and their clients prize the ability to create unique solutions. This pattern of new product development creates challenges in the downstream production and engineering processes that are not typical of other sectors, where standardized design elements are usually incrementally added to with minor modifications (Utterback, 1994).

Fourthly, construction displays a unique industrial structure, dominated by small firms with little or no professional staff. Here construction appears to suffer from the "*liability of smallness"* (Stinchcombe, 1965; Baum, 1991). The large number of small firms is in part a reflection of lack of barriers to entry and few economies of scale. Although there is a growing international market for construction, much of the competition is local in orientation. There is a relatively small number of large contracting organizations who themselves rely on a vast array of small subcontractors. Many of these small firms have little innovative capability (Gann, 2000).

The fifth factor in construction reflects the fact that design is usually separate from production and production is often separate from maintenance (Nam and Tatum, 1988; Groak, 1994). It could be called the "*liability of separation"*. Clients or their representatives often offer a range of different tenders to different parts of the sector, such as structural design, electrical and mechanical and cost consultancy. In a traditional procurement process, clients or their representatives choose among those who bid for the work and therefore determine the configuration of the design and production teams for particular projects. The selected organizations need to find new ways of working together, common practices and procedures. It is hard to ensure high levels of feedback between the different stages of the process. To overcome this problem, many construction projects are organized around design and build contracts, partnering arrangements or in longer term service contracts (Barlow *et al*., 1997; Dissanayake and Kumaraswamy, 1999; Bresnen and Marshall, 2000).

The sixth factor relates to the nature of the supply chain that can impair the rate and extent of innovation. Construction encompasses both those organizations responsible for on-site production, assembly and installation of systems, as well as a range of suppliers, such as architects, engineering consultants, cost consultants and users. This factor could be called

the "*liability of assembly*". The contractor is usually responsible for the assembly of a range of different components and the integration of different systems and suppliers. It acts as a system assembler, bringing together different subsystems and assembling these components on site. Architects, engineering consultants and cost consultants provide a wide range of services that have a profound impact on the product and its process of construction (Nicolini *et al*., 2001).

According to the Third UK Community Innovation Survey (DTI, 2004) in comparison to 11 other industry classifications construction was the worst performing industry in five of its six categories of innovation contractor (Abbott *et al*., 2008). The general rate of innovation in construction is argued to be low in comparison to other industries and this low rate has been advanced as the major explanation for poor industry performance in terms of productivity and quality (Winch, 1998; Gann, 2000; Koskela & Vrijhoef, 2001).

However, as the "Hidden Innovation" report (NESTA, 2007) has shown, this perception is perhaps undeserved. Winch (2003) contends that this is in part due to a misunderstanding of the nature and structure of construction in comparison with other industries, and that the real picture is not as bad as these raw statistics suggest. Nevertheless, the industry is still seen as underperforming. Much of the innovation remains hidden, as it is co-developed at the project level. Being a project-based and fragmented industry, the patterns of innovation in construction are different in many ways from those of others.

Construction is a very diverse sector and there is not a one single way in which innovation occurs. It will vary throughout the supply chain and project stages, and just as innovation will mean different things to different economies, so it is equally important to realise that the challenge and meaning of innovation for a small specialist sub-contractor will almost certainly be very different from that of a multinational construction contractor (Abbott *et al*., 2008). As Blayse and Manley (2004) stated, building and construction is partly manufacturing (materials, components, equipment) and partly services (engineering, design, surveying, consulting, and management) industry. Therefore, the organizational context of construction innovations differs significantly from a great portion of manufacturing innovations (Slaughter, 1998).

2.3.2. Defining Construction Innovation

"New technology" is a product or process that a company has not previously used in their construction operations (Laborde and Sanvido, 1994) and an "invention" is the idea for that new technology (Rogers, 1983). Whilst invention is the necessary pre-requisite to develop new technologies, "innovation" is the first commercial transaction involving the technology (Myers and Marquis, 1969; Freeman, 1974). Slaughter (1998) has described invention as the "detailed design" of a new technology; therefore, it is the implementation of the invention that brings the innovation into being. The broad range of general innovation definitions put forward in literature have all agreed in part about the following characteristics that can be applied to a construction innovation (Murphy *et al*., 2008):

- the notion of something "new" (Schumpeter, 1947; Freeman, 1974);
- implementation that has the "ability to effect change" (Dosi, 1982; Abernathy and Clark, 1985);
- the "first use" of a new technology within a construction firm (Tatum, 1987) or one that is new to the user (Harkola, 1995);
- the "derived benefits" to other parties in the construction project (Ling, 2003);
- the element of "associated risk" (Slaughter, 2000; Dodgson, 2000).

Construction innovations can be further defined as product (Nam and Tatum, 1989), process (Tatum, 1989) or organisational (Blayse and Manley, 2004). Slaughter (1998) attempted to account for the project based nature of the construction industry while defining innovation as "the actual use of a nontrivial change and improvement in a process, product, or system that is novel to the institution developing the change". The definition given by Ling (2003) could be considered the most comprehensive within the construction industry context. He defined innovation as "a new idea that is implemented in a construction project with the intention of deriving additional benefits although there might have been associated

risks and uncertainties". The new idea may refer to new design, technology, material component or construction method deployed in a project.

2.3.3. Classification of Construction Innovation

Historically, classification models from construction innovation literature have focused on the effect of new technologies on the construction process and the firms into which they were adopted (Howell and Casten; 1983; Tatum, 1988). Winch (1998) outlined the contextual processes that need to be managed for successful innovation and Tatum's (1987a) process of innovation was a reactive model for use on construction projects. In 1998, Slaughter revisited the classification theories from the general literature on innovation (Schumpeter, 1947; Tushman and Anderson, 1986; Marquis, 1988; Cainarca *et al*., 1989; Henderson and Clark, 1990; Nelson and Winter, 1997). From construction industry perspective, innovation can be broadly classified as either "organisational innovation" or "technical innovation". "Organisational innovation" may result by the introduction of changes to the organisational structure, introduction of advanced management techniques, and implementation of new corporate strategic orientations (Anderson and Manseau, 1999). "Technical innovation" can take form of either "product" or "process" innovation. Product innovation describes that where the new product is the outcome. Process innovation denotes innovation where the process by which a product is developed is exposed to new ideas and, therefore, leads to new and often more sophisticated methods of production (Egbu, 2004).

Slaughter (1998) presented five models of construction innovation categorized as incremental, modular, architectural, system, and radical, which can provide a basis upon which companies can select and implement the innovations. Incremental innovation is a small change, based upon current knowledge and experience, whereas a radical innovation is a breakthrough in science or technology that often changes the character and nature of an industry (Ozorhon *et al*., 2013a, b).

Slaughter's (1998) examples of the innovations were drawn primarily from civil engineering projects. The innovations contributed to the buildability and functionality of a building, e.g. on-site construction processes. The improvements evidenced by Slaughter (1988) included mechanisation of construction processes, increased rates of construction,

methods of standardisation and large-scale modular production. Slaughter did not address linkages to any aspects of building form or broaden the scope of definition any further than aspects of cost and process efficiencies. However, in a later work Slaughter (2000) highlighted the difficulties faced by manufacturers and suppliers in understanding the changes that would be required by designers to implement their innovations. The difficulties identified corresponded to the linkages of the innovations to other components, processes or systems within the building. Table 2.2 shows the Slaughter's five models of construction innovation.

Table 2.2. Innovation classification types (Slaughter, 1998).

Innovation Classification Type	**Deviations Relative to Standard Practice**	**Linkages Back to the Overall Building**
Incremental	A small change to standard practice based upon knowledge and experience	Interactions with other components and systems are negligible
Architectural	A small change in concept	A major change in the links to other components and systems substantially changing the "architecture" of the product
Modular	A significant change in concept	Links to other components and systems remain unchanged retaining the original "architecture" of the product
System	Involves the integration of multiple independent innovations that must work together to perform new functions or improve building performance as a whole	Requires the integration of all the innovations within existing components and systems, as well as the coordination of all activities related to design, fabrication, erection and connection to deliver full benefits to the building.
Radical	A breakthrough that changes the character of an industry	Has the potential to render previous solutions obsolete

Often manufacturers and suppliers tend to consider their products independently of the context into which they are being adopted. Hence, Slaughter concluded that explicit consideration of the implementation activities of designers could significantly improve both the manufacturers' products and the degree to which they are exploited within the industry (Slaughter, 2000).

2.4. Examples of Construction Innovation

2.4.1. Design Solutions

Building-information models (BIMs) are a tool for generating and managing building data through the use of CAD and ICT tools. A BIM contains spatial information, material properties, and so on and allows different actors to exchange and update information (Lee *et al*., 2006). Modern BIM tools are becoming more powerful by using parameterised models, where objects are geometrically linked together. According to Eastman *et al*. (2011), engineering to order producers might be the biggest beneficiaries of BIM in the construction process. The benefits come from fewer design errors due to virtual constructions, more accurate planning for installation using 4-D CAD, and improved pull flow due to faster production of drawings.

According to Lu (2013), Building Information Modelling (BIM) is not a simple three-dimensional (3D) model, but a process to improve the performance through the whole life cycle of buildings. Based on these understandings, BIM can be used for a wide range of purposes, e.g., design and construction integration, project management, and facilities management . Building information modelling is argued to be a useful tool for reducing the construction industry's fragmentation, improving its efficiency/effectiveness, and lowering the high costs of inadequate interoperability. Building information modelling is also recognized as a virtual design and construction (VDC) environment, a vehicle facilitating communications amongst stakeholders, an information model that can be used throughout the project life cycle, or an education platform that can be used in universities or colleges (Lu and Li, 2011).

Kaner *et al*. (2008) revealed clear improvement in engineering design quality, in terms of error-free drawings, and a steadily increasing improvement in labour productivity by applying BIM to four detailed case studies. Sacks *et al*. (2005) found that the potential benefit of adopting BIM is estimated to be in the range of 2.3% to 4.2% of total project cost for precast concrete companies. Sacks and Barak (2008) reported that BIM helps gain an increase of productivity ranging from 15% to 41% forecast-in-place reinforced-concrete structures in the drawing phase. Patrick and Raja (2007) conducted a questionnaire survey and found that quality, on-time completion, and units per staff-hour were ranked as the highest benefits from BIM. Comparing it with traditional methods, Azhar *et al*. (2008) stated that a case project with BIM in place has helped save an estimated $600,000 in extras and avoid months of potential delays. On the basis of 32 major projects using BIM, Stanford University Center for Integrated Facilities Engineering (CIFE, 2007) logged several benefits contributed by BIM, such as up to 40% elimination of unbudgeted change, cost-estimation accuracy within 3%, up to 80% reduction in time taken to generate a cost estimate, savings of up to 10% of the contract value, and up to 7% reduction in project time.

In addition to its applications in real-life projects, BIM is also recognized as a virtual environment in colleges for teaching and learning, e.g., architecture, engineering, construction, and operation. Building information modelling presents an opportunity for students to acquire necessary skills by closely mimicking the real-life practices in the industry, instead of going to real sites every time. Some researchers have advocated that design and construction education using BIM should be tied closely to the curriculum in schools. The learning effects of BIM in this instance have been frequently assessed. For example, Dennis (2006) conducted a survey to investigate the learning effects relating to a curriculum for the Construction Management Department at California State University and found that BIM appeared to have a small but positive influence on plan-reading skills. Later, Dennis (2007) conducted a similar survey and found that BIM appeared to have a positive influence on estimating. Hedges and Denzer (2008) found that BIM promotes clearly defined roles in the group-based classroom-management approach of team learning, which encourages the students to pursue more rigorous investigations of design alternatives.

2.4.2. Advanced Materials (Renewable, Improved and Innovative)

The recent and growing introduction of innovative materials and technologies in the civil engineering field has opened exciting new prospects, challenges, and opportunities. Material innovation may result from the extension to this field of materials already widely used in aerospace and mechanical engineering, such as fibre-reinforced polymer composites, or from the growing call for sustainable solutions such as recycling and environment-friendly construction materials. Among the issues arising from the use of innovative materials are durability, compatibility and environmental impact. Also, analysis and design philosophies often need to be re-thought from elementary principles, developing, if the case, new concepts and measures of safety (Lorenzis, 2006).

2.4.3. Supply Chain Management

Construction supply-chain management (SCM) offers new approaches to reduce the cost of and increase the reliability and speed of facility construction. Supply-chain management takes a systems view of the production activities of autonomous production units (subcontractors and suppliers in construction) and seeks global optimization of these activities. Limited studies in construction suggest that poor supply-chain design regularly increases project cost by 10% (Bertelsen, 1993), and this estimate is probably conservative. Project duration may be similarly affected. Whereas current construction methods tend to support the fragmentation that plagues construction, supply-chain management promises an engineering basis to design, plan, and manage construction projects in a collaborative manner. Improved coordination, costing, and control offered by construction supply-chain management is an achievable vision. It provides a background for improved production control within each subcontractor and supplier. Such an improved understanding of costs and capabilities also allows improved design of supply-chains composed of those subcontractors and suppliers, providing and engineering basis for improved coordination. Moreover, the link between cost and production allows new forms of contracts that promote system optimization (O'Brien, 1998).

The industry is fragmented and distinguished by a collection of large and small firms, material suppliers, and many other support professionals. The typical supply chain for any

given construction project could include architects and engineers, prime contractors, specialty subcontractors, and material suppliers that come together one time to build a single project for a specific owner. The final means of increasing profitability is by implementing supply chain management concepts in order to decrease delays in delivery of materials, equipment, and services to the project site (Benton *et al*., 2010).

Main contractors become more and more reliant on other actors in the construction supply chain (e.g., suppliers and subcontractors). Therefore, they need to revise their supply strategies and trading relations with subcontractors and suppliers. Some areas of application, which may be, and to a certain extent have been subjected to SCM, include the reduction of costs (especially logistical costs), lead-time and inventory in the supply chain. Firstly, the focus may be on the impact of the supply chain on site activities. Secondly, the goal is to reduce site costs and duration. In this case, the primary consideration is to ensure material (and labour) flows to the site for the sake of avoiding disturbances in the workflow. Thirdly, the focus may be on transferring activities from the site to upstream stages of the supply chain. The rationale may simply be to avoid the inferior conditions of site, or to achieve wider concurrency between activities, which is not possible in site construction with its many technical dependencies. Here, the goal is again to reduce the total costs and duration (Vrijhoef and Koskela, 1999).

2.4.4. Waste Management

Construction waste is defined as the difference between the values of those materials delivered on-site and used appropriately and the value of material that was transferred elsewhere due to damage, over ordering and issues such as design changes. Ekanayake and Ofori (2000) have divided construction waste into three categories: material, labour and machinery. Ekanayake and Ofori (2000) have classified material as most critical of the construction waste, as most of it comes from non-renewable sources. It is estimated that about 40% of waste generated globally comes from construction related activities (Kulatunga *et al*., 2006; Nitivattananon and Borongan, 2007).

Several authors have highlighted strategies for waste minimisation. One of the strategies that often referred to as 3Rs (reduce, reuse, recycle) However, recycle and reuse

are the two most economically feasible approached with high impact. Researchers worldwide have proposed a list of 11 practices that help in the implementation of waste minimisation. These practices are: standardization of design, stock control to minimise over ordering, environmental education to the work force, provision of recycling and waste disposal companies as part of the supply chain, on time/just in time deliveries, penalties for poor waste management, incentives and tender premiums for waste minimisation, waste auditing, increased use of off-site techniques, use of on-site compactors, reverse logistics (Arif *et al*., 2012).

Waste management can generate various benefits through the whole lifecycle of the waste from its generation to its final disposal. According to El-Haggar (2007), proper construction waste management will provide economic benefits by decreasing the cost of the project through proper implementation of a waste management plan. Apart from economic benefits, waste management may positively contribute to the following aspects; cost saving and profit maximization, reduced demand for landfill spaces, improved resource management, image improvement, productivity and quality improvement (Hwang and Yeo, 2010).

2.4.5. Energy Efficiency and Green Buildings

Sustainable construction is an alternative way of construction in synchronization with local climate in which solar and wind energies are utilized in numerous ways to improve energy-efficiency. According to the Brundtland Report (1987) of the World Commission on Environment and Development, sustainable development implies meeting the needs of the present without compromising the ability of future generations to meet their own needs. The awareness about sustainable construction in the United States has promoted the creation of green building rating systems. The Leadership in Energy and Environmental Design (LEED) Green Building Rating System, developed by the United States Green Building Council (USGBC) is one of the most widely accepted rating systems around the globe. “The design and construction industry has gradually accepted the LEED rating system in mainstream practice as evident through growth of LEED – New Construction (NC) certified projects over the past few years” (LEED 2005). “The design profession, which has clearly embraced this emerging trend, has largely dominated discussions on green design and construction.

However, many owners are finding that construction organizations can also play a key role in green building projects" (Riley *et al*., 2003). Owners (both public and private), architects and engineers are taking the lead in green movement to pursue sustainable design and practice. Designers have carved a leading role in the green building movement since the very beginning, as they are the creators of the initial idea for the built environment (Riley *et al*., 2003). Since, in a construction process there are three main responsible parties, the client/ owner, architect / engineer and contractor, it is very important for the contractor to be a part of any construction approach (Lohiya, 2013).

2.4.6. Off-site Manufacturing

Off-site construction, the fundamental idea is to move some effort away from the construction site to a more controlled environment of the manufacturing floor. Although construction industry have come a long way with cranes, robotics and laser guided precision construction; fundamentally, the focus of all these innovations is to speed up the construction process, minimising waste and inefficiencies, maximising quality, and improving health and safety (Arif, 2009).

"Off-site manufacturing or "off-site construction", is described by the UK based Buildoffsite alliance (Buildoffsite, 2006) as largely interchangeable terms that refer to that part of the construction process that is carried out away from the building site. It makes it more amenable for implementation of lean production concepts as it requires higher levels of repetition and process control, and hence has greater scope for enhancing productivity, customer satisfaction and profits (Roy *et al*., 2005; Apleberger *et al*., 2007; Meiling *et al*., 2012).

Clients using off-site production techniques find that many UK manufacturers now use state of the art manufacturing techniques in modern highly automated factories. Benefits include predictability, quality assurance, faster construction times, less waste, less noise and disruption to neighbours, less - even zero - defects and lower site accident rates and improved health and safety. Benefits of modern methods of construction with particular regard to the disruption caused to local residents from dust, noise and commercial vehicle movements and the environmental impact of site-generated waste (Taylor, 2009).

The scope of prefabrication ranges from the production of individual elements of a building to the prefabrication of complete buildings. If elemental prefabrication can be combined into bigger components, project costs may decrease because of the lower dependency on skilled workers and fewer resources required on site. Moreover, as the number of components is reduced, there will be fewer handling and erection costs; thus, the total cost from production to installation can be reduced. To this end, Khalili and Chua (2012) proposed the Component Configuration of Prefabricated Structures (CoCoPS) framework to configure the grouping of building elements to move beyond the individual building element approach toward higher level prefabrication. Although adopting a higher degree of prefabrication maybe advantageous, production costs in the prefabrication plant may increase as a result of the use of more complicated molds, the unique shape of components, and the possible loss of economy of scale. Furthermore, the flexibility in the design will be reduced if appropriate coordination is not established between the designer and producer (Khalili and Chua, 2014).

2.4.7. Modern Methods of Construction

The House Builders Federation in UK defines Modern Methods of Construction (MMC) as “methods which provide an efficient product management process to provide more products of better quality in less time”. In Sweden “Industrialized Construction” is used very much in the same sense, “…an efficient, profitable, diverse building (method) where customer requirements are the focus” (Lessing, 2006). MMC is defined as methods of construction that use parts manufactured and assembled off-site or components manufactured off-site and brought together on-site for assembly (Kempton and Syms, 2009). Hook (2008) stating that MMC should comprise “one evident process owner and a clear product goal of repetition in housing design and production”.

Modern methods of construction (MMC) have around the world been suggested to present opportunities to reduce the inherent uncertainties of traditional construction. Modern methods of construction (MMC) are suggested to deal more effectively with uncertainties that construction commonly presents to clients and contractors, i.e. uncertainties inherent in traditional construction regarding e.g. time, defects, safety, environmental impact, costs, profits and lifecycle performance.

One consequence of more integrated and developed MMC will be a decrease in the number of actors and the amount of work on-site, hence, a reduction of the impact of conflicting interests seems likely. This allows for more rationally coordinated processes to be executed, e.g. optimized and integrated design and construction (Paevere and MacKenzi, 2006). The integrated processes make it easier to avoid sub-optimization and delays/re-work due to conflicting sets of regulations, codes and tolerances. MMC also gives the opportunity to make the construction work more repetitive and, hence, the learning curve problems should be reduced. MMC also reduce the contractors' uncertainties as it allows for a better control over production costs through, e.g. shorter building periods, less on-site work and fewer workers, less impact of weather, reductions in transportation of materials, reduced unplanned onsite remedial works and changes to project cash flow (Gibb 1999; Barlow and Gann 2004; Sarden and Engstrom, 2010).

2.4.8. Sustainability

The term "sustainable construction" was originally proposed to describe the responsibility of the construction industry in attaining "sustainability" (Kibert, 2008). The concept of sustainable construction addresses three main pillars: environmental protection, social well-being and economic prosperity. Sustainable construction refers to the integration of environmental, social and economic considerations into construction business strategies and practice. Sustainable construction is the set of processes by which a profitable and competitive industry delivers built assets (buildings, structures, supporting infrastructure, and their immediate surroundings), which enhance the quality of life and offer customer satisfaction; offer flexibility and the potential to cater for user changes in the future; provide and support desirable natural and social environments, and maximise the efficient use of resources (Ogunbiyu *et al.*, 2014).

In view of this, there are many benefits that can be achieved by applying sustainable construction and these include environmental, economic, social, health, and community benefits. The environmental benefits are improved air and water quality, reduced energy and water consumption, and reduced waste disposal. The economic benefits are reduced operating cost, maintenance cost, and increased sales price and rent while enhanced health

and occupants comfort, and reduced liability are the health and community benefit (Luther, 2005; Ogunbiyu *et al*., 2014).

Sustainability has become an increasing concern for the construction industry due to the fact that construction activities significantly impact on waste, energy use and greenhouse gas emissions. Developing cost effective solutions for achieving sustainability in construction requires considerable effort and commitment to innovation (Ozorhon *et al.,* 2011a).

Sustainability in construction will not only benefit individuals but also contribute to the global issues. Sustainability in construction can only be achieved by rethinking operation in four major areas, i.e., energy, materials, waste and pollution. Implementation of changes to achieve sustainability will vary from firm to firm. It will be different for the larger firms from small and medium sized firms (Ahuja, 2013).

Hill and Bowen (1997) described that sustainable construction was initially proposed to describe the responsibility and role of the construction industry in achieving sustainability, in which the construction industry is deemed to include civil engineering and building construction. It is also important to avoid viewing sustainable construction as a site activity or a specific stage in the project life cycle. Apart from the comprehensive cycle of a construction project such as feasibility study, design, construction, operation, decommissioning, demolition, and disposal, a broader concern should also be addressed on the process of creating human settlements, which entails planning, design, implementation, and management. Presley and Meade (2010) also supported the view by referring to sustainable construction as not only the buildings and spaces, but also the process and activity and the infrastructure elements such as waste management, transportation, and utility transmission systems (Goh and Rowlinson, 2013).

2.4.9. Automation of Processes on Site

Innovative changes usually arise from a need to improve a given situation. Needs and potentials for automation in construction can be investigated from three different perspectives: economy, safety, and technology (Bernold, 1990). Automation and robots are

frequently mentioned as solutions to industry-wide problems of increasing costs, declining productivity, skilled-labour shortages, safety, and quality control. Productivity improvements, improved safety, improved quality, and economic savings potential motivate these developments (Everett and Slocum, 1994). Major incentives for intelligent machines use include safety, increased quality requirements, and vanishing crafts man ship (Bernold, 1990). Machines excel at physically intensive tasks that require speed, strength, repetitive motions, and operation in hostile environments. Humans are still more cost effective at information-intensive tasks that require judgment, sensing, and adaptability. Several studies have attempted to identify which types of construction work are best suited to automation. Warszawski (1990) suggest that four generic or multipurpose robots could perform 10 "basic activities" (positioning, connecting, attaching, finishing, coating, concreting, building, inlaying, covering, and jointing) common in building work. Tucker (1988) computes the "automation potential" of 17 "distinct areas". Kangari and Halpin (1989) rank 33 "processes" according to need, technology, and economics, to arrive at a "robotics feasibility" score. Demsetz (1989) advocates two-step approach, first identifying potential benefits of automation, then dividing the work between human and machine to optimize the contribution of each (Everett and Slocum, 1994).

Construction sector has experienced significant advances in automation. Such advances, founded on enabling technologies such as positioning systems, advanced control methods, and graphical interfaces, will only accelerate in the future. Computing is a key enabling technology for field automation. The use of computer technology allows a major reduction in operator stress and fatigue associated with routine decision making while providing alarms and other tools for heightened awareness when conditions warrant immediate operator attention. Software can also be used to provide resolved motion capability where needed. Computer software provides superior control, together with ease of use, by using inverse kinematics and advanced control schemes to achieve resolved motion control (Haas, 2002).

The use of automation and robotization in construction industry is rapidly expanding and reduce accidents and improves working conditions of construction workers. The reduction in the members of highly skilled craftsmen, increase in sophistication of construction materials and constant demand for increase in quality and reduction of

construction time all indicate that greater degrees of automation will be required in construction industry (Kumar *et al*., 2008).

2.4.10. Lean Construction

Lean construction is a philosophy based on lean manufacturing concepts (Koskela, 1992). However, lean construction has been used with significant benefits in countries like UK, Singapore, Brazil, Chile, The Netherlands, South, Turkey, USA, and in many other countries. The aim of lean construction is to work on continuous improvement, waste elimination, strong user focus, value for money, high quality management of projects and supply chains, and improved communications (OGC, 2000; Ogunbiyu *et al*., 2014).

Ballard *et al*. (2007) define lean as "a fundamental business philosophy – one that is most effective when shared throughout the value stream" and Diekmann *et al.* (2004) define Lean Construction as "the continuous process of eliminating waste, meeting or exceeding all customer requirements, focusing on the entire value stream and pursuing perfection in the execution of a constructed project". In this context, waste is understood as the actions and/or the use of resources or features that are not necessary to deliver a product or service to the customer. Wasteful practices consume resources but do not add value to the final deliverable.

The Lean principles relate to a higher objective of reducing or eliminating wasteful activities in a process as a means of increasing the share of value-adding content. Waste elimination, process control, flexibility, optimisation, people utilisation, continuous and efficient improvement, and value to customer have been presented as some of the key drivers of lean (Ogunbiyu *et al*., 2014).

Lean construction implementation efforts can be divided into three different stages, with increasing degree of sophistication. Green and May (2005) are of the view that lean stage one focuses on waste elimination from a technical and operational perspective. The second stage focuses on eliminating adversarial relationships and enhancing cooperative relationships and teamwork among supply chain actors. The essential parts are cooperation, long-term framework agreements, workshops, and facilitator (Ogunbiyu *et al*., 2014).

2.4.11. On-site IT Applications (GIS, GPS, RFID)

The use of Global Positioning Systems (GPS) and laser positioning sensors in the construction industry is now very common. GPS and laser positioning technology can bring many advantages to the automatic construction operation such as automated control of equipment. For example, installing positioning sensors to construction manipulators and excavators will eventually lower labour costs and improve machine performance and work quality, thus increasing job efficiency in construction sites (Haas, 2002).

Location awareness provides support for scalable decision making, timely tracking of the project status, proactive safety monitoring, and subsequently, operation and maintenance of constructed facilities. Recent advances in sensing technologies have enabled the deployment of a range of simple to complex sets of sensors for identification, location sensing, and tracking the movements of targets. Location aware computing in construction is an emerging area where the location of materials, workforce, and equipment can be used to derive knowledge about project status. Many location sensing technologies and data sources have also been developed in construction for resource and asset tracking, earthmoving operations, surveying, safety hazards predicting, and context aware construction. A study by Teizer *et al*. (2010) demonstrated that the use of remote sensing and actuating technologies such as radio frequency (RF), ultra wideband (UWB), and imaging technologies can improve construction safety by warning or alerting workers-on-foot and/or equipment operators in real-time when a too-close proximity to unknown or other construction recourses can cause hazards. A wide range of technologies were used for indoor location sensing such as indoor GPS, inertial navigation systems, infrared-based solutions, and UWB. Radio frequency identification (RFID) started to gain big momentum in the area of indoor location sensing and attracted researchers to conduct experimental studies (Razavi *et al*., 2012).

2.4.12. Application of Information and Communication Technologies (ICT)

Construction projects today are far more complicated than ever before. They involve larger capital investments, embraces several disciplines, widely dispersed project participants, tighter schedules, stringent quality standards etc. These factors coupled with

high speed developments in Information and Communication Technology (ICT) have influenced project management practices to take a new turn taking advantage of newly developed management tools and the latest technology. Information technology, by definition, is a collective reference to the integration of computing technology and information processing. IT is not a single technology but a wide range of technical approaches to a variety of problems. Information Technology in Construction (ITC) can be defined as the application of decision support tools, which uses electronic machines and programs for processing, storage, analysis, control, transfer and presentation of construction information data during the whole life cycle of a construction project (El-Ghandour, 2004).

ITC has been mainly used for planning and scheduling applications up to the late 1980s. In the latter part of that decade most research in the field of ITC focused on CAD integration, because it was considered the first and most crucial stage towards computerization in construction. In recent years, research has focused on the development of these applications as required by the industry to support electronic document management systems. As a result, there has been rapid expansion in the development of IT applications available to all construction professionals (El-Ghandour, 2004).

ICT innovation refers to the introduction of new ICT initiatives to an organisation. The organisational process of introducing ICT initiatives for adoption by expected users is defined as ICT diffusion IT innovation may be adopted by specific groups of users within an organisation. For example, use of computer aided design (CAD) by architects or estimating software used by engineers is often implemented as a stand-alone non-system integrated initiative where only a small group of expert users participate in the initiative. A firm may independently operate small-group IT innovation such as planning and scheduling applications whereas a groupware ICT innovation needs cooperation both within a group to share and exchange data and information as well as with external project team and supply chain members. Successful company-wide construction firm ICT initiatives, such as introducing groupware applications, needs team adoption by project managers, engineers and foremen etc. There may also be need to include organisation-external project participants such as designers, consultants and owners (Peansupap and Walker, 2005).

Skibniewski and Abduh (2000) proposes two strategies for adopting ICT – in-house development and outsourcing, depending upon the level of internal systems and resources that support the main organisational functions. To understand ICT implementation, the organisation should adopt a pilot project strategy to learn from experience. This could help them understand real benefits and possible constraints that may occur before diffusing the ICT initiative throughout their organisation. A pilot small-scale budget strategy can help the organisation to overcome investment barriers and it help avoid any large cost impact if the ICT implementation fails. It also helps create small wins and potential best practice model to help staff understand investment benefits (Peansupap and Walker, 2005).

Collaborative working using Information and Communication Technologies (ICT) systems in construction has become a reality as many activities are performed globally with actors located in various geographical locations. Computer Integrated Construction (CIC) is the type of ICT system that binds a fragmented and geographically distributed set of construction stakeholders collaborating together (Arayici and Aoud, 2005).

A top management decision to adopt ICT often progresses ICT implementation to the individual and group level. These people are key actors who play a significant role in how ICT diffuses throughout an organisation. The individual level constraints are; the lack of learning and training, insufficient ICT investment to meet users' needs, lack of computer skills, and lack of time to learn. Changing ICT users' way adapting to new things is difficult. To alleviate user resistance, organisations should provide enough training and learning time for users. Cited barriers are attributable to the high cost of investment, however, sufficient support-centred ICT investment influences users' ICT experience that could otherwise generate negative perceptions towards ICT use. O'Brien (2000) confirmed that lack of technology maturity affects investment cost and reliability and access service quality performance (Peansupap and Walker, 2005).

2.4.13. Web-Based Project Management and ERP

Tsung (2004) made general but comprehensive definition of ERP as "ERP is a system that aims to integrate the main business functions across all the departments within an organization". The definition of ERP should be modified for construction to be "information

technology based computer platform that allows for integration of various business processes of an organization in order to increase efficiency, and thus profits, using a single database" (Negahban, 2008).

ERP systems are seen as a foundation for the integration of organization wide information systems. ERP systems connect the entire organization's departments and their operations such as finance, accounting, human resources, manufacturing and distribution, etc. Furthermore, ERP systems also connect the whole organization to companies' customers and suppliers through the different stages of the product or the process life cycle. Enterprise resource planning (ERP) systems target to accomplish all-in-one and continuous integration of all the processes and information flowing through a firm, including but not limited to internal and external departments such as; financial and accounting information, human resource information, supply chain information between warehouses and plants, and all kind of customer information. ERP systems are being used by construction companies to improve responsiveness in relation to customers, strengthen supply chain partnerships, enhance organizational flexibility, improve decision making capabilities and reduce project completion time and lower costs. These information systems are designed to integrate and partially automate many of the company's business processes such as human resources, financial management, manufacturing, procurement, construction, operations and maintenance. The goal of ERP is to support one time entry of information at the point where it is created and to make it available to all the participants within the organization (Ahmed *et al*., 2003).

Web-based Project Management System (WPMS) and promises to enhance construction project documentation and control and to revolutionize the way in which a construction project team conducts business. WPMS is an electronic project-management system conducted through the Extranet, which is a private network that uses internet protocols to transmit information. The system is only accessible by a project team but team members can be located in different organizations. It basically provides a centralized, commonly accessible, reliable means of transmitting and storing project information (O'Brien, 2000; Nitithamyong and Skibniewski, 2004).

As pointed out by Mead (1997), there are four general categories of construction project information that are normally carried out through WPMS: project, design, management, and financial information. Project information includes details about the project, such as project participants, project e-mail directory, project description, and a photo archive of the project's progress. Design information includes any information generated by the design team, such as CAD drawings, specifications, clarifications and changes, and punch lists. Management information is developed by the Project manager and includes meeting minutes, submittals and shop drawings, change order status logs, as-built drawings, requests for information (RFIs), requests for quotation (RFQs), contract status logs, safety information, daily logs, and project schedules. Financial information is developed by the accounting staff responsible for the project and includes cash flow, projections, requisition status, general ledger, and contract status reports (Nitithamyong and Skibniewski, 2004).

As project information changes, the database on the server can be easily updated with new data. Members of the project team can then access the updated information via a digital user ID and password from remote locations at any time, eliminating the problems that occur in linear communication schemes. Since a closed network is used where no one is allowed to access the system without permission and everyone is identified (through an individual user ID and password), the system can automatically track who has seen what, and what comments or changes if any, they made. It is also possible to introduce a project hierarchy into the system, which allows documents or areas of the project to be restricted to only people at certain levels of responsibility, etc. Hence, the mistakes caused by poor communication and the delays due to the time it takes to move documents and people around for approvals and meetings would be minimized. WPMS is predicted to significantly improve the speed and quality of communication among project participants and promotes collaboration and coordination in construction projects (Nitithamyong and Skibniewski, 2004).

2.4.14. Collaborative Practices

The construction industry is often criticized for lack of cooperation, generating problems regarding both costs and quality (Chan *et al*., 2003). The relationships are competitive and adversarial rather than cooperative, especially those regarding public sector projects (Ng *et al*., 2002; Naoum, 2003). This situation is argued to derive from the

traditional procurement procedures and contract forms, as they give little incentive for cooperation to emerge (Egan, 1998). In recent years increased interest in cooperative concepts, such as partnering, has been noticeable in the construction industry in many countries (Bresnen and Marshall, 2000; Ng *et al*., 2002; Chan *et al*., 2003). Partnering, aiming at increasing cooperation and integration between the involved actors by building trust and commitment and decreasing disputes (Wong and Cheung, 2005), can bring about advantages regarding quality, sustainability, dispute resolution, innovation, and also time and cost reductions (Barlow *et al*., 1997; Egan, 1998; Chan *et al*., 2003). Implementing cooperative relationships is, however, not an easy and straight forward task (Chan *et al*., 2003b); it should therefore be done in proper way and for the proper reasons in suitable projects (Bresnen and Marshall, 2000; Ng *et al*., 2002). Because the extent of trust and cooperation is affected by the procurement procedures, this is a key improvement area (Egan, 1998) and a key factor contributing to project success (Cheung *et al*., 2001; Eriksson, 2008).

There is indeed considerable evidence from other industries that collaborative relationships help to promote product and process innovation (Shaw, 1994), and interest has grown in the construction industry in the possibility that partnering can aid the transfer of knowledge between firms (Dodgson and Rothwell, 1994). According to Provost and Lipscomb (1989), partnering provides companies with an environment, which allows them to refine and develop new competencies in a more controlled and lower risk way. A continuity of personnel from project to project in long-term partnering relationships may therefore provide organisational learning benefits (Baker, 1990; Barlow, 2000).

Successful innovation often requires effective cooperation, coordination and working relationships between the different parties in construction projects (Tatum, 1989; Gann and Salter, 2000; Ling, 2003; Blayse and Manley, 2004; Robichaud and Anantatmula, 2011). Strategic partnering between the clients and the contractors, early involvement of contractors, and supply chain partnerships have been observed to have helped the teams build trust and become committed to innovation (Ozorhon, 2013a).

2.4.15. Contract Management and Client Relations

Construction projects are often one-offs that is, once a building is constructed the relationship ends. Consequently, long term relationships based upon high levels of bilateral dependency are not always necessary for either the public authority or the contractor to achieve their objectives. This short term view has been a contributor to the construction industry's tradition of adversarial relationships. If there are no advantages to establishing long-lasting and close relationships with a client, it can be advantageous for a contractor to pursue a purely transaction-based approach. Within many member states where there is increasing emphasis on value, performance and probity, old systems of procuring construction, which are adversarial and rooted in conflict, are no longer acceptable, and a new approach based upon relationship management is becoming increasing popular and successful (SCI Network, 2011).

There have been a variety of public sector-led initiatives to drive more collaborative and integrated relationships within the construction industry, recognising that the traditional adversarial approach to management does not always deliver good value for money. It is also seeing an increasing trend of public authorities seeking to aggregate their construction requirements into programmes of work or framework agreements in order to achieve economies of scale and standardisation. These long term relationships, often involving multiple projects, provide an opportunity to establish a more strategic relationship with contractors and scope to work more collaboratively on the identification and deployment of innovative ideas. In the context of innovation, the one-off nature of construction projects mean that it can be difficult to develop and implement innovations during the delivery of a contract due to the relatively short timescale and constraints of existing design/specification. As there is also a high degree of sub-contracting within this industry, the main contractors appoint second tier contractors to deliver packages that can be easily integrated into the final solution. It is often within these sub-packages that there is scope for innovation, however traditionally the public authority is not involved in the management of these tiers and they will often change from one project to the next (SCI Network, 2011).

2.4.16. Knowledge Management

Learning and knowledge sharing are essential drivers of innovation in order to sustain the long-term competitive advantage of organisations (Robinson *et al*., 2005). Knowledge is the hidden asset of organisations, which has to be nurtured for long-term corporate sustainability (Edvinnson, 1997) and knowledge management is a method of exploiting, or transforming knowledge as an asset for organisational use to facilitate continuous improvement (Robinson *et al*., 2005). Knowledge management is becoming increasingly important in the construction context; and it appears to be more important to larger organisations as it is difficult to determine "who knows what" in such organisations (Davenport and Prusak, 1998). Larger organisations are also more likely to have a leader or a KM champion and to have the resources to support a KM strategy.

Bennett (1991) identified three distinct end products: standard construction, traditional construction and innovative construction. These products rely on a mix of tacit and explicit knowledge. For example, innovative products require a higher degree of tacit knowledge (Bennett, 2000). Product knowledge also relates to knowledge about different client types, associated relationships and market characteristics. Process factors relate to the technical and management systems used in production. Technical processes could be highly labour intensive relying on tacit knowledge or automated based on explicit (codified) knowledge in computer systems. Management processes range from programmed to problem-solving organisations. Problem-solving organisations rely on tacit knowledge to produce innovative projects. This is necessary to fulfil clients' design and construction requirements that cannot be met by established answers (Bennett, 2000). People factors relate to the characteristics of individuals and teams. While appropriate management structures are necessary, competent teams (suppliers, designers and constructors) are vital for the construction process (Robinson *et al*., 2005).

Matusik and Hill (1998) argued that the relationship between organisational knowledge and competitive advantage is moderated by an organisation's ability to integrate and apply knowledge. The key issue, therefore, is to identify localised knowledge and transform it into productive knowledge that resides within the organisation and creates value (Stewart, 1997).

KM can drive innovation, helps to attract new and retain valuable customers, and in the process increase organisational productivity and profitability. Demarest (1997) noted that "firms without knowledge management systems will be effectively unable to achieve the re-use levels required by the business model implicit in the markets they enter, and will lose market share to those firms who do practice knowledge management".

Some argue that "there is a powerful symbiotic relationship between knowledge management and information technology" (APQC, 1997), as an increasing amount of corporate knowledge is now available on intranets and other IT-based systems. However, there is widespread evidence that most organisational knowledge is in people's heads and processes, and IT is not capable of capturing some tacit knowledge without losing its context. For example, Malhotra (2000) argued that there is a "dangerous perception about knowledge management as seamlessly entwined with technology". Davies *et al*., (1998) argued for new ways of transmitting knowledge through organisations as a large amount of the knowledge within an organisation is personal, context-specific and difficult to write down. Thus, more effort should be directed in setting up and enhancing systems to facilitate person-to-person and person-to-organisation interactions (Robinson *et al*., 2005).

3. MEASURING CONSTRUCTION INNOVATION

3.1. Measurement of Innovation

As a significant economic variable, the measurement of innovation has attracted a lot of attention. However, due to the complexities inherent in the whole process, measuring innovation is not an easy task. Stages of innovation have been classified in various ways. Rogers (2003) offers five stages namely, knowledge, persuasion, decision, implementation and confirmation. Wolfe (1994) suggests ten stages including idea conception, awareness, matching, appraisal, persuasion, adoption decision, implementation, confirmation, routinization, and infusion. Tangkar and Arditi (2000) proposed a six-phase labyrinth of innovation, where the flow of successful innovation comprises need, creation, invention, innovation, diffusion, and adoption.

Hansen and Birkinshaw (2007) on the other hand presents innovation as a sequential, three-phase process that involves idea generation, idea development, and the diffusion of developed concepts that includes six critical tasks namely, internal sourcing, cross-unit sourcing, external sourcing, selection, development, and companywide spread of the idea. The whole process is referred as the innovation value chain (IVC). The first phase is to generate ideas that can happen inside a unit, across units in a company, or outside the firm; the second phase is to convert or select ideas for funding and developing them into products or practices; and the third is to diffuse those products and practices. Similarly, Roper *et al*., (2008) model IVC as a recursive process that has three main links such as 'knowledge sourcing' to assemble knowledge necessary for innovation, 'knowledge transformation' to translate knowledge into physical innovation, and finally 'knowledge exploitation' to improve the enterprise performance.

The IVC offers a tailored and systematic approach to assessing firm-level innovation performance (Hansen and Birkinshaw, 2007). Table 3.1 shows the links of value chain and key questions and key performance indicators to measure each link.

Table 3.1. The innovation value chain at firm-level (Hansen and Birkinshaw, 2007).

	IDEA GENERATION			**CONVERSION**		**DIFFUSION**
	In-house	**Cross-pollination**	**External**	**Selection**	**Development**	**Spread**
	Creation within a unit	Collaboration across units	Collaboration with parties outside the firm	Screening and initial funding	Movement from idea to first result	Dissemination across the organization
Key Questions	Do people in our unit create good ideas on their own ?	Do we create good ideas by working across the company ?	Do we source enough good ideas from outside the firm ?	Are we good at screening and funding new ideas ?	Are we good at turning ideas into viable products, businesses, and best practices ?	Are we good at diffusing developed ideas across the company ?
Key Performance Indicators	Number of high-quality ideas generated within a unit.	Number of high-quality ideas generated across units.	Number of high-quality ideas generated from outside the firm.	Percentage of all ideas generated that end up being selected and funded.	Percentage of funded ideas that lead to revenues; number of months to first sale.	Percentage of penetration in desired markets, customer groups; number of months to full diffusion.

Innovation is a complicated phenomenon having inputs and outputs as well as the impacts on several aspects of performance of companies and nations. Historically, organizations and public bodies have tended to measure innovation in terms of inputs (e.g. R&D expenditure) and outputs (e.g. patent or trademark applications) (Archibugi and Pianta, 1996). Although extensively used, these two indicators are not sufficient to measure innovation process as a whole. No single measure is able to capture innovation's multiplicity of features. In addition, metrics for inputs and outputs of innovation should be distinguished at the firm, sector and national levels.

3.2. Inputs of Innovation

Several metrics are proposed in the literature for measuring the inputs of innovation. R&D expenditures can be measured as the percentage of the gross value added of all industrial firms spent on R&D, whereas the total innovation expenditures (R&D and non-R&D) are measured as the percentage of the total turnover of industrial firms spent on innovations (Hesen, 2001).

The European Innovation Scoreboard (EIS) has three dimensions of innovation inputs including; innovation drivers (e.g. number of graduates, broadband penetration rate), which measure the structural conditions required for innovation potential; knowledge creation (e.g. R&D expenditures, share of enterprises receiving public funding), which measure the investments in R&D activities; and innovation & entrepreneurship (e.g. number of SMEs cooperating with others and SMEs using organizational innovation ICT expenditures), which measure the efforts towards innovation at firm level (European Commission, 2006).

Based on Milberg's (2004) classification, innovation input factors are listed as R&D (funding, intellectual property, patents, and scientific publications), talent (human capital, education, competencies, and experience), capital, and networks (knowledge communities, linkages, collaborations, public/private partnerships). The knowledge produced in industry, universities and government research institutes is clearly another key input for any innovation ecosystem (Turville, 2007).

3.3. Outputs of Innovation

A traditional indicator as an output measure of technological innovation is the number of patents granted. New products commercialized, market penetration and growth, cost reduction, profits, revenues and value to customers are among the output indicators of innovation (Milbergs, 2004). Output metrics used by the European Commission (2006) focus on two dimensions such as applications that measure the performance, expressed in terms of labour and business activities, and their value added in innovative sectors and intellectual property that measure the achieved results in terms of successful know-how.

3.4. Measuring Innovation as a System

As Ozorhon *et al*. (2009b) suggest systemic innovation metrics are necessary to capture the context in which organizations form and match expectations and capabilities to innovate. Besides measuring the inputs and outputs of innovation, the process and contextual variables should be investigated as well as the impacts in order to fully realize the benefits of innovation.

Modern construction companies largely function and innovate by the quality of their processes, the people operating them and the way in which they change and adapt to suit the changing business environment. Much construction innovation is project-based and unrelated to formal R&D expenditure and many innovations, particularly organizational or process innovations are neither patented nor trademarked (Slaughter, 1993). Therefore, traditional indicators poorly reflect the true level of innovative activity in construction. This gulf between practice and measurement is the real innovation gap (NESTA, 2006).

The construction industry can benefit from the diverse benefits offered by innovation particularly by adoption of new methods to improve processes and organizational effectiveness. However, being a project-based and fragmented industry, much of the innovation in construction is co-developed at the project level and therefore is difficult to capture (NESTA, 2006; Barrett *et al*., 2007). Since innovation is a multidimensional and complex process having several inputs and outputs as well as the contextual variables that

affect the level of innovativeness, a systemic analysis is necessary in order to measure innovation.

Innovation measurement tended to focus on products and related production systems that is based on measuring inputs to innovation (R&D expenditures, education expenditures, capital investment) and intermediate outputs (publications, patents, workforce size and experience, innovative products) (Milbergs and Vonortas, 2004). As NESTA (2006) stated, traditional indicators of innovation performance are heavily biased toward investments in scientific and technological invention and so do not capture innovation in non-research intensive industries and there is a gap between actual innovative activity and the conventional measures that are intended to represent it. The construction industry provides an example of a sector within which traditional measures do not reflect the true extent of the innovative activity that is taking place (NESTA, 2006; Barrett *et al*., 2007). As much of this innovation is process and organization-based and hidden at the project level; construction companies tend to invest less in R&D and rarely create new patents (NESTA, 2007; BERR, 2008), therefore such innovations are difficult to capture with the standard indicators used for technology-intense sectors. Sound policy analysis and decision-making requires relevant indicators in order to remove this gap and capture the hidden innovation in construction (Barrett *et al*., 2007).

3.5. Analyzing Innovation at Different Levels

The literature so far focused on how innovation could be implemented in construction projects (Tatum, 1987; Slaughter, 1998, 2000; Winch, 2003). There have been a number of case studies of how successful firms have been able to make a range of different organizational, managerial or technological innovations (Slaughter, 1993; 1998; Veshosky, 1998; Koskela and Vrijhoef, 2001; Sexton and Barrett, 2003a, b; Cleasby, 2004); yet there have been relatively few large-scale surveys of innovation in construction and what role these processes of innovation are having in reshaping practices.

Innovation could be investigated in different stages of the lifecycle including the design, preparation, construction, and maintenance. In addition, as Barrett *et al*. (2007) pointed out, the standard definition of construction does not include much of the value-

adding construction activity; therefore adopting a built environment view would be helpful in analysing the major economic activities of manufacturing, production, architectural and engineering consulting, asset management, project management, distribution, and services. The built environment cluster analysis provides a wider approach to analyse the operations and functions of the construction sector within the overall economy of a country (Carassus *et al*., 2006). Adopting a built environment view helps analyse the major economic activities of manufacturing, production, asset management, project management, distribution, and services Ozorhon *et al*. (2009a,d). A similar approach was adopted in one of the studies (Reichstein *et al*., 2005) that included all firms in traditional construction as well as the firms involved in architectural activities, urban planning and landscape design, quantity surveying and engineering consultancy and design activities in the variable broad construction sector.

Seaden and Manseau (2001) developed a conceptual model for the analysis of innovation in construction to describe the linkages between the business environment, business strategy, innovative practices and business outcomes. Dikmen *et al*. (2005) developed a conceptual framework to investigate value innovations within construction companies in Turkish construction industry, where the elements of the model are objectives, strategies, environmental barriers/drivers, and organizational factors. Yitmen's (2007) study focused on the investigation of the challenge of change for innovation in North Cyprus construction industry. These studies usually focused on how innovation is managed within one firm and there is a lack of focus on specific project stages as well as a lack of specific focus on different construction sectors. Only a small minority of the research articles have considered innovation at a specific stage of the project lifecycle or from the point of view of the project lifecycle in general (Dickinson *et al*., 2005). Moreover, none of these studies discussed the accurate measurement and proper indicators for construction innovation.

Milbergs (2004) proposed a framework to analyse innovation at the national level, where the major components of innovation are defined as the inputs, implementation (processes/activities), outputs, and impact, as well as the contextual (institutional) factors. According to Milbergs (2004), four contextual domains are distinguished that influence the rate and direction of innovative activity. These include the macro-economic conditions such as fiscal/monetary environment, interest rates, global economic growth rates, demographics; public policy conditions such as R&D funding policy, taxes, intellectual property,

regulations, standards and market access policies; innovation infrastructure conditions such as university research infrastructure, federal labs, capital markets, power and transportation systems, regional clusters; and national mind-set such as public attitudes to science, cultural factors, and political issues related innovation. More research should be done to explore knowledge production and utilization, technology transfer, standards, entrepreneurship, services innovation, general-purpose technologies, public policy impact, innovation infrastructure and relating these factors to the impacts at national level (Milbergs, 2004). It is possible to apply the basis of this framework and investigate the innovation process at the business level.

3.5.1. Construction Innovation at Firm Level

According to Lansley (1996) the occurrence of innovation within the construction industry is often characterised by the widespread adoption of new practices as a result of advances in technological and business processes. Modern construction companies largely function and innovate through the quality of their processes, the people operating them, and the way in which they change and adapt to suit the changing business environment.

Innovation can be observed at three different levels namely the 'sector-level', 'business-level' and 'project level'. Among these, sector-level is the most visible type of innovation and project level is the most hidden (Barrett *et al*., 2007). At the company level, innovation can be a key source of competitive advantage, offering the means through which a firm can achieve a client's objectives in a specific project or its own objectives over a range of projects (Slaughter, 2000). Studies show that there are many benefits for innovators. Previous studies have found that firm-level innovation increases a firm's export potential (Bleaney and Wakelin, 2002), profits over long periods and during recessions (Geroski *et al*., 1993), credit ratings (Czarnitzki and Kraft, 2004), chances of surviving in the market (Cefis and Marsili, 2004) and market value (Hall, 2000; Toivanen *et al*., 2002). The ability to innovate can create possibilities for firms to gain competitive advantage over their industrial rivals.

Tatum (1987a) described the technological innovation process within individual construction firms. He identified the following major elements of innovation as: recognizing

forces and opportunities for innovation; creating a climate for innovation; developing the necessary capabilities; providing new construction technologies; experimenting and refining; and implementing. Slaughter (2000) presented a detailed framework in which the six stages of innovation implementation activity are defined as identification, evaluation, commitment, preparation, use, and post-use evaluation.

Dikmen *et al*. (2005) defined construction innovation (Figure 3.1) as a system, where the elements of the model are objectives, strategies, environmental barriers/drivers, and organizational factors. These studies discuss innovation management from an individual firm's point of view.

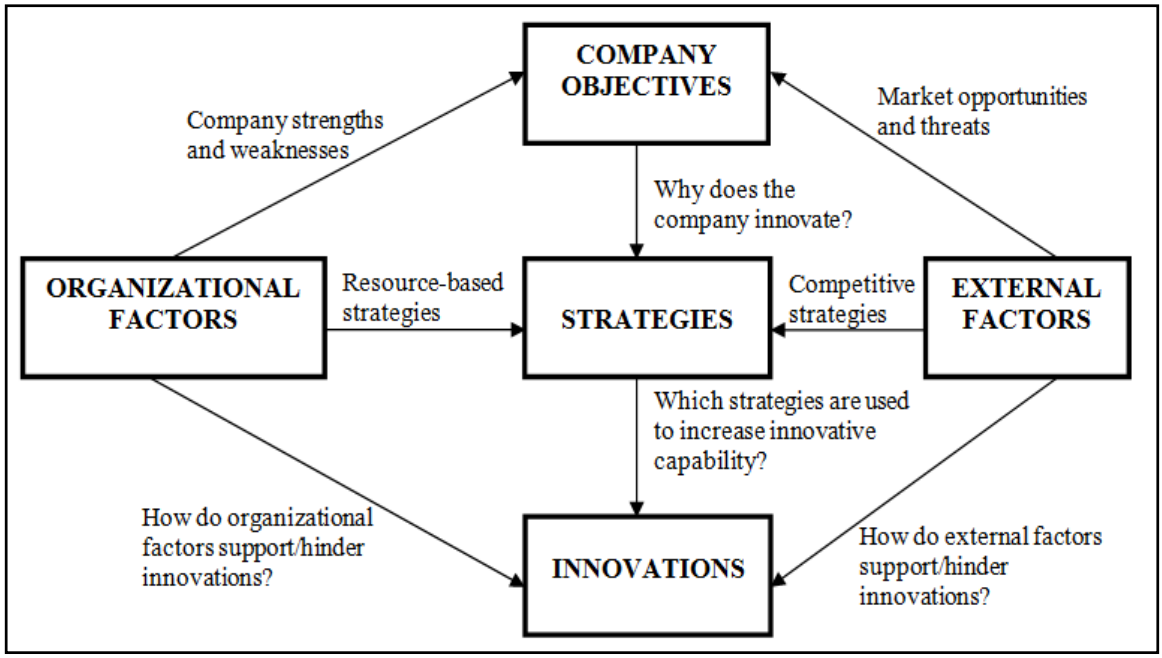


Figure 3.1. Innovation framework for firm level (Dikmen *et al*., 2005).

Ozorhon *et al*. (2009d) proposed various metrics to analyse construction innovation at firm level. Table 3.2 shows the proposed metrics.

Table 3.2. Measures of innovation at firm level (Ozorhon *et al*., 2009d).

Inputs	R&D spending Number of R&D projects Number of ideas or concepts Number of people actively devoted to innovation Sources of information (internal and external) Capital (investment in ICT, purchase of software and equipment) Networks (technology alliances)
Contextual (institutional variables)	Organizational factors (company structure, culture, organizational learning, resources) Country related factors (political, economic, regulations, public policies, socio-cultural conditions) Industry-related factors (fragmentation, competitiveness, technological advancement, project-based, lack of an agenda, no of parties, legal issues)
Implementation (processes/activities)	Tools, techniques, strategies (knowledge management, human resources, IT and R&D, design, marketing, distribution, business process reengineering)
Outputs	Number of new products introduced/commercialized/exported Number of new processes/services introduced Intellectual property (patents, trademarks, designs)
Impacts	Revenue growth due to new products or services Short and long-term profitability Increase in organizational effectiveness Increase in technical capability Improvement of service/product quality/processes Improvement of organizational structure Improvement of human resources Market penetration and growth Better company image Innovation collaborations Improvement of client satisfaction

3.5.2. Construction Innovation at Project Level

Construction projects involve the collaborative effort of multiple organizations. The same principle is valid for implementing construction innovations. Mention (2011) stated that innovation is "an interactive process between the firm and its environment, as the result of the collaboration between a wide variety of actors, located both inside and outside the firm".

Project-based firms need to manage innovation across organizational boundaries, within networks of interdependent suppliers, customers and regulatory bodies (Gann and Salter, 2000). This issue has been further investigated by Dewick and Miozzo (2004), who discussed the effect of positive inter-organizational relations in the diffusion of sustainable technologies in the Scottish housing market. Similarly, Holmen *et al*. (2005) emphasized the significance of building relationships for technological innovations and Rutten *et al*. (2009) presented a literature synthesis on the role of cooperation as an enabler of construction innovation. While these studies emphasize the need of strong inter-organizational relations in enabling innovation, they do not analyse the project-specific conditions fostering innovation.

Construction firms often innovate at the project level as their work is always unique, always delivered to bespoke designs and always achieving something new (Keegan and Turner, 2002). Unlike other industries, construction involves production of unique projects on site by a variety of teams brought together temporarily. Much of construction innovation is co-developed at the project level (NESTA, 2007) and therefore elements of innovation at the project level should be key to identifying the actual level of innovation in construction. However, most of the literature has focused on investigating innovation at the firm level, with the project level being largely ignored. This is mainly because of the difficulties in monitoring the different activities carried out by different parties in each stage of a construction project (Dulaimi *et al*., 2002; Blayse and Manley, 2004). As Barrett *et al*. (2001) have suggested, specific research into innovation in construction must be undertaken and all generic innovation research should be "envisioned, embedded and evaluated in a construction context to form a robust body of construction innovation knowledge in its own right".

As Blayse and Manley (2004) stated, “the one-off nature of most building projects limits the degree to which a given innovation will be applicable to other situations, reducing the benefits of innovation and therefore incentives to innovate.” A study by Gann and Salter (2000) points out the need for a better conceptual understanding of innovation and new management practices to link project and business processes. Business processes are ongoing and repetitive, whereas project processes have a tendency to be temporary and unique (Gann, 1998; Brusoni *et al*., 1998). However, in the case of long-term relationships with clients, contractors secure repeat business and have the opportunity to apply the same or similar innovations in other projects as well. This motivates contractors to invest in new technologies and help them transfer their knowledge and experience in future projects.

Each stakeholder within the construction value chain has a different responsibility and role in stimulating and achieving innovation. In the construction value chain, clients can act as a catalyst to foster innovation by exerting pressure on the supply chain partners to improve overall performance and by helping them to devise strategies to cope with unforeseen changes (Gann and Salter, 2000), by demanding high standards of work (Barlow, 2000), and by identifying specific novel requirements for a project (Seaden and Manseau, 2001). Contractors, on the other hand, play a mediator role in the interface between the institutions that develop many of the new products and processes (materials and components suppliers, specialist consultants, and trade contractors) and those which adopt these innovations (clients, regulators, and professional institutions) (Winch, 1998). Manufacturing firms invest far more in R&D than contractors and are subsequently more likely to develop product and process innovations (Gann, 1997), whereas in construction successful innovation often requires effective cooperation, coordination and working relationships between the different parties in construction projects (Gann and Salter, 2000; Ling, 2003).

Ozorhon (2013a) proposed a framework to explore various components of innovation at the project level. Figure 3.2 depicts the proposed innovation framework. It defines innovation as a system having several components relating to the participating organizations, as well as project-specific factors. The components of the innovation process lie on one side and the project participants on the other, within a 3-Dimensional project environment. The main components of the innovation system are the drivers, inputs, enablers, barriers, innovative activities, benefits, and impacts. The drivers represent the main motivations for

the innovation process to initiate. The inputs are the resources utilized to develop or adopt different types of innovations (product/process/organizational). The barriers act as the obstacles or challenges working against the innovation. The enablers are those factors overcoming the barriers and increasing the rate of innovations. Benefits are considered as the project-level outputs, whereas impacts are considered as wider outputs on the project participants. Each participant contributes to and benefits from the innovations introduced. The process is cyclic since the experience and knowledge gained by the project parties may be transferred to future projects in implementing similar or different innovations.

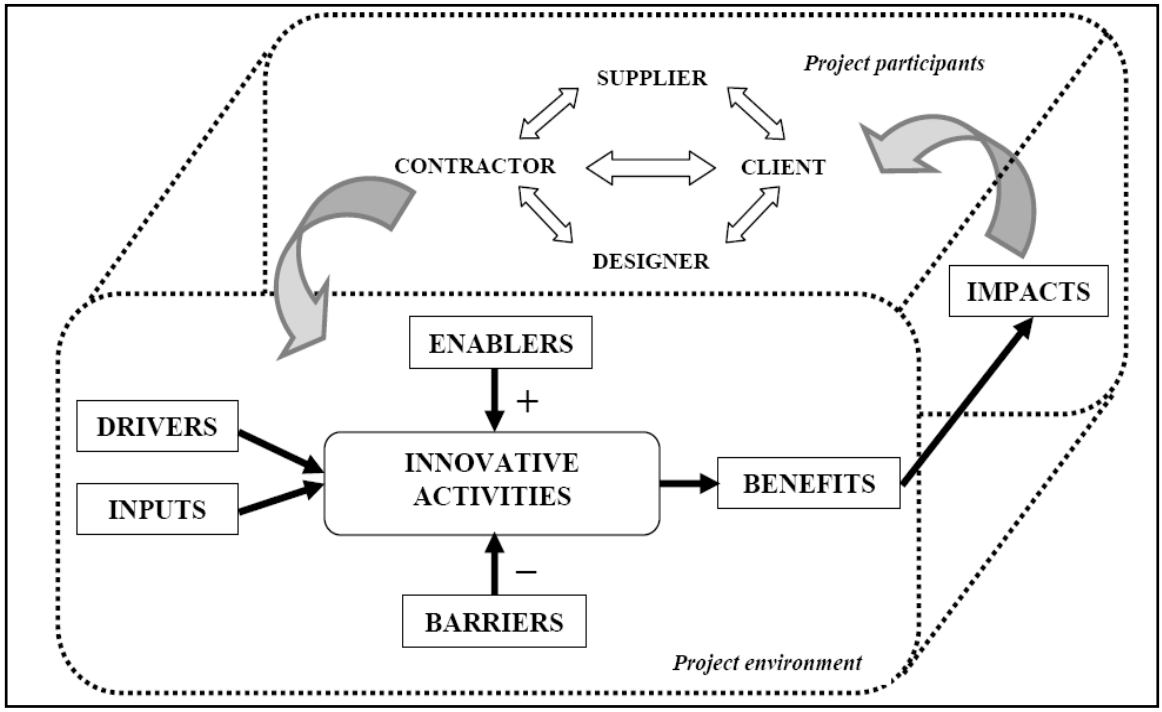


Figure 3.2. Innovation framework for project level (Ozorhon, 2013a).

4. RESEARCH METHODOLOGY

4.1. Innovation Measurement Framework

The aim of this research is to construct an integrated framework to investigate the innovation in process within construction projects and thereby measure the innovation performance in the construction industry.

As noted by Seaden and Manseau (2001) very little in-depth analysis has been done so far of various innovation framework factors affecting the construction industry. Based on the competition-based view, Pries and Janszen (1995) emphasized the dominant role of environment in construction innovations. Seaden and Manseau (2001) have reported country-specific observations drawn from case studies of 15 countries to discuss the effectiveness of public policy instruments to foster innovation in the construction industry. Likewise, temporal typologies have been proposed by examining the factors that create innovations in construction companies. Eaton (2001), and models of construction innovations have been proposed to examine the innovation process over time. Slaughter (1998) numerous studies have been conducted to examine the impact of individual organizational factors on the innovative capability of firms. The impact on innovations of organizational structure (Tatum 1986, 1987), type of leadership (Nam and Tatum, 1997), availability of slack resources (Keegan and Turner, 2002), and knowledge management practices and intellectual capital (Egbu *et al*., 2001) has been discussed extensively. Innovations realized in various construction projects have been demonstrated e.g., Slaughter (1998) as well as major IT-based innovations within the construction industry (Betts *et al*., 1999).

Although innovations may emerge from various sources and activities within an organization, research and development (R&D) usually has been denoted the major driver of innovation and highly emphasized as the critical activity within the innovation system. Thus, R&D expenditures and the number of R&D personnel, patents, and publications and their citations have been used as measures of innovative capability. It is evident, however, that being a project-based industry where product innovations are rarely realized, R&D

activities and associated measures do not reflect the real innovation capacity of the construction industry. Due to its special characteristics fragmentation, existing rules and regulations, and so on, and resulting organizational arrangements, the construction industry constitutes a special case for innovation research.

In order to develop measures for innovation that are appropriate to particular sectors, it is necessary to understand the sectors own view of the significance of innovation and how and why it does (or does not) occur. To this end, this section presents an analysis of innovation at the project level. In this respect, a questionnaire survey has been designed and administered to the members of the Turkish Contractors Association (TCA) and the Turkish Construction Employers Association (TCEA).

Figure 4.1 shows the proposed innovation framework, which is developed based on a previous work by Ozorhon (2013a). This framework investigates the innovation process within a construction project setting based on several components including the drivers, inputs, barriers, enablers, benefits, and impacts.

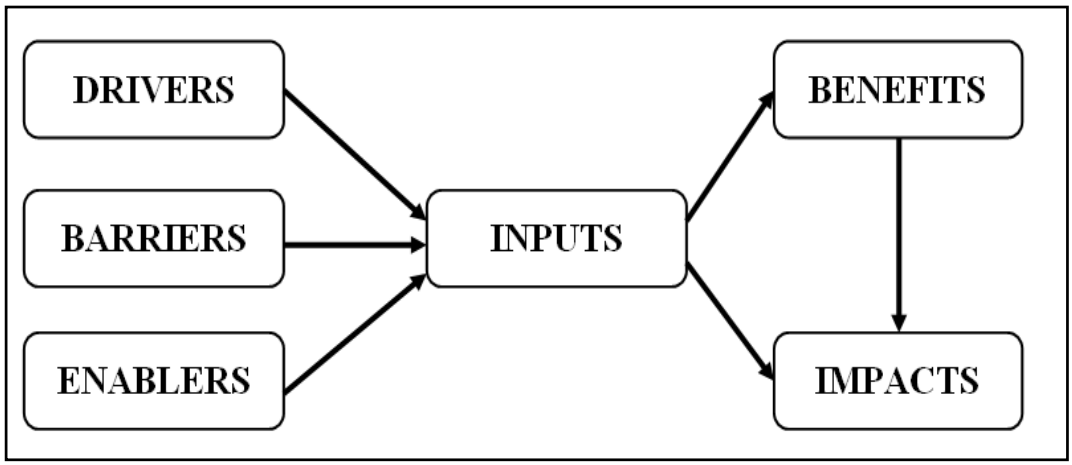


Figure 4.1. Innovation framework.

The main components of the innovation system are the drivers, inputs, enablers, barriers, innovative activities, benefits, and impacts. The drivers represent the main motivations for the innovation process to initiate. The inputs are the resources utilized to develop or adopt different types of innovations (product/process/organizational). The

barriers act as the obstacles or challenges working against the innovation. The enablers are those factors overcoming the barriers and increasing the rate of innovations. Benefits are considered as the project-level outputs, whereas impacts are considered as wider outputs on the project participants. Each participant contributes to and benefits from the innovations introduced. The process is cyclic since the experience and knowledge gained by the project parties may be transferred to future projects in implementing similar or different innovations.

The core concern of this research study is to investigate the innovation activities that the Turkish construction companies have applied in their projects and to explore the sector's innovation capability. Thus, appropriate performance measures have to be developed, the validity of these measures has to be tested and the direct and indirect influences of several variables on overall innovation performance have to be examined. For this purpose, a questionnaire study has been designed details of which are presented in the forthcoming sections.

4.2. Questionnarie Survey

There is a general agreement among researchers and industry professionals that one of the major obstacles to promote innovation in construction companies and successful construction projects is the lack of appropriate innovation performance measurement. For continuous and sustainable improvement, it is necessary to have a well-designed measurement system with valid innovation performance measures and indicators which has the ability to monitor performance of innovation as well as providing long-term strategic decisions for the company. In the light of this approach, an innovation analysis model with a bunch of appropriate innovation measures and indicators was constructed. In order to test its convenience for use, a questionnaire survey was designed and administered to construction industry professionals.

"Quantitative Research" gives emphasis to the measurement and analysis of fundamental relationships between variables, not process (Denzin and Lincoln, 1998). It is generally used in positivist studies to test hypotheses objectively or to test models that are built based on theories (Kaplan and Duchon, 2000). It is a robust and systematic way to examine and measure developed research models significantly (Denzin and Lincoln, 1998).

The most common examples of quantitative methods include survey, laboratory and field experiments and mathematics modelling (Shadish *et al*., 2002). In this thesis, there is a questionnaire survey analysis filled by 110 different professionals as quantitative method of the research. All of the survey analysis and its results are explained in the analysis of the innovation performance model chapter of the thesis.

In order to collect primary data, several collection methods were investigated and it is decided that an internet-based questionnaire would generate better results because of the nature of this research. Surveys/questionnaires are frequently used for exploration projects that are based on descriptive and explorative research approach.

The questionnaire was administered via e-mail to construction companies established in Turkey, describing the objective of the study and requesting a fill in online for firm level project based innovations. In this thesis, an internet-based online questionnaire survey is prepared. The list of targeted respondents was created utilizing several sources, but the main resource is TCA and TCEA. However, considering the fact that there were other construction companies in the industry which were not members of TCA or TCEA but showing similar characteristics with the member companies of these two associations in terms of size and type of work undertaken, the questionnaire survey was sent to some construction related organizations like project management companies, designers, suppliers, sub-contractors and other middle/large scale contractors. At the end of the survey, a total of 110 completed questionnaires were returned for data analysis out of 335 sent out. The rate of response was 33%.

4.3. Content of the Questionnaire

Given the model and the measures identified in the preceding sections, four variables namely, “drivers”, “inputs”, “barriers” and “enablers”, were developed to measure “benefits” and “impacts” of innovations at company and project level. A questionnaire survey was then developed consisting of questions that inquire about the performance determinants that measure the latent variables. Each question was associated with constituent variables of the latent variables. The descriptions of those determinants of performance will be detailed in the following parts.

4.3.1. General Information about the Company and the Project

Respondents are asked to give some information on their companies and the project they have performed innovation activity. The main goal of asking the company and project information was to generate a profile of the respondent companies and projects. The demographic information about the companies is gathered by four questions about the name of the company, the number of years the companies have been in the construction sector, areas of expertise, and the total turnover of projects undertaken so far. Project related questions mainly focus on type of innovation in the project, the type of the project which innovation occurs, value of the project, the employer of the project, and the job title of the respondent. A total of 18 questions, seven of which correspond to company-related and eleven of which belong to project-related issues, appear in this section of the questionnaire.

4.3.2. Innovation Performance

Types of construction innovation activities were explained in previous chapter. Here is the list of construction innovation activities which are asked to questionnaire participants to implement their projects.

(i) Collaborative Practices
(ii) Contract Management / Client Relations
(iii) Waste Management
(iv) Energy Efficiency & Green Buildings
(v) Knowledge Management:
(vi) Design Solution
(vii) Application of Information and Communication Technologies (ICT)
(viii) Web-Based Project Management & ERP & Intranets and Extranets
(ix) Advanced Materials (Renewable, Improved and Innovative)
(x) Off-site Manufacturing
(xi) Modern Methods of Construction
(xii) On-site IT Applications (GIS, GPS, RFID)
(xiii) Automation of Processes on Site
(xiv) Lean Construction

(xv) Sustainability
(xvi) New Organizational Methods and Marketing Strategies

The following questions aimed to measure the different components of innovation using a Likert Scale (1-5) for each question:

- To what extent do the following factors create the need for the innovation that you have implemented? *(Drivers)*
- To what extent do the following factors impede the uptake of innovation? *(Barriers)*
- To what extent do the following factors help promote innovation? *(Enablers)*
- To what extent do the following factors facilitate innovation? *(Inputs)*
- To what extent does the innovative activity benefit your project? *(Benefits)*
- To what extent does the innovative activity benefit your organization? *(Impacts)*

4.4. Drivers of Innovation

4.4.1. Client and End Users' Requirements

Clients can act as a catalyst to foster innovation by exerting pressure on the project participants to improve overall performance, as well as by helping them devise strategies to cope with unforeseen changes (Gann and Salter, 2000). They might also drive innovation by demanding high standards of work (Barlow, 2000) and by identifying specific novel requirements for a project (Seaden and Manseau, 2001).The client acted as a leader in the project and created a supportive work environment for new ideas (Ozorhon, 2013a). Knowledge and financial provision, effective leadership, and dissemination of innovations are among the key roles which clients could play (Egbu, 2008).

According to Ozorhon (2013a) research, the clients have positive role (either public or private sector) in terms of innovation. Client requirements as the major drivers of innovative solutions in the construction sector (Brandon and Lu, 2008). Kulatunga *et al*. (2011) stated that clients promote innovation in construction projects through their championing characteristics including proactive involvement, information dissemination, and effective coordination.

A champion to drive the construction industry, significant attention is paid on the potential role of the construction client (Gann and Salter, 2000; Blayse and Manley, 2004; Harty, 2005; Manley, 2006; Egemen and Mohamed, 2006; Lim and Ofori, 2007). Egan (1998) claimed that the clients should not only participate, but should take the leadership to drive construction innovation. There are research findings suggesting a correlation between client's activities and innovation in the construction process (Nam and Tatum, 1997). Further, there is compelling evidence from other industries to confirm the influence that a client can exert on the generation of innovation (Gardiner and Rothwell, 1985; Fullerton and West, 1996; Martin *et al*., 1999; Mackay *et al*., 2000; Maklan *et al*., 2008; Kulatunga, 2011).

Early research identified the client as a member of the construction process who can stimulate the innovation potential to reap benefits (Gann and Salter, 2000; Harty, 2005; Manley, 2006; Roger, 2008). According to Lu (2008), construction client can directly influence explorative innovation and indirectly influence exploitative innovation in construction firms. Manley (2006) calls for innovation competent clients to maximise the construction industries innovation potential. Nam and Tatum (1997) and Roger (2008) claim technological progress in construction requires the clients' involvement and leadership. In most cases, the willingness of the client for risk sharing, commitment to innovation and leadership in project planning and execution seemed to be critical for the success of the innovation process. In Fairclough's (2002) report, the obligation of the government as the major client of the construction industry towards its development is highlighted. The construction client is looked upon as a person (or organisation) that can coordinate and direct the construction process towards innovation. The study carried out by Roger (2008) on large engineering projects revealed that construction clients acts as innovation drivers by ensuring projects are economically viable, technically functional and socially acceptable. Egemen and Mohamed (2006), emphasise the need for change in the attitude towards the construction

client by stating “the traditional assumption that the client only need projects which are completed within budget, on schedule and with a reasonable quality should start to change”. Egan (1998) agrees that clients should take a leading role and asserts that impetus for change within the construction industry must come from major clients (Kulatunga, 2011).

Demands of clients motivate companies and individuals to innovate (Mitropoulos and Tatum, 2000; Blayse and Manley, 2004). Some of the clients had specific wishes and demands concerning sustainability, for example, an extremely high energy efficiency ratio, and stimulated architects to come up with innovative solutions and ideas (Bossink, 2004). Osmani and O’Reilly (2009) identified two main drivers: corporate social responsibility and client demands encouraging builders to integrate sustainability in their developments. Hakkinen and Belloni (2011) examined the barriers and drivers for sustainable buildings in Finland and concluded that the demand and willingness of clients eventually determines the development of sustainable buildings. The more demanding and experienced the client, the more likely it is to stimulate innovation in projects it commissions (Barlow, 2000). Clients that conduct internal research and development (R&D) or design projects themselves, have a history of innovation, or maintain long-term relationships with the same designers/contractors are found to be most likely to set the preconditions for innovative behavior on a project (Nam and Tatum, 1997).

The major clients have committed themselves to driving forward the modernisation of the construction industry (Egan, 1998). The public sector has a vital role to play in leading development of a more sophisticated and demanding customer base for construction.

4.4.2. Competition and Corporate Performance Improvement

The competitiveness of firms inevitably depends on national and regional systems of innovation, which in turn depend on government policy. For example, the level of business-funded R&D is influenced by national policies (e.g. competition and macroeconomics), and also by the behaviour of national institutions (e.g. agencies funding basic research, banks and stock markets, and systems of corporate governance) (Pavitt and Patel, 1999).

Innovations can provide the critical component of a firm's competitive strategy. Innovation can be a key source of competitive advantage for construction companies offering the means through which a firm can achieve a client's objectives in a specific project or its own objectives over a range of projects (Slaughter, 2000).

Green (2009) explains that corporate social responsibility (CSR) is often used as a proxy for sustainability, but the groundswell of interest in sustainable development has called into question any idea of a separation between construction and society. An increased public awareness of CSR and sustainability is also intertwined with the development of sustainability reporting (SR) (Etzion and Ferraro, 2010). Many large multi-nationals engage in SR, but it remains a largely voluntary activity. There is no one common approach, but there is a growing body of knowledge and some standard frameworks, such as the Global Reporting Initiative (GRI) and the emerging International Integrated Reporting Committee (IIRC) IR framework. Hence, there is growing interest in reporting that links sustainability and financial parameters in a transparent, meaningful, accessible and credible way (Glass, 2014).

Hakkinen and Belloni (2011) state, retailers regard environmental responsibility as a competitive issue, and sustainable buildings may become more important for companies when they have committed to corporate social responsibility. One of the case study which Ozorhon (2013b) examined in her paper, the client wanted to be a leader in its market by first reducing CO2 emissions in all of its operations and then sharing the acquired knowledge on innovation with other organizations (including competitors) and government to help stimulate a low-carbon economy. This would enhance the corporate image of the client and help it lead the market in green business. Client put environmental and social corporate responsibility as their top priorities in their operations. First, they took legislation very seriously, secondly they have their own environmental policies and waste management plans and were strongly committed to carbon reduction (Ozorhon, 2013b).

4.4.3. Project Performance Improvement (Time and Cost Reduction)

Globalisation of markets and production, and new regions of economic growth created pressures to innovate construction companies are exerting pressures to improve the ways in

which complex engineering and construction projects can be delivered on time, within budget and to specified quality. They also wish to improve lifecycle performance characteristics and enhance flexibility to meet unforeseen changes in demand (Gann and Salter, 2000).

Much of what is driving innovations in construction is related to changes in the market place. Privatization of public works such as electrical generating plants, railroads, and waste treatment facilities has been increasing (Tatum, 1989). Typically, private companies have more flexibility in adopting new technologies than public institutions. There is also increasing foreign competition in U.S. markets. This results in U.S. owners demanding more for their money in construction projects. In order to meet this demand, contractors are looking for more efficient and productive means of construction which innovations can provide (Goodrum and Haas, 2000).

4.4.4. Technological Developments

A study by O'Connor and Yang (2004) investigated the extent to which the adoption of new technologies contributes to project performance. Scheduling benefits were noted to be more closely associated with technology usage than were cost benefits. In an extensive follow-up study of capital facility projects in Taiwan, Yang (2007) found a strong link between overall project performance and electronic information transfer and storage (Hardie, 2010).

In addition, "technology" driver is positively associated with the "resources". Although competitors can imitate the technology, relative advantage can be created and sustained due to other complementary resources, which might make it difficult for competitors to benefit from the technology at the same level (Keittinger *et al*., 1994). Especially, the role of information technologies (IT) in creating competitive advantage for firms through differentiation has been widely mentioned in the literature (Mata *et al*., 1995; Bhatt and Grover, 2005). Since the construction industry is fragmented due to the involvement of many parties and phases involved in a construction project, there exist difficulties in documentation, communication, and coordination. Whereas, the use of IT can help overcoming these difficulties, particularly web-based systems (Nitithamyong and

Skibniewski, 2004). Therefore, the construction companies can utilize these systems to differentiate themselves (Budayan, 2013).

Design, engineering and construction firms have to manage innovation in multi-technology environments, responding to changes in software, engineering, information and materials technologies, rising costs, and the need to deal with increasing complexity due to social and political circumstances. In response to this rise in complexity, leading firms in the construction sector have developed scientific and technological capabilities across a large range of technical fields (Gann and Salter, 2000; Salter *et al*., 2003). To meet, induce, or categorize owner's demands or projects problems, the designer's or contractor's diverse mix of technology must be fully considered in the process. Their banks of technology, fragmented and dynamic in nature, should be updated continuously. The designer or contractor must effectively manage the process through which new technological information flows in from various sources (Nam and Tatum, 1992).

The choice of technology in construction takes place under conditions where it is not usually feasible to test full-scale prototypes. Simulation and modelling is therefore of great importance in front-end decision-making, planning and execution. Product definition, development, simulation, testing and production usually involve the transfer of knowledge within complex networks of suppliers and include a large number of interactions between many different specialists. This includes the need to deal with technical decisions in which the interdependency between components and subsystems creates the need for an exchange of technical know-how across a range of professional and engineering disciplines (Gann and Salter, 2000).

Despite the slow rate of technological advancement in some segments of the construction industry, several types of firms supply new technology. This includes new materials, equipment, and tools developed specifically for construction and also new technologies from other industries, e.g., aerospace and manufacturing, that have potential construction applications. This force corresponds to the “technology push” process identified in other industries. Examples include new technologies for instrumentation and process control of construction operations, further mechanization of construction operations

using equipment with increased capability, construction automation, and the use of computer tools for planning and monitoring construction (Paulson, 1985; Tatum, 1987).

Additionally, an overall improvement in technology is having an effect on innovations in construction. Construction has witnessed technology transfer of innovations from other industries. An example of this is the Global Positioning System (GPS) that originated in the military for various uses in navigation. Today it is used in design and construction to provide site layout, record as-built information and provide topographic surveys among other uses. The construction industry is also witnessing constructed facilities becoming increasingly complex, which has resulted in contractors resorting to improved technologies to build them (Tatum, 1989; Goodrum and Haas, 2000).

4.4.5. Regulations and Legislation

The link between regulatory conditions and innovation outcomes was a key driver of the introduction of performance-based regulations (Crew and Kleindorfer, 1996; Gann *et al*., 1998; Meacham *et al*., 2005). Performance-based regulations provide greater flexibility over prescriptive regulations by defining the ultimate performance that the regulating authority requires, rather than prescribing how that level of performance is to be implementation of innovation by manufacturers achieved. This flexibility allows firms to experiment with different methods, potentially leading to more efficient or effective approaches (Gann *et al*., 1998; Manley, 2008a).

Shifts in regulatory policy may create a framework within which technological innovation can flourish (Gann, 1998). Regulations generally aim to govern behaviour and at the same time establish rules that are responsive to changing technological and market conditions (Breyer, 1982). The process of developing regulations is complex, relying upon the knowledge of key players. The extent to which technological change is encouraged by setting standards depends on the availability of new knowledge, together with development of appropriate mechanisms. Where knowledge and mechanisms are limited in their scope, it is possible for the resulting regulation to govern behaviour which is beyond its intention and possibly its mandate. Regulations involving performance standards therefore have the potential to stimulate or stifle innovations (OECD, 1991; Gann, 1998).

Michael Porter argues that stringent standards for product performance, safety and environmental impact can create pressures for firms to innovate, improving quality and upgrading technologies (Porter, 1990). Standards are part of the institutional setting within which competitive advantage is created (Manley, 2008b).

Mandatory standards which force technical development are effective precisely because of their in flexibility in certain areas. By imposing requirements which are too strict for current technology, they force industry to develop new technology in order to comply. High standards may therefore induce demand for improved technologies which otherwise would be commercially unsuccessful. Legislation can stimulate innovation and improve firms' competitiveness. Clarity and simplicity is needed in the regulatory process to enable the up-take of good practice and encourage innovation (Manley, 2008b).

Construction firms operate in heavily regulated environments. Formal regulatory requirements lay a part in shaping the way firms choose materials, technologies and they focus on relationships between participants in construction processes and how adversarial conditions can be minimized between parties involved in projects (Reichstein *et al*., 2008).

Several influences in the regulatory environment of a construction firm force technological innovation. Newly imposed requirements influence both the types of projects under construction and the construction operations themselves. For example, environmental protection requirements have mandated the design and construction of major new features for industrial plants. Life safety and energy conservation requirements for buildings have also made a significant change in these projects. Regulations concerning environmental protection during construction, occupational safety, and exposure to hazardous materials at the workplace also have a major impact on construction. These requirements both increase the scope of construction and impose new restraints on construction operations (Tatum, 1987).

Manley (2008b) stated in her paper, close relationships between the manufacturers and clients were driven by government environmental regulations. In the investigated case studies the clients called for expressions of interest to help them meet Australian government mandates for resource use reduce water consumption, and to reduce energy consumption.

For example, to reduce energy consumption, some state governments require their agencies to lease only those buildings with a five-star energy rating from the Australian Greenhouse Office, and under the South Australian Energy Efficiency Action Plan, energy consumption in government-owned buildings must be reduced. In addition, the Australian Building Code sets nationally uniform standards of minimum energy performance. These regulations assisted the development of a more efficient air conditioning system. Various environmental rating schemes provide significant incentives for Australian construction firms to meet and exceed best practice. The profile of the schemes is high and the impact on reputations is significant. Case studies exemplify in particular the influence of the high profile threat of significant and imminent climate change on R&D and innovation. Regulations clearly have a big impact on the innovation opportunities of contractors and manufacturers. Solutions developed in response to performance-based regulations that give firms considerable flexibility in meeting established standards. This flexibility created room for creativity, novelty, experimentation and efficiency-improving outcomes in the projects examined (Manley, 2008b).

4.4.6. Corporate Responsibility

Companies at the higher end of corporate sustainability maturity have started to adopt their strategies, proactively including society's concerns (Zadek, 2004; Maon *et al*., 2010). Due to their large-scale impacts, multinational enterprises possess the potential to "increase innovation, spur wealth creation, transfer technology, raise productivity, meet basic needs, enhance living standards, and improve the quality of life for millions of people around the world" (Nelson, 2006; Spitzeck *et al*., 2013).

Sustainability is becoming an important focal point from a global construction perspective. For example, it has been observed that construction activities significantly impact on waste, energy use and greenhouse gas emissions. Such impacts have clearly led to a growing emphasis on corporate responsibility on sustainability. This, in turn, is reflected by pressure being exerted by clients, government and other stakeholders for the construction industry to be more accountable for its social and environmental impacts. Thus, sustainability considerations are becoming more significant in the construction process, including contract selection (Adjetunji *et al*., 2003). As a response to climate change and its

effects on the environment and energy consumption, there has been a growing emphasis on corporate sustainability (Thorpe *et al*., 2008).

Today, pioneering companies integrate social entrepreneurship into their core activities by actively funneling their R&D capabilities towards socially innovative products and services (Schwab, 2008). Borger and Kruglian (2006) found evidence of a strong relationship between the adoption of a corporate social responsibility (CSR) strategy by the firm and an effective environmental and innovative performance. According to Asongu (2007), the key to success in using any type of innovation to a company's advantage from the CSR perspective is to communicate with local municipal authorities, the press and, the most importantly, the general public that stands to benefit from such initiatives. Companies that have sustainable policies tend to be technological leaders, as they seek imaginative new methods for increasing efficiency, e.g., by reducing pollution. In many cases, these companies are able to come out with new, innovative products that outpace most of their competitors. According to Phills *et al*. (2008), many social innovations involve the creation of new business models that can meet the needs of underserved populations more efficiently, effectively, and if not profitably, at least sustainably. Many innovations tackle social problems or meet social needs, but there is only for social innovations the distribution of financial and social value spilled over the society as a whole. A social innovation can be a product, production process, or technology (much like innovation in general); it can also be a principle, an idea, a piece of legislation, a social movement, an intervention, or some combination of them (Ubius *et al*., 2009).

Social and environmental risks are potential triggers for innovation. In constructing activities, there are social risks such as resettling and economic dislocation of the affected population, among other potential social negative impacts. Additionally, there are environmental risks such as loss of habitat, reduced biodiversity and impacts on fish populations. Some issues are inter-linked, such as extensive flooding, which creates more breeding grounds for mosquitoes, transmitting malaria and other diseases. These externalities have traditionally not been considered in corporate decision-making and innovation processes as their impacts were felt mainly by the general public (Spitzeck *et al.,* 2013).

4.4.7. Aesthetics and Design Trends

There is widespread consensus that design is becoming increasingly important in determining competitiveness. Design is critical for innovation because it involves the coupling between technical possibilities and market demands and opportunities (Freeman, 1983; Rothwell and Gardiner, 1983; Lorenz, 1986; Faulkner and Senker, 1995; Roy and Potter, 1996; Walsh, 1996; Roy and Riedel, 1997; Stankiewicz, 1998; Salter and Torbett 2003).

There is a reticence amongst designers to engage in new product innovation uptake in their building designs (Stungo, 2003). Designers are wary of specifying new product innovations without full sight of the technical data. There have been a series of recent high-profile failures of innovation within buildings. However, in the current climate of international competition for work there is growing pressure on designers to continue to challenge the boundaries of building construction (Tatum, 1988; Steele and Murray, 2004). Clients are demanding more complex buildings with advanced levels of integrated technology, which are not feasible with current construction technology (Nam and Tatum, 1989; Winch, 1998; Murphy, 2008).

Design organizations face more demanding clients and increased competition for work with ever-lower margins. Salter and Torbett (2003) suggested that designers often lack the ability to demonstrate the benefits of their designs and services to the project. Innovativeness or cost-savings in design are subsumed into the totality of the project. The contribution of designers is difficult to disentangle from the activities of others, and therefore to price accurately. Moreover, according to interviewees, savings in design are notoriously hard to quantify and measure. In this environment of increased client pressure, design organizations are beginning to look to performance measures as an opportunity to show clients and contractors the value and efficiency of their design activities (Salter and Torbett, 2003).

4.4.8. Environment and Sustainability

Environmental innovation can be defined as the use of production equipment, techniques and procedures, and products and product delivery mechanisms that are sustainable (because they conserve energy and natural resources, minimise the environmental impact or footprint of human activity and protect the natural environment). They include both environmentally friendly products (for example, materials with low embodied energy, the total amount of energy used in the raw materials and manufacture of a certain quantity of material, or composed of natural resources) and processes (for example, waste management or recycling) (Dewick and Miozzo, 2002).

As the world is becoming increasingly concerned about the environment and surrounding, there is a tremendous focus on all the industries including the construction industry to adopt the proactive approach to green construction. Sustainability in construction will not only benefit individuals but also contribute to the global issues. Sustainability in construction can only be achieved by rethinking operation in four major areas, i.e., “energy, materials, waste and pollution”. Implementation of changes to achieve sustainability will vary from firm to firm. It will be different for the larger firms from small and medium sized firms (Ahuja, 2013).

The clients managed the innovation development and implementation processes in the construction projects. Environmental pressure is the pressure that is exerted by institutions and organizations and forces and stimulates other institutions and organizations to increase their innovativeness. It consists of the elements: market pull, governmental guarantees for innovative firms, governmental clients with innovative demands, and innovation stimulating regulations and subsidies (Bossink, 2004). Environmental sustainability stands alongside globalisation, new materials, and new information and communication technologies (ICT), in addition to governance and regulation, as an especially important factor in the construction industry, both now and into the future (Thorpe, 2008).

The construction sector is under increasing obligation to adopt the principles of sustainability in their activities and policies (Brandon, 2005). The construction industry has been rising up to the challenge of sustainability as they are under increasing legal and

commercial pressure to become more sustainable (Bennett and Crudgington, 2003). Due to the impact of construction industry on economy, society and environment, increasing the sustainability of construction has become a key aim of countries aspiring to follow the path towards sustainable development (Mustow, 2006).

The UK Government has been making progress towards more sustainable construction through a range of initiatives and policies (DTI, 2006). The drivers of sustainability identified in the literature include legislation, customer requirements, broad level support reputation and brand integrity, regulators, shareholders or investors' expectations, increasing competitive advantage, business pressure, government policy and regulation, new client procurement policies, environmental concerns, long-term survival of business, improved corporate image, cost savings/operational efficiency, enhanced relations with suppliers, peer pressure within the industry and increased realisation of the importance of construction image (Sustainable Construction Task Group, 2002; Adetunji *et al*., 2003; Simpson *et al*., 2004; Yu and Bell, 2007; Ogunbiyi, 2014).

Based on the literature review, the following hypotheses are developed:

H1: Drivers have a positive influence on the inputs.

4.5. Barriers of Innovation

4.5.1. Unsupportive Organization Culture and Unwillingness to Change

Some industries are widely reported to have largely failed the challenge to adopt new attitudes and modes of operation (Reichstein *et al*., 2005, 2008). The construction industry in the international context has been broadly criticised as slow to absorb both new management practices and new technologies (Latham, 1994; Egan, 1998; Fairclough, 2002). Cole (2003) also identified "an unwillingness within industry leadership to recognise the long-term advantages of structural and cultural change, accepting instead a short-term project driven profit process".

Management support is essential to break the employees' resistance to change. In order to break the resistance to change in the construction firm, the managing director has to act as an innovation champion (Ozorhon, 2013a, b).

Although human resistance to change is not unique to the construction industry, there are variables unusual to construction that impedes potential innovations. The construction industry as a whole is conservative in dealing with risks. Contractors often want to build a job by means and methods that have proven profitable in the past (Goodrum and Haas, 2000).

The literature on factors which result in resistance to change in the construction industry is extensive. Resource-based factors which have been identified as contributors include: (1) the proliferation of many very small businesses who have difficulty surviving let alone growing (Winch, 2000; Koksal and Arditi, 2002); (2) the insecurity of much employment in the industry (Walker *et al*., 2001); (3) the tacit and individualised nature of much of industry experience, skills and knowledge (Vakola and Rezgui, 2000; Fernie *et al*., 2003; Hari *et al*., 2005); (4) lack of expertise in and value placed on human resource management (Kangari and Miyatake, 1997; Bossink, 2004); and (5) contractual risk shifting towards those who can least afford to bear the cost (Hinze, 1994; Langford *et al*., 2000; Zaghloul and Hartman, 2003).

Structural factors which have been identified as impediments to change and innovotion in the construction include: (6) its temporary project-based nature (Dubois and Gadde, 2002; Towill, 2003); (7) procurement systems which stress lowest price rather than best value (Wong *et al*., 2000; Salter and Torbett, 2003; Turner, 2004); (8) the complexity and lack of integration in existing industry supply chains (London and Kenley, 2001; Dainty *et al*., 2001; Briscoe *et al*., 2004; Kumaraswamy *et al*., 2004a, b; Love *et al*., 2004); (9) resistance to standardisation and modularisation because of the inherent diversity of industry participants (Fox *et al*., 2001; Gibb and Isack, 2003); and (10) self-perceptions of the industry's nature which limit both top-down and bottom-up innovation (Koskela and Vrijhoef, 2001; Hardie, 2010).

4.5.2. Lack of Financial Resources and High Investment Value

Dikmen and Birgonul (2003) mention that financial resources are the most critical resources and differentiated services for the construction companies through innovative project development. Therefore, financial resources were considered as an important resource (Budayan, 2013).

Different ways of thinking emerge about the role of industry-based factors in innovations. According to Dikmen research (2005) the project based nature of the construction industry hinders the innovation process, as the time for the return on investments for innovation might be longer than the project duration, or an innovation process/product realized in one project might not be useful in another. They stressed that retaining the risks of innovation is not feasible as the projects are not repetitive in nature (Dikmen *et al*., 2005).

Construction sector also suffers from an overdependence on cost as opposed to value as the means of determining the distribution of work. A multi-criteria contractor selection process has many advantages over simple lowest cost selection (Wong *et al*., 2000). At times, the experience, skill base, safety record and appropriate capitalization of tenderers can be ignored in favour of a low tender price from a less reputable firm that may be ultimately undeliverable. Along with this attitude is a short-sighted tendency to under resource the design time allocation for a project in order to cut costs (Salter and Torbett, 2003). As a result, the various design alternatives may not be fully explored because of the need to restrict design costs and the end result may not be the "best for project" solution. Turner (2004) points out that the information available on the parameters of a construction project is inevitably incomplete at the time a contract is awarded. In these circumstances, a reliance on tender price as the only measure of selection is particularly problematic. The broader assessment approach taken by some relationship procurement methods is likely to be much more effective in the long-term (Hardie, 2010).

4.5.3. Temporary Nature of Projects

A further factor which tends to exasperate adversarial atmosphere in construction is the fact that much industry knowledge and skill is tacit and uncodified and resides in the minds of individuals who have acquired their knowledge through experience over time and on diverse projects (Vakola and Rezgui, 2000). In addition, the rationale for decisions is often not written down or recorded in any way, making it difficult for the organization as opposed to the individual to learn from project experience. This highly personalised nature of construction knowledge means that the ability to make sensible decisions is very difficult to transfer to others (Fernie *et al*., 2003). Hari *et al*. (2005) looked specifically at this transfer process in small construction enterprises and found a specific lack of awareness of the issues of knowledge transfer within a firm. When these issues were managed well, it tended to be because of the vision of the organization's owners rather than through any systematic process (Hari *et al*., 2005; Hardie, 2010).

The project-based structure of the industry means that groupings of discrete businesses coalesce and then separate around the delivery of relatively short-term projects. Although some continuity is provided by the tendency to work with groups where there is some connection from a previous project, the temporary nature of the relationship can lead to suspicion about the sharing of information. This is not an atmosphere conducive to the diffusion of successful innovations (Hardie, 2010).

Construction activity is essentially carried out by teams who come together for short-term projects. Linkages between companies are often temporary and unstable. Dubois and Gadde (2002) have described the difficulties associated with a "loosely coupled" system as such a project-based industry is, almost inevitably. The strong project focus inherent in such an industry structure makes coordination with those outside the project difficult and even pointless (Dubois and Gadde, 2002). The construction industry produces artefacts which are very long lived and continue to impact on the environment and society for many years after their production. This combination of short-lived project teams with long-lived effects is one of the essential problems for the delivery of quality project outcomes (Hardie, 2010). Given the temporary nature of the project teams and the short-term relationships between

organizations that have come-to-be the norm, transfer of innovations from project-to-project and firm-to-firm has been extremely difficult (CPN, 1997; Sexton and Barett, 2010).

4.5.4. Lack of Materials and Technology

There are many possible benefits from the standardization of building products but the structure of the industry tends to resist pre-assembly, prefabrication and modularisation of components (Gibb and Isack, 2003). A new component has to win acceptance not only from the ultimate purchaser but also from the variety of consultants, contractors and tradesmen who will need to integrate the new component into their own operations. Some benefit needs to accrue to all parts of the delivery chain or the change is likely to be difficult to implement (Hardie, 2010).

Although construction has tended to be a bespoke industry because of its scale of operation and the complexity of its inputs, there is an increasing place for standardized and modularized buildings and the economies they produce. This is particularly true of standardized components for on-site fabrication (Fox *et al*., 2001). Input from the builder at the design stage is essential if such standardized components are to be successfully adopted throughout the industry (Hardie, 2010).

Companies that have sustainable policies tend to be technological leaders, as they seek imaginative new methods for increasing efficiency, e.g., by reducing pollution. In many cases, these companies are able to come out with new, innovative products that outpace most of their competitors (Hardie, 2010).

4.5.5. Lack of Experienced and Qualified Staff

New technologies often require new ways of working and thinking, i.e. require change. Change, however, can hardly take place, nor be effective without a “proper” and “efficient” workforce that is equipped with the “appropriate” skills (Hauk and Rockwell, 1997; Leitch, 2005; Gurjao, 2006). The advancement in new material, equipment, systems, processes, and practices necessitate the introduction of new skills (Eurich, 1990; Construction Skills, 2008), not to mention enhancing existing skills. Skills dictated by change often require effective

policies for education and training to help develop and "polish" those skills. In this respect, policy makers are required to define and measure those skills (Stasz, 2001; Nadim and Goulding, 2010).

Education is seen as a major component of the potential solution. The underlying problems differ however, typically including demographic trends that see fewer young people electing to undertake vocational training, rather favouring the higher education route and careers in other sectors. The image of the construction sector as dangerous, exhausting and unrewarding was also seen as a major blocker of incoming talent. A result of the dwindling numbers of people coming into the sector and the incumbent workforce retiring is the erosion of knowledge and skills in the sector (Boddy and Abbott, 2010).

Construction firms tend to be led by people with technical expertise and often there is an associated lack of human resource management skill. Kangari and Miyatake (1997) pointed out that in contrast to western countries; management culture in Japan is quite proactive in incorporating "people skills" in technical enterprise management. Bossink (2004) identified the manager's leadership style as an important issue in the progression of innovative ideas. Training for such managers has sometimes tended to avoid the area of human resources management in favour of the technical competence issues. The result is a lack of expertise in many parts of the industry and a lessened ability to benefit from newer management ideas and practices (Bresnen *et al*., 2003; Hardie, 2010).

In an attempt to investigate the profile of current and future skills requirements, DfEE (2000) reported an increase in managerial/professional, and customer-focused staff, a decline in skilled manual workers, and fair increase in less-skilled manual workers. This aligns with Dainty *et al*. (2005), who argued that shortages of professionals and managers were just as acute as manual skill shortfalls. In the past, the term "skill" was arguably used to refer to the capabilities to undertake a particular task, while today, it is often used interchangeably with the term "competence", implying attributes which encompass adaptability, flexibility to change, and possessing "transferable behavioural characteristics" (Parhalad and Hamel, 1990; Drejer, 1996; Klein *et al*., 1998; Taylor, 2005). Skills problems can be manifested in skills shortages and/or skills gaps. Skills shortages occur when skills demand in a particular sector outstrips supply of the required specialist skills resulting in

recruitment difficulties (Gann and Senker, 1998; Mackenzie *et al*., 2000; DfEE, 2000; ONS, 2002; Harrison, 2005; Construction Skills, 2006; CIOB, 2006). Skills gaps, however, refer to skills deficiency in an employer's existing workforce, resulting in "holes" in the knowledge and competence of existing staff, leading to reduced performance, quality and safety (DfEE, 2000; ONS, 2002; LSC, 2005; Construction Skills, 2006; Nadim and Goulding, 2010).

4.5.6. Lack of Long Term Clear Benefits and Risky Investment

Koksal and Arditi (2002) in an extensive study of construction business failure in the USA, cite insufficient profits, heavy operating expenses and burdensome institutional debt as the most significant factors affecting business survival. While this might seem an obvious conclusion which could apply to any industry, it is important to note that the proliferation of such undercapitalised and overstretched businesses is a feature of the construction industry in most parts of the world. Such firms have difficulty in achieving a survival mode and are in no position to innovate. In addition, Winch (2000) noted that continued strong reliance by some firms on self-organizing groups of workers for actual production means that many construction organizations can fail to develop and maintain their core competencies. The historic influences on innovation shift from an employer/employee relationship to a contractor/subcontractor relationship has resulted in a strict focus on cost rather than on sensible allocation of resources to allow continuity of employment and maintain a skills bas (Hardie, 2010).

The construction industry is a low capital intensity industry (Tatum, 1986), therefore construction managers must be cautious with their investments on new construction technologies. If a technology appears to be limited in its flexibility to be used on multiple projects, construction managers will have difficulty justifying the potential return on investment of the innovation (Goodrum, 2000).

Innovation is the implementation in a firm of significantly new processes, products or management approaches in order to increase its efficiency (i.e. improved quality, lower production costs) and/or effectiveness (i.e. greater market share, client satisfaction). It is also agreed that innovation is risky, requires significant investments and is often resisted within

the firm. To innovate is to change and that is never easy. Over the years, there has been mounting evidence of client dissatisfaction with the construction industry's inability to deliver quality products and services on time, at a reasonable price (The Economist, 2000; Seaden *et al*., 2001).

4.5.7. Time Constraints

Construction companies exist under constant pressure to deliver their projects on time and under budget. This can result in avoidance of new ideas, because there is perceived to be no spare capacity to test new products or systems. Shortage of time contributes to a perceived lack of interest in innovation, especially in small construction firms (Davidson, 2001). The time required to adequately test and develop a technical innovation is also a barrier to SME innovation (Hardie, 2011).

Time is one of the most critical factors in construction operations and has significant legal consequences. The project owner sets rigid beginning and ending dates for the construction process. Delays are costly and are specifically addressed in contract documents in anticipation of liquidated and other damages. Pricing in construction can be lump sum, cost plus, negotiated, or unit price. All pricing in construction depends on the time that the contractor determines it will take to complete a job. Barring any circumstances caused by the project owner and outside of the control of the contractor, the contractor must meet the time set by the project owner or lose money. Time factors are even more complicated in construction because the working environment may be outside for part or all of a project, which means that progress is influenced by weather conditions (Benton *et al*., 2010).

Based on the literature review, the following hypotheses are developed:

H2: Barriers have a negative influence on the inputs

4.6. Enablers of Innovation

4.6.1. Collaborative Partnering and Supportive Work Environment

Tatum (1989a) found that to foster innovation, there must be implicit vertical integration. This is confirmed by Dulaimi *et al*. (2002), who found that procuring more contracts based on design–build method would enable companies to increase their innovation, compared to design–bid–build, which is known to be one of the causes of fragmentation (Ling, 2003). Scholars argue that successful innovation often requires effective cooperation, coordination and working relationships between the different parties in construction projects such as the contractors, subcontractors, suppliers, architects, engineers, clients, the government, universities, etc. (e.g., Tatum, 1989a, b; Gann and Salter, 2000; Ling, 2003; Blayse and Manley, 2004; Robichaud and Anantatmula, 2011; Ozorhon, 2013a). For example, strategic partnering between the clients and the contractors, early involvement of contractors, and supply chain partnerships have been observed to have helped the teams build trust and become committed to innovation (Ozorhon, 2013a).

Construction projects involve the collaborative effort of multiple organizations. The same principle is valid for implementing construction innovations. As Mention (2011) states, innovation is the "outcome of an interactive process between the firm and its environment, as the result of the collaboration between a wide variety of actors, located both inside and outside the firm". Holmen *et al*. (2005) emphasized the significance of building relationships for innovations. Gann and Salter (2000) stated that project-based firms need to manage innovation across organizational boundaries, within networks of interdependent suppliers, customers and regulatory bodies. This issue has been further investigated by Dewick and Miozzo (2004), who discussed the effect of positive inter-organizational relations in the diffusion of sustainable technologies in the housing market (Ozorhon *et al*., 2013).

Partnering involves two or more organizations working together to improve project performance and organizational relations through agreeing mutual objectives, devising a way for resolving disputes, and committing themselves to continuous improvement, measuring progress and sharing benefits (Egan, 1998). Implementing new products and processes usually require intensive R&D, considerable investment, strong commitment, and

collaborative partnering among the supply chain (Ozorhon *et al*., 2010). Since the construction industry is a conservative sector, it is difficult to change business processes. Adopting new principles and pushing the industry for innovation requires a cultural change as well. In this respect, mutual trust and teamwork was essential to ensure the successful diffusion of innovations (Ozorhon *et al*., 2013).

The integration of design and build activities was a common practice. Architects consulted their clients and contractors from the start of the design process to the final design stage. Some of the clients had specific wishes and demands concerning sustainability, for example, an extremely high energy efficiency ratio, and stimulated architects to come up with innovative solutions and ideas. The clients decided to what degree it was financially wise to develop sustainable innovations and dictated the innovation ambition level in the projects. Interdisciplinary teams combined their expertise and their innovative concepts, like for example, an ecological water management system for the whole area, were implemented in the construction project. In all projects innovation leaders and champions were the driving forces behind the initiation and realization of innovative ideas (Bossink, 2004).

4.6.2. Early Contractor Involvement

Early engagement in projects are effective ways of developing trust among parties and thereby facilitating innovation. Early contractor involvement is critical to establish a trust-based cooperative relationship in order to facilitate contractors' contributions in the design stage (Korczynski 1996). Increased integration and cooperation through early involvement of contractors is believed to help team members achieve efficient and value-adding solutions (Barlow *et al*., 1997; Briscoe *et al*., 2004).

The preparatory work for large infrastructure projects often consumes an extraordinary amount of time, money and human resources and is not particularly cost-effective. Some of this inefficiency is caused by traditional procurement methods which bring contractors into the process after many key decisions have been made. The clients and consultants are asked to make design decisions with insufficient information and know-how as to the available technology, equipment and potential innovative solutions.

Early Contractor Involvement (ECI) provides an efficient means of designing and planning infrastructure projects in a cost-effective, more efficient and less adversarial structure. Using ECI with a properly executed contract that reflects a partnering relationship should increase transparency and therefore reduce risk, increase shared responsibility and limit the reasons for litigation.

Early Contractor Involvement (ECI) involves the creation of a contractor/design consultant team, led by the contractor, which caters for the consideration of buildability issues earlier in the design process, leading to shorter construction periods and reduced impacts during construction. The benefit of ECI is that it utilises contractors' unique understanding of construction processes to optimise the design and delivery process. The difference is, as the name implies, that ECI involves the contractor far earlier. With ECI, the contractor joins the team right at the start and is involved with planning, assessing buildability, cost estimating and value engineering (IADC, 2012).

4.6.3. Leadership

Leadership has been referred to as one of the main enablers of innovation in the construction literature (Tatum, 1987; Ozorhon *et al*., 2010). Previous research shows that leaders can play a critical role in shaping project spirit (Aronson *et al*., 2010; 2013). Effective leadership results in commitment of the project team to the project objectives (Aronson *et al*., 2006). According to Mention (2011), managers should put in place the mechanisms and tools that foster knowledge sharing within a group in order to facilitate innovation. The client's role as a leader guided the project team first by engaging the contractor early in the project and then pushing them to innovate. As Aronson and Lechler (2009) suggested a project culture, which is constructive, entails a risk taking, trusting and proactive approach that encourages experimentation and open dialogue among the members and therefore in such a culture members are receptive to change and innovation. Patanakul and Aronson (2012) found that organizational culture and team management competency have a significant direct effect on project success. At this point, the leadership of the managing director of the contractor organization should be noted. He acted as an innovation champion and created a culture in the company that facilitated innovation. Otherwise, the reluctance of the company members to change their routines could have prevented the adoption of

innovative practices. The full commitment and strong leadership from the senior management was critical in management support is essential to break the employees' resistance to change this respect. Since the managing directed has shown strong devotion to innovation, company resources and employees were well-organized to create, share, and implement new ideas. This shows that open leaders empower their employees and encourage their creativity; they form an environment that is conducive for innovation (Aronson *et al*., 2008; Ozorhon, *et al*., 2013).

Nam and Tatum (1997) studied 10 successful innovations in the US construction industry with regard to the role of individuals who exert great influence in the process of technological innovation. They found that effective leadership is essential for technological innovation. In addition, technological competence is a prerequisite for effective leadership for innovation. Lastly, the role of technical champion can be delegated only with slack resources and adequate power (Ling, 2003).

4.6.4. Commitment

To enable the innovation to be successfully implemented, it is necessary that the stakeholders are committed. Tatum (1984) found that having a planning team that has an energetic champion, team members who are willing to evaluate alternatives and interdisciplinary co-ordination within design teams are important manifestations of commitment for innovation success. There must also be key individuals, who act as gatekeepers to identify external technology, and champions who absorb the risks and drive the innovation. Gann (2000) referred to them as innovation directors, technology managers and facilitators (Ling, 2003).

A construction firm's philosophy can influence construction innovations (Tatum, 1989). Those firms with an attitude to question anything and anyone, a persistent pursuit of improving productivity and an atmosphere of competition to find ways to improve tend to promote an innovative culture. In addition, firms with a long-term perspective and patience to wait for an innovation to deliver an appropriate rate of return are conducive to innovations. It is important for a firm to have a tolerance of risk, failure, and mistakes if it is to promote innovations (Tatum, 1989; Goodrum and Haas, 2000).

According to Nam and Tatum (1997) client has a key role in innovation. The owner's risk sharing, commitment to innovation and leadership in project planning and execution seemed to be critical for the success of the innovation process. Findings from investigations of manufacturing point out that a conducive attitude and commitment of top management towards innovation is critical for success. In addition, it seems that for the engineering and construction industry a higher level of technical expertise and technical commitment of the top management is an essential precondition for the success of construction innovation. Top executives in innovative firms appear to assume responsibility actively for technological decision-making and have sufficient technical expertise to do so (Nam and Tatum, 1997).

4.6.5. Knowledge Management Practices

Organisations and individuals participating in a project bring their own unique skills and resources, which may include proprietary and commercial applications, knowledge and data. Learning and knowledge sharing are essential drivers of innovation in order to sustain the long-term competitive advantage of organisations. The industry has also been made increasingly aware of knowledge sharing through initiatives such as the Construction Best Practice Programme (CBPP) and Movement for Innovation (M4I) (Robinson *et al*., 2005). Knowledge is the hidden asset of organisations, which has to be nurtured for long-term corporate sustainability (Edvinnson, 1997) and knowledge management is a method of exploiting, or transforming knowledge as an asset for organisational use to facilitate continuous improvement (Robinson *et al*., 2005).

Matusik and Hill (1998) argued that the relationship between organisational knowledge and competitive advantage is moderated by an organisation's ability to integrate and apply knowledge. The key issue, therefore, is to identify localised knowledge and transform it into productive knowledge that resides within the organisation and creates value (Stewart, 1997). Developing a strategy to manage knowledge therefore requires an understanding of the dimensions of knowledge and its business context (Robinson *et al*., 2005).

Knowledge management can drive innovation, helps to attract new and retain valuable customers, and in the process increase organisational productivity and profitability.

Demarest (1997) noted that "firms without knowledge management systems will be effectively unable to achieve the re-use levels required by the business model implicit in the markets they enter, and will lose market share to those firms who do practice knowledge management" (Robinson *et al*., 2005).

4.6.6. Reward Schemes, Grants and Funds

Tatum (1989) found that firms that foster innovation have organizational structures that maintained flexibility in unit size and grouping to allow attention to innovation. These organizations made the effort to have special linkages for both internal and external co-ordination. Dulaimi *et al*. (2002) found that successful innovation may come about if companies establish a reward system to recognize innovators and to promote innovation. They also found that increased co-operation among organizations involved in construction to co-ordinate innovation effort within a particular project may lead to successful innovation (Ling, 2003).

Independent of the relative success of the innovation with respect to the project and company objectives, the personnel involved in the implementation stages should be rewarded (Meyer and Goes, 1988; Laborde and Sanvido, 1994). Some of the rewards are intrinsic to the innovation process itself, in providing personal pride and challenges to the people involved, as well as developing their professional competencies and reputation. In addition, the construction company can provide explicit rewards to personnel involved in the innovation process. These rewards may range from formal recognition within the company (e.g. an internal award) to public recognition (e.g. nomination for a national or international construction innovation award). They can also focus on the employee's job itself, such as explicit expansion of the job description to include innovation or other related activities, increased project or company responsibility and the opportunity to formally act as the company's liaison with innovation sources or collaborators. Finally, the rewards can include monetary amounts, either as a project bonus or through an upward adjustment of salary (Slaughter, 2000).

4.6.7. Education and Training Policy

As constructed facilities become ever more complex the specialist skills required to create them advance also. The challenge of continual learning and updating of skills and knowledge at individual, organisational and sectoral level was identified as significant. Training through more direct collaboration between industry and educational institutions was seen as crucial to the development of a more technically competent workforce (Budayan, 2013).

In order to obtain a distinct competitive advantage based on high quality, the firms must be flexible enough to adjust quickly their production and organizational resources to meet changing markets and customer demands (Arthur, 1992). Therefore, human resources must have the skill and training to perform a variety of different tasks. For example, the field supervisors should have both training in project management and IT. In addition, the project managers should have law knowledge in order to achieve a dialogue about a conflict. Human resources management can build a strong competitive position in an industry like construction in which employee turnover rates are extraordinarily high (Budayan, 2013).

The on-site personnel must learn about the innovation and how to use it. Different types of innovation may require different levels of training to effectively use them, and the sources of the training can differ (Cross, 1983). This on-site training and learning can be particularly important when an innovation has the potential to make existing skills and competencies obsolete, since either the existing personnel can resist the implementation of the innovation, or the personnel implementing this innovation may not be drawn from the traditional labour pool (Slaughter, 2000).

Based on the literature review, the following hypotheses are developed:

H3: Enablers have a positive influence on the inputs.

4.7. Inputs of Innovation

4.7.1. R&D Spending and Number of R&D Projects

Construction professionals see R&D as a part of their project management practice and do not consider it as a specific effort to produce innovations. Since R&D expenditure is one of the main indicators of innovativeness, construction is considered to be a low innovating industry. However, this might be improved with companies registering their R&D expenses.

Several metrics are proposed in the literature for measuring the inputs of innovation. R&D expenditures can be measured as the percentage of the gross value added of all industrial firms spent on R&D, whereas the total innovation expenditures (R&D and non-R&D) are measured as the percentage of the total turnover of industrial firms spent on innovations (Hesen, 2001). Based on Milberg's (2004) classification, innovation input factors are listed as R&D (funding, intellectual property, patents, and scientific publications), talent (human capital, education, competencies, and experience), capital, and networks (knowledge communities, linkages, collaborations, public/private partnerships). The knowledge produced in industry, universities and government research institutes is clearly another key input for any innovation ecosystem (Turville, 2007; Ozorhon, 2009d).

Although formal R&D expenditure in construction is low, there is evidence to show that construction firms can benefit from these types of investments. For instance, Japanese, Swedish, German and French construction firms have invested considerable resources in R&D compared to those in the UK and this has given strong capabilities in areas such as earthquake engineering in Japan (Gann, 2000). Construction R&D expenditure is often directed toward the capture of knowledge external to the firm rather than on developing new products. This form of R&D assists firms in making use of ideas generated externally (Cohen and Levinthal, 1989). Given the degree of regulation and nature of production, the ability to capture external ideas can be an important spur to new developments in the sector. Therefore, it can be anticipated that firms which invest in R&D will be more likely to innovate (Reichstein, 2008).

4.7.2. Human Resources (People Actively Devoted to Innovation)

One of the important resources in the construction industry was determined as "human resources". Warszawski (1996) mentioned about human resources as probably the most critical resource and the key to success in the construction industry. In addition, the relationship between the achievement of the differentiation strategy and human resources is also mentioned by Sun and Pan (2011) and Budayan (2013).

Tatum (1989) found that firms that foster innovation have organizational structures that maintained flexibility in unit size and grouping to allow attention to innovation. These organizations made the effort to have special linkages for both internal and external co-ordination (Ling, 2003).

Sullivan (1998) defines human capital as the capabilities of employees, contractors, suppliers and other company people to solve customer problems. To measure the knowledge held by personnel, the European Innovation Scoreboard (EIS) employs the percentage of the labour force with particular educational attainments as a proxy. This proxy is based on the assumption that the higher the attainment, the more likely the people are to be sources of knowledge and to be able to capture knowledge for value creation (Commission of the European Communities, 2004). Another measure suggested by the OECD (2002) is to use the full time equivalent (FTE) value of R&D personnel. FTE is defined by the Frascati Manual (OECD, 2002) as providing the true volume of R&D. It is a measurement of the man-year utilisation of intangible and non-replicable knowledge residing in researchers. Past studies, have employed similar quantification of knowledge and skills in investigating their impacts on construction innovation. For instance, Na *et al*. (2006) and Lim *et al*. (2010) have employed FTE as a measure of the research capabilities of construction firms. The contribution of each employee depends on several parameters such as experience, effort, skills and education (Kafouros, 2008).

For the construction industry, innovations often originate from the on-site to solve immediate problems and do not always require experts. Therefore, measuring R&D personal alone may be insufficient. To identify the effect of experience, effort, skills and education of the construction personnel on construction firms' performance in innovation, an

appropriate proxy for the human capital of construction firms' innovation should be expressed not only in FTE of R&D personnel, but also the FTE of non-R&D personnel in innovation activities (Lim and Peltner, 2011).

4.7.3. Internal Idea Generation

The majority of the companies agreed that innovations mostly come from the top management level. These top managers generally include the board of directors, general managers, and department coordinators, especially R&D and business development departments. Moreover, practical solutions to the problems that arise at construction sites usually result in innovations. This highlights the importance of the project management team and site personnel for the innovation process. Although the interviews show that innovations usually emerge from internal sources (Dikmen *et al*., 2005).

Managers can take several actions to facilitate the internal coordination and special types of feedback that are required for the process of innovation. Technology transfer between active projects is an important form of internal communication. For example, several firms conduct periodic planning meetings involving representatives from a specific discipline, such as electrical engineering or construction, on several projects. This fosters communication regarding common problems and innovative solutions. It also helps avoid repetition of the same problem on several projects (Tatum, 1989a).

The development of new technology may require investments in research and development activities. These activities can range from major R&D laboratories to focused efforts to develop a specific new computer program or machine. This strategy involves setting priorities based on the problems of existing operations and developing new technology by allocating funds and effectively managing development activities (Tatum, 1989a).

Incremental innovations appear most often within the organizations that have the knowledge, experience, and control to affect the improvements which can be any of the organizational types listed as sources (Myers and Marquis 1969; Slaughter, 1998).

4.7.4. External Idea Generation

Project-based firms need to manage technological innovation and uncertainty across organisational boundaries, within networks of interdependent suppliers, customers and regulatory bodies. Knowledge is differentiated and distributed throughout these networks. Under these conditions, the management of technical know-how has become a significant strategic consideration for suppliers and operators. There is a need for integrity of information between suppliers, designers, systems integrators, engineers, constructors, clients and end-users (Gann and Salter, 2000).

Many factors work against traditional R&D in the construction industry. Managers and observers cite many reasons: it has not been a basis of competition; profit margins limit resources; the suppliers should do it; projects are too different (Tatum, 1987a). These reasons may be changing, but most construction firms do not develop a new technology using processes recognizable as R&D. Despite this, many are innovative, and many technologies with potential application in construction developed in other industries. The technological gatekeeper thus becomes a key role. He or she identifies external technology and has the perception to visualize potential applications in the firm. The gatekeeper makes a conscious effort to identify and transfer beneficial technology to the firm. Technical journals and trade magazines may report directly related research, but seldom describe innovative construction methods developed on competitor's projects. Potentially more significant is the wealth of new technology developed in other industries, such as manufacturing and aerospace that has significant potential applications in construction. Advanced materials, lasers, and process control systems are just a few examples (Tatum, 1989b).

Although very difficult to monitor and tap, technology developed outside the construction industry is a major source of innovation. New materials for aerospace, new integrated systems and machines for factory automation, and new instrumentation and other microelectronic devices are just a few of the potentially beneficial technologies. Using this source requires systematic monitoring and creative thinking to apply the technology in situations. Devices for factory automation, extended and adapted to the construction environment, offer major potential benefits for construction operations on future projects.

Effective interaction with regulators is necessary to anticipate and avoid potential problems with new technology (Tatum, 1989a).

4.7.5. Capital (Investment in ICT, Software and Equipment)

Construction companies can increase or extend their innovative capabilities through investments in new knowledge, R&D and organizational practices (Cohen and Levinthal, 1990; Teece and Pisano, 1994) .Construction projects today are far more complicated than ever before. They involve larger capital investments, embraces several disciplines, widely dispersed project participants, tighter schedules, stringent quality standards etc. These factors coupled with highspeed developments in Information and Communication Technology (ICT) have influenced project management practices to take a new turn taking advantage of newly developed management tools and the latest technology. The development of new technology may require investments in research and development activities. These activities can range from major R&D laboratories to focused efforts to develop a specific new computer program or machine. This strategy involves setting priorities based on the problems of existing operations and developing new technology by allocating funds and effectively managing development activities (Tatum, 1989a).

The development of process innovations primarily involves thinking about alternatives and experimenting with small applications. It may require designing new tools or specialized equipment. The financial resources needed for these. Providing equipment and personnel to support the activities of a lead supplier as he develops an innovative new product for construction is another example, such as the use of a contractor's earthmoving equipment to test automated control systems developed by outside firms (Tatum, 1987a).

An international study of innovation (Tatum, 1982) found that larger firms are more able to afford the new investment for innovation and more able to tolerate the risk of adoption, whereas the smaller firm is more likely to value the technology and has less complex decision-making processes. Construction companies rarely have the capital resources to last through decreases in demand, and so have scarce resources to invest in long-term innovation development. Their lack of capital also discourages investment in specialized equipment or other real property that cannot pay back the investment within a

short time (Manski 1973; Tatum 1986; Slaughter, 1993). Therefore, the companies should be aware that they have to make important investments in improvement of their management process and the resources of the company, if they want to differentiate.

4.7.6. Consultancy

The use of an innovation may require special resources (e.g. special equipment or trained personnel) and these resources may only exist within specialty companies. Therefore, the third consideration for the incorporation of an innovation into a specific project is the type and source of special resources (Slaughter, 1998).

Innovations emerge from the sharing and shaping of ideas in generative debates. Consultants must stay significantly ahead of their clients to provide valuable advice. For instance, IT or engineering consultants invest around 15% of sales in R&D and capabilities building; 18% of staff time is allocated to innovation (Miller and Olleros, 2007). The means used by consultants to foster innovative competencies include working relationships with leading clients facing significant challenges; alliances with technology suppliers to understand expected new technologies; formalisation and codification of strategic or engineering methodologies; and, accumulation of past experience in archives, knowledge management systems or expertise directories. Many strategy or engineering consultants fund research institutes to explore and build scenarios about the future evolution of the sectors that they serve (Roger, 2008).

Based on the literature review, the following hypotheses are developed:

H4: Inputs have a positive influence on the benefits.

H5: Inputs have a positive influence on the impacts.

4.8. Benefits of Innovation (Project Level)

There are many net benefits in fostering innovation in the construction sector, especially at the project level. Innovation in construction may become a fourth competitive dimension to be added to the existing dimensions of cost, quality and time (Newton, 1999). Innovation is required because there are pressures from clients to improve quality, reduce costs and speed up construction processes (Gann, 2000). To realize these benefits, it is necessary to manage and control significant factors that affect innovation success. (Ling, 2003). Gann (2000) argued that the pressures for innovation are often strongest in construction when there is demand-pull. For example, he observed that significant innovation is more likely to take place when clients require the following: buildings that need to be provided with enhanced information services; flexible spaces that need to accommodate information intensive activities; and buildings that need to have reduced environmental impact. Innovations have the potential of improving many aspects of construction. Companies primarily pursue innovations to increase their productivity and efficiency (Slaughter 1998; Goodrum and Haas, 2000).

Based on the literature review, the following hypotheses are developed:

H6: Benefits have a positive influence on the impacts.

4.9. Impacts of Innovation (Company Level Benefits)

4.9.1. Improvement of Experience

A strong interaction with the field forces using the new technology is an excellent opportunity to gain user input to refinement and further innovation. Experience in using technology also provides information to assist in planning and estimating for use on future projects. Once the new technology is used on several different types of projects, with successful results and demonstrated benefits in many applications, it can become the standard practice for the firm. This requires awareness and acceptance by each of the functional elements involved in the projects (Tatum, 1987a). The companies gain experience through the innovation which can be applied to future projects.

4.9.2. Better Company Image and Improve Competitiveness

With diffusion and implementation, the new technology can become a basis for competitive advantage. If the firm emphasizes fixed-price work, the new technology should offer a cost, schedule, or quality advantage that makes it more competitive in winning new projects. If the major emphasis is negotiated work, a record of success in developing and using new construction technology should give the firm a marketing advantage. Many owners seeking "more construction for the money" now see innovation as a means to achieve this. Because few firms now pursue advanced construction technology, those with a demonstrated capability gain an important advantage (Tatum, 1987a, b).

Innovations may also provide significant benefits that cannot be adequately measured in direct monetary savings and gain, but can, nonetheless, add to a company's competitive position. For both the innovators and the early users of the innovations, certain intangible benefits can be obtained from innovations, such as improved reputation, ease of work, and attraction of promising new hires. These intangible benefits can often be more important for the early use of innovations than the expected dollar savings, as examined in the adoption of new information technologies for construction (Ramcharan, 1997; Slaughter, 1998).

The construction industry is currently suffering from a poor image problem. Innovations can help solve this problem by making construction easier, safer and more productive (Slaughter, 1998). This improves the reputation of the construction industry and attracts a larger workforce (Goodrum and Haas, 2000).

Construction-related innovations can also have significant social benefits (Seaden, 1996). When the cost of constructed facilities is reduced, the facilities themselves become more affordable, and, therefore, more accessible to a greater proportion of the population. Improvements in the efficiency of residential construction to improve the quality of life for citizens is a focus of many national construction programs. In the same way, reducing the environmental impacts of construction-related activities through innovations provides social benefits regionally, as well as globally (Slaughter, 1998).

4.9.3. Increase in Technical, Organizational and Management Capability

The experience of using a technology on a project often produces a rich source of ideas for improvement. Given the opportunity, field personnel will work with engineers and mechanics to improve methods that show promise. This includes both new hardware and new techniques to use the existing equipment and tools. This step emphasizes the benefits of experience on several projects using similar technologies and the need for planned means of transferring experience between projects (Tatum, 1987a).

4.9.4. Short and Long Term Profitability

Innovation on individual construction projects places several demands on the firm. Adequately responding to these demands is necessary to take advantage of the opportunity for improved performance on a specific project. In turn, successful project innovation can influence the business planning and long-term direction of the firm if it provides a technology that can give a competitive advantage (Tatum, 1989a, b).

Under certain conditions, the act of innovating itself can provide strategic benefits and the successful implementation of an innovation can enhance a company's reputation (Christensen and Rosenbloom, 1995; Hampson and Tatum, 1997). Even if the expected project-based benefits of an innovation do not appear to offset the expected costs, the companywide benefits in the competitive and strategic implications over a longer time, or more projects, may reveal strong incentives to use an innovation (Slaughter, 2000).

4.9.5. Market Penetration, Growth and New Partnership Opportunities

Construction innovations can also provide multiple benefits to society. Improved productivity and efficiency make construction more affordable. Among other things, this helps spur market growth and provide more affordable residential housing (Slaughter 1998; Goodrum and Haas, 2000).

Innovation can also be associated with market growth, through the provision of new or improved products and services, and reductions in the cost of production (Slaughter, 1998).

4.10. Hypotheses of the Research

Based on the literature review, the following hypotheses are developed:

H1: Drivers have a positive influence on the inputs.

H2: Enablers have a positive influence on the inputs.

H3: Barriers have a negative influence on the inputs.

H4: Inputs have a positive influence on the benefits.

H5: Inputs have a positive influence on the impacts.

H6: Benefits have a positive influence on the impacts.

5. ANALYSIS OF THE INNOVATION PERFORMANCE MODEL

In this chapter, an in depth statistical analysis of the collected data will be explained. The target construction companies were members of the Turkish Contractors Association (TCA), the Turkish Construction Employers Association (TCEA) and other construction companies in the industry such as designers and subcontractors. A total of 335 questionnaires were sent out and 110 completed questionnaires were returned for data analysis. The rate of response was 33%. First of all statistical findings will be summarized and descriptive statistics will be mentioned, literature related to structural equation modelling (SEM) will be given and the whole model will be analysed with SEM and will be explained comprehensively.

5.1. Descriptive Statistics

Within this study, 110 responses are collected from 48 construction companies. The questionnaire is composed of 18 questions. The first step in the analysis of these data is to search for some descriptive statistics, to identify the general characteristics of the companies and to recognize the overall picture of the projects that contain innovative activities carried out by Turkish construction companies. The following part discusses the descriptive statistics about the characteristics of the companies and the projects.

5.1.1. General Information about the Respondent Companies

Demographic information about respondent companies provides some facts regarding the profile of the companies participated in the survey. In search of descriptive statistics about the respondents' characteristics, the mean, standard error, median, mode, standard deviation, sample variance, kurtosis, skewness, range, minimum, and maximum values of the gathered data are calculated. Following are some important information about the profile of respondents and characteristics of the projects.

- **Type of business area**

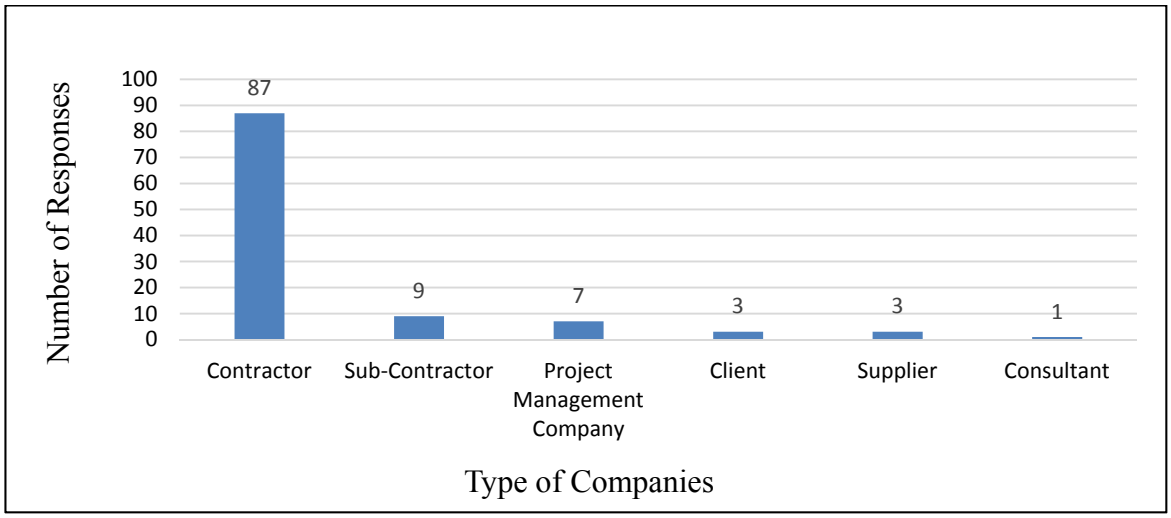


Figure 5.1. Distribution of companies in terms of their business area.

According to type of business area, most of the responses come from contractors (79% of all respondents). Sub-contractors and project management companies follow the contractors, respectively but their share of those is only 14%.

- **Number of years of operation in construction sector**

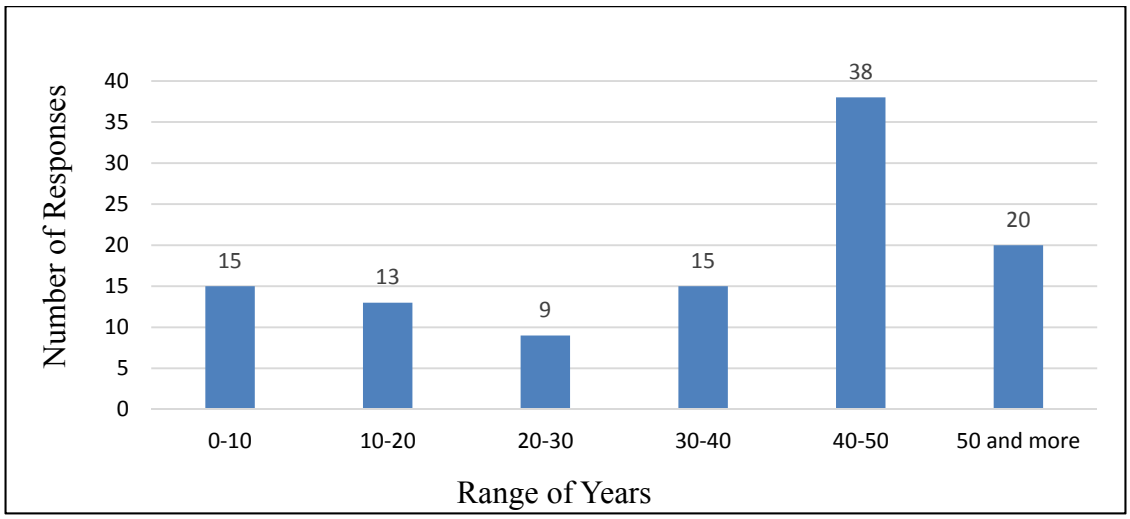


Figure 5.2. Distribution of companies in terms of their ages.

The average age of the respondent companies is 39.43 years. The maximum age is found to be 72 years and minimum to be 2. The distribution of the average ages of the respondent companies based on their types can be seen in Figure 5.3.

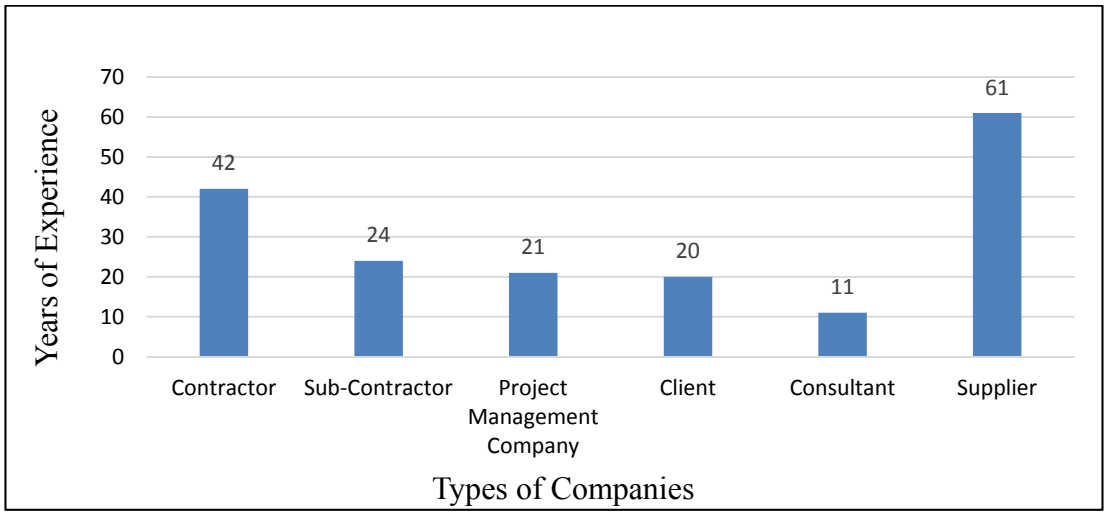


Figure 5.3. Distribution of sectors in terms of their ages.

The average age of the contractor companies is 42 years. The subcontractors', project management companies' and clients' average age is almost same around 20-25. It can be seen that supplier companies are the most experienced ones.

- **Total turnover**

The average turnover of the respondent companies is 480 Million USD and the maximum value for turnover is 4.45 Billion USD. Half of the respondents companies' turnover is around 0 – 400 Million USD.

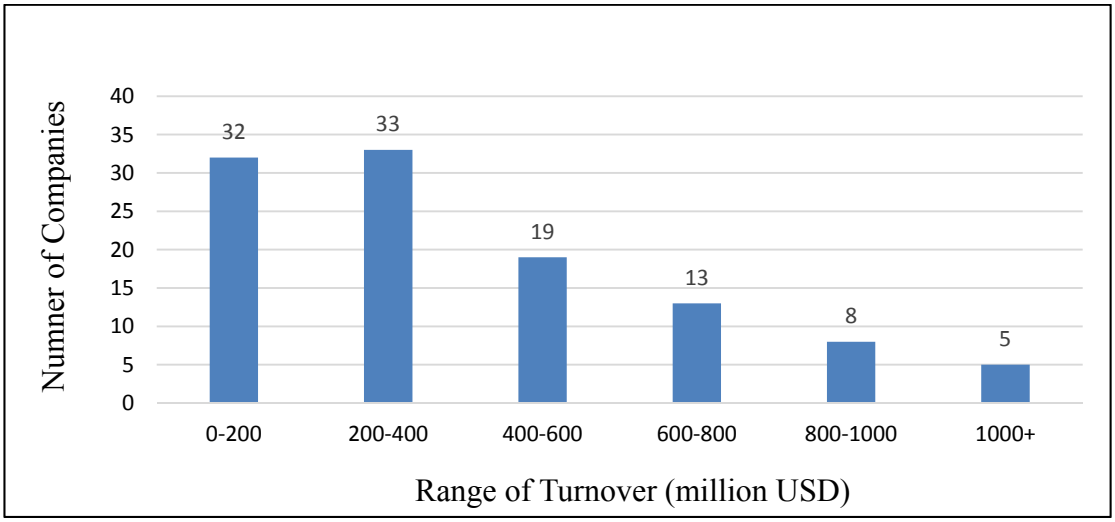


Figure 5.4. Distribution of companies in terms of total turnover.

Below figure 5.5 shows turnovers of the companies by types.

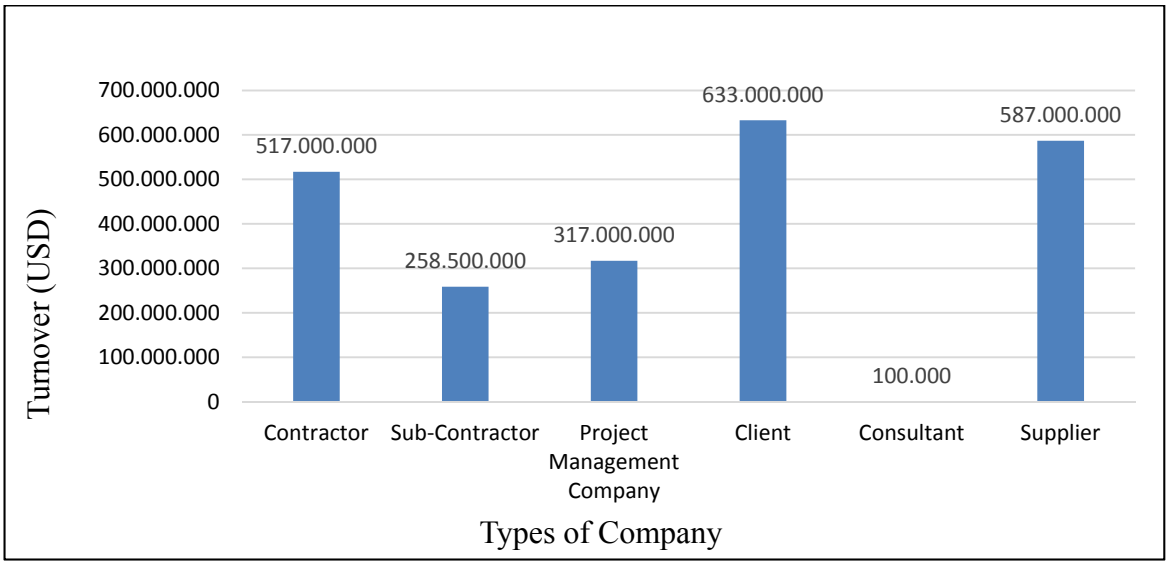


Figure 5.5. Distribution of sectors in terms of total turnover.

5.1.2. General Information about the Projects

Below figures gives some information about projects which respondents stated that implemented innovation activities.

- **Types of the innovation**

According to types of innovation, Web-Based Project Management, ERP, Intranet and Extranet is the most implemented innovation types. In addition, collaborative practices, MMC, contract management and client relations are the following most common innovation types. Application of ICT on site, on site IT applications and knowledge management practices are not popular innovation types according to responses.

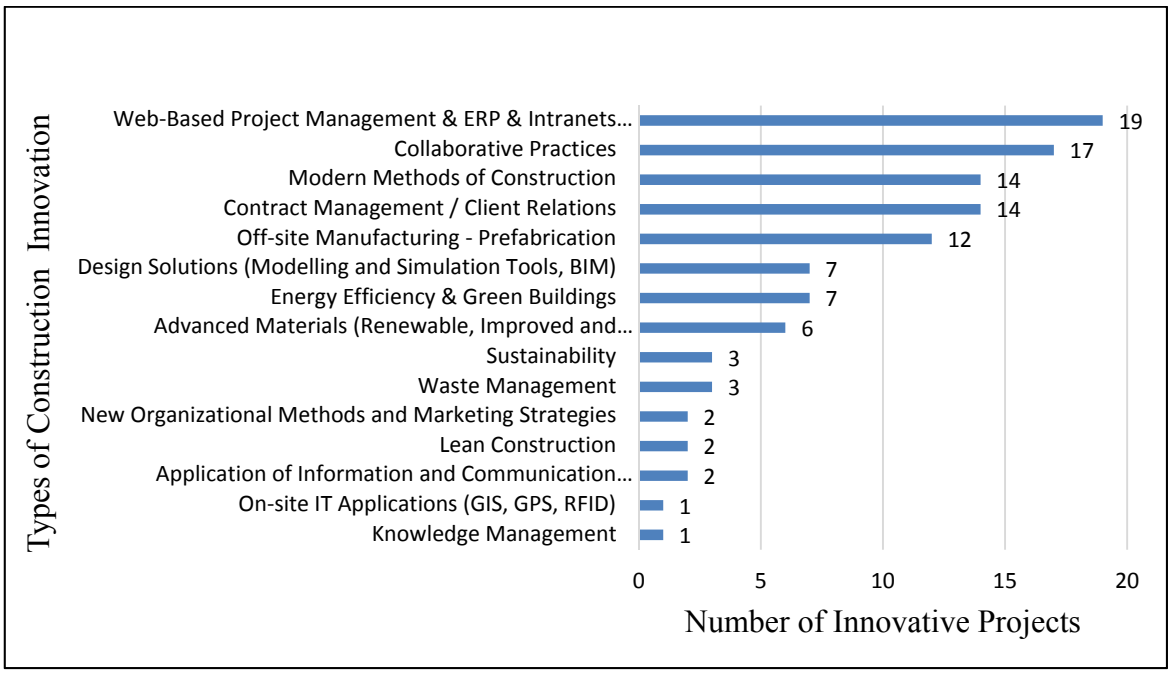


Figure 5.6. Distribution of projects in terms of innovation types.

- **Type of the projects that contain innovation**

Figure 5.7 shows the distribution of the type of projects that have at least one type of innovation. The dominant project type is transportation projects (35%), followed by general buildings (32%) and infrastructure projects (12%).

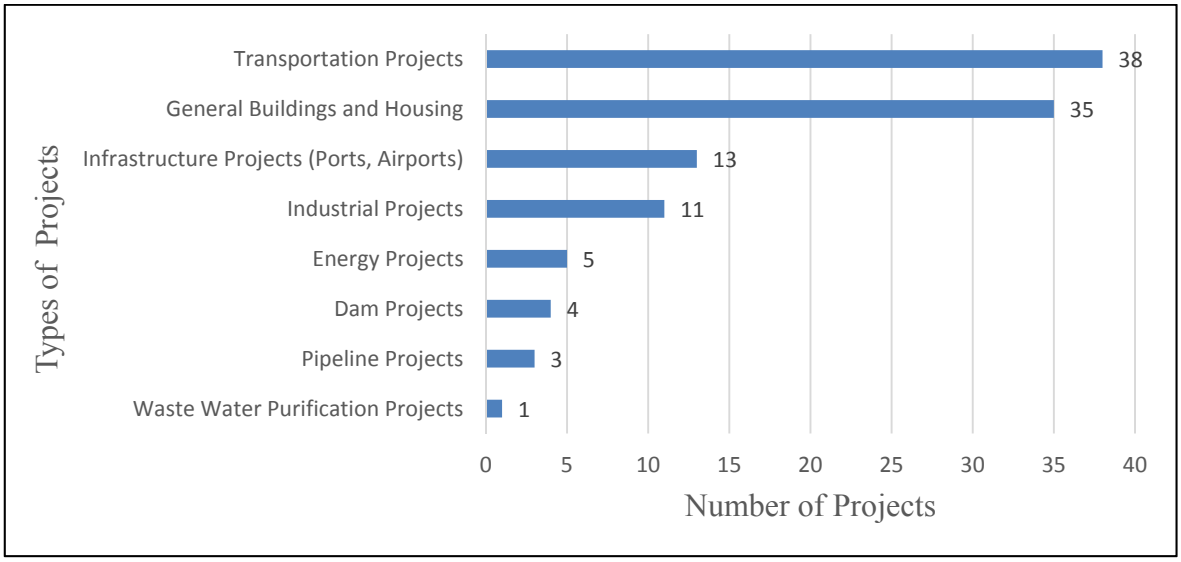


Figure 5.7. Distribution of projects in terms of type.

- **Size of the projects**

Figure 5.8 shows the project size in million USD. When the statistics are analyzed, it is observed that the mean project size is 460 million USD. The minimum size was hundred thousand, whereas the maximum size was 6 billion USD.

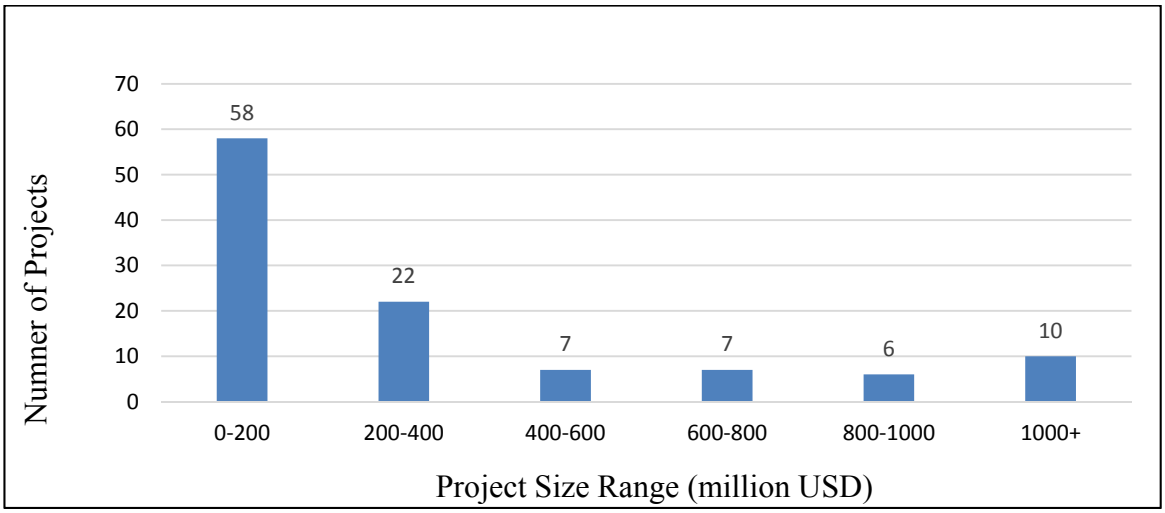


Figure 5.8. Distribution of projects in terms of size.

- **Type of the client**

Client of 52 projects were private organizations, whereas public sector was the owner of 58 projects. Almost an equal distribution of owner type is observed.

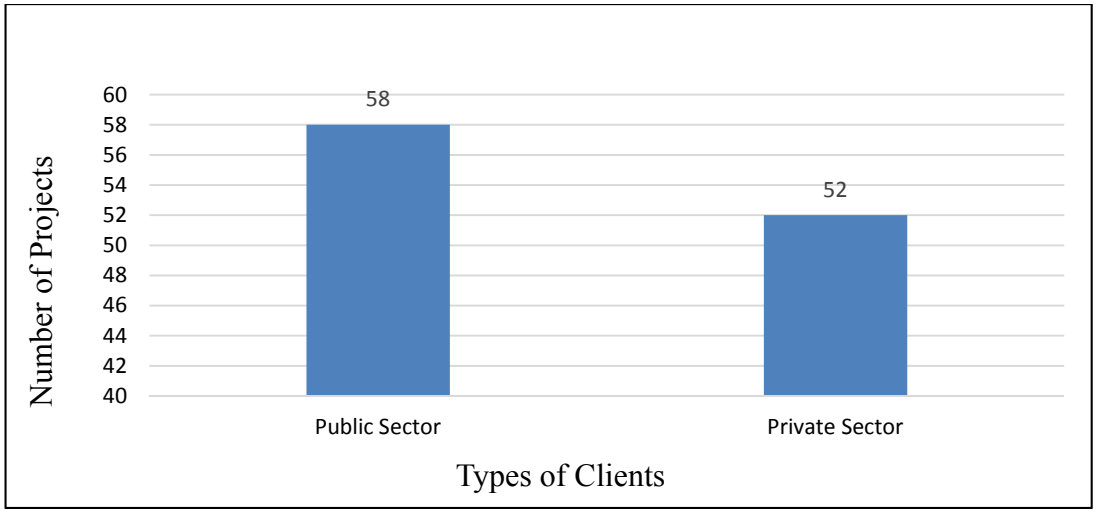


Figure 5.9. Distribution of projects in terms of client type.

5.1.3. Distribution of Rating Levels of Performance Parameters

The parameters selected as being the inputs and the outputs of innovation were investigated through their ratings assigned by the respondent companies. Figures 5.10, 5.11, 5.12, 5.13, 5.14, and 5.15 in the following parts present the ratings for the parameters. The figures also demonstrate that all parameters were found to be highly important based on the respondents' perceptions.

This finding reinforces the aim of the study which was the need for developing a comprehensive innovation measurement framework for the construction industry that can help companies to measure and improve their innovation performance.

5.1.4. Drivers of Innovation

According to Figure 5.10, unsurprisingly "project performance improvement" and "competition level and corporate performance" parameters were found to be the most important among others. Results have similarity with Slaughter's (2000) statement that innovations can provide the critical component of a firm's competitive strategy. Innovation can be a key source of competitive advantage for construction companies offering the means through which a firm can achieve a client's objectives in a specific project or its own objectives over a range of projects. Nevertheless, "client/end user requirements" and "technological developments" are close behind. The least important parameter of the "drivers of innovation" of a company was found to be "regulations and legislations" and "corporate responsibility" which can be explained with the government does not force the construction companies to innovate and the companies do not believe that innovation can improve their corporate responsibility. These findings are similar to those found in other studies (Slaughter, 1993; 1998; Gann, 2000; BERR, 2008; Ozorhon; 2013a, b).

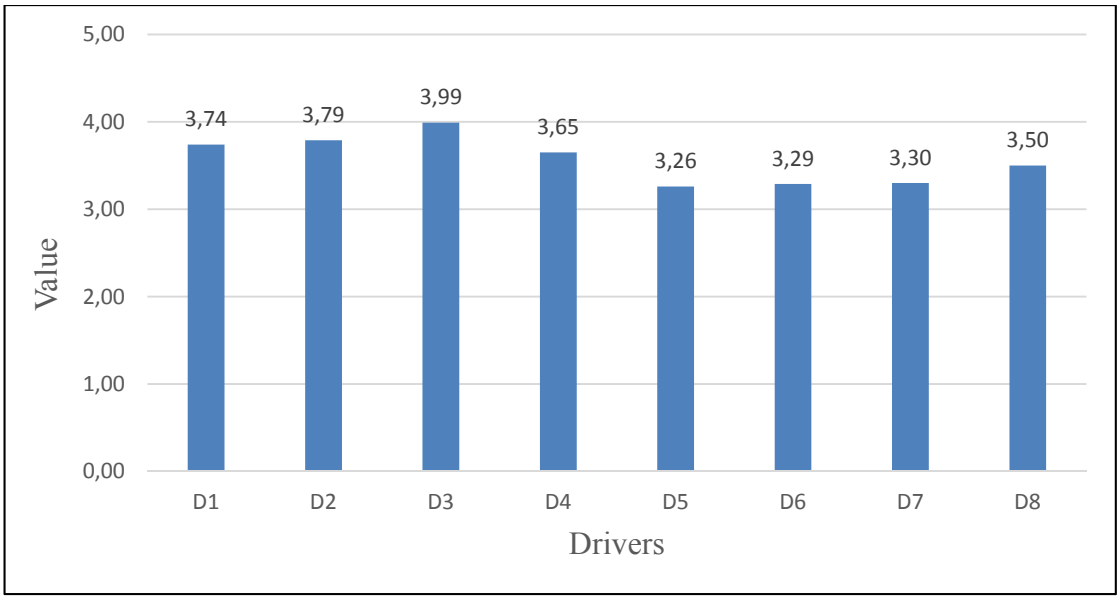


Figure 5.10. Distribution of drivers of innovation.

Below table explains abbreviation of drivers of innovation for above figure.

Table 5.1. Abbreviation of drivers of innovation.

Abbreviation	Drivers of Innovation
D1	Client & End User Requirements
D2	Competition Level & Corporate Performance
D3	Project Performance Improvement
D4	Technological Developments
D5	Regulations & Legislations
D6	Corporate Responsibility
D7	Aesthetics & Design Trends
D8	Environmental & Sustainability

5.1.5. Inputs of Innovation

The respondents indicated that "internal knowledge sources" is the main factor in fostering innovation. In addition, Dikmen *et al*. (2005) found same results in their research; innovations usually emerge from internal sources. The respondents also rated "consultancy" and "capital and investment for innovation" highly as inputs of innovation. It is interesting to note that "R&D spending and number of R&D projects" and "external knowledge sources" are not regarded as an important input.

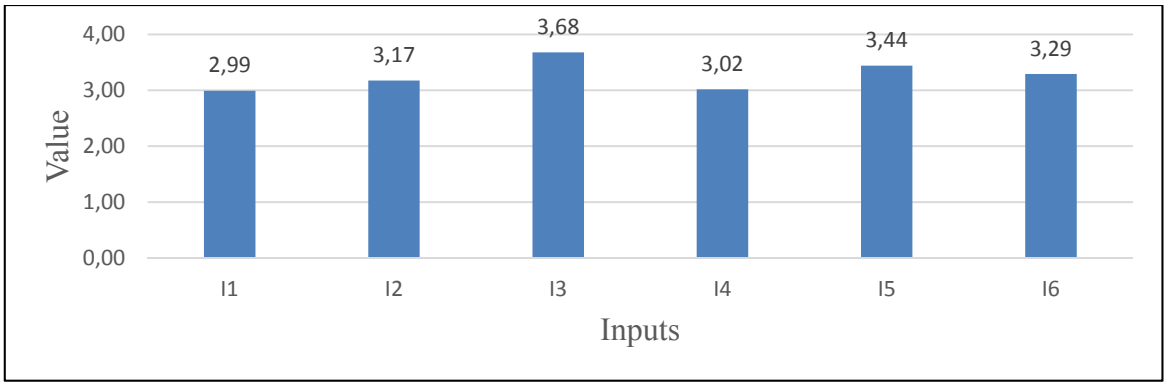


Figure 5.11. Distribution of inputs of innovation.

Below table explains abbreviation of inputs of innovation for above figure.

Table 5.2. Abbreviation of inputs of innovation.

Abbreviation	Inputs of Innovation
I1	R&D Spending & Number of R&D Projects
I2	Number of People Actively Devoted to Innovation
I3	Internal Knowledge Resources
I4	External Knowledge Resources
I5	Capital & Investment for Innovation
I6	Consultancy

5.1.6. Enablers of Innovation

The top factor is seen to be "leadership". The next most significant factors are "knowledge management and problem solving techniques", "commitment" and "collaborative partnering and communication". This is also suggested by Tatum (1987a, b) and Ozorhon *et al*. (2010) who has shown that leadership, supportive organisational structure, collaboration, and customer orientation are the main enablers of innovation within the organisation. On the other hand, "reward schemes", "education and training" do not appear to be significant enablers of innovation.

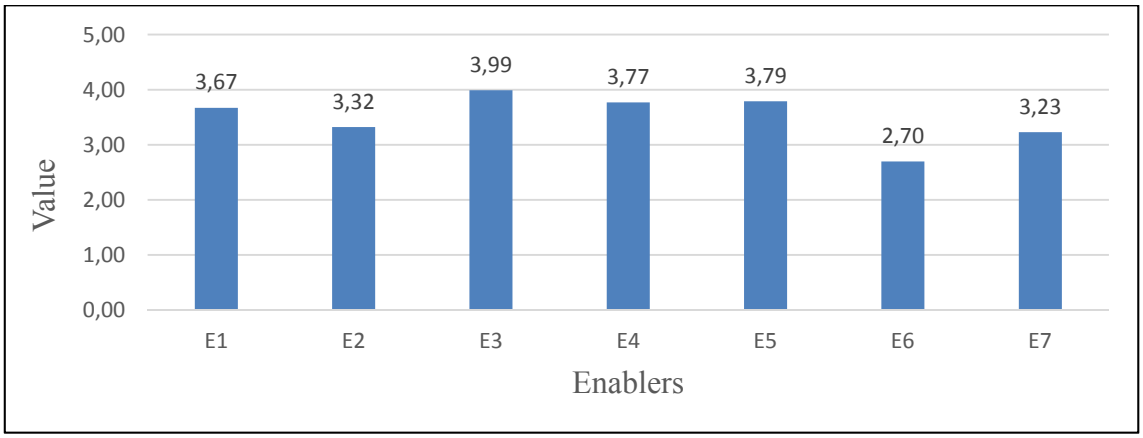


Figure 5.12. Distribution of enablers of innovation.

Below table explains abbreviation of enablers of innovation for above figure.

Table 5.3. Abbreviation of enablers of innovation.

Abbreviation	Enablers of Innovation
E1	Collaborative Partnering & Communication
E2	Early Contractor Involvement
E3	Leadership
E4	Commitment
E5	Knowledge Management & Problem Solving Techniques
E6	Reward Schemes & Awards, Grants, Funds
E7	Innovation Education & Training Policy

5.1.7. Barriers of Innovation

According to Figure 5.13, all variables have almost the same importance level. “Time constraint” was found the most important barrier followed by “lack of experience and qualified staff” and “unsupportive work environment and unwillingness to change”. As Davidson (2001) stated shortage of time contributes to a perceived lack of interest in innovation, especially in small construction firms. “Lack of materials and technology” and “lack of clear benefits and risky investment” are found to be the lowest barriers among others.

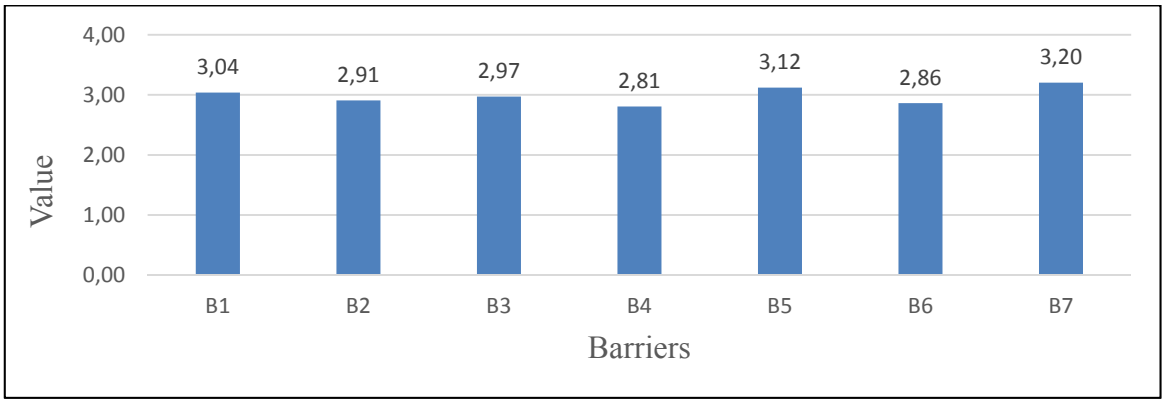


Figure 5.13. Distribution of barriers of innovation

Below table explains abbreviation of barriers of innovation for above figure.

Table 5.4. Abbreviation of barriers of innovation

Abbreviation	Barriers of Innovation
B1	Unsupportive Organization Culture & Unwillingness to Change
B2	Lack of Financial Resources
B3	Temporary Nature of Projects
B4	Lack of Materials and Technology
B5	Lack of Experience and Qualified Staff
B6	Lack of Clear Benefits and Risky Investment
B7	Time Constraint of Projects

5.1.8. Project Level Benefits of Innovation

Companies stated that they benefitted most from "client satisfaction" as a result of their innovations. Respondents stated that client requirements was one of the most important drivers of innovation. In addition, "increase in productivity" and "decrease in project cost" are highly rated as project level benefits of innovation. Gann (2000) summarizes all these findings very well, he stated because of the client requirements construction companies have innovate an as a result they improved project quality, reduce cost and speed up construction processes.

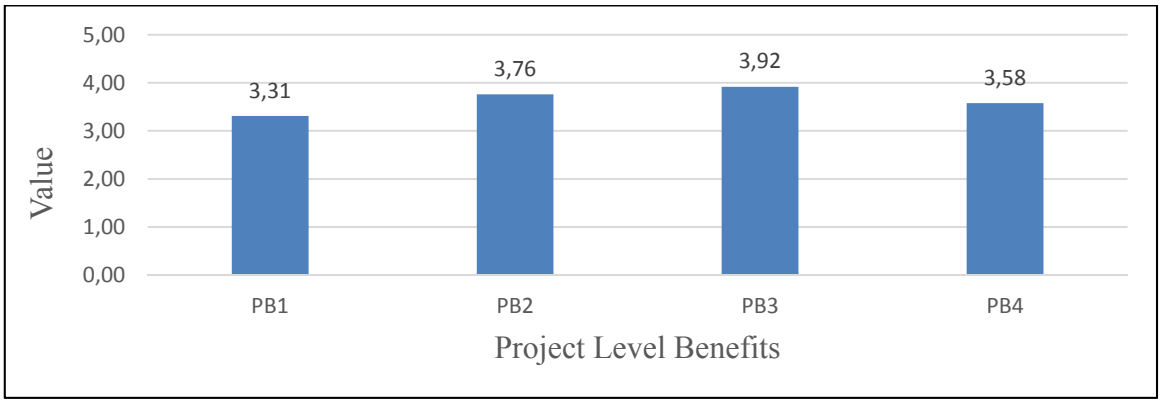


Figure 5.14. Distribution of project level benefits of innovation.

Below table explains abbreviation of benefits of innovation for above figure.

Table 5.5. Abbreviation of project level benefits of innovation.

Abbreviation	Project Benefits of Innovation
PB1	Decrease in Project Duration
PB2	Increase in Productivity
PB3	Improvement of Client Satisfaction
PB4	Decrease in Project Cost

5.1.9. Impacts (Company Level Benefits) of Innovation

Based on the findings, "improvement of competitiveness and better company image" was the most common company level benefit. As Tatum (1987) suggested reputation is the most valuable asset for a construction firm and is effective in sustaining long term competitive advantage. This is followed by "gaining experience" and "improvement of technical and management capacity" which can be grouped together. Long term benefits also among the most widely achieved benefits by the respondents. "Intellectual property" and "new market penetration and future business collaborations" are the lowest rated among others. This is a significant finding which reinforces that although innovation may be important for contractors per se it is external factors such as image, services and satisfaction that are seen to provide the most significant benefit to an organisation (Ozorhon *et al.*, 2010).

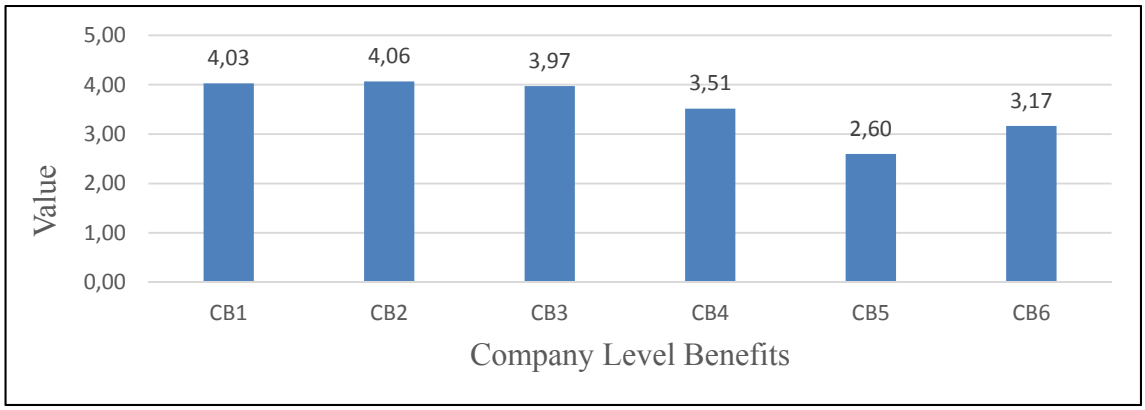


Figure 5.15. Distribution of impacts of innovation.

Below table explains abbreviation of impacts of innovation for above figure.

Table 5.6. Abbreviation of impacts of innovation.

Abbreviation	Company Benefits (Impacts) of Innovation
CB1	Gaining Experience
CB2	Improvement of Competitiveness & Better Company Image
CB3	Improvement of Technical & Management Capability
CB4	Long Term Profitability
CB5	Intellectual Property (Patents, Trademark, Design)
CB6	New Market Penetration & Future Business Collaborations

5.2. Structural Equation Modelling (SEM)

Structural equation models (SEMs), also called simultaneous equation models, are multivariate (i.e., multiequation) regression models. SEM is a multivariate statistical technique used to examine direct and indirect relationships between one or more independent variables and one or more dependent variables. The variables in the model may be continuous or discrete. SEM is also referred to as causal modelling, causal analysis, simultaneous equation modelling, analysis of covariance structures, path analysis, dependence analysis, or confirmatory factor analysis (Kline, 1998).

SEM deals with measured and latent variables. A measured variable is a variable that can be observed directly and is measurable. Measured variables are also known as observed variables, manifest, or indicator variables. A latent variable is a variable that cannot be observed directly and must be inferred from measured variables. Latent variables are also known as factors, constructs or unobserved variables.

The general form of a SEM consists of two parts (Kline, 1998): the measurement model and the structural model. The measurement model specifies how the latent variables or the hypothetical constructs are measured in terms of the observed variables, and it describes the measurement properties, such as the validities and reliabilities, of the observed

variables. The structural equation model specifies the causal relationships among the latent variables and describes the causal effects and the amount of unexplained variance. SEM is excellent for examining complex and multidimensional relationships and is the only analysis that provides complete and concurrent tests of all the relationships.

5.2.1. Definitions of Terms

As Ozorhon (2007) explains, SEM has the following components:

(i) Path diagram: Path diagrams provides investigator with a visual way to examine the outputs.

(ii) Measurement models: Models that represent a priori hypothesis about relations between observed variables and latent variables. Confirmatory Factor Analysis (CFA) can be used for measurement models. Purposes of them are to describe how well the observed variables serve as a measurement instrument for latent variables.

(iii) Structural models: They include the relationships among the latent constructs. In the diagram, one-headed arrows represent regression relationships, while two-headed arrows represent correlational relations.

(iv) Observed variables: These are also called indicator or manifest variable. These are variables that can be manipulated by researchers and their effects can be observed. Observed variables of independent and dependent latent variables are designated by X and Y, respectively.

(v) Latent variables: These variables can only be measured indirectly. They are unobservable, hypothetical constructs. Their effects cannot be observed directly. Rather, effects of observed variables are used to represent the latent variables' effects.

(vi) Latent endogenous variables: Also called latent dependent variables. These are represented as the effects of other latent variables. Measurements of these variables are made on observed dependent variables. They are designated by (η).

(vii) Latent exogenous variables: Also called latent independent variables. These variables affect other variables in the model. Measurements of these variables are made on observed independent variables. They are designated by (ξ).

(viii) Direct effect: In a model, it depicts causal effects that are presumed to flow from one latent variable to another. Statistical estimates of direct effects are called path coefficients.

(ix) Indirect effect: Also called mediator effect. This is the effect involving one or more intervening variables that transmit some of the casual effects of prior variables onto subsequent variables.

(x) Diagrammatic syntax: The latent variables or factors are indicated by circles. The observed variables are indicated by squares. The observed exogenous variables are labeled X. The latent exogenous variables are labeled ksi (ξ). The observed endogenous variables are labeled Y; the latent endogenous variables are labeled eta (η). The paths from the latent to the observed variables are labeled lamda (λ). The paths from the exogenous to the endogenous variables are labeled gamma (Γ). The paths from the endogenous variables to other endogenous variables are labeled beta (β). The correlations among the exogenous variables are labeled phi (φ). Finally, there are three kinds of errors. One kind of error is a stray cause of the latent endogenous variables, called psi (ζ). There are also errors of the observed variables. For the observed exogenous variables, these errors are called delta (δ) and for the observed endogenous variables, these errors are called epsilon (ε). Structural equation models are most often represented graphically. Figure 5.32 shows a graphical representation of a structural equation model.

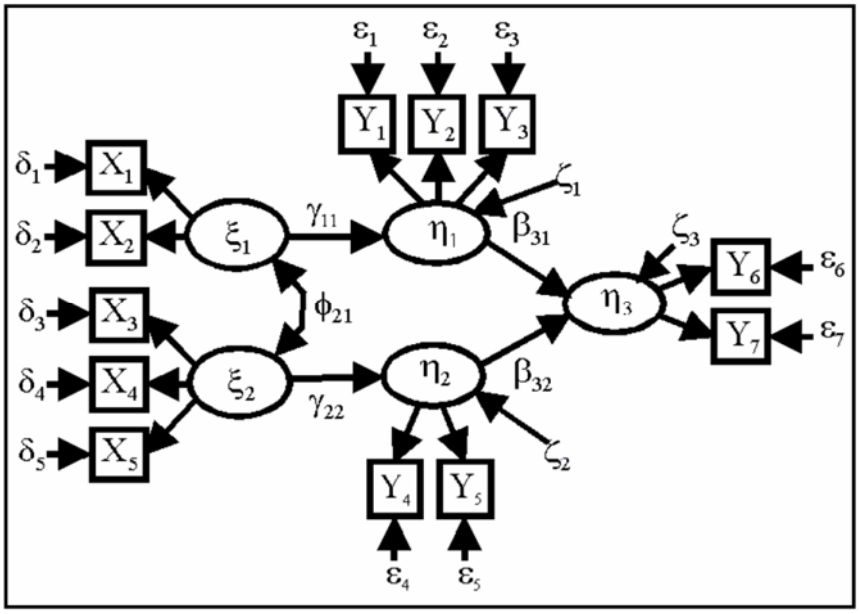


Figure 5.16. Graphical representation of a structural equation model (Gefen *et al*., 2000).

5.2.2. Steps of SEM

Ozorhon (2007) stated there are four steps in structural equation model construction: (i) model specification, (ii) model identification, (iii) test of model fit, and (iv) model modification.

5.2.2.1. Model Specification. Model specification is the formal statement of a model. Relationships between variables are determined by setting parameters fixed or free. The choice of which parameters are fixed and which are free should be consistent with the researcher's a priori hypothesis. A theory based model produces its own unique covariance matrix.

5.2.2.2. Model Identification. Model identification and estimation depend on the choice of model and the specification of fixed, free or constrained parameters. A unique value should be obtained for each free parameter from the observed data. There are several methods of model estimation. Some frequently utilized methods include maximum likelihood (MLS), generalized least squares (GLS), asymptotically distribution free (ADF) estimator, weighted least-squares (WLS), unweighted least-squares (ULS), and two-stage

least-squares (TSLS). The choice of method depends on the sample size and distribution of the data.

5.2.2.3. Model Fit. Model fit or goodness of fit may be assessed by examining the results of the analysis, in particular the solution (parameter estimates, standard errors, correlations of parameter estimates, squared multiple correlations, coefficients of determination), the overall fit (chi-square based and non chi-squared comparative fit indices), and the detailed assessment of fit (standardized residuals and modification indices).

(i) Chi-Square (χ^2): This statistics is based on generalized likelihood ratio. In larger samples it is interpreted as a Pearson chi-square statistics with the degrees of freedom that are equal to the difference between the number of observations and number of parameters. Low and non-significant chi-square values are desired. It has two drawbacks. First, since its lower bound is zero, there is no upper level, therefore there is no standardized way to interpret it. Second it is very sensitive to sample size. With larger samples, it tends to give significant values.

(ii) Goodness of Fit Index (GFI): One of the indices which are less sensitive to sample sizes and which are more standardized is GFI. Its values theoretically range between 0 (poor fit) and 1 (perfect fit). Values greater than 0.9 are acceptable for GFI.

(iii) Comparative fit index (CFI): CFI is one of a class of fit statistics known as incremental or comparative fit indexes, which are among the most widely used in SEM. The CFI compares the existing model fit with a null model which assumes the latent variables in the model are uncorrelated (the "independence model"). CFI varies from 0 to 1. CFI close to 1 indicates a very good fit. CFI should be equal to or greater than 0.9 to accept the model, indicating that 90% of the covariation in the data can be reproduced by the given model.

(iv) Normed fit index (NFI): NFI varies from 0 to 1, with 1=perfect fit. NFI reflects the proportion by which the researcher's model improves fit compared to the null model (random variables). By convention, NFI values below 0.9 indicate a need to respecify the model.

(v) Adjusted Goodness of Fit Index (AGFI): This index is used in more complex models, and those with more values, which tend to fit the same data better than the simpler ones do. AGFI corrects downward the value of GFI as the number of parameters increases. Like GFI, its range is between 0 and 1 and values greater than 0.9 are acceptable for GFI.

(vi) Root Mean Square Error of Approximation (RMSEA): RMSEA provides a measure for discrepancy per degree of freedom based on the analysis of residuals. Values lower than 0.10, 0.05, and 0.01 indicate a good fit, a very good fit and perfect fit, respectively.

5.2.2.4. Model Modification. If the estimated covariance matrix does not provide a reasonable and parsimonious explanation of the data, the model may be re-specified by changing model parameters. When analysing samples from several populations simultaneously, some or all of the parameters may be constrained to be equal across groups.

5.2.3. SEM Software Packages

There are many excellent SEM software programs, including LISREL, SIMPLIS, SAS CALIS, AMOS, and EQS. In this research, EQS (Multivariate Software, Encino, CA) is planned to be used since it is a user-friendly program and it is easy to follow the processes.

5.2.4. Benefits of SEM

SEM serves purposes similar to multiple regression, but in a more powerful way which takes into account the modelling of interactions, nonlinearities, correlated independents, measurement error, correlated error terms, multiple latent independents each measured by multiple indicators, and one or more latent dependents also each with multiple indicators. SEM may be used as a more powerful alternative to multiple regression, path analysis, factor analysis, time series analysis, and analysis of covariance. That is, these procedures may be seen as special cases of SEM, or, to put it another way, SEM is an extension of the general linear model (GLM) of which multiple regression is a part (Isik, 2009).

Advantages of SEM compared to multiple regression include much more flexible assumptions. The use of confirmatory factor analysis to reduce measurement error by having multiple indicators per latent variable, the attraction of SEM's graphical modelling interface, the desirability of testing models overall rather than coefficients individually, the ability to test models with multiple dependents, the ability to model mediating variables rather than be restricted to an additive model, the ability to model error terms, the ability to test coefficients across multiple between-subjects groups, and ability to handle difficult data (time series with auto correlated error, non-normal data, incomplete data). Moreover, where regression is highly susceptible to error of interpretation by misspecification, the SEM strategy of comparing alternative models to assess relative model fit makes it more robust. (Isik, 2009).

According to Hair *et al*. (2006), compared with other types of multivariate-data analysis methods, SEM has three distinct characteristics, which are as follows:

- It has the ability to estimate multiple and interrelated dependence relationships,
- It has the ability to represent unobserved concepts in these relationships and to correct measurement errors in the estimation process,
- It has the ability to define a model explaining the entire set of relationships.

5.3. Analysis of the Measurement Model

The first step in constructing a structural equation model involves specifying the relationships among the latent variables and determining how the latent variables will be measured. In order to structure the casual relationship between the 38 variables which were selected as being the key measures and the indicators of innovation as described in the previous chapter, six latent variables namely, “drivers of innovation”, “barriers of innovation”, “inputs of innovation”, “enablers of innovation”, “project level benefits of innovation” and “impacts (company level benefits) of innovation” were hypothesized. The data collected from a total of 110 questionnaires were analysed using the SEM software package called EQS 6.2, an SEM tool.

5.3.1. Validity of the Innovation Measures and Indicators

Testing the construct validity of innovation measurement variables provides the degree to which a latent variable measures what it intends to measure. Construct validity testing is comprised of numerous sub-dimensions, all of which must be satisfied to achieve construct validity. The validity of the performance measures is evaluated by means of tests that assess "content validity", "scale reliability", and "convergent validity" and "discriminant validity".

5.3.1.1. Content Validity Testing. Content validity refers to the degree that the construct is represented by items that cover the domain of meaning for the construct (Dunn *et al*., 1994). The domain of a concept is bound by its theoretical definition, which should reflect the meanings associated with the concept in prior research and make its dimensions clear (Bollen, 1989). Since there is no formal statistical test for content validity, researcher judgment and insight must be applied (Garver and Mentzer, 1999). The content validity of the measures depends upon the extent to which academic and professional experts have discussed or conducted studies that made use of the measures of innovation performance. An extensive literature survey was conducted to specify the variables that define latent variables. Table 5.7 shows the result of content validity.

5.3.1.2. Scale Reliability Testing. Reliability is traditionally defined as the consistency of measurement. From a structural perspective, the reliability of a measure is the magnitude of the direct relations that all variables (except the error terms) have on that measure (Bollen, 1989). The scale reliability is the internal consistency of a latent variable and is measured most commonly with a coefficient called Cronbach's alpha. The purpose of testing the reliability of a construct is to understand how each observed indicator represents its correspondent latent variable.

According to the EQS analysis results, as seen in Table 5.8, Cronbach's alpha values were 0.816 for "drivers", 0.838 for "barriers", 0.875 for "enablers", 0.827 for "inputs", 0.809 for "benefits" and 0.890 for "impacts". These reliability values are satisfactory since the

Table 5.7. Results of content validity

DRIVERS	INPUTS
1. Client & End User Requirements	1. R&D Spending & Number of R&D Projects
2. Competition Level & Corporate Performance	2. Number of People Actively Devoted to Innovation
3. Project Performance Improvement	3. Internal Knowledge Resources
4. Technological Developments	4. External Knowledge Resources
5. Regulations & Legislations	5. Capital & Investment for Innovation
6. Corporate Responsibility	6. Consultancy
7. Aesthetics & Design Trends	**ENABLERS**
8. Environmental & Sustainability	1. Collaborative Partnering & Communication
BARRIERS	2. Early Contractor Involvement
1. Unsupportive Organization Culture & Unwillingness to Change	3. Leadership
2. Lack of Financial Resources	4. Commitment
3. Temporary Nature of Projects	5. Knowledge Management & Problem Solving Techniques
4. Lack of Materials and Technology	6. Reward Schemes & Awards, Grants, Funds
5. Lack of Experience and Qualified Staff	7. Innovation Education & Training Policy
6. Lack of Clear Benefits and Risky Investment	**COMPANY LEVEL BENEFITS (IMPACTS)**
7. Time Constraint of Projects	1. Gaining Experience
PROJECT LEVEL BENEFITS	2. Improvement of Competitiveness & Better Company Image
1. Decrease in Project Duration	3. Improvement of Technical & Management Capability
2. Increase in Productivity	4. Long Term Profitability
3. Improvement of Client Satisfaction	5. Intellectual Property (Patents, Trademark, Design)
4. Decrease in Project Cost	6. New Market Penetration & Future Business Collaborations

Cronbach's alpha coefficients are all above 0.70, the minimum value recommended by Nunally (1978).

Table 5.8. Cronbach's alpha coefficients of the latent variables.

Latent Variables	**Cronbach's Alpha Values**
Drivers	0.816 (0.809)
Barriers	0.838
Enablers	0.875
Inputs	0.827
Project Level Benefits	0.809
Company Level Benefits (Impacts)	0.890

*Number in parentheses belong to initial analysis before the model improvement.

5.3.1.3. Convergent Validity Testing. Convergent validity tests if all the items measuring a latent variable cluster together and form a single latent variable. Two methods are utilized to examine convergent validity; assessment of overall goodness of fit and examination of factor loadings.

The overall fit of the model can be assessed by examining goodness-of-fit indices. The goodness-of-fit for each construct was assessed through non-normed fit index (NNFI), comparative fit index (CFI), the root mean square error of approximation (RMSEA), and the ratio of χ^2 to degrees of freedom (dof). Having obtained significant and convergent indicators for all the constructs. The results are presented in Table 5.10. Convergent validity could also be examined by investigating the statistical significance of the factor loadings of each construct (Anderson and Gerbing, 1988). Convergent validity is the extent to which the latent variable correlates to corresponding items designed to measure the same latent variable. Ideally, convergent validity is tested by determining whether the items in a scale converge or load together on a single construct in the measurement model. Dunn *et al*. (1994) state that if the factor loadings are statistically significant, then convergent validity exists. Since sample size and statistical power have a substantial effect on the significance test, this

statement needs expanding. To assess convergent validity, the researcher should also assess the overall fit of the measurement model, and the magnitude, direction, and statistical significance of the estimated parameters between latent variables and their indicators. The model parameters were assessed and all factor loadings were found to be significant at $\alpha = 0.05$, except V5 and V6 as in Table 5.9. These variables were removed from the initial model. An assessment of the overall fit of the measurement model is going to be held after presenting the specified model.

Table 5.9. Latent and constituent variables of the model with factor loadings.

	MODEL VARIABLES	**FACTOR LOADINGS**
F1	**DRIVERS**	
V1	Client & End User Requirements	0.364
V2	Competition Level & Corporate Performance	0.331
V3	Project Performance Improvement	0.686
V4	Technological Developments	0.504
V5	Regulations & Legislations	0.283*
V6	Corporate Responsibility	0.218*
V7	Aesthetics & Design Trends	0.826
V8	Environmental & Sustainability	0.926
F2	**BARRIERS**	
V9	Unsupportive Organization Culture & Unwillingness to Change	0.524
V10	Lack of Financial Resources	0.561
V11	Temporary Nature of Projects	0.492
V12	Lack of Materials and Technology	0.652
V13	Lack of Experience and Qualified Staff	0.463
V14	Lack of Clear Benefits and Risky Investment	0.755
V15	Time Constraint of Projects	0.602

Table 5.9. Latent and constituent variables of the model with factor loadings.

F3	**ENABLERS**	
V16	Collaborative Partnering & Communication	0.453
V17	Early Contractor Involvement	0.406
V18	Leadership	0.627
V19	Commitment	0.565
V20	Knowledge Management & Problem Solving Techniques	0.499
V21	Reward Schemes & Awards, Grants, Funds	0.781
V22	Innovation Education & Training Policy	0.901
F4	**INPUTS**	
V23	R&D Spending & Number of R&D Projects	0.598
V24	Number of People Actively Devoted to Innovation	0.653
V25	Internal Knowledge Resources	0.661
V26	External Knowledge Resources	0.744
V27	Capital & Investment for Innovation	0.303
V28	Consultancy	0.644
F5	**BENEFITS**	
V29	Decrease in Project Duration	0.532
V30	Increase in Productivity	0.905
V31	Improvement of Client Satisfaction	0.768
V32	Decrease in Project Cost	0.441
F6	**IMPACTS**	
V33	Gaining Experience	0.779
V34	Improvement of Competitiveness & Better Company Image	0.958
V35	Improvement of Technical & Management Capability	0.884
V36	Long Term Profitability	0.499
V37	Intellectual Property (Patents, Trademark, Design)	0.463
V38	New Market Penetration & Future Business Collaborations	0.473

*Factor loading not significant at $\alpha=0.05$

Table 5.10. Reliability values and fit indices for the constructs of the model.

		Proposed Model					
	Recommended Value	**Drivers**	**Barriers**	**Enablers**	**Inputs**	**Benefits**	**Impacts**
Cronbach's Alpha	> 0.7	0.816 (0.809)	0.838	0.875	0.827	0.809	0.890
NNFI	0 (no fit) to 1 (perfect fit)	0.950 (0. 815)	0.802	0.954	0.876	0.892	0.933
CFI	0 (no fit) to 1 (perfect fit)	0.899 (0.835)	0.820	0.969	0.895	0.948	0.921
RMSEA	< 0.10 indicates good fit	0.064 (0.083)	0.065	0.054	0.077	0.090	0.087
χ^2/dof	< 3	1.569 (2.089)	2.003	1.286	1.478	2.015	1.596

Numbers in parantheses belong to initial analysis before the model improvement.

Note: The reliability of all constructs meet Nuanally's (1978) recommendation, as the Cronbach's alpha values exceed 0.7 for all of them. Fit indices are also within acceptable ranges. All in all, the measurement model shows a good fit to the data.

5.3.1.4. Discriminant Validity Testing. Discriminant validity refers to the principle that the indicators for different constructs should not be so highly correlated as to lead one to conclude that they measure the same thing. For discriminant validity, we need to verify that scales developed to measure different constructs are indeed measuring different constructs. This is particularly important when constructs are highly correlated and similar in nature. In essence, items from one scale should not load or converge too closely with items from a different scale. Different latent variables that correlate too highly may indeed be measuring the same construct rather than different constructs. Relatively low correlations between variables (constructs) indicate the presence of discriminant validity.

"The correlation matrices calculated for all constructs show that all intercorrelations are below 0.90, suggesting that there is no multicollinearity (Hair *et al*., 1998) but indicating that the constructs have discriminant validity. These correlations provide evidence that the variables are different from each other (Appendix C.) and that they are complementary.

5.4. Analysis of the Structural Model

The selection of SEM for use in this research was based on the structure of the proposed model that is composed of a number of direct and indirect interdependencies between the independent and dependent variables. SEM tests the hypotheses between the validated constructs. Based on the hypotheses of the model, interrelations between the determinants of innovation performance and influences of these determinants on innovation performance are analysed.

5.4.1. Specification of the Model

A series of literature reviews were examined to develop a conceptual model that shows how the 4 variables affect "project level benefits of innovation" and "company level benefits (impacts) of innovation" directly and indirectly as well. Based on the input of these subjects, the model was restructured as in Figure 5.17.

Although many researchers begin the process of specification by drawing a diagram of a model using a set of symbols, the model can alternatively be described as a series of equations.

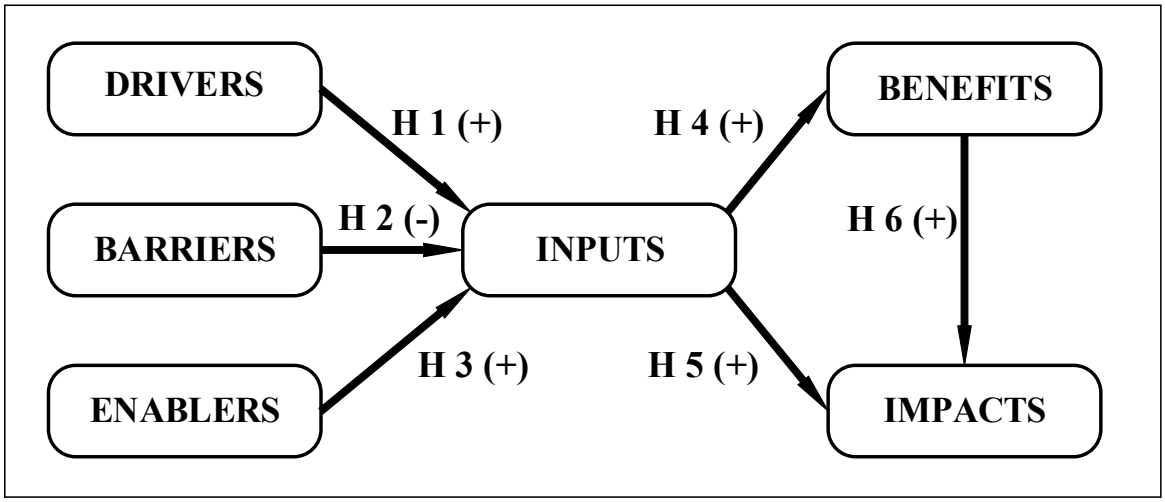


Figure 5.17. Innovation framework model.

This model is specified by the following direct path equations:

- Inputs = path coefficient 1* drivers + path coefficient 2* barriers + path coefficient 3* enablers + error term 1

- Benefits = path coefficient 4* inputs + error term 2

- Impacts = path coefficient 5* inputs + path coefficient 6* benefits + error term 3

5.4.2. Estimation and Identification of the Model

There are several methods of model estimation. Some frequently utilized methods include maximum likelihood (ML), generalized least squares (GLS), asymptotically distribution free (ADF) estimator, and robust statistics. The term maximum likelihood (ML) describes the statistical principle that underlies the derivation of parameter estimates: the estimates are the ones that maximize the likelihood (the continuous generalization) that the

data (the observed covariances) were drawn from this population. That is, ML estimators are those that maximize the likelihood of a sample that is actually observed (Winer *et al*., 1991). It is a normal theory method because ML estimation assumes that the population distribution for the endogenous variables is multivariate normal. Other methods are based on different parameter estimation theories, but they are not currently used as often. In fact, the use of an estimation method other than ML requires explicit justification (Kline, 1998).

The strength of robust method is that the normality is not required. In this method, the chi-square and standard errors are corrected to the non-normality situation. The chisquare test is corrected in the conceptual way described by Satorra and Bentler (1994). Also, robust standard errors developed by Bentler and Dijsktra (1985) are provided as an output of the robust analysis, and they are correct in large samples even if the distributional assumption regarding the variables is wrong (Bentler, 2006). Although these robust statistics are computationally demanding, they have been shown to perform better than uncorrected statistics where the assumption of normality fails to hold and performs better than ADF (Chou *et al*., 1991; Hu *et al*., 1992). One important caveat regarding the use of robust statistics is that they can be computed only from raw data (Byrne, 2006).

The selection of estimation method depends on the sample size and distribution of the data. Therefore, a quick assessment on non-normality and sample size of the data should be covered at this point.

SEM generally hypothesizes the multivariate normality of data. According to Mardia (1970), if the estimated z-score is over ± 1.96 in a 0.05 confidence interval, normality hypothesis is rejected. Data in this study was found to be non-normal. Therefore, due to the non-normality conditions, robust methodology was used. When the data are not normal, the Satorra-Bentler (1994) robust methodology that is developed in EQS 6.2 is recommended. Moreover, the robust model fit indices such as NNFI, CFI and RMSEA are provided in the analysis report.

5.4.3. Evaluation of the Model Fit

It means to determine how well the model as a whole explains the data. Once it is determined that the fit of a structural equation model to the data is adequate, innovation performance measurement model is completed. The hypothesized relationships for "innovation performance" are shown in Figure 5.18.

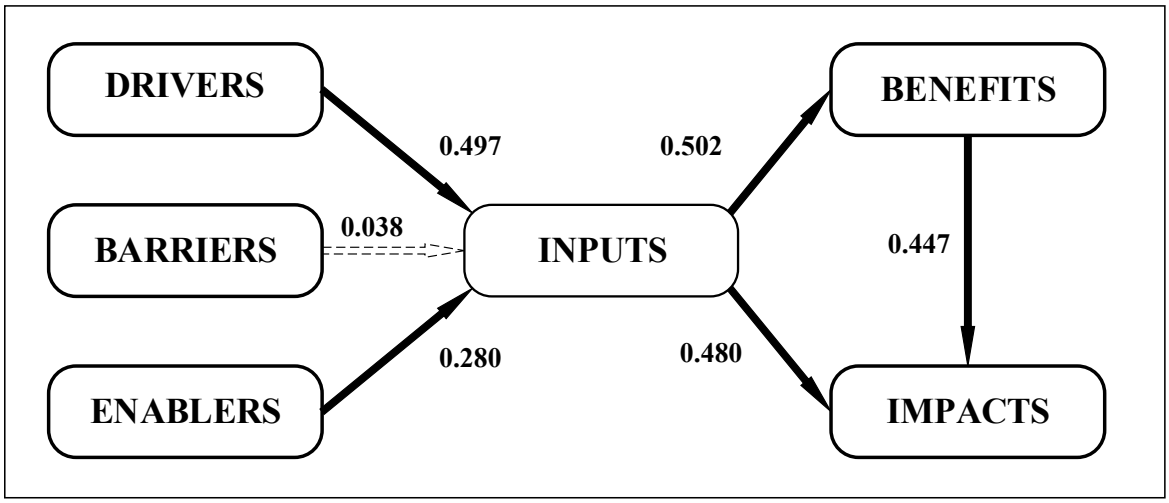


Figure 5.18. The initial structural equation model with path coefficients.

- Inputs = 0.497*Drivers + 0.038*Barriers + 0.280*Enablers + 0.820D (R^2 = 0.327)
- Benefits = 0.502*Inputs + 0.865D (R^2 = 0.252)
- Impacts = 0.480*Inputs + 0.447*Benefits + 0.595D (R^2 = 0.645)

According to analysis results, two variables, "V5: Regulations & Legislations" (0.283) and "V6: Corporate Responsibility" (0.218) in drivers of innovation are not statistically significant at 5%, were eliminated from the model. Figure 5.19 shows the modified structural equation model with path coefficients.

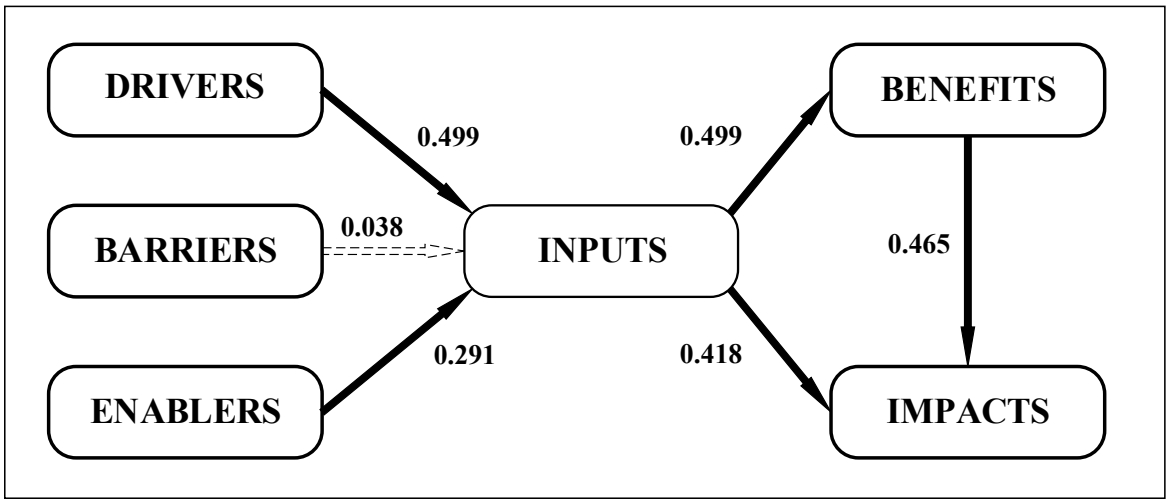


Figure 5.19. The modified structural equation model with path coefficients.

- Inputs = 0.499*Drivers + 0.038*Barriers + 0.291*Enablers + 0.815D (R^2 = 0.335)
- Benefits = 0.499*Inputs + 0.867D (R^2 = 0.249)
- Impacts = 0.418*Inputs + 0.465*Benefits + 0.643D (R^2 = 0.586)

The analysis suggest that "drivers" and "enablers" have a positive effect on innovation inputs with a path coefficient of "0.499" and "0.291", respectively. Inputs has a positive and significant effect on "benefits" (path coefficient: 0.499) and "impacts" (path coefficient: 0.418). In addition, project level benefits have a direct and positive affect on "impacts (company level benefits)". On the other hand, barriers do not have a significant relation with innovation activities in construction. According to hypothesis, barriers should have negative effects on innovation but since the drivers and enablers have a positive impact on the inputs, the effect of the barriers has become negligible.

Table 5.11 shows the reliability values and fit indices for the initial and modified model. The χ^2 to dof ratios were smaller than 3 as suggested by Kline (1998). The CFI and NNFI values of around 0.9 also demonstrate a slightly good fit of the model to the data. Moreover, the RMSEA values were found to be below the recommended value of 0.10 (Kline, 1998). The correlation matrices calculated for all constructs show that all

intercorrelations are below 0.90, suggesting that there is no multicollineraity (Hair et al., 1998).

According to Table 5.11., the Cronbach's alpha coefficient of the final model in Figure 5.19 was found to be 0.897; slightly better than the one obtained with the initial model that took into consideration all variables (0.873). The NNFI and CFI were found to be 0.952, 0.948, respectively for the final model whereas these were lower (0.914, 0.895) for the initial model. These values provide evidence that the fit between the final model and the data is quite satisfactory.

Table 5.11. Fit indices for the model.

	Recommended Value	**Initial Model**	**Final Model**
Cronbach's Alpha	> 0.7	0.873	0.897
NNFI	0 (no fit) to 1 (perfect fit)	0.914	0.952
CFI	0 (no fit) to 1 (perfect fit)	0.895	0.948
RMSEA	< 0.10 indicates good fit	0.096	0.089
χ^2/dof	< 3	1.298	1.273

6. SUMMARY AND DISCUSSION

In this chapter, major findings will be summarized and how the findings agree or disagree with the previous findings will be discussed. In this study, a questionnaire survey as a quantitative method was used to measure innovation performances of construction companies.

Content validity of the measures is achieved through an extensive review of the literature and a pilot study with industry experts. A structural equation model was proposed to evaluate the empirical validity of the measures, including reliability, convergent, and discriminant validity. In the measurement model, all constructs of the model were validated; indicators not having significant factor loadings were deleted, satisfactory values for reliability and fit indices were achieved. After validating all constructs within the model, the hypothesized relations between these constructs are tested.

6.1. Discussion on the Drivers of Innovation

According to extensive literature research; "Client & End User Requirements", "Competition Level & Corporate Performance", "Project Performance Improvement", "Technological Developments", "Regulations & Legislations", "Corporate Responsibility", "Aesthetics & Design Trends" and "Environmental & Sustainability" were determined as most important drivers of construction innovation (Figure 6.1). As a response to climate change and its effects on the environment and energy consumption, there has been a growing emphasis on environmental and sustainability issues (factor loading 0.926). According to Bossink (2004) environmental pressure is the pressure that is exerted by institutions and organizations and forces and stimulates other institutions and organizations to increase their innovativeness. It is also supported by other studies in the literature (e.g., Brandon, 2005; Thorpe *et al*., 2008; Robichaud and Anantatmula, 2011; Ozorhon, 2013a, b; Ogunbiyi *et al*., 2014). Aesthetics and design trends (0.826) has an extensive effect on driving innovation. Clients are demanding more complex constructions with advanced levels of integrated technology, which are not feasible with current construction technology and companies need to innovation to overcome this problem (Nam and Tatum, 1989; Winch, 1998; Murphy *et*

al., 2008). Project performance improvement (0.686), technological developments (0.504), client and end user requirements (0.364), competition level and corporate performance (0.331) are the other main drivers of innovation with high factor loadings. Clients can act as a catalyst to foster innovation by exerting pressure on the project participants to improve overall performance, as well as by helping them devise strategies to cope with unforeseen changes (Gann and Salter, 2000). They might also drive innovation by demanding high standards of work (Barlow, 2000) and by identifying specific novel requirements for a project (Seaden and Manseau, 2001).The clients are reported to act as leaders in the projects and create a supportive work environment for new ideas (Ozorhon, 2013a, b). It is interesting to note that two variables "regulations/legislations" and "corporate responsibility" do not have significant effect on innovation and they were removed from the final model. Drivers as a construct has a moderate positive effect on inputs of innovation (path coefficient: 0.499).

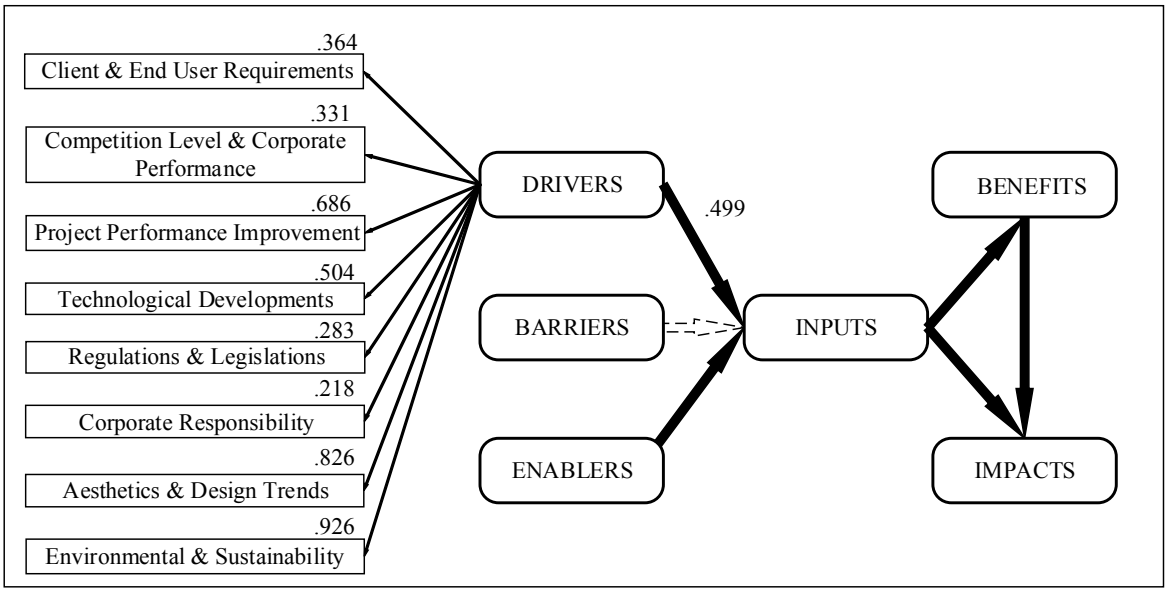


Figure 6.1. Effects of drivers on innovation performance.

6.2. Discussion on the Barriers of Innovation

Construction companies stated that lack of clear benefits and risky investment (0.755) of innovation are the main barriers. The construction industry is also a low capital intensity industry (Tatum, 1986). Insufficient profits, heavy operating expenses and burdensome

institutional debt as the most significant factors affecting construction companies' survival. Therefore construction managers must be cautious with their investments on new construction techniques (Goodrum, 2000; Winch, 2000; Koksal and Arditi, 2002; Hardie, 2010). Construction companies exist under constant pressure to deliver their projects on time (0.602) and under budget (0.524), this can result in avoidance of new ideas (Davidson, 2001; Hardie, 2011). Unsupportive organization culture and unwillingness to change (0.561) are found important barriers to innovate. The construction industry in the international context has been broadly criticised as slow to absorb both new management practices and new technologies (Latham, 1994; Egan, 1998; Fairclough, 2002). Cole (2003) also identified "an unwillingness within industry leadership to recognise the long-term advantages of structural and cultural change, accepting instead a short-term project driven profit process". Management support is essential to break the employees' resistance to change (Ozorhon, 2013a, b). Lack of experienced and qualified staff (0.463), lack of materials and technology (0.652) are other barriers for innovation. Repeatability of the projects has been another influential factor since the benefits of innovations can be reaped in the long rather than short-term. The temporary nature of projects (0.462) means that groupings of discrete businesses coalesce and then separate around the delivery of relatively short-term projects. Although some continuity is provided by the tendency to work with groups where there is some connection from a previous project, the temporary nature of the relationship can lead to suspicion about the sharing of information. This is not an atmosphere conducive to the diffusion of successful innovations (Hardie, 2010).

It is interesting that in this study, it was found that barriers do not have a significant effect on construction innovation with a path coefficient of 0.038. According to hypothesis developed based on previous studies, barriers should have negative effects on innovation but since the drivers and enablers have a positive impact on the inputs, the effect of the barriers has become negligible.

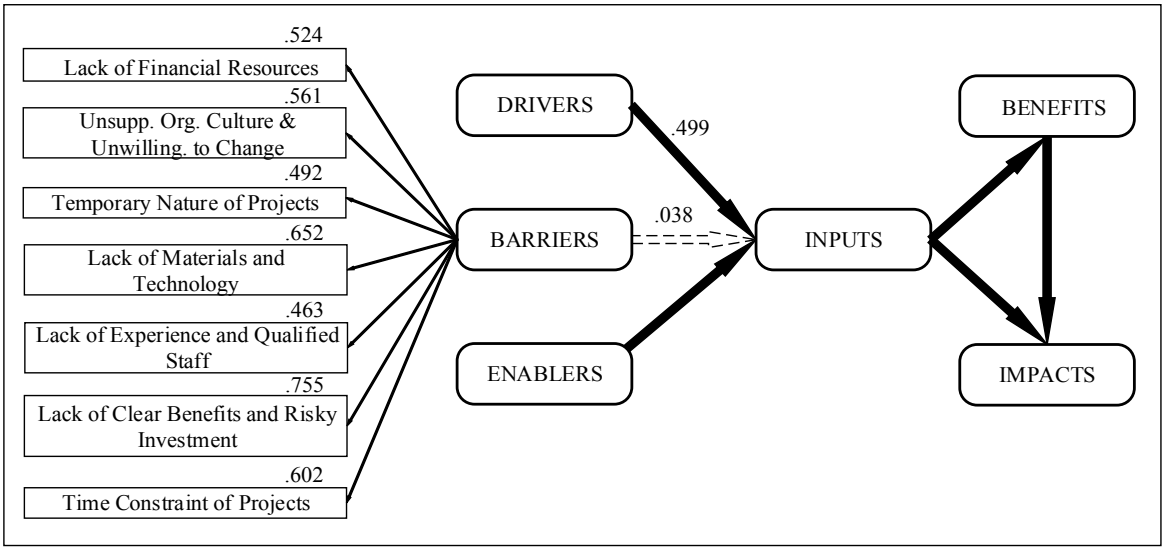


Figure 6.2. Effects of barriers on innovation performance.

6.3. Discussion on the Enablers of Innovation

"Innovation Education and Training Policy" with a factor loading 0.901 is a major indicator of enablers of innovation. The on-site personnel must learn about the innovation and how to use it. Different types of innovation may require different levels of training to effectively use them, and the sources of the training can differ (Cross, 1983). This on-site training and learning can be particularly important when an innovation has the potential to make existing skills and competencies obsolete, since either the existing personnel can resist the implementation of the innovation, or the personnel implementing this innovation may not be drawn from the traditional labour pool (Slaughter, 2000). Rewards schemes, award, grants and funds large influences (0.781). Dulaimi *et al*. (2002b) found that successful innovation may come about if companies establish a reward system to recognize innovators and to promote innovation. Independent of the relative success of the innovation with respect to the project and company objectives, the personnel involved in the implementation stages should be rewarded (Meyer and Goes, 1988; Laborde and Sanvido, 1994). Leadership (0.627) has been referred to as one of the main enablers of innovation in the construction literature (Tatum, 1987; Ozorhon *et al*., 2010). Nam and Tatum (1997) found that effective leadership is essential for innovation. Previous research shows that leaders can play a critical role in shaping project spirit (Aronson *et al*., 2010; 2013). It also provides evidence for Kulatunga *et al*.'s (2011) assertion that clients promote innovation in construction projects

through their championing characteristics including proactive involvement, information dissemination, and effective coordination. Effective leadership results in commitment (0.565) of the project team to the project objectives (Aronson *et al*., 2006; Ozorhon, 2013a; b). A construction firm's philosophy can influence construction innovations (Tatum, 1989). Those firms with an attitude to question anything and anyone, a persistent pursuit of improving productivity and an atmosphere of competition to find ways to improve tend to promote an innovative culture. Knowledge management and problem solving techniques (0.499) are enablers of innovation, help to attract new and retain valuable customers, and in the process increase organisational productivity and profitability. Demarest (1997) noted that "firms without knowledge management systems will be effectively unable to achieve the re-use levels required by the business model implicit in the markets they enter, and will lose market share to those firms who do practice knowledge management". The influence of collaborative partnering, communication and early contractor involvement on innovation were found to be moderate which is supported by other studies such as those by Korczynski (1996), Barlow *et al*. (1997), Ling (2003), Briscoe *et al*. (2004), Barett (2007), Ozorhon (2013a; b). Veshosky (1998), suggested in his work joint effort is required to innovate in construction; collaboration among project members is an essential ingredient Barrett's (2007) work stated that project teams aiming at engaging end- users from the early phases of projects designed for public use are more likely to achieve end-user satisfaction. Scholars argue that successful innovation often requires effective cooperation, coordination and working relationships between the different parties in construction projects such as the contractors, subcontractors, suppliers, architects, engineers, clients, the government, universities, etc. (e.g., Tatum, 1989, Gann and Salter, 2000; Ling, 2003; Blayse and Manley, 2004, Robichaud and Anantatmula, 2011; Ozorhon *et al*., 2013). Enablers as a construct has a moderate effect on the inputs of innovation with a path coefficient of 0.291.

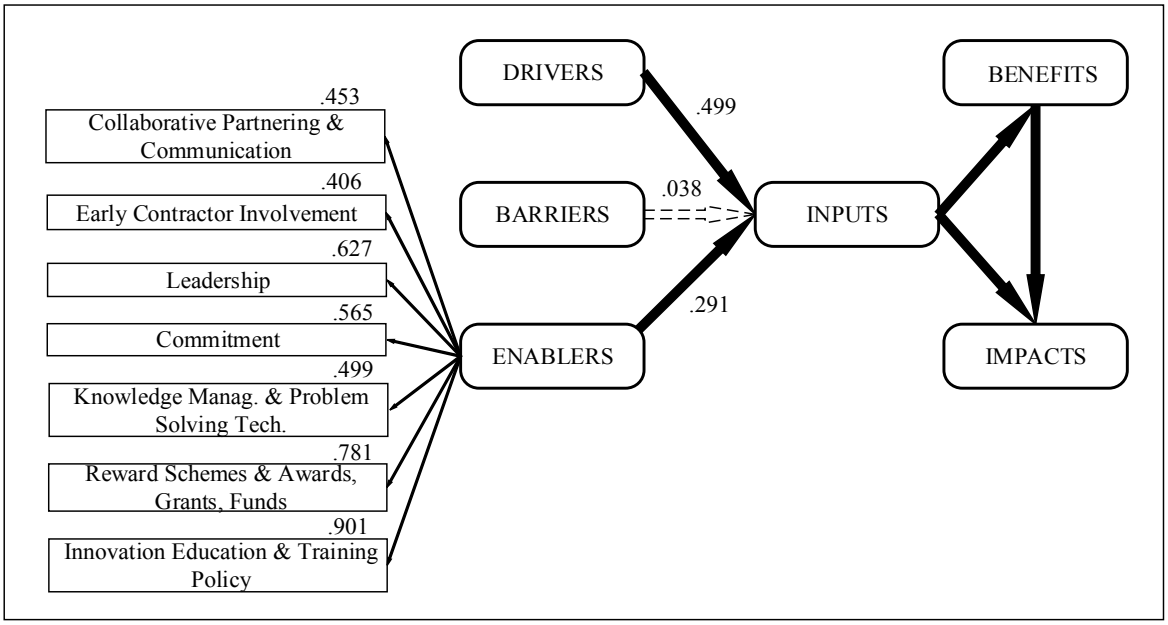


Figure 6.3. Effects of enablers on innovation performance.

6.4. Discussion on the Inputs of Innovation

Data analysis reveals that inputs have a highly positive effect on innovation. This expected effect was also supported by many researchers (Gann, 2000; Hesen, 2001; Milberg, 2004; Reichstein, 2008; Ozorhon *et al.*, 2009a; b; c; d). Project-based firms need to manage innovation and uncertainty across organisational boundaries, within networks of interdependent suppliers, customers and regulatory bodies (Gann and Salter, 2000).

Based on the factor loadings, external knowledge (factor loading: 0.744), internal knowledge (factor loading: 0.661), human resources (factor loading: 0.653), and consultancy (factor loading: 0.644) are the most important indicators of innovation inputs. Most construction firms do not develop a new technology using processes recognizable as R&D. Despite this, many are innovative, and many technologies with potential application in construction developed in other industries (Tatum, 1989). Previous research shows that innovations usually emerge from internal sources (Dikmen *et al*., 2005). Managers can take several actions to facilitate the internal coordination and special types of feedback that are required for the process of innovation. Technology transfer between active projects is an

important form of internal communication (Tatum, 1989). One of the important resources in the construction industry was determined as “human resources”. Warszawski (1996) mentioned human resources as probably the most critical resource and the key to success in the construction industry. Tatum (1989) found that firms that foster innovation have organizational structures that maintained flexibility in unit size and grouping to allow attention to innovation. These organizations made the effort to have special linkages for both internal and external co-ordination. (Ling, 2003).

The use of an innovation may require special resources and these resources may only exist within specialty companies. Therefore, the third consideration for the incorporation of an innovation into a specific project is the type and source of special resources (Slaughter, 1998). Consultants must stay significantly ahead of their clients to provide valuable advice. The means used by consultants to foster innovative competencies include working relationships with leading clients facing significant challenges; alliances with technology suppliers to understand expected new technologies; formalisation and codification of strategic or engineering methodologies; and, accumulation of experience in archives, knowledge management systems or expertise directories (Ozorhon. 2013a; Roger, 2008; Miiler and Olleros, 2007; Slaughter, 1998).

Construction companies rarely have the capital resources to last through decreases in demand, and so have scarce resources to invest in long-term innovation development (Manski 1973; “Construction” 1982b; Tatum 1986; Slaughter, 1993). Figure 6.4 shows the factor loadings of inputs of innovation.

Inputs have a direct effect on both benefits of innovation (path coefficient: 0.499) and impacts of innovation (0.418). In addition, they have an indirect effect on the impacts over benefits.

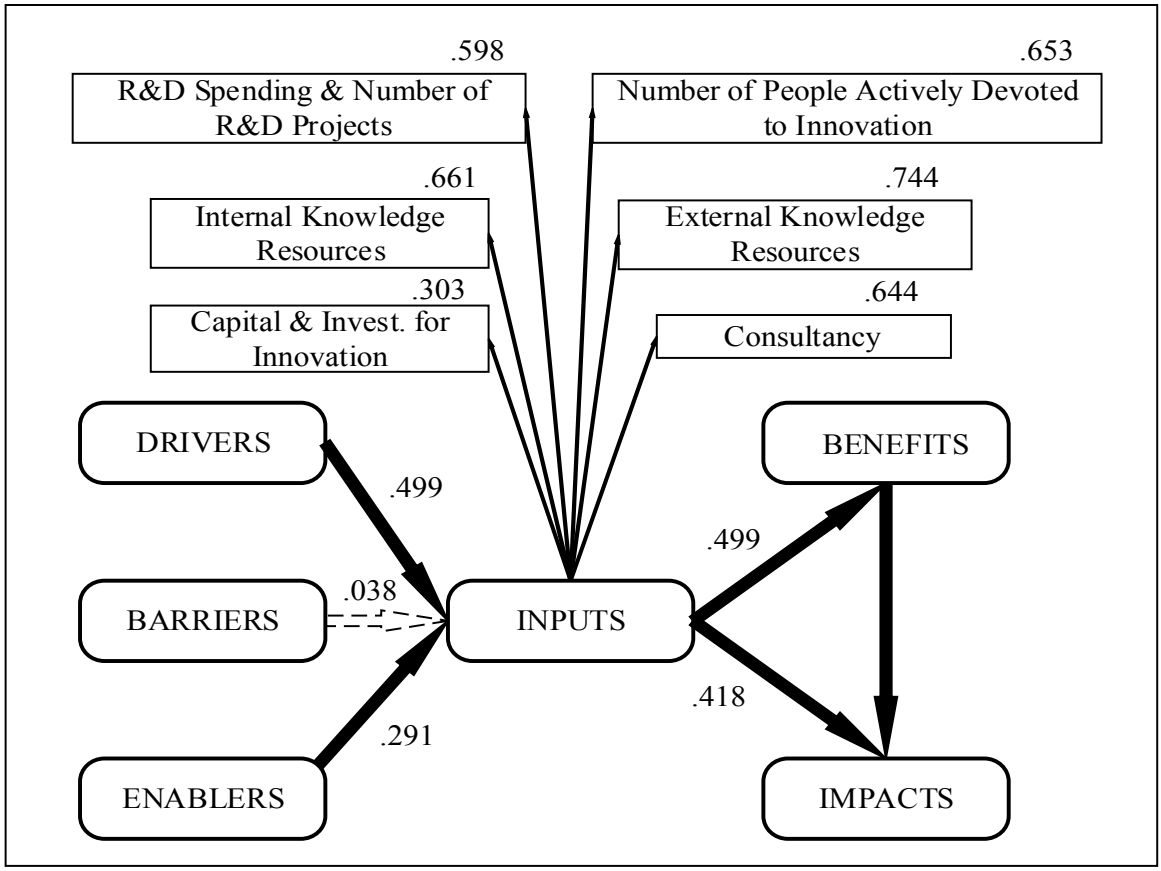


Figure 6.4. Effects of inputs on innovation performance.

6.5. Discussion on the Benefits of Innovation

There are many net benefits in fostering innovation in the construction sector, especially at the project level. Innovation in construction may become a fourth competitive dimension to be added to the existing dimensions of cost, quality and time (Newton, 1999). Innovation is required because there are pressures from clients to improve quality, reduce costs and speed up construction processes (Gann, 2000; Ozorhon, 2013b). According to data analysis, increased productivity (0.905) was the most important project level benefits which occurred through innovation. Gann (2000) argued that the pressures for innovation are often strongest in construction when there is demand-pull. For example, he observed that significant innovation is more likely to take place when clients require the following: buildings that need to be provided with enhanced information services; flexible spaces that need to accommodate information intensive activities; and buildings that need to have reduced environmental impact. Innovations have the potential of improving many aspects of

construction. Companies primarily pursue innovations to increase their productivity and efficiency (Slaughter, 1998; Goodrum and Haas, 2000).

It should be noted that different benefits might accrue depending on the project objectives. For instance, innovation might bring financial benefits in one case, whereas it might only improve environmental performance in another. The extent an innovative activity is successful should be measured against the initial targets set by the project teams. Figure 6.5 shows the factor loading of benefits of innovation.

Benefits as a construct has a moderate effect on the long-term impacts of innovation (path coefficient: 0.465).

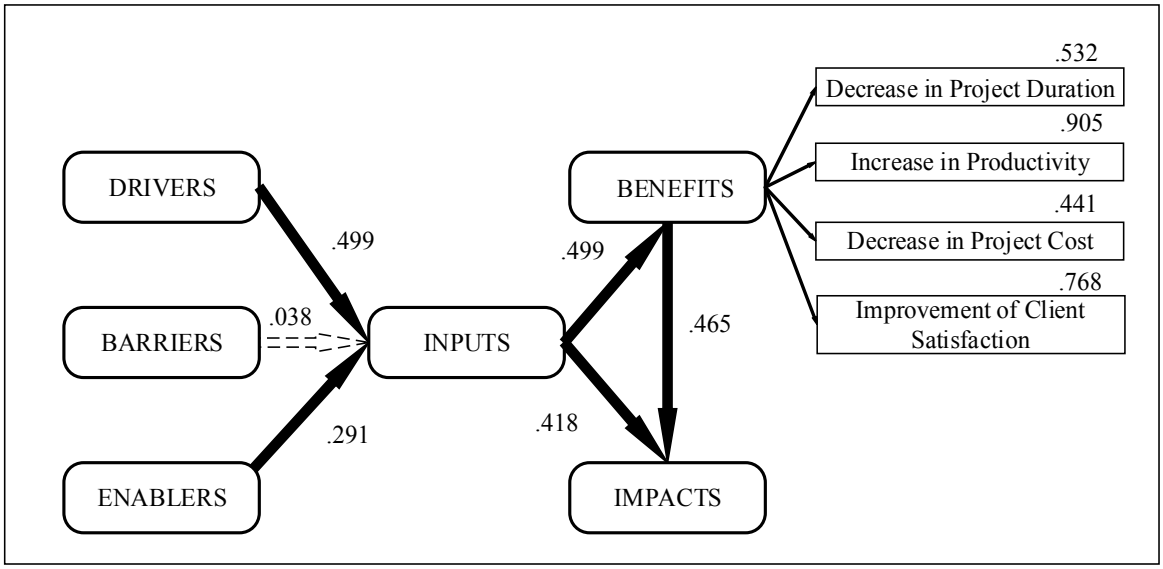


Figure 6.5. Benefits of innovations.

6.6. Discussion on the Impacts of Innovation

Inputs and benefits are found to enhance impacts of innovation. The positive influence of inputs and benefits are supported by other studies in the literature. Based on the high factor loadings in Figure 6.6, it can be stated that improvement of competitiveness, better company image, improvement of technological and management capability and gaining experience are important impacts of innovation. Innovations may also provide significant

benefits that cannot be adequately measured in direct monetary savings and gain, but can, nonetheless, add to a company's competitive position (Ramcharan, 1997; Slaughter, 1998).

The construction industry is currently suffering from a poor image problem. Innovations can help solve this problem by making construction easier, safer and more productive (Slaughter, 1998). Under certain conditions, the act of innovating itself can provide strategic benefits and the successful implementation of an innovation can enhance a company's reputation (Christensen and Rosenbloom, 1995; Hampson and Tatum, 1997).

Tatum (1987) stated a strong interaction with the field forces using the new technology is an excellent opportunity to gain user input to refinement and further innovation. Innovation also benefits the participating organizations in the long run. Experience in using technology also provides information to assist in planning and estimating for use on future projects. Successful project innovation can influence the business planning and long-term direction of the firm if it provides a technology that can give a competitive advantage (Tatum, 1989).

Therefore, construction professionals should not be reluctant to innovate and discouraged by the initial challenges and additional costs incurred (Ozorhon, 2013a).

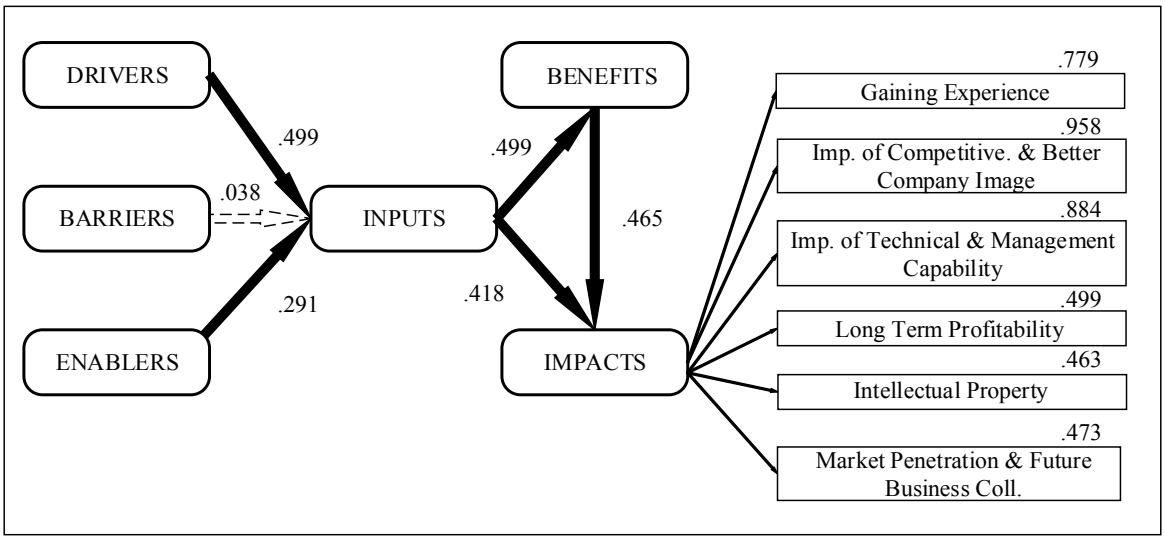


Figure 6.6. Impacts of innovation.

6.7. Overall Discussion on the Structural Relations between the Variables

Given the very strong path coefficients, the hypothesis set forward in this study appears to have held, with exception of barriers negative effect on innovation. Drivers and enablers have a positive influence on the inputs. Inputs have a positive influence on the benefits. In addition, inputs and benefits have a positive influence on impacts.

As a consequence, of this part of the research, a complete measure of construction innovation performance has been achieved.

7. CONCLUSION

Due to their increasing strategic importance in global competition, innovation has been an important research topic. Globalisation brought more capacity and resources to construction companies, expanded the market areas, variety of projects and partners and thereby increased a major driver of improvement called competitiveness. Consequently, innovation performance measurement as a strategic decision making tool became an important subject of interest during the last decades.

Construction innovation literature includes various studies related to performance issues, such as assessment, determinants and indicators of innovation performance. However, evaluating the success of an innovation is still difficult due to the disagreements on the definition and the measure of performance. It is certain that to obtain a complete understanding of performance, researchers should use multidimensional constructs as innovation performance measures.

Considering these, it can be said that innovation performance measurement is important for companies to evaluate its actual objectives against the predefined goals and to make sure that they are doing well in the competitive environment.

Despite the fact that, innovation performance measurement has numerous benefits to the companies. It appears that the use of performance measurement systems have both negative and positive effects on the company. But in the meantime it can easily be argued that the solution is not to avoid the use of performance measurement systems but to design and materialize a system of which measures and indicators of performance are properly selected with a comprehensive review of the literature and the judgements of the industry professionals.

Hence, considering the needs of the industry and the potential benefits, an innovation performance measurement model including four latent variables, namely “drivers”, “enablers”, “barriers” and “inputs” were determined to evaluate the “benefits of innovation” and the “impacts of innovation”. All latent variables had their constituent variables with a

total number of 38 variables. In order to collect information about those mentioned 6 latent variables and their constituent 38 variables, a questionnaire survey was administered to construction companies, a majority of which were the members of TCA and TCEA and established in Turkey. With this purpose, importance level of the variables and their extent to be used in the companies were asked (in a 1-5 Likert Scale) to the respondents who were at the managerial level of those companies.

Statistically analysing the general information on the 110 respondent companies, it was seen that the average age was 39 with an average total turnover of $480 million fort he last years of operation. According to type of innovation, web-based project management (17%), collaborative practices (15%), modern methods of construction (13%), contract management and client relations (13%), off-site manufacturing (11%), design solutions (6%), energy efficiency and green buildings (6%) are listed. The dominant project type, which has at least one innovation, is transportation projects (35%), followed by general buildings (32%) and infrastructure projects (12%). Client of 52 projects were private organizations, whereas public sector was the owner of 58 projects.

Information statistically analysed related to the characteristics of the respondent companies justified their reliability taking into consideration their long-term stable structure and success in the construction industry.

7.1. Major Findings and Contributions of the Study to the Literature

Data collected from the companies were analysed using a statistical technique called Structural Equation Modelling (SEM) to examine the validity of the measures and to construct valid interrelationships within the measures and the indicators of the model. Eventually, an innovation performance measurement model was specified showing the interrelationships and their path coefficients between the predetermined measures of performance. Hypotheses regarding the relations among determinants of performance are tested; and their influence on construction innovation performance is analysed.

- Based on an extensive literature survey: drivers, enablers, inputs, barriers, benefits and impacts are defined within the context of this research. In the proposed conceptual

model, considering the inter-dependencies among these factors, several hypotheses are developed.

- A model consisting of six constructs were designed in order to understand their role in innovation performance measurement. Validity of the constructs and the constituent variables were verified with content and construct validity testing. The final model which has a potential to be used in construction companies is extremely close to the needs and the requirements of the industry as all redundant measures were eliminated and the mostly used and proper ones were added as measures and the indicators. Analysis results also verified the validity of the constructs.

- In this study, it is postulated that construction innovation performance is influenced by drivers, enablers, barriers and inputs. The major objective of this paper was to explore the direct and indirect benefits and impacts of factors on innovation performance in construction. In addition, the interrelations between these factors were investigated.

- “Drivers” was found to highly affect “inputs”. This finding revealed that, there are many reasons for construction companies to innovate. Climate change and its effects on the environment and energy consumption make pressure on organizations and companies to increase their innovativeness to achieve sustainability. According to factor loadings, aesthetics and design trends is second important factor that drive construction sector to innovate. Clients are demanding more complex construction projects with integrated high-level technology, which are not feasible with current construction technology. Design is critical for innovation because it involves the coupling between technical possibilities and market demands and opportunities. Project performance improvement is highly important drivers. In fact, companies first and initial aim is make a profit. It can be possible with innovation which helps to decrease project duration and cost. In addition, clients play a significant role and take the lead on innovation in the construction industry. Construction organisations have a role and duty to respond to the need of clients as resulted in research. It should be noted that, according to respondents regulations, legislations and corporate responsibility have not seen as a driver of innovation.

- The results also suggest that “enablers” are moderately associated with inputs, which supports the view that collaborative partnering, communication, early contractor involvement, leadership, commitment, knowledge management, rewards schemes and training are main factors that foster construction innovation. Innovation education and training are the most important enablers, new technologies can be implemented effectively only by properly trained and skilled workers. Companies should also establish a reward system to recognize innovators and promote innovation. It is necessary to foster, stimulate, and reward the creativity of all employees. Leadership is one of the main enablers of innovation. Leadership in innovative construction projects is often seen as an important management function, based on human capabilities such as: entrepreneurship, championship and strategic vision (Tatum, 1989; Nam and Tatum, 1989; 1997; Winch, 1998; Gann, 2000; Bossink, 2004). Managers perform charismatic, instrumental, strategic, and interactive leadership styles to stimulate the innovative output of organizations.

- The client can act as a leader in the project, first guided the project team then, engage the contractor early in the project, and then pushing them to innovate. Early contractor involvement is another enabler of innovation because it develops trust among parties, and trust based co-operative relationship foster innovation. Early involvement of contractor is essential to achieve innovation via early starts in the planning procedure that gives him more time for innovation. Top managers should have commitment to innovation. They must have vision to create the environment for innovation, to be patient and realize the long-term benefits of innovation. Although, they encountered the barriers, try to keep process alive. Overall, successful innovation requires effective cooperation, coordination and working relationships between stakeholders of project. Collaborating, while lowering costs and improving efficiency, reduce delays and ensure completion of projects on time within budget and in required quality.

- One of the most interesting findings is that there is so significant relationship between “barriers” and “inputs”. According to hypothesis developed based on previous studies, barriers should have negative effects on innovation but since the drivers and enablers have a positive impact on the inputs, the effect of the barriers has become negligible. On the other hand, lack of financial resources, lack of clear benefits of innovation,

unwillingness to change, unsupportive organization culture, temporary nature of projects, lack of advanced materials and technology, lack of experienced and qualified staff can be stated barriers of construction innovation.

- In this study, it is postulated that construction innovation "benefits" and "impacts" influenced by "Inputs" that include R&D spending, number of R&D projects, human resources, internal and external knowledge idea generation, capital, investment, consultancy. Companies that invest in R&D will be more likely to innovate. In addition, R&D expenditures support the capture of external knowledge. In construction industry innovations usually emerge from internal sources, practical solutions to the problems that arise at construction sites usually result in innovations. On the other hand, many technologies with potential application in construction developed in other industries that are major sources of innovation in construction innovation. Construction projects today are far more complicated than ever before. There are new technologies, materials, tools, project management practices etc. required to achieve complicated projects. Allocating funds and capital to innovation is essential to success of new-tech construction projects. Specialized companies such as consultants may be required to implement innovation.

- According to responses, they increased productivity through the innovation at the project level. In addition, client satisfaction is acquired via innovative practices in project level. Decreased of cost and duration are another benefits of construction innovations.

- Besides project level benefits of innovation, long-term benefits which named impacts of innovations are more sustainable for construction industry. An innovative company must be willing to accept a moderate loss on a current project that is being used experimentally with a new technology. Temporary nature of construction projects and lack of capital investments, innovation seems to be burden on construction companies. However, in the long-term perspective construction companies could be increase competitiveness that is necessary for today's business world. Innovation helps to construction companies to improve their company image, and increase their technical and managerial capabilities. They can gain experience on special areas, these

stimulates new collaborations with international companies, and opening for new markets. According to final model, same results can be found.

According to questionnaire survey, construction companies believed that investments on innovation could be effect positively their companies' financial performance in the medium and long term. In addition, they stated that innovation is highly important for construction industry, and they follow up very closely innovation activities related to construction.

Every decision involves risk, whether innovative or not. Innovators need not be high-risk takers; they are prudent and aware of the risks involved in their decision to try something new. Careful analysis and planning can help minimize risk. In fact, sometimes, not being innovative may prove to be riskier. Using old methods to solve new problems may lead to inefficiency and loss of competitiveness (Laborde and Sanvido, 1994).

Turkish construction companies are very competitive and the second country after the China in the ENR Top International Contractors List. However, this will not continue for a long. Turkish contractors should be differentiated and specialized in specific construction areas with the support of innovation. Innovation must be a companywide ideal lead by upper management. They should also concentrate on long term company level impacts, which have the ability to provide sustainability to the companies, of innovations rather than short-term profits.

Hence, a comprehensive and valid innovation performance measurement tool was provided for construction companies to assess not only their current performance in means of retrospective terms but also to assess their future performance by prudential success factors which lead them to set strategies in the long term.

7.2. Limitations of the Study

Findings based on the proposed framework reflect the experiences of Turkish contractors. Questionnaire survey was administered to companies established in Turkey therefore perceptions of only Turkish companies were acquired. The conclusions of the research may be tested in different countries than Turkey and a more global view of the innovation capabilities of construction companies in practice may be determined. Study presents a general framework; the model could produce different results depending on the respondent, project size, and the project type.

Sample size was actually small for such a statistical analysis, however satisfactory results were obtained due to the robust method capability incorporated in EQS analysis.

7.3. Recommendations for Future Work

It is expected that this thesis would be helpful for the construction sector professionals who want to have knowledge about the current innovation capability of Turkish construction sector and what are the factors that affect innovation in sector.

In order to strengthen the findings of this thesis and to diversify the resources used in it, a qualitative research method can be applied as a future research. Case studies can be used in the same study to examine the innovation capability of Turkish construction sector more deeply.

The proposed model was designed corresponding to the requirements of the current business environment. However, the requirements of a competitive business environment such as construction industry change so fast. In the future, a new study can be designed and performed with an increased number of case studies and interviewees. Thus, in the future, the investigation of innovation measures may be maintained constantly and updated to catch new developments. Such a study will be helpful to compare the findings and observe the similarities and differences between the conditions.

APPENDIX A: A SAMPLE OF THE QUESTIONNAIRE

(i) Please state the name of the company:

(ii) Please state the main business area of your company:

(iii) Please state the years of experience of the company:

(iv) Please state your company's total turnover:

(v) Please state which type innovation has been applied in the project:

(vi) Please state the type of the project:

(vii) Please state the client in this project:

(viii) Please state the size of the project:

(ix) Please state your position in the project:

(x) Do you believe investments for innovation will have positive effect on company's financial performance in the medium and long-term?

(xi) Do you believe innovation is very important for your company and industry which you are working?

(xii) Do you follow innovation activities in construction industry?

(xiii) To what extent do the following factors create the need for the innovation that you have implemented? (Drivers)

Table A.1. Drivers of Innovation.

DRIVERS		Very Low	Low	Medium	High	Very High
		1	2	3	4	5
1	Client and End User Requirements					
2	Competition Level and Corporate Performance					
3	Project Performance Improvement					
4	Technological Developments					
5	Regulations and Legislations					
6	Corporate Responsibilty					
7	Aesthetics and Design Trends					
8	Environmental and Sustainability					

(xiv) To what extent do the following factors impede the uptake of innovation? (Barriers)

Table A.2. Barriers of Innovation.

	BARRIERS	Very Low	Low	Medium	High	Very High
		1	2	3	4	5
9	**Unsupportive Organization Culture and Unwillingness to Change**					
10	**Lack of Financial Resources**					
11	**Temporary Nature of Projects**					
12	**Lack of Materials and Technology**					
13	**Lack of Experience and Qualified Staff**					
14	**Lack of Clear Benefits and Risky Investment**					
15	**Time Constraint of Project**					

(xv) To what extent do the following factors help promote innovation? (Enablers)

Table A.3. Enablers of Innovation.

ENABLERS		Very Low	Low	Medium	High	Very High
		1	2	3	4	5
16	Collaborative Partnering and Communication					
17	Early Contractor Involvement					
18	Leadership					
19	Commitment					
20	Knowledge Management and Problem Solving Techniques					
21	Reward Schemes, Awards, Grants and Funds					
22	Innovation Education and Training Policy					

(xvi) To what extent do the following factors facilitate innovation? (Inputs)

Table A.4. Inputs of Innovation.

INPUTS		Very Low	Low	Medium	High	Very High
		1	2	3	4	5
23	R&D Spending and Number of R&D Projects					
24	Number of People Actively Devoted to Innovation					
25	Internal Knowledge Resources					
26	External Knowledge Resources					
27	Capital and Investment for Innovation					
28	Consultancy					

(xvii) To what extent does the innovative activity benefit your project? (Benefits)

Table A.5. Benefits of Innovation.

BENEFITS		**Very Low**	**Low**	**Medium**	**High**	**Very High**
		1	**2**	**3**	**4**	**5**
29	**Decrease in Project Duration**					
30	**Increase in Productivity**					
31	**Improvement of Client Satisfaction**					
32	**Decrease in Project Cost**					

(xviii) To what extent does the innovative activity benefit your organization? (Impacts)

Table A.6. Impacts of Innovation.

IMPACTS		Very Low	Low	Medium	High	Very High
		1	2	3	4	5
33	Gaining Experience					
34	Improvement of Competitiveness and Better Company Image					
35	Improvement of Technical and Management Capability					
36	Long Term Profitability					
37	Intellectual Property (Patents, Trademark, Design)					
38	New Market Penetration and Future Business Collaborations					

APPENDIX B: DESCRIPTIVE STATISTICS

Table B.1. Descriptive statistics of general information on respondent companies

Statistics	Age	Company Turnover ($M)	Project Value ($M)
Mean	39.43	310.05	201.84
Sum	4337.00	34105.50	22202.68
Median	48.00	350.00	130.00
Sum of Square	47398.92	6859129.98	5337819.48
Standard Deviation	20.85	250.85	221.29
Kurtosis	-0.43	-0.96	0.62
Skewness	0.064	0.315	1.221
Range	99	907	850
Minimum	1	1	0
Maximum	100	908	850

Table B.2. Descriptive statistics of "Drivers of Innovation"

Statistics	V1	V2	V3	V4	V5	V6	V7	V8
Mean	3.73	3.79	3.99	3.65	2.62	2.73	2.81	3.06
Sum	411.00	417.00	439.00	401.00	288.00	300.00	309.00	337.00
Median	4.00	4.00	4.00	4.00	3.00	3.00	3.00	3.00
Sum of Square	133.36	138.19	150.99	137.17	171.96	159.82	160.99	194.56
Standard Deviation	1.11	1.13	1.18	1.12	1.26	1.21	1.22	1.34
Kurtosis	0.34	0.52	1.05	0.01	-0.97	-0.83	-0.85	-1.03
Skewness	-0.94	-1.02	-1.34	-0.88	0.28	0.22	0.03	-0.12
Range	4.00	4.00	4.00	4.00	4.00	44.00	4.00	4.00
Minimum	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maximum	5.00	5.00	5.00	5.00	5.00	5.00	5.00	5.00

Table B.3. Descriptive statistics of "Barriers of Innovation"

Statistics	V9	V10	V11	V12	V13	V14	V15
Mean	3.04	2.91	2.97	2.81	3.12	2.86	3.20
Sum	334.00	320.00	327.00	309.00	343.00	314.00	352.00
Median	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Sum of Square	65.86	63.09	78.92	54.99	79.46	63.67	81.60
Standard Deviation	0.77	0.76	0.85	0.71	0.85	0.76	0.87
Kurtosis	0.65	0.32	-0.26	0.83	-0.62	0.02	-0.23
Skewness	-0.94	-1.02	-1.34	-0.88	0.28	0.22	0.03
Range	3.00	3.00	3.00	3.00	3.00	3.00	3.00
Minimum	2.00	2.00	2.00	2.00	2.00	2.00	2.00
Maximum	5.00	5.00	5.00	5.00	5.00	5.00	5.00

Table B.4. Descriptive statistics of "Enablers of Innovation"

Statistics	V16	V17	V18	V19	V20	V21	V22
Mean	3.66	3.28	3.99	3.76	3.79	2.70	3.24
Sum	403.00	366.00	439.00	414.00	417.00	297.00	356.00
Median	4.00	4.00	4.00	4.00	4.00	3.00	4.00
Sum of Square	96.56	162.22	100.99	135.86	116.19	189.10	183.86
Standard Deviation	0.94	1.22	0.96	1.12	1.03	1.32	1.30
Kurtosis	0.35	-0.79	0.90	0.26	0.65	-1.26	-0.97
Skewness	-0.68	-0.43	0.97	0.87	0.98	0.13	-0.40
Range	4.00	4.00	4.00	4.00	4.00	4.00	4.00
Minimum	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Maximum	5.00	5.00	5.00	5.00	5.00	5.00	5.00

Table B.5. Descriptive statistics of "Inputs of Innovation"

Statistics	V23	V24	V25	V26	V27	V28
Mean	2.99	3.17	3.67	3.02	3.45	3.29
Sum	329.00	349.00	404.00	332.00	379.00	362.00
Median	3.00	3.00	4.00	3.00	4.00	3.00
Sum of Square	172.99	143.72	130.22	145.96	155.17	162.69
Standard Deviation	1.26	1.15	1.09	1.16	1.19	1.22
Kurtosis	-1.04	-0.96	-0.09	0.81	-0.62	-0.96
Skewness	-0.038	-0.20	-0.85	-0.14	-0.46	-0.24
Range	4.00	4.00	4.00	4.00	4.00	4.00
Minimum	1.00	1.00	1.00	1.00	1.00	1.00
Maximum	5.00	5.00	5.00	5.00	5.00	5.00

Table B.6. Descriptive statistics of "Benefits of Innovation"

Statistics	V29	V30	V31	V32
Mean	3.31	3.76	3.92	3.57
Sum	364.00	413.00	431.00	393.00
Median	4.00	4.00	4.00	4.00
Sum of Square	191.49	136.37	130.26	150.92
Standard Deviation	1.33	1.12	1.09	1.18
Kurtosis	-0.99	0.32	0.66	-0.81
Skewness	-0.39	-0.97	-1.15	-0.41
Range	4.00	4.00	4.00	4.00
Minimum	1.00	1.00	1.00	1.00
Maximum	5.00	5.00	5.00	5.00

Table B.7. Descriptive statistics of "Impacts of Innovation"

Statistics	V33	V34	V35	V36	V37	V38
Mean	4.03	4.06	3.97	3.52	2.60	3.16
Sum	443.00	447.00	437.00	387.00	286.00	348.00
Median	4.00	4.00	4.00	4.00	3.00	3.00
Sum of Square	90.92	86.56	86.92	131.46	164.40	165.06
Standard Deviation	0.91	0.89	0.89	1.10	1.23	1.23
Kurtosis	0.38	0.42	0.27	-0.20	-0.83	-0.90
Skewness	-.085	-0.83	-0.72	-0.59	-0.32	-0.23
Range	4.00	4.00	4.00	4.00	4.00	4.00
Minimum	1.00	1.00	1.00	1.00	1.00	1.00
Maximum	5.00	5.00	5.00	5.00	5.00	5.00

APPENDIX C: CORRELATION MATRIXES

Table C.1. Intercorrelations for the variables of "Drivers".

F1	V1	V2	V3	V4	V5	V6	V7	V8
V1	1.0000	0.1027	-0.1005	0.0940	0.3033	0.1445	0.2216	0.2846
V2	0.1027	1.0000	0.2685	0.3984	0.0403	0.2337	0.1516	0.1126
V3	-0.1005	0.2685	1.0000	0.4492	0.1342	0.0884	0.0437	0.1112
V4	0.0940	0.3984	0.4492	1.0000	-0.0970	0.1781	0.2325	0.3580
V5	0.3033	0.0403	0.1342	-0.0970	1.0000	0.3652	0.2583	0.1732
V6	0.1445	0.2337	0.0884	0.1781	0.3652	1.0000	0.5129	0.5212
V7	0.2216	0.1516	0.0437	0.2325	0.2583	0.5129	1.0000	0.6121
V8	0.2846	0.1126	0.1112	0.3580	0.1732	0.5212	0.6121	1.0000

Table C.2. Intercorrelations for the variables of "Barriers".

F2	V9	V10	V11	V12	V13	V14	V15
V9	1.0000	0.4245	0.2373	0.3617	0.1732	0.3024	0.0437
V10	0.4245	1.0000	0.3221	0.4260	0.0449	0.2768	0.1533
V11	0.2373	0.3221	1.0000	0.3253	0.0045	0.2054	0.3564
V12	0.3617	0.4260	0.3253	1.0000	0.2191	0.3371	0.2418
V13	0.1732	0.0449	0.0045	0.2191	1.0000	0.4343	0.3278
V14	0.3024	0.2768	0.2054	0.3371	0.4343	1.0000	0.5161
V15	0.0437	0.1533	0.3564	0.2418	0.3278	0.5161	1.0000

Table C.3. Intercorrelations for the variables of “Enablers”.

F3	V16	V17	V18	V19	V20	V21	V22
V16	1.0000	0.2486	0.2396	0.2642	0.1063	0.2435	0.3508
V17	0.2486	1.0000	0.3463	0.2661	0.1859	0.2501	0.2171
V18	0.2396	0.3463	1.0000	0.3480	0.2842	0.3307	0.4641
V19	0.2642	0.2661	0.3480	1.0000	0.2353	0.2945	0.4185
V20	0.1063	0.1859	0.2842	0.2353	1.0000	0.3987	0.3314
V21	0.2435	0.2501	0.3307	0.2945	0.3987	1.0000	0.6210
V22	0.3508	0.2171	0.4641	0.4185	0.3314	0.6210	1.0000

Table C.4. Intercorrelations for the variables of “Inputs”.

F4	V23	V24	V25	V26	V27	V28
V23	1.0000	0.4768	0.2843	0.3085	0.0210	0.3296
V24	0.4768	1.0000	0.4109	0.2738	0.2380	0.3105
V25	0.2843	0.4109	1.0000	0.4690	0.2746	0.2094
V26	0.3085	0.2738	0.4690	1.0000	0.1403	0.5283
V27	0.0210	0.2380	0.2746	0.1403	1.0000	0.1432
V28	0.3296	0.3105	0.2094	0.5283	0.1432	1.0000

Table C.5. Intercorrelations for the variables of “Benefits”.

F5	V29	V30	V31	V32
V29	1.0000	0.3982	0.2709	0.3855
V30	0.3982	1.0000	0.5912	0.2821
V31	0.2709	0.5912	1.0000	0.2793
V32	0.3855	0.2821	0.2793	1.0000

Table C.6. Intercorrelations for the variables of “Impacts”.

F6	V33	V34	V35	V36	V37	V38
V33	1.0000	0.6178	0.6309	0.2053	0.2225	0.2246
V34	0.6178	1.0000	0.6940	0.3972	0.3420	0.4171
V35	0.6309	0.6940	1.0000	0.3607	0.3162	0.2462
V36	0.2053	0.3972	0.3607	1.0000	0.4000	0.3101
V37	0.2225	0.3420	0.3162	0.4000	1.0000	0.4201
V38	0.2246	0.4171	0.2462	0.3101	0.4201	1.0000

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