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DEVELOPMENT OF LEAN DESIGN PROCESS FOR BUILDING CONSTRUCTION PROJECTS

By

Ismawi Haji Md. Yusof

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ABSTRACT

Complex designs in construction projects may lead to various problems in the construction industry. The design process in the earlier part of a construction project can be considered as the most influential phase capable of affecting the performance of the project. An approach of integrating lean thinking into the design process of constructions projects can achieve substantial benefit at the design stage. The research presented in this thesis investigates and demonstrates the adaptation of lean thinking towards performance improvement of the design process.

The aim of this research is to develop an innovation of design processes that supports the implementation of lean thinking for building construction projects. The proposed design process provides a systematic approach, which is structured into stages and activities in order to obtain a lean design process.

The development of the proposed design process starts with the framework of innovation. The framework comprises of seven knowledge domains: application, design management, design process, people, information flow, performance and measurement, and techniques and tools. The proposed design process was developed based on the principles of 'Set-Based-Concurrent-Engineering' as the core enabler.

The research makes the following contributions: (1) identification of wastes and enablers in the design process; (2) elimination of the identified wastes in the design process; (3) the applicability of the proposed lean design process in the construction industry; (4) the performance measurement as a tool for design process review.

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CONTENTS

LIST OF TABLES

List of Figures

LIST OF ABBREVIATIONS AND ACRONYMS

AHP – Analytical Hierarchy Process

ARCOM – Association of Researchers in Construction Management

CF – Contribution Factor

IGLC – International Group for Lean Construction

JIT - Just-in-Time

KPI – Key Performance Indicator

LC – Lean Construction

LCI – Lean Construction Institute

LE – Lean Enabler

LPDS – Lean Project Delivery System

LT- Lean Thinking

PBD – Point-Based Design

PMBOK – Project Management Body of Knowledge

PMI – Project Management Institute

PMS – Performance Measurement System

PP – Project Performance

QFD – Quality Function Deployment

RIBA – Royal Institute of British Architects

SBCE – Set-based Concurrent Engineering

TFV – Transformation, Flow, and Value

TPS – Toyota Production System

TQM – Total Quality Management

1. INTRODUCTION

1.1. Background of Study

The construction industry has long been recognised as having lower productivity growth rates compared to other sectors such as manufacturing (Egan 1998). Problems in the construction industry including delayed project delivery, poor construction quality, poor performance and cost overruns have occurred in many construction projects. In the trend of improving construction projects' performance, Egan (1998) examined, the drivers of improvement. Such drivers are based on the construction industry being linked with problems. The chronic problems faced by the construction industry include insufficient quality, low productivity, poor coordination and high cost, driven by client-acceptance of the lowest price tender.

The approach of adopting the concept of lean thinking into the construction industry has been widely promoted by practitioners. Lean thinking is the improvement philosophy that focusing on the elimination of waste and creating value (Womack et al., 1991). In the action of improving construction project this improvement philosophy is heralded as a way to prevent the problems mentioned above. The idea of lean thinking derived from the manufacturing industry, where the application focuses more on efficiencies in the production process, initially in automotive engineering. Then construction industry was adopting the improvement philosophy and identified it as Lean construction (LC). Since the adoption, LC has been the subject of research for more than a decade in the construction industry, where the focus has been on improving the construction process (Ballard 2008); (Alves & Tsao 2007).

It has been almost two decades since the researchers' and practitioners' study on this subject, which focuses on improving the construction process, project administration, project management and supply chain. However, the performance of construction projects continues to cause significant concerns with regards to lead-time, cost, and quality. Analysis of published research papers of the International Group for Lean Construction (IGLC) conference from 2000 to 2006 showed that application of lean methods in the design management area is one of the most common topics being studied in LC (Alves & Taso, 2007), but not design itself and the process. However, other researchers have proposed that lean techniques used in the construction process can also be used and applied in the design process as well (Deshpande et al., 2012).

Although initiatives have been taken to explore the adaptation of lean thinking in the early stage of the construction projects (design phase), where the focus is more on the development of design. Improvement in planning and design process also capable to mitigate the poor project performance problems (Jørgensen et al., 2004). This suggests that there is a potential for lean techniques to create value and eliminate waste at the early stages of the project, as well as at the management and construction stages.

It is the intention of this research to develop a framework for implementation of lean thinking into the planning and design process of construction, based on the construction project life cycle presented by RIBA (RIBA Plan of Work 2013).

In this research, there will be two parts to the framework development.

- The first part focuses on adopting lean production and LC principles to develop a design process framework in building construction projects. This is to ensure that the lean concept primarily improves the design process performance.

- The second part elaborates on the development of performance measurement of the design process as a way of indicating the improvement.

1.2. Problem Statements and Research Gaps

In the flurry of activity during the implementation of project planning, construction on site has become the focus for improvement, which can be physically seen and the performance tracked through the life cycle of the construction project. However, the design phase of the construction projects is not being considered for improvement (Jørgensen 2006). In other engineering industries, the success of the downstream activities relies on the performance and efficiency of the upstream activities and outcomes. Whereas in construction industries this can be implied as the success of the construction projects relies on the planning and design stage of the projects.

In the progressive development of the design process in construction projects, there is a need to monitor and mitigate waste. This will enable the design process to achieve the targeted performance at an early stage. This targeted performance will lead to enhancement of the performance of the whole project once the project is completed. In the manufacturing industry the application of lean in their design process had given a success in improving the overall performance (Khan et al., 2011). Their research aims to develop an innovation of design process by integrating lean principles to reduce the design rework. With their developed design process model emphasises on the design activities and method of implementation, the model was able to gain positive impact to the one of the manufacturing companies in their case study. Their approach is by adopting SBCE design process principles and incorporating problem solving method to create innovation in the design process.

With the argument of manufacturing production has rapid repetitive process and construction projects has one-off project, there is possibility of different approach of integration of lean principles in the design process of construction projects. This research strive to fill in this gap in current lean implementation knowledge by identifying waste and creating value in design process and eliminate the identified wastes by adopting lean enablers.

Furthermore, in consideration of the construction phase may suffer significant and repeat deviations in work instructions arising from deficiencies in the design phase, development of a performance measurement system for design process to capture information that can detect poor performance at an early stage in the project id necessary (Mossman, 2013). This detection will act as an early warning so that the wastes identified can be minimised. This research explores the on the how to monitor the performance of a project at the early stage.

1.3. Research Aim and Objectives

The main aim of this research is to develop a design process that supports the implementation of lean thinking for building construction projects. Subsequently the second aim is to identify the project performance improvement.

The objectives of the research are defined by the research questions presented below and as elaborated upon in Table 1.1.

1. To review lean design processes and identify the trend of literature on the subject of applying lean principles in the construction design process.
2. To identify waste in the design process that hinders constructability and the quality of building design.
3. To extract the principles and enablers of lean design process from the literature.
4. To develop a lean design process that will improve the project performance at the design phase of building construction projects.
5. To test the proposed design process through field application in industry.

1.4. Rationale and Research Questions

The design process that will be developed combines lean product development principles and practices and provides a conceptual phase in the design process. The target of the proposed design process is to provide a support for an organisation to develop new design process that are client-focused and innovative while reducing project waste and enhance project performance. All of these will contribute to the improvement of design process performance.

Table 1.1 Primary Research Questions, Research Objectives and Supplementary Questions

Primary research question	Research objective	Supplementary question
What does lean design process mean?	**Review lean design processes and identify the trend of literature on the subject of applying lean principles in the construction design process.**	**How does the design process improve the PP for building construction projects?** **Are there any case studies on the lean design process?** **What are the components of lean design process and is there any agreement among researchers?**
What are wastes in relation to the design process?	**Identify waste in the design process that hinders constructability and quality of the building design.**	**What are wastes in the design process?** **Is it the same as in construction, manufacturing, and other industries?**
How should the lean design process be structured and presented?	**Extract the principles and enablers of lean design process from the literature.**	**What are the activities of design process that can eliminate waste in design process?**
How can design process and performance measurement system be integrated in the design phase of building construction projects?	**Develop a design process and performance measurement system that will improve the project performance at the design phase of building construction projects.**	**What tools and methods support a lean design process?** **Which tools can be used to support the implementation of a lean design process?** **What activities can support the implementation?**
How do proposed design process principles and performance measurement system interact with the project performance in building construction projects?	**Test the proposed design process through industrial application**	**Is the proposed design process effective in addressing design process challenges?**

1.5. Research Process

The research process illustrated in Figure 1.1 contains the methodological steps to achieve the aims and objectives of this research. These steps will be used throughout the course of this research. The research is divided into three phases namely;

- Phase 1: Literature review and establishment of research objectives;
- Phase 2: Development of the framework, data collection and analysis;
- Phase 3: Implementation of the framework in architectural design practices, collect data, analyse the findings and present the results, conclusions and recommendations.

The first phase of this research is the literature review to answer the research questions in Table 1.1. The understanding of research area such as the design process in building construction, review the past research on the lean design process, identify waste and lean enablers for the design process will be developed through this literature review.

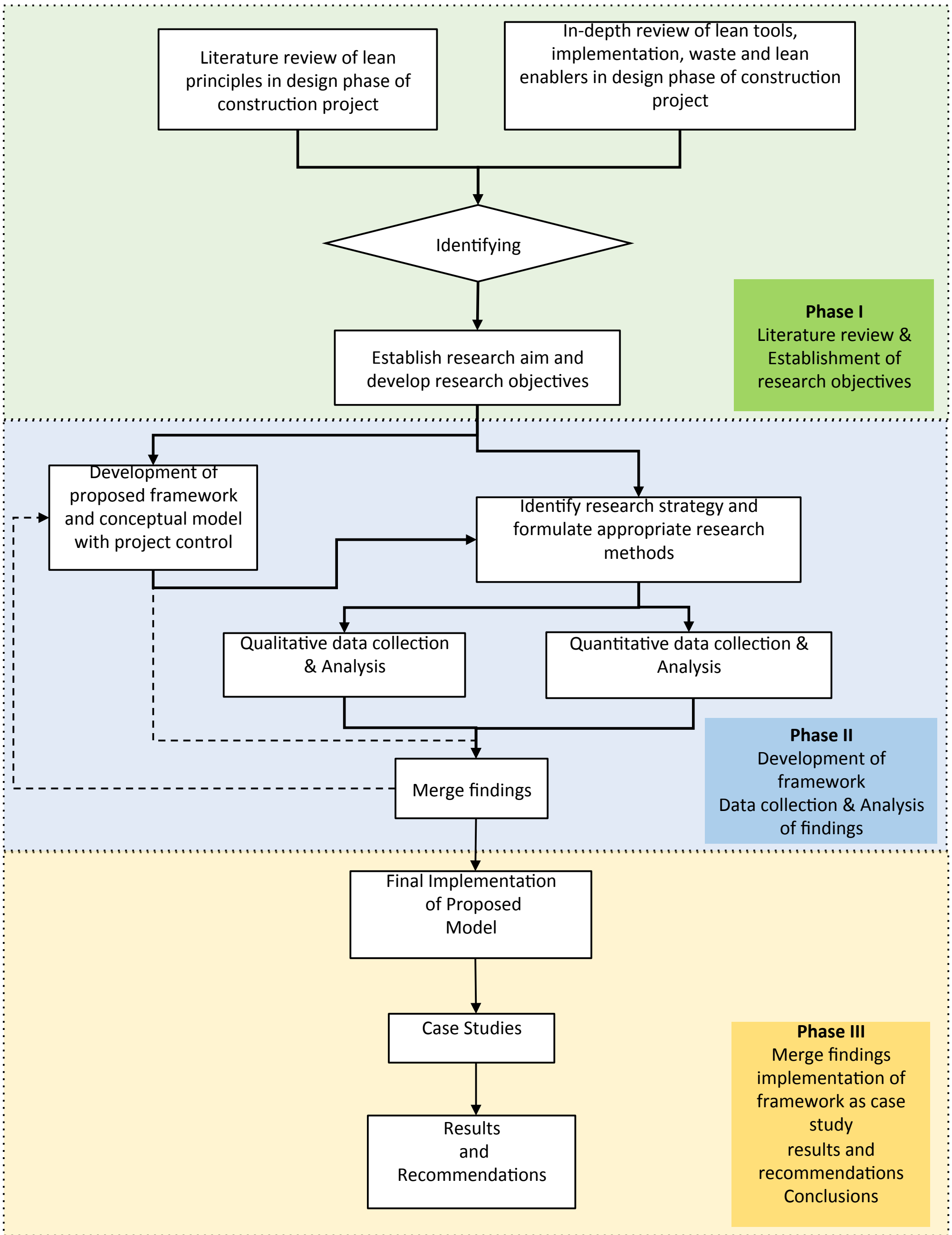
The second phase is the framework development for the proposed design process, which is based on the outcome of the literature review in the first phase. It focuses on the elimination of waste and value creation for the design process. The outcome of this phase will be the proposed framework and a design process.

The third phase is the implementation of the proposed design process, in which the opinion of experts in industry will be obtained. In this way, the proposed design process will be assessed in the context of where it is tested, which is in the construction industry of Brunei. The developed evaluation method for design process performance will be used to compare the results of implementation with the theoretical results.

Conclusions from the research will then be drawn, along with recommendations for further research and implementation.

The main output of this research is the proposed design process which is able to eliminate the identified wastes in design process through the design process activities that adopting the lean principles. While the design activities will be measured based on the design review process by using a set of KPIs acts as the performance measurement of the project. Building towards a novel approach, the proposed design process would seek to integrate lean thinking principles which will ensure the successful elimination of wastes and aim to create value through the identified core enabler.

Figure 1.1 Research Process



1.6. Expected Outcomes of the Research

The research will explore the adaptation of lean thinking in the design process of construction projects and how this adaptation can improve the PP when implemented at an early stage. The proposed design process is developed to help construction industry in their journey towards utilising lean principles that focus on enhancing the project performance at the early stage of construction projects.

The main outcome from this research can be described as follows:

- Establishing the origins of waste in the design process of construction projects.
- Identifying and classifying the lean enablers for the design process.
- Mapping the design process with set-based concurrent engineering (SBCE) as the main lean enabler.
- Identifying and classifying the key performance indicators for the design process.
- Establishing performance measurement indicators for projects at the early stages.

1.7. Scope of the Research

This research is mainly focusing on the planning and design phases of the project cycle as defined by RIBA (RIBA Plan of Work 2013). Therefore the implementation of lean thinking will only be considered from the stage Zero (0) to Stage three (3):

Stage 0 – Strategic definition, identifying client's requirements for the project,

Stage 1 – Preparation and Brief, development of project objectives, Stage 2 – Concept Design, preparation of concept design,

Stage 3 – Developed Design, preparation of developed design.

The data collection for this research is conducted through qualitative and quantitative method. Subsequently, the validation of the proposed design process is undertaken through analysis of results from the case study. This case study will determine the applicability of the proposed design process in the construction industry.

The company selected for implementation of this research is an architectural firm (an architect and designer), registered with Ministry of Development, Brunei Darussalam. The company is considered representative of companies that have experience in handling government projects. The company also holds licence to practice in the country, which gives them credibility to handle big projects. This company was chosen on the basis of its capacity to control and innovate during the design process.

Furthermore, its involvement in construction projects from their inception, through to completion of the project carries a high reputation and hence will provide a reliable opinion as to the design process and the effect of the framework on their construction. Through understanding the issues faced in the design process, the findings may prove to be beneficial to project management, by improving the performance of a project.

1.8. Structure of Thesis

This thesis is structured in eight chapters. A brief breakdown of the chapters and what the research seeks to address in each chapter is elaborated below.

Chapter 1 provides the basis of the research through the background of study. Discusses the problem being research and provides problem statement that stimulate the research interest. Subsequently identify the research gap. The chapter also includes aim and objectives, rational and research questions, research process, expected outcome of the research and scope of the research.

Chapter 2 reviews the background and previous works related to the research domain. The issues being reviewed include the lean thinking in construction, building design process, research trends in application of lean thinking in building design, representation of lean design, importance of value in design, waste identification and elimination, and performance measurement.

Chapter 3 discusses the thesis research paradigm and general methodological approach. Subsequently provides reviews, justifications and discusses the various aspects of the methodology employed in this research. This includes the how the objectives of the research be achieved through the research methodology.

Chapter 4 presents the results and discussion of conducting the interview and questionnaire. Summary of the finds also discussed in this chapter.

Chapter 5 elaborate the development of proposed design process starting from the framework. The development of performance measurement of the design process also discusses. Then the implementation process is presented in this chapter.

Chapter 6 presents the case study conducted for this research. The discussion, analyses of the results are evaluated

Chapter 7 discusses the overall finding of the research.

Chapter 8 summarises the entire thesis by providing the answers to the research questions. It also discusses the limitations of the research together with recommendations for future research.

2. LITERATURE REVIEW

2.1. Introduction

The design process in construction can be considered as the essential part of the project development. The design process can be considered the interpretation of the client information and transform it to the construction information. In this literature review , the strategy of conduction the review of literature is described. Understanding of lean principles and their evolution from manufacturing industry to construction industry is covered. Some previous work on lean principles that have been developed in construction industry is overviewed. Subsequently, the performance measurement of design process is reviewed and finally the identified research gap is discussed.

2.2. Literature Review Strategy

Significant research has been conducted on the subject of lean design and improved construction efficiency. In the UK, the 1998 Taskforce report, headed by Sir John Egan concluded that one of the five key drivers for change was integrated processes and teams (Egan, 1998) and following this, in 2003 the Construction Lean Improvement Programme (CLIP) was set up to support industry deliver these ideals (Watson, 2004). The integrated processes as a key driver for change has opened the door for the researchers to explore and merge various theories and methods to improve the construction efficiency. In this research, the exploration of integrated processes becomes the prime strategy for the literature review in this thesis, where the chosen strategy gives proven performance improvement results.

While the focus is on the lean design research area which has the common goal for performance improvement as well.

Therefore, different research contributions to the subject area is essentials to be reviewed where, as a result, this will identify how this research could contribute to the research aim. The following review of publications that are related to lean design, found in the English language, will identify the waste in design process and the enablers.

In this research, a systematic literature search was carried out to identify and analyse the published body of knowledge on the subject (Robson, 2011). Thus the review of the literature is done in steps to manage the portion of information available.

The goal of the first stage of this review is to present the ideas in a simpler form. This was achieved through reading textbooks in order to gain foundational understanding of the subject. In the second stage, academic research publications are utilised to understand the contribution of researchers in the subject area. This is gained through a mixture of journal and conference papers database: ASCE Library, Scopus, ProQuest, EBSCO, Springerlink, Emerald, Google Scholar and Science Direct. All of these were available on the Internet.

In the third stage, tracing back the sources references found in the literature is used to ensure the important contributions were not overlooked or misquoted. This is to overcome the limitation of keyword search that cannot detect other literature that might be important to this research. Researchgate.com is used to alert the additional and new contributions by particular researchers or match subject through automated email.

The use of keywords in the search is the one that defines the research subject and similar terms also included. The keywords were: ‘lean design, ‘lean design process, ‘lean product development, and ‘lean design management’.

Logical terms were also used to identify literature such as ‘lean AND design process’, and ‘lean OR Toyota AND design’. Abbreviating terms were also used such as ‘architecture$’ or ‘design*’. Any publications that were not relevant to design or design process were not reviewed such as lean construction, lean production process, supply chain or architectural software. The relevant literature is reviewed and critically analysed below.

2.3. Background of Study

In engineering improvement initiatives, lean has become the most popular word and ‘The Machine that Changed the World’ by Womack et al. (1991) acknowledged Toyota as the developer of the term lean that is able to improve the manufacturing production. Following the popularity of the term lean, ‘lean thinking’ philosophy became the trend in the manufacturing industry process management. The five lean principles which promote the elimination of waste are: (1) specify value; (2) identify the value stream; (3) flow; (4) pull; and (5) perfection (Womack et al. (1991). The following sub-section will overview the evolution of the lean thinking philosophy and the subsequent sub-section will identify the applicability of the philosophy to construction industry.

2.3.1. Lean Thinking

The lean history can be traced back in early 1900's from the production process of Henry Ford car manufacturing system (Mossman, 2009a). With the integration of the production system of car production, this company was initiating some innovation in their car production line. They identified some shortcoming in their production line where some parts and components of the car model is not similar and can not be used with their other models. This creates problems in manufacturing the specific parts and components for the particular car model which creates waste in terms of resources. In solving this problem, Ford improved the flow of the manufacturing by combining interchangeable parts and components that can be used in almost every model. They made this as a standard process for their car production to reduce the manufacturing time of the car and the cost of labour to install the similar parts on different car models. With this improvement, they were able to increase the production to a level that had never been achieved before. This type of production has come to be known as 'mass production'.

Subsequently, in the early 1950's, the American cars were under pressure in the market due to higher cost and the lower quality of the production (Mossman, 2009b). Japanese cars on the other hand, were able to produce better quality cars at a lower cost within the same market. Furthermore, these cars were built in less time, used half of the space and had fewer defects. This drove the car manufacturers in America to study the way the Japanese manufactured their cars.

The results of the study revealed that Toyota car manufacturer was revisiting Ford's original thinking which is improving the flow of manufacturing and improved the system which called lean manufacturing system. Womack et al. (1990), in their book, elaborated the lean principles as the elimination of waste in the process activities to reduce the process cycle. This improved the quality of the product and increased the efficiency of the production.

In the lean context, engineer from Toyota called Taiichi Ohno defined waste as the overproduction, over-processing, delay, excess inventory and motions, failure, and defects (Ohno, 1988). As a result, Toyota developed as system called Toyota production system (TPS) that function as elimination of wastes in the manufacturing process.

There are five further steps that support the TPS based on Taiichi Ohno innovation towards improvement of deficiency in a system:

i. Create a standard worksheet: Standard methods for each procedure.

ii. Instilling a team mentality: Focusing the process of the production as the product moves from one process to the next.

iii. Addressing supply: Adoption of Just-in-time (JIT) method.

iv. Adopting Kanban: 'Kanban' is a method of visualising process and is used to control the JIT supply known as scheduling system for inventory control in manufacturing that is designed to identify and eliminate bottlenecks in the processes.

v. Production Levelling: The production is done according to the demand and the capacity of production to produce the item in a specific time.

2.3.2. The Principles of Lean Thinking

As stated above, with the principles of lean production derived from Toyota manufacturing company, the significant success achieved triggered the adoption of LT in the non-automotive industry. As engineer Ohno working on the identification and elimination of waste, whereas Womack and Jones developing principles based on TPS so that they can be applied in other areas of industries.

Hence five basic principles of LT were established: value identification; value stream

mapping; value stream flow; achieving customer pull; and striving for perfection and continuous improvement. These are explored below.

Value Identification

Specifying value is the initial step to identifying waste in an organisation. In identifying the value, one should consult the ultimate customers in order to interpret it (Womack et al., 1991). According to Leite, they can be divided into internal customers and external customers (Leite et al., 2013). The internal customer is the next phase of the process that receives the product or outcome and value for the participants of the delivery team, whereas the external customer can be the client for the project and the value that the project should end up with (Emmitt et al., 2005).

However, Leite et al. (2013) argued that in building construction projects, the client was one of the stakeholders and in consideration of taking other stakeholder views, Leite suggest that it is necessary to have an approach of specifying value for each of the stakeholders. Therefore based on the consideration of stakeholders, design process should look into the both internal and external stakeholders in order to properly identify value.

Value Stream Mapping

This is the identification of all the activities and tasks required to make the product, creating value by mapping each production process.

There are three critical management evaluations that the activities and tasks need to go through:

Problem-solving - This is the development of solutions to the problems from concept through detailed design and engineering to production launch.

Information Management - This is the acquiring of client's requirements through detailed scheduling to delivery.

Physical Transformation - This is the conversion of materials from raw to the finished product in the hands of customer.

The identified activities then classified by the following designations:

1. Activities which unambiguously add direct value to the construction projects.
2. Activities which add no value to the construction projects but are avoidable with the current technological limitations of the production processes/technologies.

3. Activities which add no value to the construction projects and are immediately avoidable.

In lean construction, there are three theories that can be associated with the production. Transformation oriented where value can be achieved through resources such as workers and machines.

After the value stream has been mapped, all the classified activities should be eliminated from the total production process.

Value Stream Flow

The subsequent step is to make the value-creating steps in the process. This is where the product is developed through a series of processes. In construction projects, the process can be varies depending on the requirement of internal customer in the next stage of the process (Leite & Barros Neto, 2013). Such requirement might be in a form of information such as the full measurement of the building drawing for quantity surveyor to do ‘quantity and estimating’.

Achieving Customer Pull

According to Womack and Jones, (1991), the “pull” in lean can be defined as where the upstream production can only produce goods or services when the downstream asks for it. The customer will be able to pull value from the producer faster and the customers will also be able to order on the basis of current need. This will create reduced production lead times and product development lead-time. In construction, the pull in can be defined as, any issues in the construction phase of a project are discussed at the design phase to provide solutions. This is where the project team and relevant stakeholders give their ideas and make decision based on their experience and expert.

Striving for Perfection and Continuous improvement

Womack and Jones (1991) defined this stage as the on-going process of waste identification, which goes back to the initial stage of what the customers want. They also warn that there might be waste removed and technology utilised in the first round of the process, but this might remove one type of waste but incorporate a less significant ‘new waste’. In manufacturing, similar process can be done over multiple times. This allows for detection of error and mistakes during the process. However, in view of the construction project as one-off project and high level of customisation, so many variables can contribute to the success or failure of the project. One of the variables in construction projects is the project team that always changing rom project to project. Therefore the continuous improvement might be impossible to achieve. On the other hand, different approach is suggested where the organisational learning can be established where the collective experience is initiated through knowledge management in order to achieve continuous improvement.

2.4. Lean Thinking in Construction

The LC concept has been studied and promoted since 1990s. There are two organisations that are continuously working on the development of LT in the construction industry namely, the Lean Construction Institute (LCI) from the United States and the International Group for Lean Construction (IGLC).

The term ‘LC’ was introduced by Koskela (1992) in his report in the first conference hosted by IGLC in Finland. He concluded that there are many approaches and solutions to improve construction performance, but with the production philosophy from the manufacturing industry, the construction industry will have the potential for tremendous improvement and solutions to the chronic problems currently suffered. This conclusion led to further investigations among researchers who have interests in improving construction performance.

A review made by Biton & Howell (2013) on the past research papers presented at the meeting held by International Group for LC between 1992 and 2000, proposed that the construction industry should embrace production principles and techniques when managing projects. Also, Biton and Howell emphasised on the poor performance of the construction which has become a long-term problem in the construction industry and they suggested that a change should be made to the management of construction (Biton and Howell, 2013).

Following that, other researchers agreed with a change in the management of construction, as there had been a degree of pressure to force the construction industry to improve its modus operandi, taking into account the global pressure of competition with political and economic considerations (Egan, 1998).

Traditional management methods, focused on contractual relationships and scheduling (traditional method) as a project management tool, have always been reported as having a poor delivery record in terms of time, cost and quality. Furthermore, Koskela and Howell (2002) called for reform on the underlying theoretical foundation of project management, as espoused in the Project Management Body of Knowledge guide by Project Management Institute, declaring it obsolete (Beatham et al., 2004). This encouraged the LC community to argue that there is a better way to manage projects.

The new philosophy introduced by Koskela provided a basis within likeminded academics and professionals to change for the better in managing building construction projects. The proposed new model was synthesised by Koskela from the principles of Transformation, Flow and Value generation (TFV) in Table 2.1.

Table 2.1 Production Principles

(Source: Koskela and Howell, 2002)

Subject theory		Relevant theories
Project		Transformation Flow Value generation
Management	Planning	Management-as-planning Management-as-organising
	Execution	Classical communication theory Language/action perspective
	Control	Thermostat model Scientific experimentation model

Based on these principles, the development of LC became a theory of the principles of TFV and management. This model is capable of assisting the construction industry in delivering projects efficiently and resolving conflicts effectively (Biton and Howell, 2013).

Since the 1990s, LC has been aimed at enhancing project management by eliminating waste, improving planning efficiency and reliability, improving productivity and maximising value. LC has been called the new way to manage construction more efficiently and effectively (Biton and Howell, 2013). The continuation of development on LC has been predicted by Ballard et al. (2002), with conclusions that state:

> *"A true revolution in construction management is underway and it is as yet far from achieving its full potential. Indeed, the lean ideal suggests that 'full potential' will never be reached, as pursuit of the ideal eclipses all previous performance benchmarks. New tools and techniques will undoubtedly be developed in the never-ending pursuit of perfection."*

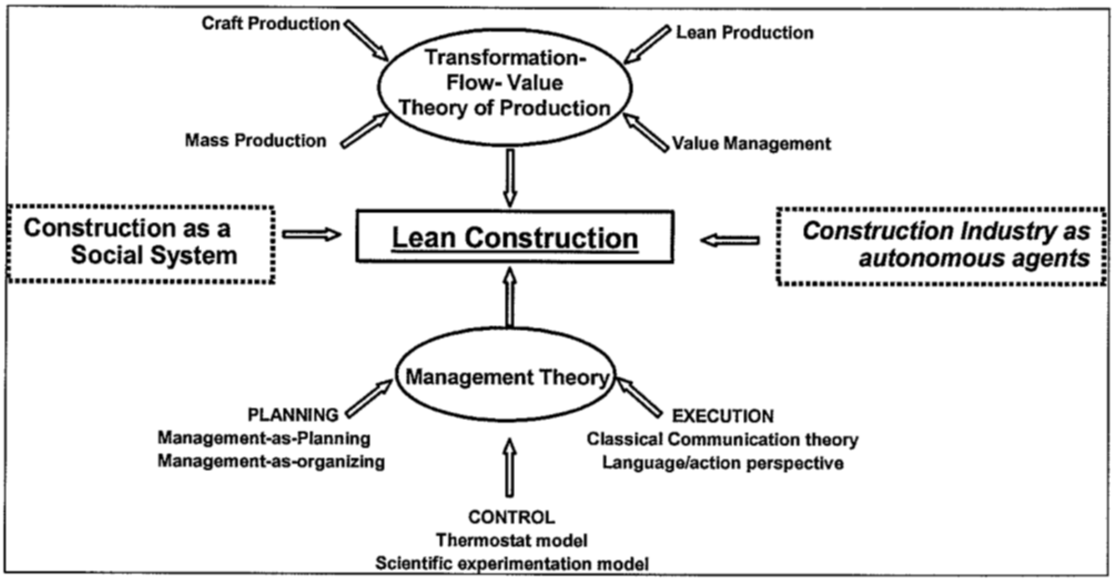
Ballard is thus predicting changes in various aspects of LC development related to the new version of the aims, goals, theoretical values concept techniques and tools in this field. These have yet to be seen by practitioners interested in construction.

From this summary, it can be seen that perfection is not the aim of these new management techniques. As time evolves, new tools and techniques need to be developed and absorbed into the construction management process. If perfection is not the element pursued, then it is safe to say that by adopting and developing these tools and techniques, this will help in creating a much improved management system in the hope of achieving the expected results in projects.

An alternative view was provided by Abdelhamid, who revealed the validity of LC theory by reviewing the theory of production (TFV) and theory of new management, as had been developed by Koskela (1992) and Koskela and Ballard (2002) respectively (Abdelhamid, 2004). Abdelhamid used Boyd's theory of 'Destruction and Creation' to show the robustness of LC theory and how it will be obsolete if the nature of construction is considered to be a complex system. A new theory of LC was synthesised, along with a theory of new management, with the complexity system that was explored by Bertelsen (Bertelsen, 2002), creating one model as presented in Figure 2.1 Conceptualise Lean Construction. This shows the amalgamation of the theories which Abdelhamid predicts will sustain the validity of LC with the complexity of the construction system.

Figure 2.1 Conceptualise Lean Construction

(Source: Abdelhamid, 2004)



2.4.1. Benefits and Barriers in Implementing Lean Thinking in Building Construction Projects

The early work by Koskela (Koskela, 1992) showed that for construction, there were three aspects of lean production that need to be considered to achieve the same benefits as derived from the manufacturing industry: a production method that is effective and waste-free; a philosophy of general management; and tools and techniques for quality improvement.

Later Koskela (2000) defined the production method practiced in construction was seen as process flow rather than conversion only. This is due to the conventional method of production in construction project only focusing on schedule and cost of activities without considering the value of the customer. Hence the theory of TFV developed in order to resolve the deficiencies. Furthermore, benefits of adopting these kinds of perspectives were predicted to lead to the removal of non-value adding activities, such as waiting, transporting and inspection of materials. The general management philosophy for adopting lean production is by re-organising the workforce to allow new operating processes and readiness for cultural changes within the firm and individuals. These can be achieved effectively with the support of tools and techniques which were developed specifically for any particular industry.

A number of case studies reported in the literature review identified the current good practice tools and approaches in the implementation of LC. Implementation of LC has happened in various countries around the globe such as Australia, Brazil, Denmark, Equador, Finland, Peru, Singapore, the United Kingdom, the United States, and Venezuela (Ballard and Howell, 2003). However, the procedures used in the

implementation of LC was inconsistent between the countries and organisations generally apply one, two and at most four varying tools (Al Sehaimi et al., (2014); Picchi and Granja, (2004); (Al Sehaimi et al., 2009); BRE (2003); (Skinnaland and Yndesdal, 2010); (Tezel and Nielsen, 2013)).

Yet lean tools and techniques are very powerful in achieving high performance in building construction project provided that all elements of the lean system are applied (Bashir et al., 2013).

Another study classified a set of nine implementation barriers to adopting LC (Ballard et al., 2002): fragmentation and subcontracting; procurement and contracts; culture and human attitudinal issues; adherence to traditional management concepts due to time and commercial pressure; financial issues; lack of top management commitment and support; design/construction dichotomy; lack of adequate lean awareness/understanding; educational issues; and lack of customer-focused and process-based performance measurement systems (PMS). These barriers can be used as guidance for developing a framework model for lean implementation. Two studies compared LC implementation (Sarhan and Fox, 2013): one was made in the United Kingdom (Tezel and Nielsen, 2013), which demonstrated a higher awareness of LC; the second was in the Netherlands (Common et al., 2000), which demonstrated limited knowledge in LC. In those studies, despite the different levels of awareness in each country, both countries' practice demonstrated a slow adoption rate of the lean.

It is concluded that slow implementation should not be considered a barrier to implementation, as there are other factors which may contribute to the slow adoption rate of the lean movement. In other words, the barriers listed above are in no way exhaustive and they may differ from one construction industry/country to the other.

Other implementation factors could be drivers that motivate practitioners to use LC in their project. Most of the drivers are identified as the inherent problems of a building construction project, as identified by a number of parties (Johansen et al., 2002), (Ahiakwo et al., 2013), (Cerveró-Romero et al., 2013), (Fernandez-Solis et al., 2013) and (Fuemana et al., 2013); these papers identified various motivation factors by using lean principles in building construction projects, ranging from: issues of planning; funds; inflation; bankruptcy of contractors; variation of project scope; political factors; productivity; competency of project managers; estimating; adequacy of cost control; product designs; and delayed payment of contractors and suppliers.

Considering the above factors, LC practitioners aimed to create a solution to the way the building construction projects are managed. With the known existence of these drivers, the decision process behind adopting LC was then considered. The perceived benefits from the previous case studies, research findings and explorations of LC also played a role in influencing practitioners to adopt the lean production principles. Although there are a number of LC tools and techniques developed to support the Lean production principles, the most popular LC tool is the Last Planner System (LPS). This system was developed by Ballard and it has been considered as the best known LC technique which have been tested and refined over the last decade (Al-Sehaimi et al., 2014). With the development of this LC tool, its implementation was not seen as a straightforward application.

Al-Sehaimi showed case studies from different countries and continents which try to implement LC (namely Mexico, Nigeria, Brazil, New Zealand and Saudi Arabia) that there was one common barrier to implementing LC. All of them suffered from the ‘transition of method’ problem. The transition of method can be explained as bringing all parties working in the project to embrace a new system after having been used to the traditional way of working (AlSehaimi et al., 2014). This type of barrier should be considered significant, as most new systems introduced may cause a negative impact on the projects. Therefore, the implementation strategy needs to be planned before the implementation of LC and all parties involved should understand every aspect of LC well. Although some researchers have stated the above as a barrier, some have not, although they may have experienced it. This may be because they may not regard transition of method to be a difficult issue or problem.

Other barriers mentioned by (Ahiakwo et al., 2013), (Ahiakwo et al., 2013), (Cerveró-Romero et al., 2013), (Barbosa et al., 2013) and (Fuemana et al., 2013) are: promoting understanding to the field employees, lack of knowledge of LC, lack of top management commitment, partially or incorrect implementation, first time user difficult to cope with experience user, participants not willing to be transparent in discussion, and designer reluctant to contribute during the construction process.

Taking into account the above issues, although there are benefits from implementation of lean principles in construction industry, there appears to be an inconsistency of procedures and methods of implementation used by the five case studies reviewed. With this inconsistency, it is difficult for the interested parties and practitioners to adopt LC to any building construction project.

2.4.2. Importance of Design in Building Construction Projects

The design phase is a vital part of any building construction project. The approach taken in the design phase will affect the overall success of a project and the effectiveness of meeting the expectations of the client. The impact of design at the initial part of the building project has major influence on the life cycle; it can have either a bad or good impact on the project's performance (Austin,1999; Ballard & Koskela, 1998; Cornick, 1991; Tzortzopoulos & Formoso, 1999).

The main issues that develop with design are usually due to the combination of poor communication, unbalanced resource allocation, lack of coordination between disciplines, and erratic decision making (Tzortzopoulos & Formoso, 1999). They added that this was due to the complexity and uncertainty in design process.

Design in building project can be considered an iterative process, which requires assumptions and estimates of information (Austin et al., 1999). These assumptions and estimates will lead to the repetition of work until a solution is achieved. Most of the design management and control tools are using techniques which control construction activities. Thus, it is realised by some researchers and practitioners that design activities are different from construction activities and should be treated differently to get appropriate results, arguing that network analysis is only appropriate for the planning of construction activities; network analysis cannot account for the iterative nature of design, which commonly only makes small changes, yet sometimes can create large changes to the design, or even revert to the original design.

In terms of monitoring the progress of design, the output is normally assessed by the completed number of drawing, which does not quantify the amount of design effort in such drawing, or the resulting construction effort, and the effort cannot easily be measured. One of the reasons is the iteration process of design, compared with the construction stage that has sequential processes (Alarcón & Mardones, 1998; Austin et al., 1999).

- In design, activities use iteration processes, where the solution can be reviewed and much effort focused on solution improvement, rather than the design outcome such as a drawing, which is why the number of drawing cannot be used to quantify effort.
- The sequential processes applicable to construction activities can be quantified and the progress can be programmed, monitored and controlled.

In addition to that, Alarcon identified other problems in the design phase (Alarcon & Mardones, 1998). These were the lack of interaction among designers, constructors and specialists when producing the complete design. This results in unreliable solutions, constructability deficiencies and increased numbers of change orders in the construction phase.

The project life cycle for a building has various stages and steps, including the client's brief (sometimes called the "Employer's Requirements"), the outline design, the detailed design and the construction (e.g. Winch, 2010). The stages are usually in a sequential dependent process, where the following stages rely on the current and preceding stages. According to Haponava, during the design stage, the level of efficiency of the project can be affected due to the poor design and will affect the final product (Haponava & Al-Jibouri, 2010). This can give a chain reaction effect to the later stages if any substantial developments and changes are made, or information is late or otherwise poorly prepared.

2.5. The Building Design Process

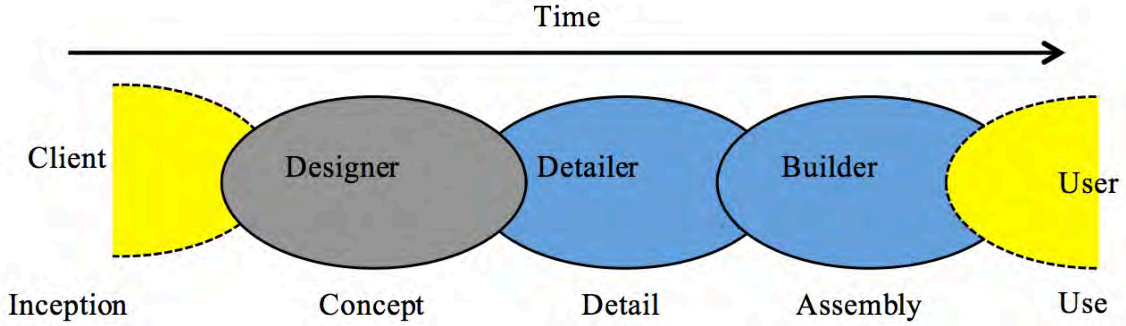
The review of literature for the building design process in this section is part of the conference paper presented by the author of this thesis published by ARCOM. Generally, the construction process can be divided into three large phases: Project conception; project design; and project construction (Chan & Kumaraswamy, 1997). This can be described as linear project delivery (Emmitt, 2002).

- Project conception involves clients and designers and is identified as the inception phase where feasibility of the ideas and intention are being analysed.
- Project design involves two sub-phases where designer and detailers work together to produce first an outline or "concept" design and then convert it to the detailed design.
- Subsequently, project construction is assembly where builders materialise the clients requirements.

These phases are completed over a specific time period as illustrated in Figure 2.2.

Figure 2.2 The Linear Project Delivery Model

(Source: Emmitt, 2002)



The construction process is also referred to as the design and production process, also variously “design and construct” or “design and build”, which have been practiced in different countries such as USA, UK, Australia and Canada (Yusof et al., 2015). On this type of project, the design and production phase obviates detailed design and commonly introduces an additional step of “value engineering”, where the design and construct team review the outline design and sometimes the original project conception, to offer alternative approaches.

In the USA, the design and production process is started by analysing the site and the programme, which is then followed by a schematic design and design development. Then the construction phase comprises of preparation of construction documents and bid/negotiating for the administration of construction (AIA, 2007). The is also said to be where an architect prepares study drawings, documents, or other media that illustrates the concept of design for client’s review during the schematic design (Lam et al., 2012).

In the UK, the Royal Institute of British Architects (RIBA) adopts different terminologies for the phases, with every phase being denoted by a number starting from Stage 0 (Strategic definition) to Stage 7 (In Use), with therefore eight phases and which are named “Stages” in the RIBA Plan of Work, 2013 edition; this is a revision to the previous RIBA Plan of Work 2007, where it was previously applicable only for single procurement routes. With the Plan of Work 2013, the outline can be customised. The Task Bars, which was known previously as ‘Description of key Tasks”, can be switched on or off depending on the type of project.

Starting from Stage 0, the project is appraised and defined before the detailed brief is created. Stage 1, is the preparation of activities and briefing of the project. Stage 2, is the development of concept design. Stage 3 is the development of design and at the end of this stage, cost information is prepared. Stage 4, will include the Technical design of the project. These stages can be considered as the planning and pre-construction process of a project. Thus, the remaining stages would be the construction and post-construction process where Stage 5, 6 and 7 are Construction, Handover and In-Use respectively.

In Canada, the construction process follows a five-phase approach: schematic design, design development, construction documents, bidding or negotiation and contract administration (RAIC, 2009). In Australia, the construction process is similar to the RIBA Plan of Work 2007.

Although the construction process has been established in these countries, there is a lack of detail on how these phases should be carried out (Orihuela et al., 2011). While it has been suggested by the Institutions that these are only guidelines for the practitioners, nevertheless, these approaches still lack details of the activities that need to take place (Yusof et al., 2015).

The guidelines set out above are made easy to follow and to understand. However, from a practical perspective, it is also very complicated (Freire & Alarcón, 2000), and the architectural design process itself possesses complicated management problems. Freire explained that the problems in design involve thousands of decisions which may take over a period of years to be resolved. However, all the guidelines for the process above are still valid and practiced regardless of the problems encountered by the practitioners (Yusof et al., 2015).

2.6. Research Trends in Application of Lean Thinking in Building Design

In identifying the research trends a systematic literature review has been conducted. The literature that focused on the research area of design in building construction projects was considered. Then the topics of research were collected where any similar terms that have same meaning are put in one theme. Further, the themes are divided into categories for easy identification. There are seven categories that are relevant to the research theme established (Appendix A).

Literature can be one of the tools to find the trending areas that are favourable for research in the design phase, giving indications of saturation or self-destruct (Abdelhamid T. S., 2004), where old theories can be diminished and replaced by the new theories, due to the availability of new empirical data that create chaos to the existing theory. This is also true with the adaptation of Boyd’s theory to make evidence clear. Hence the following trend in design represents new research areas that have been explored.

The largest number of category is in the area design process. The design phase is considered the most important phase in a building construction project, as it is well known to be influential on the construction life cycle and can affect the performance of the whole project (Formoso et al., (1998); Venkatachalam et al., (2009)).

Identification of the research trend is based on secondary data, which have been collected from the study of the design phase in the building project as presented in Figure 2.3. Many publications dated within the last five years give current trends, yet publication beyond this time period would be considered as ‘continual improvement culture’ (Mossman, 2009b). Thus using this time cut-off, the number of relevant publications is reduced to 92 items from various resources, including journals and proceedings.

There are 35 themes of published papers identified and these have been categorised into seven groups. The seven categories can be described as follows:

1) Application: those applying the lean principles into the design.

2) Design Management: those developed and innovate the design process

3) Design process: improve the process flow of the design to be effective

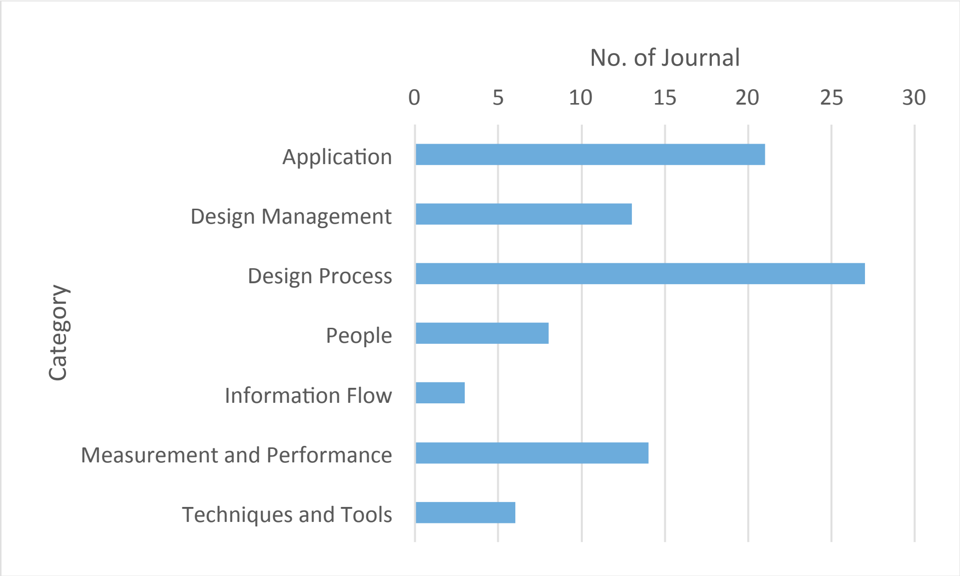
4) People: focusing on the involvement of the design team and stakeholders.

5) Information flow: effective management of the information where interpreting values is the main focus.

6) Measurement and Performance: looking into the effective performance of construction design and design process and development of the performance measurement at the early stage of the projects.

7) Techniques and Tools: development, utilising and implementing the techniques and tools available for the design in order to improve the projects.

Figure 2.3 Categorisation of Theme on Design Topic



The lack of self-operating architecture is said to be one of the causes of low productivity, creating uncertainties in the building construction project (Lee et al., 2012). This refers to design process that is using Point-based Design (PBD) processes that would not be able to take account of problems that appear when the construction process has started. This is due to the characteristic of building design that is considered as unique, which creates complexity to the management of the project (Mohamad et al., 2013). Project complexity can be reduced by the introduction of modular construction, utilising off-site construction principles. However, Mohamad argues that the procedure in adopting this method of design needs to be developed to align the nature of the building project as a one-off concept. This is because customer satisfaction is difficult to achieve with standard design, as the individuals have their own design constraints and aspirations.

Another research trend in design that appears in the literature review is the effort of improving the overlapping activities between design and construction. Primarily, the overlapping method is adopted to reduce the length of project completion. Analysis shows that the preliminary information has influenced in the amount of design rework during the construction (Hossain & Chua, 2014).

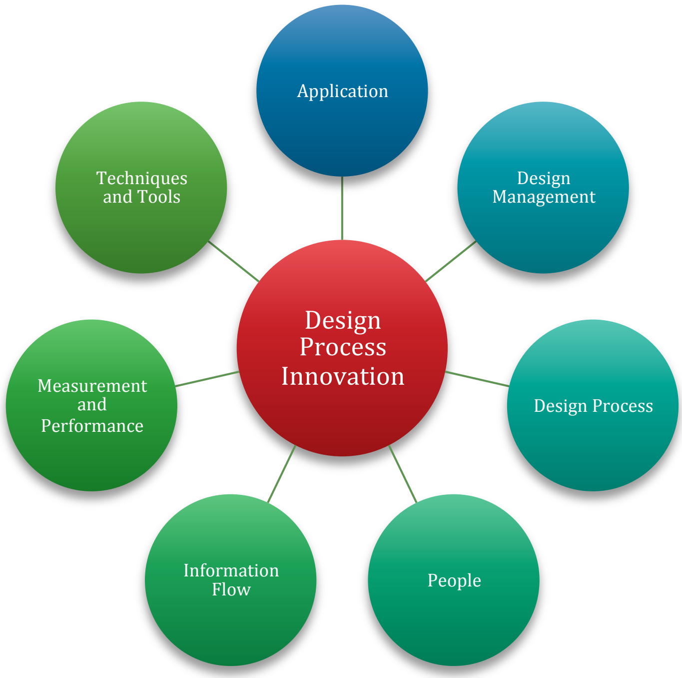
The ability of the Project Manager (PM) to handle the complexity of the project was the topic of study by Ahadzie et al. (2014), concluding that the knowledge required by a PM should be related to the job being undertaken. At the same time, the PM should possess various items of job knowledge that are relevant to the project management environment.

The research trends in design can be identified through categorisation of the research relevancy and the theme the research falls into.

In a review of the design research area, the categories of the themes can be used as the 'knowledge domains'. Through this review, the author found that design process innovation has focused on what elements that need to be considered in order to improve the project performance, rather than recommending the method of implementation.

Subsequently, these domains create a framework for innovation of design process, depicted in Figure 2.4.

Figure 2.4 Integration of Knowledge Domains for Development of a Framework



The design process innovation is the integration of the seven knowledge domains identified from research in the design area. These domains will be used for the development of framework for innovation for lean design process that will be elaborated more in Chapter 5.

2.7. Representation of Lean Construction

Three frameworks have been put forward to represent lean construction implementation. These frameworks are significant in terms of the methods of integration with other principles and theories in order to achieve improvements on various aspects such as process, implementation, quality, time and effectiveness. These frameworks will be discussed in this section.

2.7.1. Lean Project Delivery System

The Lean Project Delivery System (LPDS) (Ballard, 2000) is shown in Figure 2.5, giving the model theory for a project-based system that can be applied to building projects.

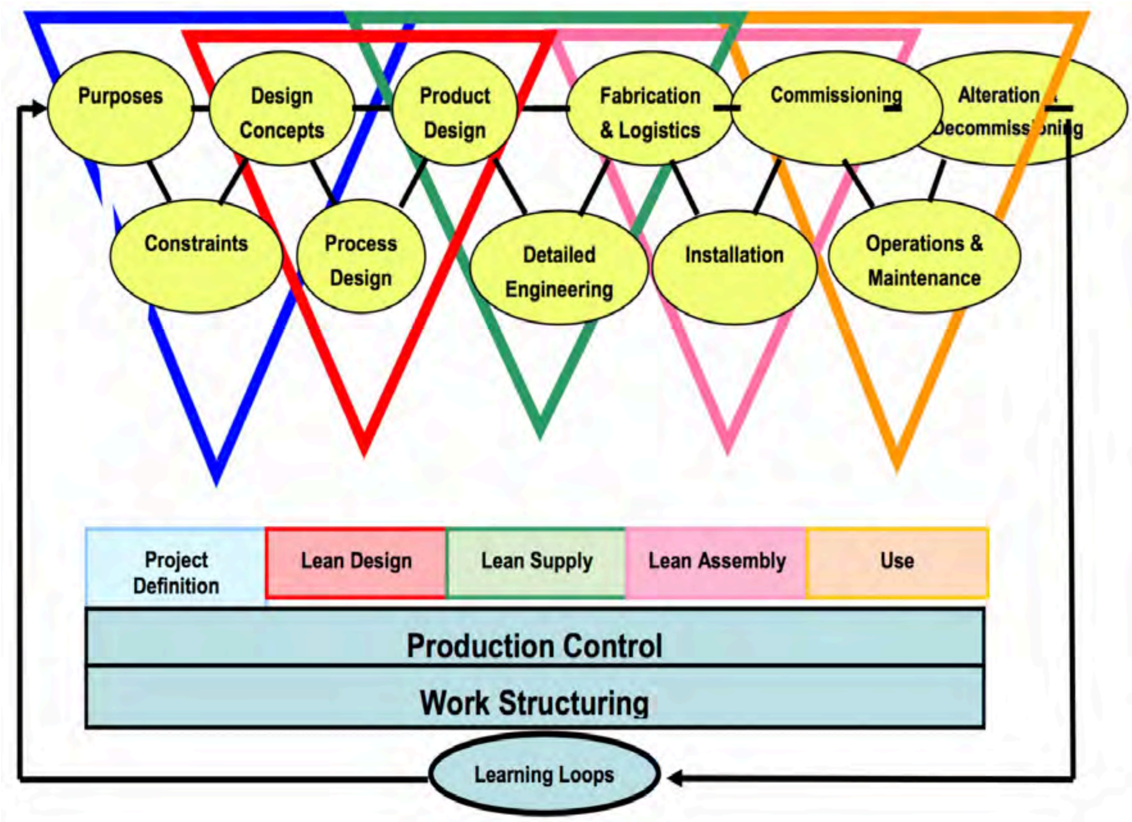
This model is claimed to be suitable for the temporary production system as can be referred to building construction projects where the project team member only work for the specified project together. As building projects are considered to be one-off organisations, where different project elements such as tasks and specialists are not similar to other projects. Therefore, this model is suitable for the implementation of LC. The features of the model are listed as follows (Ballard, 2000):

- The project is structured and managed as a value generating process;
- Downstream stakeholders are involved in front-end planning and design through cross-functional teams;
- Project control has the job of execution as opposed to reliance on after-the-fact variance Detection;
- Optimisation efforts are focused on making work flow reliable as opposed to improving Productivity;
- Pull techniques are used to govern the flow of materials and information through networks of cooperating specialists;
- Capacity and inventory buffers are used to absorb variability;
- Feedback loops are incorporated at every level, dedicated to rapid system adjustment; i.e., learning.

This system introduces the elements of life-cycle of construction project where the lean principles are incorporated. There is interlink within each triangle of the project stage and there is interconnectivity between the former and subsequent stages. The structure of the system can be adopted for this research. However the are missing details of stage activities and method of execution for each stage.

Figure 2.5 Lean Project Delivery System

(Source: Ballard, 2000)



2.7.2. Lean Construction Framework with Six-Sigma

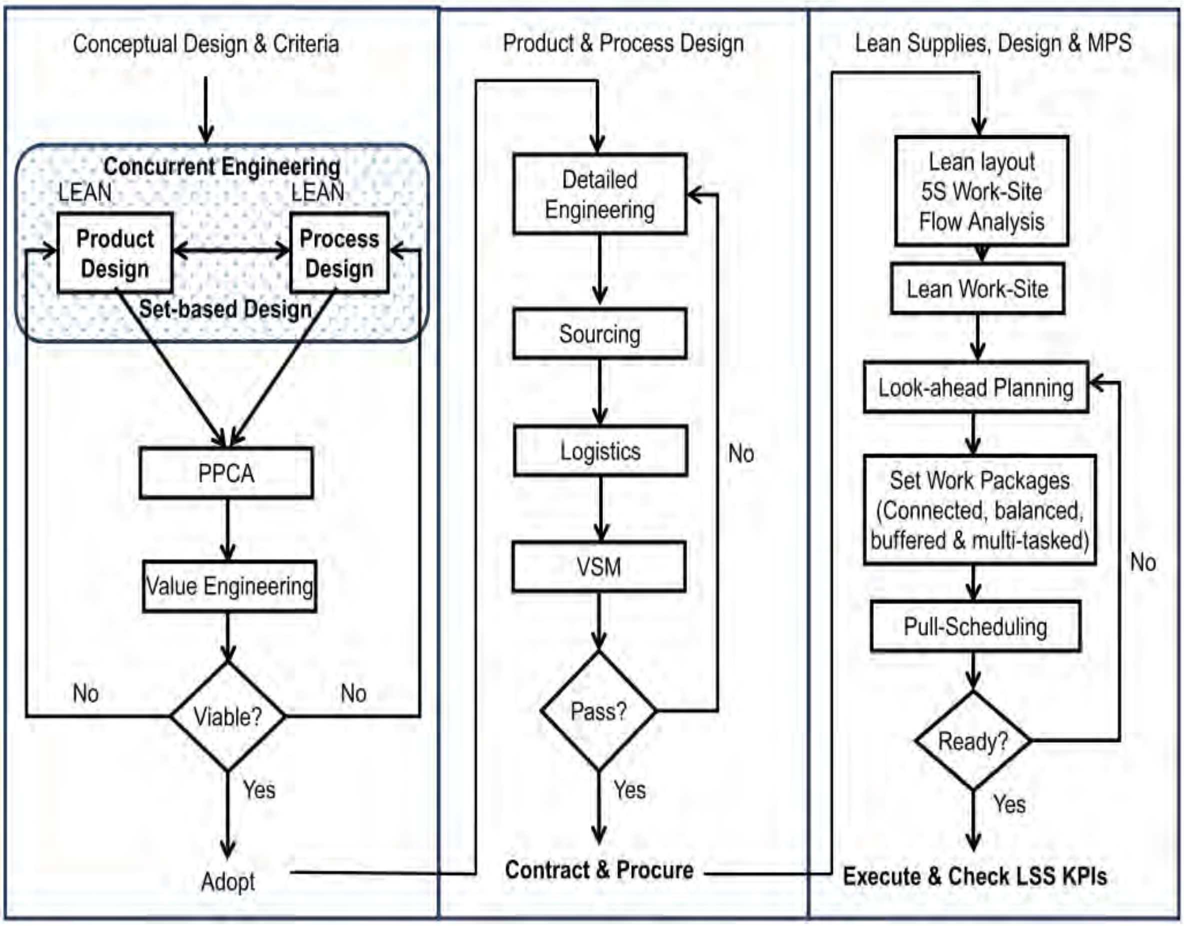
The framework shown in Figure 2.6 is based on the outline of the relevance and role of various lean practices at each stage in the building construction project (Al-Aomar, 2012). The development uses guidelines provided by LPDS of LCI (Ballard, 2000). The approach emphasises LT during all activities in the project stages in order to implement LC. The framework includes the design-supply-assembly process, which integrates lean practices at each stage to complete the lean transformation. Then, Six Sigma is used to assess the building construction PP. The significant of using Six Sigma in this framework is to improve quality, reduce variability, and error. The Six-Sigma process is comprised of six steps process named define, measure, analyse, improve and control. This will reduce variability and increase quality and at the same time will quantify the performance.

The cycles will continue to iterate until the project is successfully completed and a lean delivery process is then set to transfer the project to the client. The lean construction framework depicted also utilising the elements of project life-cycle. The approach is by the integration of two principles that can improve project performance and measure the achievement of performance which can be used for benchmarking of the work quality. As in this research is seeking the effectiveness of the project performance therefore the approach of integrating two or more different principles can be applied. Although the proposed framework can be adapted to other segment of construction industry, most of the recommended tools, waste identification and elimination have to be refined if it is going to be utilised in design phase of construction projects.

Furthermore the six sigma approach in quantifying the work activities would be limited if it is going to be applied in design phase for example there is no definite percentage of completion in design in order to measure performance as recommended by this framework.

Figure 2.6 Lean Construction Framework with Six-Sigma

(Source: Al-Aomar, 2012)



2.7.3. True North Route Map

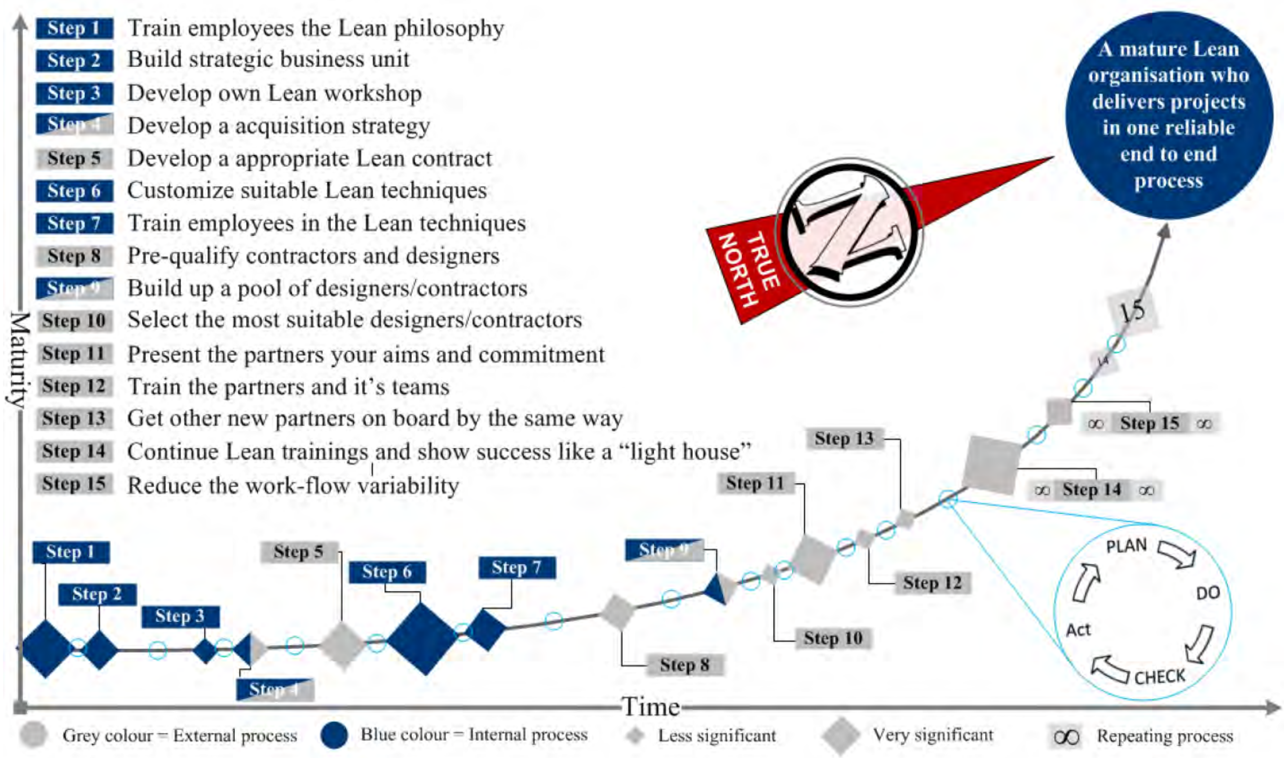
This framework model was developed for Germany's construction environment, where a construction management company desired to have a new strategy on the improvement of the project productivity, to enhance stakeholders' satisfaction and to achieve high-quality construction (Nesensohn et al., 2013). Based on this, the stakeholders decided to adopt LC principles and practice. The decision was said to be relevant to the implementation of a desired new strategy, where previous researchers have indicated the availability of benefits of lean principles (Nesensohn et al, 2013). In developing the framework, the company reviewed the TPS and used the benchmarking approach to validate the process of lean application in various companies that already implemented lean principles. Then, a framework was proposed, called a route map by the researchers, which was considered as a guide for the implementation of LC in the construction management firm. This framework was called the 'True North route map' (Figure 2.7).

The development of this framework is based on the Reading Model for benchmarking. Nesonsohn claimed that the selected model for benchmarking is easy to implement and flexible in different situation which makes it suitable for construction projects. Although the framework proposed was intended to be used in construction, its direct applications of the lean principles will not have the same impact as LC tools are used, because the nature of the building construction project is based on using the project-based system (Nesensohn, 2013).

Nevertheless the method of adopting different model for construction is feasible. The integration of lean principles and lean construction in design phase requires different approach. This research will adopt the approach of using suitable model and develop the details according to the design context of construction projects.

Figure 2.7 True North Route Map,

(Source: Nesensohn et al., 2013)



2.8. The importance of value in design

The concept of value in a building construction project can be defined in various ways and using various terms. This is mostly dependent on the perspective of the team, individuals or stakeholders. The value should be a comprehensive definition to everybody, in which all perspectives should be considered (Tillmann et al., 2013). Value in construction can therefore be defined as achieving a project purpose, or meeting the reason that motivated its implementation. These could be the secondary goals of the project, which become the most satisfying outcome for the project team: an example would be a building that is constructed for the main purpose of business centre that then becomes a prominent landmark (Tillmann et al., 2013).

For a complex project, there is a challenge in focusing on value-generation in project management, as the focus is to solve the complex problems of the project (Tillmann et al., 2013). Value perception is normally based on the human preference, which might prove to be contradictory among the different parties, such as the building construction project coalition, the project team and external stakeholders (Winch, 2006).

According to Koskela, creating value for the client can be through the fulfilment of project constraints e.g. time and cost (Koskela & Ballard, 2006). However, this fulfilment should be synchronised with the client's needs and requirements. Therefore, value management techniques in lean design management can be utilised to engage stakeholders and to agree on the project goals, which is usually held in the design briefing (El.Reifi, Emmitt, & Ruikar, 2014).

The design briefing at the early stage of the construction life cycle is considered a vital step in understanding and communicating the client's requirement and this will contribute to the value generation.

2.9. Performance Measurement

The influence of performance measures on behaviour, means they are able to induce certain courses of action. The performance measures are able to affect the implementation of strategies, as they state what to expect and what outcome will be expected. The performance measures are also being used for the strategic control loop, which can show whether objectives have been met (Neely et al, 1996). These measures are also used to establish competitive advantage for a firm on the non-financial aspects of objectives, which can be used to indicate performance (Waal & Counet, 2009).

Performance improvement has been given attention by researchers in the construction industry. However, there is less publication of research on performance improvement found in the design phase of the project compared to the construction phase. This might be due to the different understandings and definitions of performance itself. According to Yin (2009), the definition of performance is diversely defined in the design phase. As a result, he has listed the various definitions of performance related to design. Based on that, this research adopted the definition of performance as a process of quantification and action which consists of a set of metrics to quantify the PP identified. PP for this research can be referred to the quality, time cost and sustainability.

It would be advantageous to have a performance indicator in a project. This will enable the architect to assess the quality of his design and services. In ensuring quality, future clients will be assured of the existence of quality in projects and more business will be secured through that architect.

A uniform understanding of the term 'performance' is essential to achieve efficiency and effectiveness on a project. Performance measurement can be defined as a process of quantifying action and that action can be referred to achieving goal by satisfying customers with efficiency and effectiveness, while performance can be defined as the efficiency and effectiveness of action and the measurement is the process of quantification (Neely et al., 1996). Neely also defines other terms used in performance measurement, as summarised in Table 2.2.

Table 2.2 Definitions of Performance Measurement

(Source: Neely et al., 1996)

Term	Definition
Performance measurement	**The process of quantifying the efficiency and effectiveness of action**
Performance measure	**A metric used for quantifying the efficiency and/or effectiveness of action**
Performance measurement system	**The set of metrics used to quantify the efficiency and effectiveness of action**

The terms in Table 2.2 can be considered as the essential components in developing performance measurement. Although these definitions are still valid, it has more recently been argued that these definitions should be extended and proposed some additional definitions as follows (Bourne & Neely, 2003):

"Performance measurement (as promoted in the literature and practised in leading companies) refers to the use of a multi-dimensional set of performance measures. The set of measures is multi-dimensional as it includes both financial and non-financial measures, it includes both internal and external measures of performance and it often includes both measures which quantify what has been achieved as well as measures which are used to help predict the future."

With the concept of a multi-dimensional set of performance measurement, it is appropriate to look at the procedure of performance initiative that has been developed. According to Bourne & Neely (2003), performance measurement can be divided into procedure and approach perspectives. They developed procedure with three categories of 'need led', 'audit led' and 'modelled'.

- The 'need led' category is the top down procedure, where the needs of the customer, the business and the stakeholders are identified. Then, these needs are used for the basis of performance measurement. The intention of this approach is to monitor the progress towards achievement of the needs.
- The 'audit led' approach acts as the corrective measure to improve the performance. Thus, the approach is bottom up to the design of a performance measure.
- The last approach, 'modelled', is designed to measure the performance by developing a structured methodology of organisation of the attributes.

Subsequently, the approach perspective comprises of 'consultant-led' and 'facilitator-led' categories (Bourne & Neely, 2003).

- The 'consultant-led' approach can be described as the external team carrying out performance measurement on the management team, who collect data, analyse and report back to the team. The senior management will plan and design the performance improvement that needs to be implemented based on the consultant recommendations.
- The 'facilitator-led' approach is carrying out performance measurement within the management team. The team themselves will do the discovery and analysis of the work to make improvements. The planning and designing of the performance improvement also made within the team based on the result achieved.

2.9.1. Development Considerations in Designing Performance Measurement Tool

In conducting performance measurement with potential users, development of a design performance measurement tool is needed to identify the potential users of the tool and their interactions in the process (Yin et al., 2011). Previous researchers have focused on the development of a performance measurement tool by considering multiple aspects, such as the success and failure factors of new tool development, financial based measurement and efficiency and effectiveness based measurement (Yin et al., 2011). However, these have limited guidance on how to use the tool effectively and do not address the appropriate user. As stated by Chen, the importance of knowing the user and their needs is highly recommended in order to achieve success in product design (Chen and Koo, 2002). By considering user needs, expectations and concerns, this will lead to better design of the tool (Mayhew, 1999); (Norman & Stephen, 1986). Therefore, it is important to explore the potential users of the performance measurement tool and understand their requirements in developing a successful solution.

2.9.2. Performance Measurement in Design.

There are three users that will be beneficial in having design performance measurement. These can be categorised as the company, design team and customer or market. For the company, their performance measurement of the design will be based on the business perspective where the most common criteria would be the return of investment, achievement of the set goal, and break-even. In contrast, Knotten et al. (2014) argue that the typical criteria for design performances in construction projects are aesthetics, usability and functionality. From the customer's perspective, the customers' satisfaction of the building design would be the ultimate criteria (Knotten et al., 2014).

While the focus of this research is the design process, the target user will be the design team or designer. Support from the company and customer will be the stakeholders of the design product, such as the contractor, quantity surveyor, engineering consultant and the client.

The criteria for each user cannot be mixed with each other or integrated in order to achieve overall performance (Yin, 2009). From this finding, based on the literature survey on design performance measurement for design companies, the design companies and customers cannot be considered as potential users for the purpose of the design performance measurement tool during the design process. The reasons are that the criteria are more focused on the financial aspects of the company, such as the return on investment and relative profit. For this reason, the research will only focus on the design team as they are involved in the design process.

2.9.3. Design Performance Measurement Applications

The function of project management is to ensure there is a well-coordinated and successful project through proper planning and control (Nassar et al., 2014). This can be achieved by effective progress monitoring of the building construction project, where various aspects of performance need to be considered to provide effective monitoring.

Typical performance measures are based on cost and schedule status. Without considering other major aspects such as quality, sustainability, customer satisfaction, project term satisfaction, etc., some project management systems quantify PP attributes independently, without integration of other project attributes. The performance is then assessed based on personal experience without a set of evaluation procedures. This would create contradictions between two project managers when assessing performance on the same building construction project with the same data (Rad, 2003).

Conversely, the PP will always measure the overall performance of the project. This can only be done once the data is completed towards the end of the project. The assessment is therefore only valid at the end of the project, where there is an availability of data. There is normally little effort made to measure the performance of the project by stages of the building construction project life cycle. This, however, can be initiated, as can be seen in the construction phase where performance is measured at every progress point in the project.

Although there are complexities when measuring PP at the design phase of a building construction project, there is a need to measure the performance based on the available data to: forecast the performance, identify the effect of decisions, and compare outcomes across different projects. Performance evaluation therefore needs to be taken into account.

The objective of this research is to present the evaluation framework, such that the contributors to the design phase of a building construction project can use this to assess design performance during the design phase. This research proposes a framework to integrate the PP and formalise the evaluation process by introducing four performance indices which are quality, cost, time, and sustainability.

Generally, in building construction projects, construction-performance evaluations are used to calculate the degree of success, which is specifically from the contractor's perspective (Nasar and AbouRizk, 2014). The degree of success is related to the attributes of project success that are identified from the established project control. A number of methods have been developed to evaluate the overall PP to gain project control improvements. These methods are: the S-curve; program evaluation and review technique (PERT); earn value management system (EVMS); and stochastic S-curves (SS). However most of these methods are only used for and relevant to construction performance (Li, 2004); (Fleming and Koppelman, 2000); (Christensen, 1994) and (Barraza et al., 2000).

This research focuses on the design stage of the building construction project which is quite different from the construction phase in terms of the activities and performance to be measured. According to the RIBA Plan of Work (RIBA, 2013), the activities are clearly distinguished in every phase of the project cycle. For example, in the briefing, it is not possible to measure quality based on the methods established in the construction phase. In the construction phase, quality can be measured based on the consistency of application of project standards and procedures (Nassar & AbouRizk, 2014). Whereas in the design briefing, there are no standards established that can be followed. Based on this example, it is clear that the method of performance measurement used in the design phase needs to be established.

2.10. Identified Research gap

At this point, key definitions of lean design process and measurement of performance in the design phase are point out. It has been identified that design process can be described as design with two criteria, which are the process of design and production. Whereas, performance measurement in design can be described as measuring the set performance of the outcome of design, or the function of the design of a building. In gathering a clear picture of how lean design evolves in improving PP, the basic definition of lean in construction is also discussed. The definition of LC and review of the case studies have also been explored to describe the practice of lean construction.

From the literature search on lean design in building construction projects, some commonly cited enabling factors have been extracted. Additionally, their manner of influence on the PP has also been presented. Although there are conflicting views in the literature as to which factors are needed and which are not, there is a common consensus within the literature that some elements are required for improving a PP.

The previous sections have compiled and discussed the enablers of lean design, which is essential for forming generic pre-requisites for improving PP at the early stage. It has also been set out that the enablers of waste elimination and performance measurement system in building construction projects are not considered at an early stage, compared to the construction stage. However, their role and influence in improving PP are significant.

The frameworks, models and recommendations produced in previous studies were also discussed, by looking at the aims and findings. There is a relatively limited number of design process models which adopt the lean principle in the design phase and that take into account the principle of the TPS known as 'set based concurrent engineering' (SBCE). Although

there are some researchers focusing on SBCE in design, these are only at the framework level and the model does not provide detailed activities for each phase or stage proposed. This might be due to the origin of the SBCE method in design that only describes the principles and components.

The activities of the process need to be developed by the user by trial and error. Subsequently the lean design process is related to the performance improvement in a project, where performance measurement needs to be in place. From the literature, most of the performance measurement can only be carried out towards the end of the project, or at the end of the project, where the completed activities can be analysed.

There has been very limited research done on performance measurement at the early stages of the project, especially in the design stage. Some literature only mentions the benefits of having early performance measurement at the early stage of the project, but lack the procedure and tools to do that. These findings reflect the need to explore the use of SBCE in design for building projects and develop the stages and activities to be followed, where the gaps in knowledge can be filled with this research in order to achieve lean design process.

2.11. Summary

In this chapter the strategy of extracting literature and relevant information has been discussed. The understanding of design process in building construction projects, LT, lean design, and performance measurement in design have been reviewed. Moreover, the existing framework in lean thinking that is relevant to the research context has been elaborated and taken into consideration for the development of a proposed design process. An overview of the performance measurement has been carried out in relation to Design Company or organisation where the applicability in construction industry is the target user for the proposed performance measurement in this research.

3. METHODOLOGY

3.1. Introduction

This chapter discusses the methodology used in this research. The general flow of the research outline is presented in order to give clear structure of the chapter.

3.2. General Flow of Research Outline

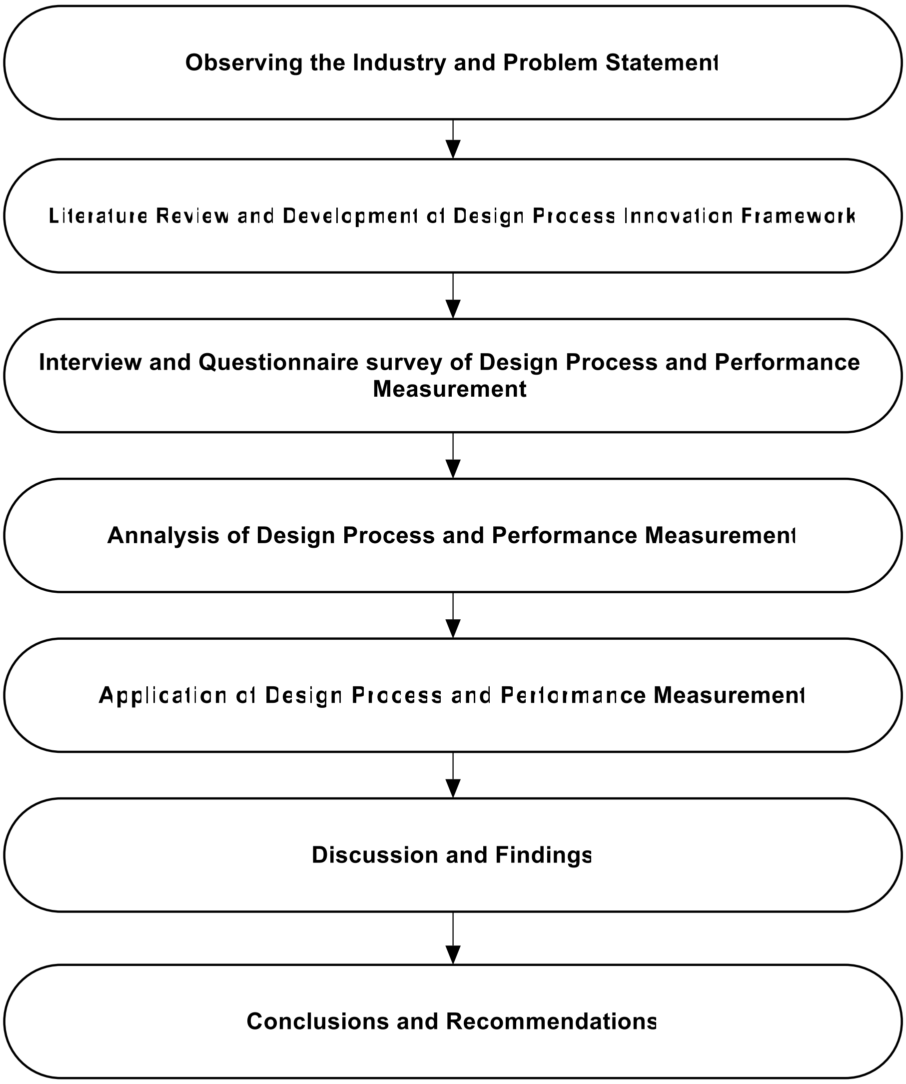
In this chapter, a combination of qualitative and quantitative methods are applied to explore the waste, enablers, tools, activities in design process, and to develop an innovative design process to improve the project performance in design phase of building projects. The main methodologies adopted in this research are described in the following sections. The general flow of the research is shown in Figure 3.1.

3.2.1. Literature Reviews and Development of Design Process Innovation

Foundation of the study is fundamental in this research, where the knowledge of the topic is crucial to understand such as the definitions, philosophies and principles (Marhani et al., 2013). Review of the literature is able to provide the understanding and analysis of various recent literatures in design process. Review of literature also gathers the information on the development of other models to make the research more credible.

In this research, existing models in the construction industry and a general model will be reviewed and analysed. The advantages and disadvantages of the current model will be studied to solve the problems.

Figure 3.1 General Flow of Research Process



This will provide a theoretical basis for developing a new design process that will not only fill the gaps in other models but also present the innovation of a design process in the construction industry.

A literature review is the evaluative documentation of information from a thorough review of work that has been published, or from unpublished secondary data, in the areas of specific interest to the researcher (Saunders et al., 2009; Sekaran, 2003). With this common definition Saunders et al. (2009, pg 59) emphasise the importance of the systematic review of literature such that the review can be divided into two major steps: the first is the preliminary search that allows the researcher to generate and refine the search ideas; the second comprises the critical review of the findings as the part of the research.

The purpose of the literature in this research can be explained as being an aid to the reader, giving the overall framework of the topic from previous research and pointing out where this piece of work fits in the bigger picture. Therefore the literature review conducted in this research is intended both to capture the gap in knowledge for the design process in architectural firms and to acquire secondary data for this research. Various literature have been included such as LC, lean design management, design management, waste in construction management, performance measurement, project control previous case study.

From the literature reviews, there are 15 wastes and 30 enablers identified in the design process that is relevant to the building construction projects. SBCE is considered the core enabler that is suitable for design process and stage review is developed as performance measurement.

Subsequently based on the knowledge and evaluation of literatures, the proposed design process framework that support lean thinking principles has been developed which presented in Chapter 5. This proposed design process is implemented by using case studies in order to analyse its validity and applicability in the real world setting.

3.2.2. Interview of Proposed Design Process and Performance Measurement

As for the qualitative research method, as part of the mix method chosen in this research, the semi-structured interview is selected. According to Bryman & Bell (2015), interview is the most common qualitative research method due to its flexibility in capturing important ideas and detailed opinions to enrich the research. Interview in research, as opposed to other categories of interview, can be categorised into several types based on either highly formalised and structured or informal and unstructured discussions (Saunders et al., 2009). There are levels of formality and structure involved in using this type of data collection method. The common type of interviews are structured, semi-structured, and unstructured (Saunders et al., 2009).

In this research, the qualitative data collection is using the approach of semi-structured interviews. The procedure of the interview and a set of questions is predetermined before the interview. As the nature of this type of interview has flexibility, the interviewees will be given the opportunity to discuss their opinions and interests in the field of lean design process. The interviews is conducted face-to-face so that exploration of the details and descriptions of issues brought by the interviewee can be clarified at the time (Bryman & Bell, 2015).

Interviews with architects in the construction industry and an in-depth study of the initial proposed design process help to amend and improve the proposed design process to enable it to be more effective and efficient in the architects' practices. Interviewees were asked on general opinion on important aspects of the design process that is currently being practised in their organisation. Then they were asked to evaluate the components of the proposed design process and provide their opinions and suggestions as to its suitability for improving the process.

The stages of proposed design process comprise design activities that create value for the client. The waste were analysed so that the activities in design have functions to eliminate the wastes. In order to determine and analyse the proposed framework and list of wastes in the construction industry in Brunei, registered architectural firms that practice in the country were targeted and taken as representatives.

The proposed design process framework and list of waste that were obtained from the literature review were used to form the basis of questionnaire. This questionnaire is used to sample the consensus of the respondents on the list of waste and the elimination of waste by the design activities in the proposed design process framework. Through the data collection and analysis, the relative importance of the waste can be identified and the consensus of the elimination might be achieved. The detail research approach will be presented in the following sub-sections.

3.2.3. Questionnaire Survey of Proposed Design Process amd Performance Measurement

The questionnaire survey is the most favourable tool for collecting quantitative data due to its efficiency in terms of time spent in getting results. The questionnaire survey can be used to confirm, deny or enhance what was already believed or known. The result can be interpreted the same way by all respondents with the standardised questions (Robson, 2011). This will enable the researchers to gain a large population of data without the strain of analysing the data.

The purpose of questionnaire in this research is to get agreement from the practitioners in the construction industry on the list of the types of waste in the design process and investigate the elimination of the listed waste. The analyses data help the research to reach a final enhanced version of the proposed design process that can improve project performance in construction.

3.2.4. Case study

Yin (2009) stated that when the research questions focus mainly on “how” and “why” questions, the case study will satisfactorily address the research question if the focus is on the current condition in the real-life environment.

Since the primary research question of this research is to investigate how the design process interacts with the design process environment in building construction project, this method has been considered to address the question. In this research, the case study is used to check the applicability of the proposed design process and its performance measurement. This will reveal any issues that cannot be covered by the interview and questionnaire. Such issue can be the commitment of the participants towards new procedure, as they cannot see the benefits to them.

The case study was following the protocol developed in this research so that consistent result can be obtained. Basically there three stages involve in this protocol namely 1) understand the requirements, 2) design the new approach and, 3) implement the new approach. These stages were decomposed into several activities and the details are described in Chapter 5.

3.3. Research Instruments

The main research instruments for this research are the semi-structured interview questions and questionnaire to collect information from actual industry practice on the design process for the qualitative and quantitative analysis respectively. Whereas the case study is used to implement the proposed design process and its performance measurement where the applicability and validity would be the main concern. The dimension and research questionnaire items are presented below.

3.3.1. Questions for Semi-structured Interview

The followings are the description and rationale of the semi-structured questions and the full version can be found in Appendix B:

PART 1: Design practice and performance

SECTION I- Profile of the Participants and Organisation

This section begins with a series of general questions, that aiming to capture the general information of the participant and their current organisation. The demography of the participants is recorded so that the validity of the answers can be determined that it is from the focus group of practitioners from construction industry.

SECTION II- Understanding of the Design Process.

In this section, the participants were asked a series of questions in relation to the current design process in their organization. This section primarily seeks to determine the participants' personal understanding of design process and their awareness of project development stages.

SECTION III – Awareness of performance improvement in design process

This section aimed at awareness of early warning of project performance at the design stage of construction projects. The participants also asked to recommend area to be improved in order to achieve high project performance in design stage. The participants also asked to give their opinion on the causes of overall performance of construction projects based on their experience.

SECTION IV - Element of performance improvement in design process

This section aimed at the awareness of the participants on the significant contribution of design phase in the projects and to list the essential improvements should be made and design activities should be included in the design phase.

SECTION V – Performance improvement measurement.

The participants were asked to give their opinion on the elements that should be included in the performance measurement for the design process. Subsequently the participants were asked to state their agreement on the hierarchy of the key performance indicators as described in the literatures.

PART 2. The evaluation of the proposed design process

The proposed design process was presented in this part. The objective is to discuss and acquire the participants' agreement on the design activities. Series of questions are design for each activity.

PART 3. Waste in design process and their elimination

In this section the participants were asked their agreement on the list of wastes as stated in the literature. Subsequently go through the matrix for the elimination of wastes by the proposed design activities. The outcome of this matrix is the elimination of waste by the proposed activities. This also will be used in the questionnaire in order to gain further agreement from the practitioners.

3.3.2. Dimensions and Items Included in the Questionnaire for waste elimination and Proposed Design Activities.

The questionnaire is divided into four sections (Appendix D):

SECTION 1-Participant's Background

This section of questionnaire aims to get the demography of the participants. This will determine the required characteristics of the participant whether they have experience in the construction industry or not. The knowledge will also give impact on the answer given to the questionnaire.

SECTION 2-Wastes in Design Process

This section is aiming to quantify the agreement of practitioners on the list of waste developed in this research. Any additional wastes that deem to be relevant to design process by the participants through their experience, they need to list down in a separate space. This will enable the practitioners to contribute to the development of wastes based on the local context.

SECTION 3-Proposed Design Process for the elimination of wastes

In this section the proposed design process is presented and the participants are given time to study it. Then they were asked to rank their agreement on the suitability of the proposed design process from the stages, activities and method of executing the process. Subsequently the participants were asked to rank their agreement on the elimination of wastes as listed in the literature.

SECTION 4-Evaluation of the proposed Design process

This section aims to evaluate the proposed design process by asking the participants' agreement on the provided statement on the suitability of the design process to eliminate the wastes, clearness of the design process, easiness of the design process to be used by others, the alignment of the proposed design process with other design process, adaptability of the proposed design process into the current practice, readiness of the participants to use the proposed framework, feasibility of the framework to improve the project performance, achievement of the proposed design to be recommended as innovative design process, and willingness of the participants to adapt the proposed design process.

3.4. Data Presentation Methods

There are various way of presenting data after the analysis have been done. According to Saunders et al. (2009), that data can be in a form of categorical or numerical. Categorical data is always involves a group or a type and numerical data involve numerical form. The common methods of presenting the data are Tables, Line graphs, Histograms, Pie Charts and Bar graphs. In this research, only tables, pie charts, and bar graphs are being used to highlight the findings.

3.5. Objectives of This Research and The Corresponding Methods of Investigation

The discussion of the methods of investigation has been presented in the previous section. Table 3.1 shows the corresponding method of investigation that address the research objectives.

Table 3.1 Methods of Investigation to Achieve Research Objectives

No.	Research objectives	Methods of Investigation			
		Literature review	**Semi-structured interviews**	**Questionnaires**	**Case Study**
1	**To review lean design processes and identify the trend of literature on the subject of applying lean principles in the construction design process.**	√			
2	**To identify waste in the design process that hinders constructability and the quality of building design.**	√			
3	**To extract the principles and enablers of lean design process from the literature.**	√	√	√	
4	**To develop a design process and project control that will improve the PP at the design phase of building construction projects.**		√	√	√
5	**To test the proposed design process through field application in industry.**				√

In relation to data collection, this research will be employing a mix of methods using the questionnaire to obtain the qualitative data on waste, and semi-structured interviews for obtaining the rich quantitative data. In the process of data collection specific themes are developed which reflect the research objectives to be achieved:

- Understanding of the design waste
- Awareness of waste in design process
- Consensus of wastes elimination
- Evaluation of the conceptual design process

These four themes help guide the development of the questionnaire components and semi-structured interview questions to enable to have agreement from the industry on the proposed framework and model. The questions for questionnaire were developed based on the framework identified from the literature review such as the wastes in design, elimination of waste and activities of the design process.

3.6. Research Considerations

3.6.1. Ethical Issues

In this research, it is realised that this research involves in applying some of the processes and methodologies in settings or situations which are difficult and sometimes impossible to control. There are some potential problems in conducting this research which already taken into consideration. One of the problems in conducting a research would be the ethical issues (Lancaster, 2005). Ethical issues can be from data collection methods; data recording and analysis techniques and reporting research findings. All of these have to be taken into consideration when planning a research. Therefore this research has been incorporating the ethical issues which may arise during the research. The researcher also submitted the ethical review which is part of the University requirement of doing a research.

- **Ethical issues anticipated before conducting fieldwork**: invitation letters were sent to acquire voluntary participation. Brief explanation and objectives of the research were included in the letter. Further action from the participants was clearly stated in the letter.

- **Ethical issues anticipated during data collection**: the questionnaires were sent to the agreed participants. The questionnaire comprises of brief instruction of answering the questions. A significant period of time was considered for the participants to give their feedback. Confidentiality of the information given by the participant was given the utmost priority within the questionnaire for example, the name of the participants and company's name for case study has been disguised.
- **Ethical issues anticipated during data analysis and interpretation**: all data will be treated with full confidentiality and solely used for the purposes of the research only. Their names and details will not be disclosed for anonymity issues.

3.7. Summary

In this chapter, the step-by-step procedure of research methodology was shown in order to fulfil the aim and objectives of the research. General flow of the research outline are presented and discussed. The research first considered the literature review in order to understand the subject being researched. Subsequently the development of the design process innovation is explored through the review of specific literatures. In order to answer the research questions. The qualitative and quantitative research methods were used to analyse the data and were collected through interview and questionnaire. The purpose of the case study in this research is to validate the applicability and suitability of the proposed design process with its design process performance measurement in real world setting.

4. INTERVIEWS AND QUESTIONNAIRES

4.1. Introduction

In this chapter, the list of waste in design process which was extracted and analysed from the literature is included in a survey questionnaire. In addition, both the innovation of design process framework development and proposed design process are becoming part of the survey questionnaire. A Semi-structured interview was used to get the agreement of the practitioners from industry.

The structure of this chapter comprises a discussion of the objectives and purpose of the interview and questionnaire. The rationale of the questions in the interview and questionnaire are discussed. This is followed by review and analysis of the participants’ responses to the interview questions. For the questionnaire survey section, the details of the questionnaire design are discussed. This follows the review and analysis of the questionnaire results.

4.2. Objectives and Purpose of the Questionnaire

4.2.1. Interview

The semi-structured interview questions were design in order to understand the design process being practiced in the construction industry. This will revealed the problems and current issues in the design process of the in the design process. Other elements of design process improvement are also explored.

The proposed design processed developed based on the literature review and wastes identified are presented during the interview and will be evaluated by the participants. This will receive comments and suggestions for the improvement.

The aim of the interview is to determine if the practitioners in design phase of construction projects understand the overall concept of lean construction. Apart from the interview also seeks to know if the practitioners understand about project performance and whether they would consider adopting innovation of design process in their projects for project improvement.

4.2.2. Questionnaire

The aim of the current research is to develop a design process framework in construction projects. The objective of the questionnaire is to get the awareness level of practitioners on the wastes (elements that might affect the performance of design) in design process project performance. If these wastes can be eliminated, it is believed that the project performance will be enhanced. The proposed framework developed is based on the RIBA, Plan of Work 2013 with consideration of lean thinking for the design process. The principles of ‘set-based concurrent engineering’ (SBCE) which originated from the Toyota Production System (TPS) is adopted in the design process.

4.3. Interviews

4.3.1. Demography of the Participants

The participants in the interviews comprised practitioners involved in the architectural design of construction building projects, including architects and designers at various levels of experience and qualification.

The interviews were conducted on six interviewees on separate occasions. The interviewees comprised: two principal architects with more than 10 years of experience

in building design; a senior architect with experience in designing and managing building projects for more than 10 years; two architects with more than 5 years of experience in design and managing building projects; and a junior architect with developing experience in design and managing building projects. All of the participants were individually selected based on the experience they held. They were also chosen from different architectural firms which practised different design processes.

A staged filtration on the responses and results was carried out to ensure that information received was relevant and would help develop and improve the proposed design process. All interviews were conducted on a face-to-face basis, which enabled spontaneous responses if other issues arose during the interview.

In adopting the semi-structured interview, the open-ended questions approach was optimised to encourage respondents to openly discuss their opinions and ideas. In this way, the discussion allowed the researcher to identify important issues that were essential for the development of the proposed design process in the context of construction projects.

4.3.2. Analysis of the Responses

The proposed conceptual design process was presented to the interviewees and the discussion was based on the activities of the proposed design process. Although questions were prepared beforehand, other aspects that were deemed to be relevant in improving the development of the design process, were also considered. Thus, the semi-structured interview questions acted as a guideline, based on the scope of the topic which was to be explored.

Analysis of the results was made using a qualitative analysis approach. The interviewee's opinions, perspectives and ideas will reflect their agreement or non-agreement on the proposed design process. Their comments and suggestions helped towards improvement in the form of additions, modification or omissions. Overall, the respondents received the proposed design process with positive comments and were of an optimistic view on its applicability, appropriateness and innovativeness. The discussions of the interviews conducted are elaborated in the following sub-section.

4.3.3. Results

Design Process

The first version of the proposed design process was presented during the interview. Amongst the comments received for this version was that the numbering of the stages in the proposed design process were contradicting from what RIBA suggested in their project development stages, although the name of the stages was similar. However, the graphical representation of the stages was clear and the activities recommended for each stage were deemed relevant.

Other comments from the interviewees were that the terms used under the waste list column were described inadequately for the proposed activities. For example, the term ‘Align with company strategy’ stated under Stage 0 Activity 3 was criticised. According to the interviewees, this description gives the impression that more emphasis is given on the business strategy, rather than on the design project strategy, considering that the aim of the activity is to deal with the design process and not the organisation’s processes. Therefore, the descriptions have been reviewed and improved and the description of the relevant activity. Based on the above comment, the researcher further enhanced the description of other activities in the proposed design process.

Positive comments were that the method of implementation of the activities appeared applicable and informative. All architects interviewed have heard of various types of design processes in their architectural profession. They described the existence of similar design processes. However, each process carried out will be based on their experience and knowledge from previous studies in architecture and projects handled.

A few of the interviewees commented that studying and understanding the design process was only an academic exercise, as one needed first to acquire the essential architectural knowledge and skills.

One comment was that while the RIBA work of plan can be referred to in the design process, it becomes more of a guide throughout the design. Other interviewees commented that the design process they practised was very much influenced by the government ‘standard operation procedure’ manual. However, some of the factors in the design manual may not be practical in a small sized architectural firm, for example when the manual requires the division of design tasks for each design team. Considering the number of employees in the government sector, this division of tasks would be feasible. However, when there are fewer employees available in the private sector, there may be only two design teams. Therefore, the division of tasks will be less practical, resulting in each design team having several tasks.

Furthermore, the decision-making process in the government sector goes through a number of stages. However, the decision making in the private sector is mainly controlled by the principal architect, who will be responsible for checking and evaluating the design.

Each interviewee gave their opinion on what factors should be present in the design process. One commented that knowledge and experience were important factors, as these can assist in solving design problems and challenges. Another interviewee commented that information from the client was a vital part of the design process, as this can provide the architect with valuable information so as to understand the clients objectives. Two interviewees mentioned that design review should be practised in the design process, so that any discrepancies can be detected at an early stage. This would give the architect the opportunity to assess the design and planning in order to achieve client's objective.

Characteristic of Guidance

During some of the interviews, it became apparent that some of the limitations in the design processes were mainly due to the lack of guidance at the design stage of a project. In one interview, it was noted that a particular company was in the process of developing and mandating guidance details of the proposed design process, which consisted of lengthy procedures and hundreds of pages of guidelines to follow. However, this approach was eventually discarded due to the issues of responsibility, control and adherence within the organisation. Other issues included unnecessary tasks conducted or activities which were not properly communicated to the design team members, which led to important project works being delayed. Some of the interviewees stated that the non-conformance of the design process was common. However, there is great flexibility however in existing design processes that are currently being practised in many different organisations.

Tools and Techniques

From the above, it appears that companies in Brunei still apply the traditional method of the design process. This therefore indirectly influences the selection of techniques and tools for the design process that are being practised in these organisations. The enabling techniques and tools being used are quite traditional, in that the designer still relies on the iterative method of developing the design.

One interviewee described a situation where the company relied on the client to provide all the information before proceeding with the conceptual design. The wait can be time consuming for the design team and may hinder the design process from being expedited.

In the situation where additional information is given by clients at a later stage or mid-way through the design, the team may be required to redesign accordingly to incorporate new information, creating wasted effort. There is no limit on the number of changes that can be made to the design, as long as the conceptual design meets the requirement of the client. According to Sobek et al. (1999), the iterative method to develop a design can be effective if the iteration or feedback cycles are prompt. However, the traditional method of design in the construction industry involves complex stakeholders, so getting agreement and feedback is often slow. Therefore, producing accurate design details can still be an issue in construction.

Knowledge and Experience Management

The knowledge and experience from previous projects are gained by the individual designers themselves. There is currently no practice of knowledge management in most participating organisations. One interviewee commented that when dealing with a project, individuals are able to experience and gain knowledge for themselves, but

which only they themselves can apply to future projects as they see fit, which is a source of waste.

However, during a separate interview, more specifically on processes in the Brunei government sector, it was discovered that individuals practising the 'standard operating procedure' are required to document and record activities in an allocated file which can then be referred to by others within the organisation.

From the interviews conducted, the research identified there were no clear design processes, procedures and guidelines that have been documented or laid out within the interviewees' organisations. One interviewee stated that there are so-called procedures created by their organisation, but the indication was these would be beneficial in a commercial context, as opposed to benefitting designs or projects by way of improvements.

Complexity

In studying the outcomes of the interviews, none of the companies had a wide degree of awareness of formal design process procedures, techniques and tools. The iterative process is one that is well accepted by these organisations, where numerous parameters have to be constantly evaluated through feedback. According to Harputlugil et al. (2014), the design process can be described as "complex" due to the content, context, stakeholders, ill-defined problems, and multifaceted interactions. These organisations also exhibit these complexities. Amongst the complexities commented on during the interviews, were:

- **Stakeholders**. Those who may have been involved in the project from the start, can be of varied levels of seniority and experience. Thus, this can cause issues in decision-making, as some stakeholders may be of different opinions to others, based on the different levels of experience each stakeholder possesses.
- **Requirements of the client**. A client's changing requirements may require a number of iteration on designs and solutions. This may be time-consuming as a solution will need to be reached to satisfy those requirements.
- C**hange of leadership.** This can occur during the process of designing a project. As individuals or leaders, as the case may be, have different opinions or requirements, a change of leadership, may disrupt the flow of the process. The new leader may require changes to the design in order to fulfil a new perception of requirements, which may differ from those of the previous leader.

Although design processes are in place within these organisations, the procedure of its implementation appears unclear. Unfortunately, it appears they have limited knowledge on how to deal with complexities.

Project Performance

Throughout the interviews, it appears that none of the organisations had much incentive to improve their design process performance, despite their acknowledgement of the ineffective and inefficient design processes which were still being practised in their organisations. Having said that, a few organisations had "informal" initiatives to improve the design outcome, by keeping the previous design information as their references. One interviewee commented that making a to-scale model for their design was the thing of the past, as they currently use computer models and simulation software, which are cost-efficient.

With the lack of awareness on current methods and techniques to improve the PP in every aspect, interviewees were only be able to focus on the design improvement of the project whereas, with the aid of the tools currently available, other aspects of a project may also be improved together. In the study made by Gerber et al. (2010), the application of BIM technology and methodologies has been proven to increase value for clients and minimise wastes in terms of time, material and financing. Therefore, PP can be improved through the enhancements achieved from applying the latest current methods and techniques in projects.

The interviewees recognised there was flexibility in carrying out the design process and the steps taken in order to complete design projects. However the design review, which is one of the essential elements in the design process, acts as a control measure of the flexibility in the design process. Although the interviewees were aware of the need for essential elements in the design process, they were also aware of constraints in implementing these elements. For instance, in obtaining client information and subsequently interpreting and using this in the next stage, requires efficient techniques and tools. Without the availability of these techniques and tools, they continue to use traditional techniques.

During the interviews, none of the interviewees seemed to have knowledge and experience in ‘lean’ or ‘lean thinking’. Hence, the interviewees did not seem to have enough exposure to the new techniques available in the design process. Because of their individual or personal work constraints and limited resource or opportunity, new techniques may not be readily accessible to them. It is probably these reasons which contribute to their unawareness of the concept of lean thinking.

Project awareness was presented in this interview and some interviewees had different perspectives on PP. One interviewee mentioned that performance can be evaluated once a project has been completed and there are no further complaints from stakeholders. Further, some who have received compliments from stakeholders have indicated motivation in achieving quality design and services. It therefore appeared that

there was no formal evaluation of PP either during the design phase or at the completion stage.

With the complexity of having different stakeholders in construction projects, interviewees felt it was difficult to measure and improve the performance of projects. From the interviews, there was no indication that the interviewees knew how effective their design processes were or what elements were required to make them effective. One commented that the design performance was subjective. Other interviewees commented that the design performance can be improved only if the design brief is provided by the client at the initial stage.

Continuous Improvement

An overview of the interviews has shown that interviewees were not familiar with the term ‘lean thinking’, as noted above. One commented that in practice, they are only able to focus on the architectural aspects. Very few of the interviewees were familiar with continuous improvement, as suggested in lean thinking principles.

There was an attempt at 'continuous improvement', where the organisation made the effort to archive the previous project information for future references. One interviewee commented that by having this archiving practice, their innovation and creativity would be limited and future work would tend to be conditioned by the previous information. Therefore, the designer should not be limited only to the procedures laid out, although, they may be used as a guideline. The justification was that this would enable innovation and creativity in their practice.

The Elimination of Wastes

The list of wastes extracted from the literature review was presented to the interviewees to gain agreement based on their experience. All participants agreed that 15 types of wastes are present in the design process. However, the participants were unable to identify solutions to eliminate these wastes.

Having explained this, the researcher presented to them the elimination of wastes mechanism (see Appendix B). For this part of the interview, the interviewees were required to discuss waste elimination and give recommendations by selecting those design activities where they felt they would be able to eliminate wastes in the design phase. The interviewees were given the list of wastes identified in this research and were allowed to study the list at least a week, before a further discussion was conducted. They were given the opportunity to add to, or subtract from the original list as they thought appropriate. However, a justification for doing so was required, in order to be able to understand the rationale behind their recommendations. The researcher remained present and acted as a facilitator for the purposes of clarifying descriptions which were not familiar to the interviewees.

This interview can be considered a non-structured type, although the discussions were guided by the design process chart which had been proposed for this research. The waste list was then analysed by the interviewees. After the discussion, interviewees were required to identify which wastes were eliminated by a certain design process activity. This is illustrated in Table 4.1, which records the decisions. A review was made at the end of the session with the interviewee to confirm the decisions made. The full result is provided in Appendix C.

Table 4.1 Snapshot of the outcome of the discussion and interview

Stage 0	Activities	Waste
Define Value	**0.1**	**W1 W2 W3 W4 W5 W6 W7 W8 W9 W10 W11 W12 W13 W14 W15**
	0.2	**W1 W2 W3 W4 W5 W6 W7 W8 W9 W10 W11 W12 W13 W14 W15**
	0.3	**W1 W2 W3 W4 W5 W6 W7 W8 W9 W10 W11 W12 W13 W14 W15**
	0.4	**W1 W2 W3 W4 W5 W6 W7 W8 W9 W10 W11 W12 W13 W14 W15**
	0.5	**W1 W2 W3 W4 W5 W6 W7 W8 W9 W10 W11 W12 W13 W14 W15**

Table 4.2 shows a summary of the outcome of the interviews and discussions made by the six interviewees for this research. One section of the questionnaire was designed based on this summary. The aim of this part of the questionnaire was to have consensus from industry on the elimination of waste. The following section lays out the description of the questionnaire.

Table 4.2 Outcome of the Interview on Waste Elimination by the Proposed Design Process

Source: *Yusof et al. (2015)*

Phase	Activity	Type of waste eliminated
Stage 0 Define Value	0.1 Classify projects	Poor client briefing Lack of project definition
	0.2 Explore client value	Poor client briefing Lack of project definition Making design decision on cost not value of work
	0.3 Align project with company strategy	Lack of project definition Poor level of commitment to quality of improvement among design professionals
	0.4 Translate value to designers	Poor client briefing Lack of project definition Design defects Making design decision on cost not value of work
	0.5 Internal review	Design changes Inadequate pre-design project meetings Inadequate involvement of other professionals and teamwork during the design stage Poor communication among design team Poor level of commitment to quality improvement among design professionals
Stage 1 Map Design Scope	1.1 Identify sub-design solution targets	Design defects
	1.2 Decide on level of innovation to sub-design solution	Design defects
	1.3 Define feasible regions of design scope	Design defects Insufficient and unrealistic constraints of project cost Insufficient and unrealistic constraints of project time Lack of constructability review

		of design Making design decisions on cost not value of work
	1.4 Internal review	**Design changes** **Inadequate pre-design project meetings** **Inadequate involvement of other professionals and teamwork during the design stage** **Poor communication among design team Poor level of commitment to quality improvement among design professionals**
Stage 2 **Concept Design Development**	**2.1** **Extract design concepts**	**Design changes** **Poor level of commitment to quality improvement among design professionals**
	2.2 **Create concept design for sub-design solution**	**Design changes**
	2.3 **Explore the concept design for sub-design solution**	**Design changes** **Inadequate technical knowledge**
	2.4 **Capture knowledge and evaluate**	**Design changes** **Inadequate technical knowledge** **Poor specification**
	2.5 Communicate concept designs to others	**Design changes** **Inadequate pre-design project meetings** **Poor specification**
	2.6 Internal review	**Design changes** **Inadequate pre-design project meetings** **Inadequate involvement of other professionals and teamwork during the design stage** **Poor communication among design team Poor level of commitment to quality improvement among design professionals**
Stage 3	**3.1**	**Design changes**

Concept Integration	**Determine concept design intersections**	**Poor specification**
	3.2 **Explore possible designs**	**Design changes** **Poor specification**
	3.3 **Seek conceptual robustness**	**Lack of constructability review of design** **Effect of design code and standard on quality**
	3.4 **Evaluate concept design for lean construction**	**Design changes**
	3.5 **Begin process planning for construction**	**Poor specification** **Design changes** **Lack of constructability review of design**
	3.6 Integrate the final concept design of sub design solution	**Design changes** **Inadequate involvement of other professionals and teamwork during the design stage** **Lack of constructability review of design** **Poor communication among design team**
	3.7 Internal review	**Design changes** **Inadequate pre-design project meetings** **Inadequate involvement of other professionals and teamwork during the design stage** **Poor communication among design team Poor level of commitment to quality improvement among design professionals**
Stage 4 **Detailed Design**	**4.1** **Release final specification**	**Design changes** **Poor specification**
	4.2 Define construction tolerances	**Design changes** **Poor specification** **Lack of constructability review of design**
	4.3 **Full project definition**	**Design changes** **Poor specification**

	4.4 Internal review	**Design changes** **Inadequate pre-design project meetings** **Inadequate involvement of other professionals and teamwork during the design stage** **Poor communication among design team Poor level of commitment to quality improvement among design professionals**
W1=Poor client briefing **W2=Inadequate pre-design project meetings** **W3=Lack of project definition** **W4=Design defects** **W5=Inadequate technical knowledge** **W6=Poor specification** **W7=Design changes** **W8=Insufficient and unrealistic constraints of project cost** **W9= Insufficient and unrealistic constraints of project time** **W10=Inadequate involvement of other professionals and teamwork during the design stage** **W11= Lack of constructability review of design** **W12=Poor communication among design team** **W13=Making design decisions on cost and not value of work** **W14=Poor level of commitment to quality improvement among design professionals** **W15=Effect of design code and standards on quality**		

4.4. Questionnaire Survey

4.4.1. Overview of Questionnaire Survey

The main aim of the questionnaire survey was to get empirical data on waste in the design process, as identified in the literature review, and to investigate the applicability of the elimination of the listed waste by the proposed design process. The intention was to target practices in Brunei and illicit written responses to a series of questions, through an on-line questionnaire.

The questionnaire comprised of four main sections as described in chapter 3.

Section 1 involves questions regarding the profile of the participants. This section is intended to identify the characteristic of each respondent.

Section 2 concerns questions on how each participant would rate the listed waste factors. This section also allows the respondents to list other wastes which they feel are relevant.

Section 3 requires participants to provide their ratings on different design elements that eliminate waste factors in design. Respondents were given an opportunity to give their suggestions on this subject matter.

Section 4 asks the respondent to provide their ratings on the evaluation of proposed design process presented.

4.4.2. Design and Development of the Questionnaire

The steps in the development of the proposed framework and design process are elaborated in Chapter 5. From the literature review, it was believed that the proposed framework and the proposed design process would be able to improve the PP and at the same time create value for clients should the phases and activities presented be followed through. However, empirical data needs to be obtained to ensure the elements of the proposed framework are analysed, evaluated and calibrated. Therefore, in this research, the proposed framework and activities are used to design the questionnaire so that the desired agreement from the practitioners can be obtained.

In this research, the questionnaire was further developed in accordance with the guidelines proposed by Gillham (2007) for questionnaires used in a survey. The major concern which Gillham suggests are the weigh of the questions should be equal for easy analysis of the data, the questionnaire is intended to self-administered, the format of the questionnaire is a mix of open ended and closed ended questions, the questionnaire can be completed in 15 minutes. All of these have been incorporated in the developed questionnaire for this research.

The developed questionnaire for this research remains divided into four major sections. The first section asks about the background of the respondent. The second section presents the list of the waste. The respondent was asked to rate the importance of the wastes in the list by using the Likert scale. The next part is the elimination of waste by the design activities. In this third section, the respondent was asked to rate on a scale of agreement of waste elimination by the design activities. At the end of the second and third section, the respondents were given a chance to express their opinions and to add additional elements if any which should be included. This supplement will be considered as a very important scale for this survey.

In the final section of the questionnaire, the respondent was asked for their opinion of the proposed framework and their personal willingness to participate in this research. From there, respondents who were willing to participate in this research would be contacted again to participate in case studies.

A cover letter was used to explain the intention of the research, background of the research and the objective of the survey. The survey also promised confidentiality on the answers provided, which were to be used anonymously and only for this research. A few companies advised they were unable to participate as they were currently involved in projects. An email was sent to the companies which were able to participate, which included an embedded link to the on-line questionnaire. They would then fill in the questionnaire on that link and submit it back on-line.

4.4.3. Characteristics of Selected Construction Companies

The focus group for this research is the design team involved in a construction project, who typically leads the project in either the Government or the private sector in Brunei. It was essential for this research to obtain data based on the local context to ensure local practice and experience is applied.

List of registered architectural firms was obtained from the Ministry of Development in Brunei who publishes a list of registered Architect firms. The Ministry in accrediting these firms is following strict policies, rules and regulations, to ensure high quality and consistent professional services are provided to the public. Among the regulations required are that the owner of the firm is a local or permanent resident of Brunei Darussalam. It is also a requirement that the owner possesses a professional qualification in this field that is accredited by the Government. This sampling frames determines the research population which is relevant to the research topic being conducted.

In this research the non-probability sampling technique is adopted as the list of architectural firm is used where the number of the registered firmn is know. Subsequently, the purposive sampling is used where the participants were hand-picked based on their involvement in the design phase of construction projects. This will determine the reliability of the representatives' view from the expert of the research area. With their contribution on giving their opinion and answering the questions for thir research, the proposed design process, list of waste and elimination, and proposed performance measurement can be fine-tuned so that they meet the real condition. Furthermore, their suggestions for improvement of the proposed design process and performance measurement can be calibrated with the local context.

In this research, there are 42 registered architectural firms listed. There were 22 responses received from the firms. The response rate is 52% which can be used for a data analysis.

4.4.4. Reliability and Validity of the Questionnaire Results

It is important to test the reliability and validity of the questionnaire results before any further analysis is conducted. Reliability can be described as a checking tool for the consistency of the research instrument in producing accurate results (Lancaster, 2005). According to Saunders et al., (2009) such consistency can be referred to as the instrument that will produce similar results at different times and under different conditions, including different samples. Therefore, in this research a reliability test was conducted on the questionnaire so the results obtained can be confirmed from the appropriate data collection tool. There are three common methods available for testing the reliability of research instruments (Bryman & Bell, 2015):

- Stability (test-retest method)
- Inter-observer consistency
- Inter reliability (Cronbach’s alpha)

For the stability method, the questionnaire is administered two times to the respondents and the data then correlated. A typical problem would be a tendency for the respondents to answer the questionnaire in the same manner twice, probably due to the repetitive questions, lack of time to think, and a predictable answer that will deter the reliability of the instrument (Bryman & Bell, 2015; Saunders et al., 2009). Salem et al. (2005) reported on the use of the test-retest method to check the reliability of their questions, whereby they found that the researchers were asking too many questions and were interrupting their interviewees’ work. In this situation, the researchers have difficulty in persuading the respondents to answer the same questions twice, as the participants feel that doing so is delaying their work, making the value less. Therefore the reliability test is not an option for this research.

The Inter-observer reliability test is intended to check whether the results given out are consistent in observation between two or more observers using the same instrument to record the data. According to Lancaster (2005), this method of should yield a high level of reliability, where the results can be compared instantly as the observers are from the same team or group of observers. Another feature of this method is the use of point or interval sampling, where each result at the interval or point can be compared (Caro et al., 1979). However, this research does not require time interval or points. Furthermore, Bryman & Bell (2015) argue that this test needs more than one observer to give a subjective judgement and to provide agreement on the results. As the researcher is the sole observer for this research, the applicability of this method for a quantitative reliability test was also not feasible.

Therefore, for this research, to ensure the reliability of the questionnaire, the questions were tested based on the consistency of responses given by the respondents. It involves correlation of responses to each question for inter-reliability. The method commonly used in measuring internal consistency is known as Cronbach’s alpha. It is one of the most popular methods available for determining reliability. It uses the value between 0, which represents no correlation and means no internal consistency, and 1.0, which is considered a perfect correlation (Saunders et al., 2009). The reliability test in this research applied Cronbach’s alpha method. Gliem & Gliem (2003) stated that the target value for the Cronbach’s alpha for reasonable reliability should be 0.8. For easy interpretation of the value, George & Mallery, (2003) gave a rule of thumb: ≥0.9-Excellent, ≥0.8-Good, ≥0.7-Acceptable, ≥0.6-Questionable, ≥0.5-Unacceptable.

Table 4.3 shows the result from the reliability test applying Cronbach's alpha computation from the 22 respondents' responses. The value obtained is 0.913 for the overall questions in this research. This indicates that the responses obtained are homogenous and have excellent internal consistency. Therefore, the results from the questionnaire can be used in the analysis.

Table 4.3 The Cronbach's Alpha Value for the Research Questionnaire's Reliability

Cronbach's alpha	Cronbach's Alpha Based on Standardized items	N of Items
0.913	**0.920**	**37**

Validity can be described as the procedures followed to test the accuracy of findings (Bryman & Bell, 2015). Saunders et al., (2009) described that the test of validity is to determine the ability of the questionnaire to measure what is intended to be measured. In other words, the answers derived from the questionnaire are a true representation of reality. There are three common methods that are popular among researchers when conducting a test for the validity of a questionnaire (Cooper & Schindler, 2014). These are content validity, criterion-related validity and construct validity.

Content validity refers to the method of questioning used in the questionnaire to provide adequate coverage of the issue (Saunders et al., 2009). Adequate coverage may be obtained through careful definition of research through the literature reviewed and can be supported by prior discussion. Other ways of establishing adequate coverage can be through assessments carried out by external experts on whether the questions in the questionnaire are ‘essential’, ‘useful but not essential’, or ‘not necessary’ (Saunders et al., 2009).

In this research, the questionnaire was developed based on the findings of the literature review. The content validity was then evaluated by asking the practitioners to review each item according to (1) how the item represented the waste and how waste elimination met the objectives of the questionnaire, and (2) whether the Likert scale was applicable to each item. The input given by the practitioners when evaluating the content of the questionnaire has been acknowledged and incorporated to improve the questionnaire instrument for use in the data collection.

4.4.5. Analysis of the Survey Responses

The data collected from the survey questionnaire was to provide numerical scoring for section 2, 3 and 4. This numerical scoring is the expression of the respondent’s opinions on the degree of agreement for each question, allowing the data to be analysed using statistical methods

Section 1 : Response Characteristics

The objective of the first section of the questionnaire is to obtain the demography of the sample. The questions focused on the details of the respondents. The questions include: Job title, involvement in the construction industry, type of operation, size of the company, the type of the client from the last completed project, and type of project from the last completed project.

The demographic characteristics of the respondents were then analysed based on facts such as job title, length of experience in the construction industry, the scope of operation of respondent's company, number of employees in the company, type of client based on the last completed project, and the type of project based on the last completed project. The percentage, valid percentage, and cumulative percentage of the frequency for each demographic variable were calculated and are presented in Table 4.4.

Frequency is described as the number of respondents counted for each group of a particular demographic variable. The frequency percentage is calculated based on the total number of respondents of 22. The valid percentage will indicate if there are any missing data from the survey conducted.

In this research, there were no missing data encountered. Therefore, the value of percentage and valid percentage is the same. While the cumulative percentage is calculated by adding up the valid percentage data for each group.

Table 4.4 Results of Demographic Variables

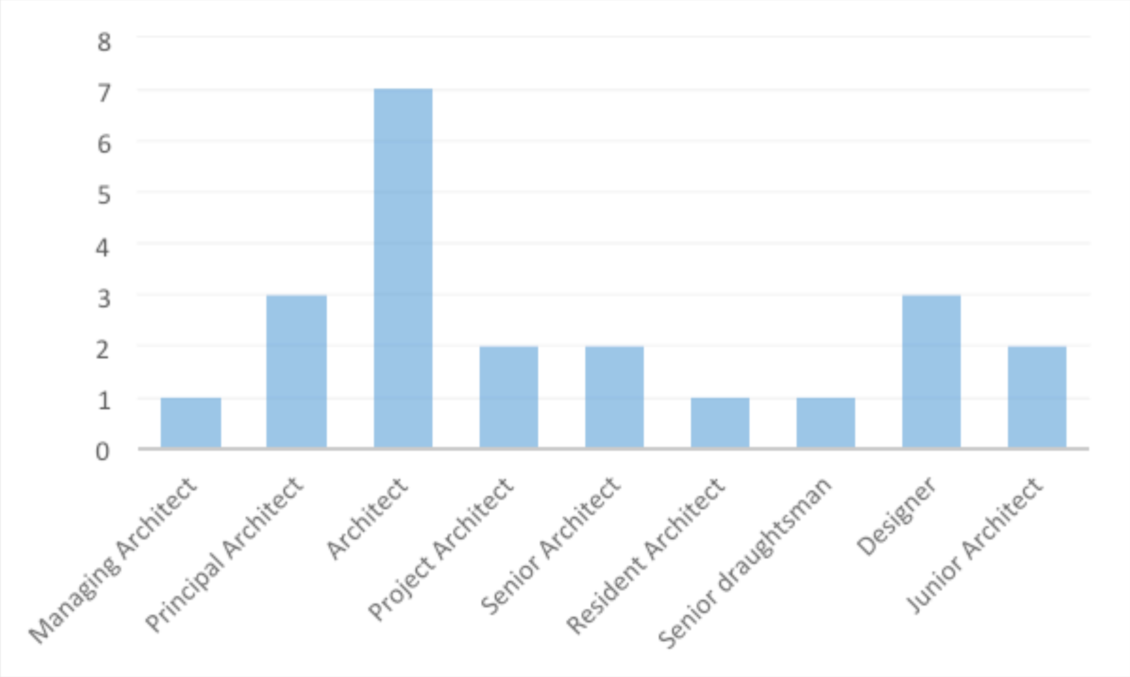
Job Title	Frequency	Percentage	Valid Percentage	Cumulative Percentage
Managing Architect	**1**	**4.5**	**4.5**	**4.5**

Principal Architect	**3**	**13.7**	**13.7**	**18.2**
Architect	**7**	**31.8**	**31.8**	**50**
Project Architect	**2**	**9.1**	**9.1**	**59.1**
Senior Architect	**2**	**9.1**	**9.1**	**68.2**
Resident Architect	**1**	**4.5**	**4.5**	**72.7**
Senior draughtsman	**1**	**4.5**	**4.5**	**77.2**
Designer	**3**	**13.7**	**13.7**	**90.9**
Junior Architect	**2**	**9.1**	**9.1**	**100**
Total	**22**	**100**	**100**	
Length of Experience	**Frequency**	**Percentage**	**Valid Percentage**	**Cumulative Percent**
More than 10 years	**15**	**68.2**	**68.2**	**68.2**
6-9 years	**0**	**0**	**0**	**68.2**
3-5 years	**3**	**13.6**	**13.6**	**81.8**
Less than 2 years	**4**	**18.2**	**18.2**	**100**
Total	**22**	**100**	**100**	
Scope of Operation	**Frequency**	**Percentage**	**Valid Percentage**	**Cumulative Percent**
World Wide	**0**	**0**	**0**	**0**
Nation Wide	**12**	**54.5**	**54.5**	**54.5**
Specific Region	**10**	**45.5**	**45.5**	**100**
Other	**0**	**0**	**0**	**100**
Total	**22**	**100**	**100**	
Size of the Company	**Frequency**	**Percentage**	**Valid Percentage**	**Cumulative Percent**
More than 101 (large)	**4**	**18.2**	**18.2**	**18.2**
51-100 (medium)	**0**	**0**	**0**	**0**
6-50 (small)	**16**	**72.7**	**72.7**	**90.9**
Less than 5 (micro)	**2**	**9.1**	**9.1**	**100**
Total	**22**	**100**	**100**	
Type of Client from the last completed project	**Frequency**	**Percentage**	**Valid Percentage**	**Cumulative Percent**
Government	**9**	**40.9**	**40.9**	**40.9**
Private	**6**	**27.3**	**27.3**	**68.2**
Both	**7**	**31.8**	**31.8**	**100**
Other	**0**	**0.0**	**0.0**	**100**
Total	**22**	**100**	**100**	
Type of Project from the Last Completed Project	**Frequency**	**Percentage**	**Valid Percentage**	**Cumulative Percent**
Housing/building	**16**	**72.7**	**72.7**	**72.7**

Industrial Construction	**2**	**9.1**	**9.1**	**81.8**
Civil Engineering	**2**	**9.1**	**9.1**	**90.9**
Other	**2**	**9.1**	**9.1**	**100**
Total	**22**	**100**	**100**	

It was important for this research to identify the respondent's background to ensure that he/she meets the criteria of the research sample, as described above. In this part of the survey, the respondent's job title indicates the position of the respondent and level of responsibility handled with regards to design activities in the design process. This shows the role of the respondent in the decision-making process. The position of the respondents' job titles are categorised in three groups namely: top management, middle management and lower management. Although the results show that the distribution of the respondents' positions in their companies is well versed the majority of the respondents are from the top and middle management.

Figure 4.1 The Distribution of the Job Title in the Research Sample



This confirms that the results obtained will be valid in terms of the target respondent group, as most of them are senior enough to be involved in decision making in the design process. Considering their positions in management, it can be assumed they acquire a vast knowledge of design and the design process. As such, their judgment would be of value and should be reliable. This would be especially useful in answering open-ended questions contained in the questionnaire.

With the distribution of job titles being high in the middle management of the company, not only will their knowledge be a reliable contribution to this survey but also the challenges they may have experienced during their involvement in projects will positively influence the way they tackle questions contained in the questionnaire.

The time of involvement of the respondents in the construction industry was measured to add to the reliability of their feedback; the longer their involvement, the more mature will be the experience in the design process. Out of the whole sample population, more than 68% of the respondents were those who have had experience in the industry for more than 10 years. Thus, their maturity in career development was considered to be a reliable factor and their contribution would provide high quality feedback for the questionnaire. Therefore, the target respondents for data collection in this research were considered appropriate for the analysis in this research.

The scope of operation is to indicate variability in the design process being practised in responding architectural firms, within the nation and the specific regions of the target country, Brunei. All of their projects were based within the country. Therefore it has been assumed that the design process would be similar among each architectural firm.

The size of the company is measured to give an idea of the type of organisational management of the firm. As shown in the analysis results, more than 72% are from the category of small enterprises, according to the definition given by the 'The Commonwealth Secretariat Final Report on Marketing Services for Brunei Darussalam Small and Medium Enterprises in March 2008'. Therefore, the majority of the respondents are working in forms of between 6 and 50 employees.

With this type of organisation, the establishment of the standard operating procedures should already been established and being practised. Therefore, the design process of these architectural firms can be assumed to be in place, giving the respondents better understanding of this research's topic area and their answers can be considered reliable.

Section 2-Waste in Design Process

Frequency Distribution of Responses

In question 9 of the questionnaire, the respondents were given a list of wastes which affect the design process. This list was the outcome of the interviews conducted prior to the questionnaire survey. The respondents were given a brief explanation of the criteria for wastes in the design process, either through e-mail or during face-to-face meetings. The questions required the respondents to rate on a five-point Likert scale, where 5 represents strongly agree and 1 represents strongly disagree, their agreement on wastes; the wastes had previously been identified from the literature review.

Individual wastes were given an identification code for easy analysis. The percentage of the frequency distribution for the responses is shown in Table 4.5. However, the list is not exhaustive as there will be other wastes that can be unique to the respondents' knowledge and experience throughout their career. Question 10 in the questionnaire allows the respondent to provide any other wastes they consider to be relevant to this research.

The answers to Question 10 were also collected and analysed. The additional list of wastes provided by the respondents were categorised and grouped. As some of the wastes listed had similar definitions to wastes already listed earlier this research, the researcher decided to incorporate the additional list into the existing list in this research.

Some different answers were given in the form of explanations. However, the explanations given appeared to have a similar meaning to the waste already listed. Therefore, having analysed the answers from Question 10, no new additional wastes were identified from the questionnaire.

Table 4.5 Frequency Distribution of Waste

Waste		Strongly Disagree	Disagree	Neutral	Agree	Strongly agree	Total	Mean	St.D
W1 Poor client briefing	**Frequency**	**-**	**-**	**3**	**13**	**6**	**22**	**4.1**	**0.64**
	Percentage	**-**	**-**	**13.6**	**59.1**	**27.3**	**100**		
W2 Inadequate pre-design project meetings	**Frequency**	**-**	**2**	**3**	**15**	**2**	**22**	**3.8**	**0.75**
	Percentage	**-**	**9.1**	**13.6**	**68.2**	**9.1**	**100**		
W3 Lack of project definition	**Frequency**	**-**	**2**	**3**	**12**	**5**	**22**	**3.9**	**0.87**
	Percentage	**-**	**9.1**	**13.6**	**54.5**	**22.7**	**100**		
W4 Design defects	**Frequency**	**-**	**3**	**6**	**10**	**3**	**22**	**3.6**	**0.91**
	Percentage	**-**	**13.6**	**27.3**	**45.5**	**13.6**	**100**		
W5 Inadequate technical knowledge	**Frequency**	**-**	**-**	**2**	**12**	**8**	**22**	**4.3**	**0.63**
	Percentage	**-**	**-**	**13.3**	**46.7**	**40.0**	**100**		
W6 Poor specification	**Frequency**	**-**	**-**	**4**	**15**	**3**	**22**	**4.0**	**0.58**
	Percentage	**-**	**-**	**18.2**	**68.2**	**13.6**	**100**		

W7 **Design changes**	**Frequency**	**-**	**2**	**4**	**9**	**7**	**22**	**4.0**	**0.95**
	Percentage	**-**	**9.1**	**18.2**	**40.9**	**31.8**	**100**		
W8 **Insufficient and unrealistic constraints of project cost**	**Frequency**	**-**	**2**	**7**	**7**	**6**	**22**	**3.8**	**0.97**
	Percentage	**-**	**9.1**	**31.8**	**31.8**	**27.3**	**100**		
W9 **Insufficient and unrealistic constraints of project time**	**Frequency**	**-**	**3**	**7**	**6**	**6**	**22**	**3.7**	**1.04**
	Percentage	**-**	**13.6**	**31.8**	**27.3**	**27.3**	**100**		
W10 **Inadequate involvement of other professionals and teamwork during the design stage**	**Frequency**	**-**	**5**	**2**	**7**	**8**	**22**	**3.8**	**1.18**
	Percentage	**-**	**22.7**	**9.1**	**31.8**	**36.4**	**100**		
W11 **Lack of constructability review of design**	**Frequency**	**-**	**-**	**10**	**9**	**3**	**22**	**3.7**	**0.72**
	Percentage	**-**	**-**	**45.5**	**40.9**	**13.6**	**100**		
W12 **Poor communication among design team**	**Frequency**	**-**	**3**	**5**	**13**	**1**	**22**	**3.5**	**0.80**
	Percentage	**-**	**13.6**	**22.7**	**59.1**	**4.5**	**100**		
W13 **Making design decisions on cost and not value of work**	**Frequency**	**-**	**-**	**3**	**12**	**7**	**22**	**4.2**	**0.66**
	Percentage	**-**	**-**	**13.6**	**54.5**	**31.8**	**100**		
W14 **Poor level of commitment to quality improvement among design professionals**	**Frequency**	**-**	**2**	**4**	**15**	**1**	**22**	**3.7**	**0.72**
	Percentage	**-**	**9.1**	**18.2**	**68.2**	**4.5**	**100**		
W15 **Effect of design code and standards on quality**	**Frequency**	**-**	**-**	**14**	**8**	**-**	**22**	**3.4**	**0.50**
	Percentage	**-**	**-**	**63.6**	**36.4**	**-**	**100**		

The agreement rating on the overall list of wastes, showed that most respondents were accepting the list. However, analysing individual ratings of agreement would be beneficial to understand their perception of respondents on wastes in the design process. Therefore, the following represents an analysis of the individual results of the waste.

W1- Poor client briefing

Client briefing is an essential stage in the design process of architecture. This design stage comes at the beginning of the design phase. Without a proper design brief from the client, it is impossible to fulfil the client's requirements, so the client briefing can be considered as a requirement of the customer.

From the results presented above (Table 4.5), the respondents appear to understand the importance of client briefing. Without prior client briefing, respondents will present a design that is either that typically required by their previous clients, or a design which they feel would meet the client's requirements. However, the accuracy of their assessment of the client's requirement will be dependent upon the briefing for the project.

From the percentage of the results presented in the table above, 59.1% agreed that waste is related to poor client briefing of which 27.3% strongly agreed. An incomplete briefing about the client's requirement may result in the designer having to guess what their clients require, leaving a risk that client may disagree with the end result. Therefore, this may be a cause for the clients to be dissatisfied with the result provided to them and the work would, therefore, provide no value to the client.

W2-Inadequate pre-design project meetings

The results for waste W2 show that 9.1% of respondents disagreed with this being in the waste list. Disagreement may be because the respondent is the sole designer for that project and may not consider team meetings as an important requirement in design projects. However, 68.2% of the respondents agreed to this being a suitable waste, with 9.1% strongly agreeing. Therefore, from these results the majority is in agreement with this waste.

W3-Lack of project definition

This type of waste refers to the lack of project definition, and gave a high percentage in the *strongly agree* rating of 22.7%, with the *agree* rating of 54.5% which gives a high percentage of agreement for this type of waste. This indicates the respondents understand the definition of success in construction projects, as it is important to have a definition of success in a project as this is a tool for measuring performance. Further, 13.6% of the respondents rated neutral, which could be due to the fact that the respondents do not have roles or responsibilities in decision-making and would normally follow the tasks given to them within the project.

W4-Design defects

The results show the percentage rate of respondents in agreement was 45.5%, indicating the respondents were aware of the existence of design defects and that these can only be detected during the construction phase. This means the design defect could not have been considered in the design process, as it could still have been changed during the design phase. A percentage of 13.6% strongly agreed that the design defect can be detected and avoided during the design phase by having checks or a design review system.

W5-Inadequate technical knowledge

Results show high percentage ratings of respondents who agree and strongly agree with W5, of 46.7% and 40.0% respectively. Only 13.3% of the respondents rated the waste as neutral. It is beneficial for designers to possess technical knowledge in designing a project. This may be an advantage, as designers will be able to ensure the design created will also meet the technical aspects of other project team members such as engineers and quantity surveyors. This, in itself, will reduce queries from the other project team members with regard to the design. It is essential therefore for designers to update their knowledge on the specific areas in order to address any lack of technical knowledge.

W6-Poor specification

Performance of the project may be disrupted or affected by a poor specification, especially in cases where new technology is being introduced. Specifications are required to be detailed and complete. Without a proper specification, the design may involve complicated construction or a failure to complete the work. Respondents have shown consistent agreement as to how this inadequacy can affect PP. Ratings show that 68.2% of the respondents agreed and 13.6% strongly agreed with this issue.

W7-Design changes

Some designers allow design changes during the construction process, as this will improve the constructability of their design. Only 9.1% of the respondents showed disagreement with the statement that design changes can be treated as waste in a design process, with 40.9% agreeing and 31.8% strongly agreeing. Frequent design changes during the design phase will waste the time and effort of the designer in completing the tasks.

W8-Insufficient and unrealistic constraints of project cost

Results show, 31.8% and 27.3% of the respondents agree and strongly agree with this waste respectively. Respondents may have experienced unrealistic project costs for the size of the project, lack of available resources, unrealistic client requirements, lack of innovation, the type of design, and the technology adopted. This may result in an insufficient budget to execute the project successfully. This may then lead to design changes and omissions throughout the design and construction phase.

W9-Insufficient and unrealistic constraints of project time

Respondents who agreed and strongly agreed with this type of waste have rated their agreement equally at 27.3%. They note that ample time is required in order to deliver innovative and creative designs to the project. Time constraints in delivering a project may have a negative impact on the quality of the design as the designers are required to meet unrealistic deadlines for urgent projects. The design is considered as tacit knowledge possessed by the designer and they may be unable to transfer the idea to others. Delegation is therefore deemed difficult.

W10-Inadequate involvement of other professionals and teamwork during the design stage

The involvement of other professionals during the design stage could be dependent on the complexity of the project. Some architectural companies may already have a design team with technical experience and knowledge, which may be beneficial to their design. They would, therefore, feel that it is unnecessary to outsource this technical knowledge

as they feel that inputs are readily available within their peers. The agreement was 31.8% for this type of waste and 38.4% strongly agree. This may mean that the lack of agreement comes from a portion of the respondents with limited resources within their firm, or with innovation for the project.

W11-Lack of constructability review of design

Some projects allow the design to be prolonged into the construction phase of the project (depending on the contract type). This is to facilitate the constructability of the design, which creates the opportunity to consult the contractor for advice. Advice may not be able to be sought in the design phase, as contractors or sub-contractors have not yet been appointed (in the case of design/bid/build contracts). Therefore, it is important to ensure that the constructability of the design is clarified at the design phase. Respondents have shown agreement of 40.9% while 45.5% of the respondents rated it neutral. Those that have rated neutral may have experienced simple projects where sample designs and information is readily available.

W12 Poor communication among design team

More than half of the respondents agree with this type of waste. Communication is key in ensuring the smooth flowing of the process. Communication also creates harmony within the design team, as each member is able to understand their role and tasks in the project. However, results show that 13.6% disagree with poor communication as being a type of waste in the design process. This may be because the respondent is the sole designer of that particular project. This is common within a small architectural firm.

W13-Making design decisions on cost and not value of work

High ratings of agreement were given by the respondents for this type of waste, with 54.5% agreeing and 31.8% strongly agreeing. The respondents were aware that the design should be value-related to meet the client's requirement. The respondents understood that in working within client's budgets constraints, the value of work for the client should not be neglected. They also know that in placing value on the design, clients may wish to engage them in future projects.

W14-Poor level of commitment to quality improvement among design professionals

The level of commitment to quality improvement can be referred to the individual designer's effort to make improvements on the project. For this type of waste 68.2% of the respondent agree that commitment is essential to PP. They understand the significance of contributions by individuals towards the PP and success. The respondents were also aware that individual roles and responsibilities in a design team need to be clear, so that the tasks carried out will be efficient and effective. For sole designers, a high level of commitment is an essential requirement to ensure business runs smoothly and efficiently.

W15-Effect of design code and standards on quality

63.6% of the respondents rated neutral for this type of waste. Respondents use design codes and standard as their guideline for their innovation and creativity, which can be considered highly conservative. They may find it difficult to accept that design codes and standards are capable of affecting their design process. 8% of the respondents agree with this as a type of waste and this may probably be due to the fact that a high level of innovation is involved in their designs and may lead them to consider that design codes and standards are a restriction on their design innovation.

Section 3: Agreement of Waste Elimination

This section is divided into two parts. The first part is seeking agreement from the respondents on the proposed stages for the design process in relation to the proposed activities. The second part is seeking the agreement of the respondents on the elimination of identified wastes by the proposed activities at every stage in the design process.

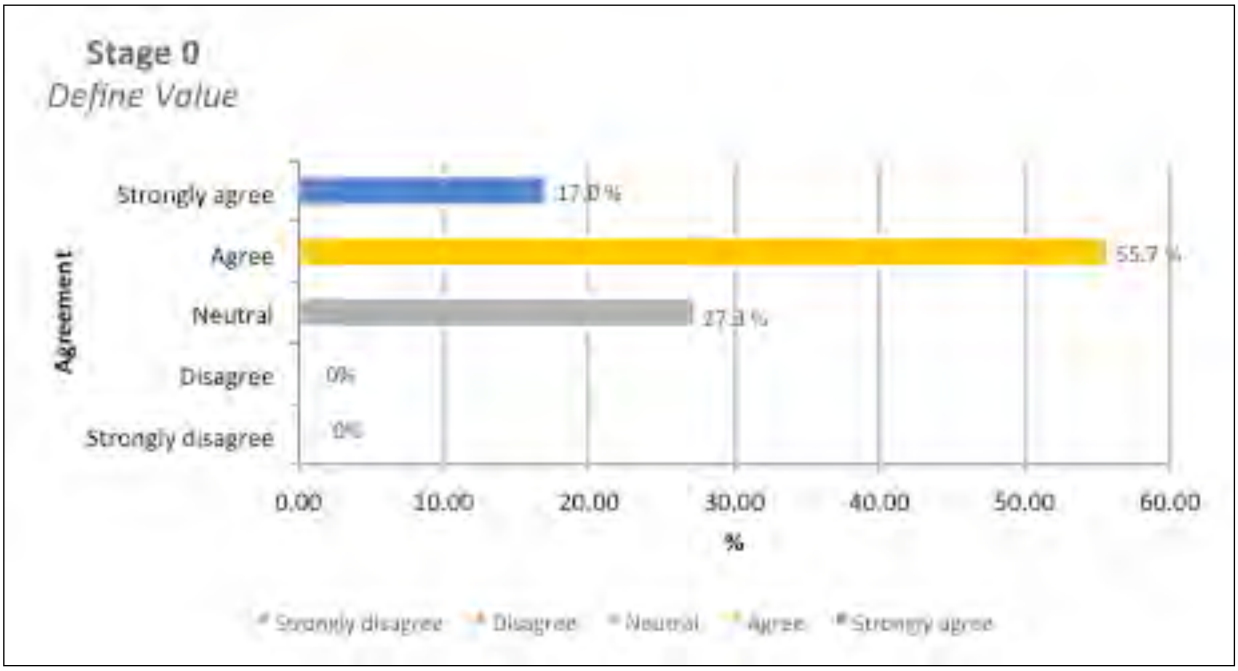
The analysis of the results is presented below. The sequence of the discussion is based on the questions in the questionnaire. Table 4.6 shows the frequencies and percentages of the survey for section three in the questionnaire.

Part 1: Agreement on the proposed Design Stages

Stage 0: Define Value

The percentages of the responses were calculated for the activities in each stage (Figure 4.2). The results show 72.7% of the respondents agree that the first stage should be related to seeking the client's requirements for the project. It is important to match the client's requirements with the project constraints in order to produce the optimal design. Therefore, this stage is agreed by the respondents to be the first stage of the design process.

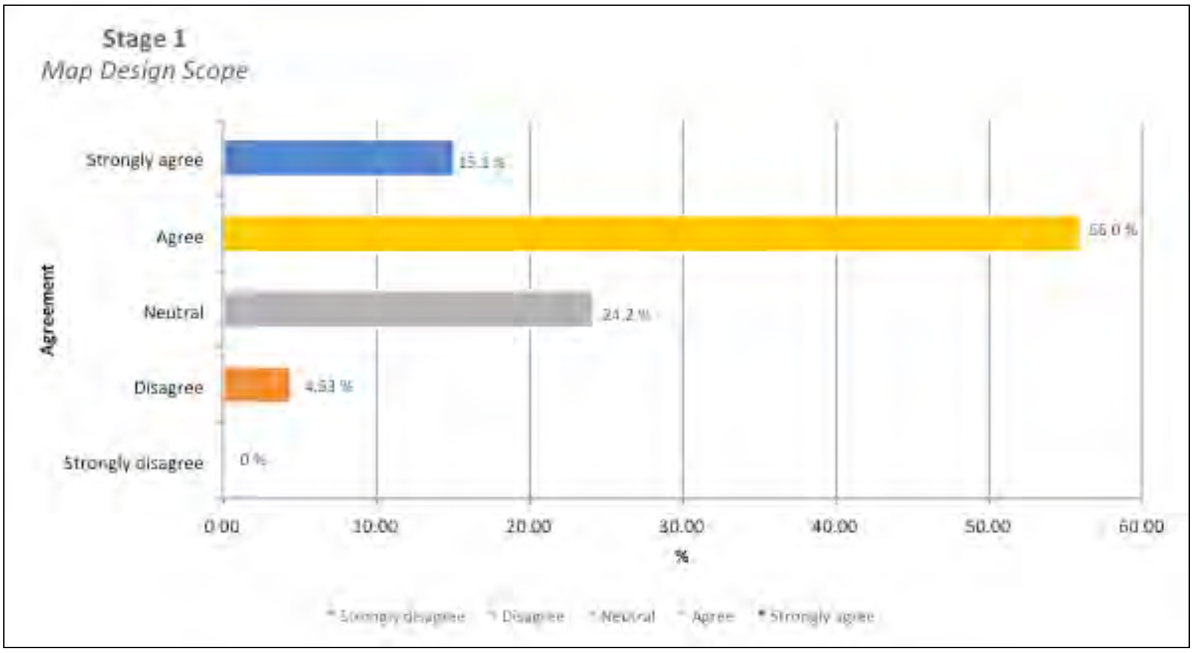
Figure 4.2 The Evaluation of Stage 0



Stage 1

The results from Figure 4.3 show that the majority of respondents agreed with this stage, where 'map design scope' is relevant to the planning of the design of a project. At this stage, the decision-making process is comprehensively involved. This will determine whether the project can proceed to the next stage or not. However, 4.53% disagree with the stage. This might be due to the nature of the complex decisions that need to be finalised, where some respondents might have no decision-making authority.

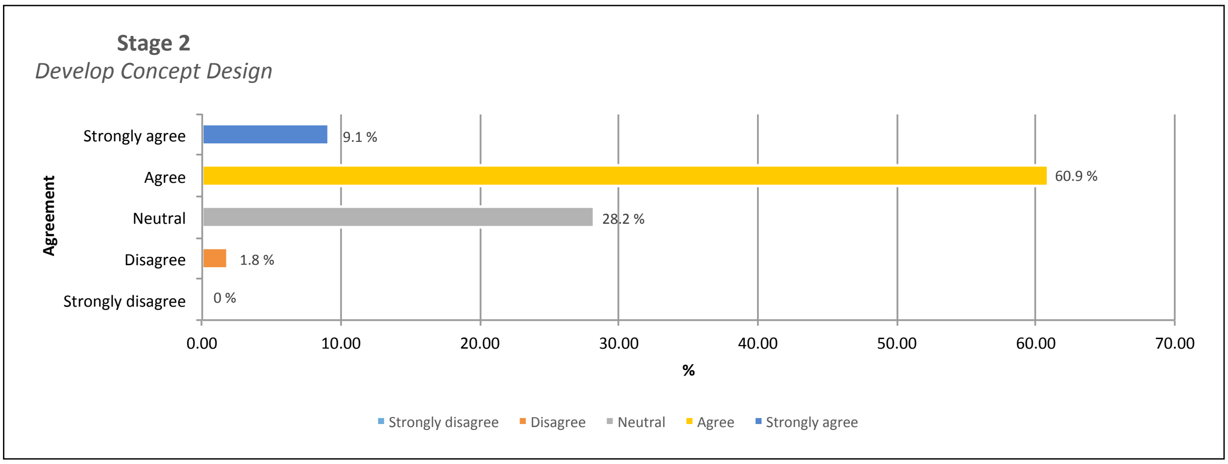
Figure 4.3 The Evaluation of Stage 1



Stage 2

Results show that 60.9% agreed with the stage as shown in Figure 4.4. This stage involves design development based on the information gathered from Stage 0 and Stage 1. This is where designers explore every aspect of the design and present it to the design team. It seems likely that the respondents are highly familiar with this stage, showing their agreement at a level of 70%.

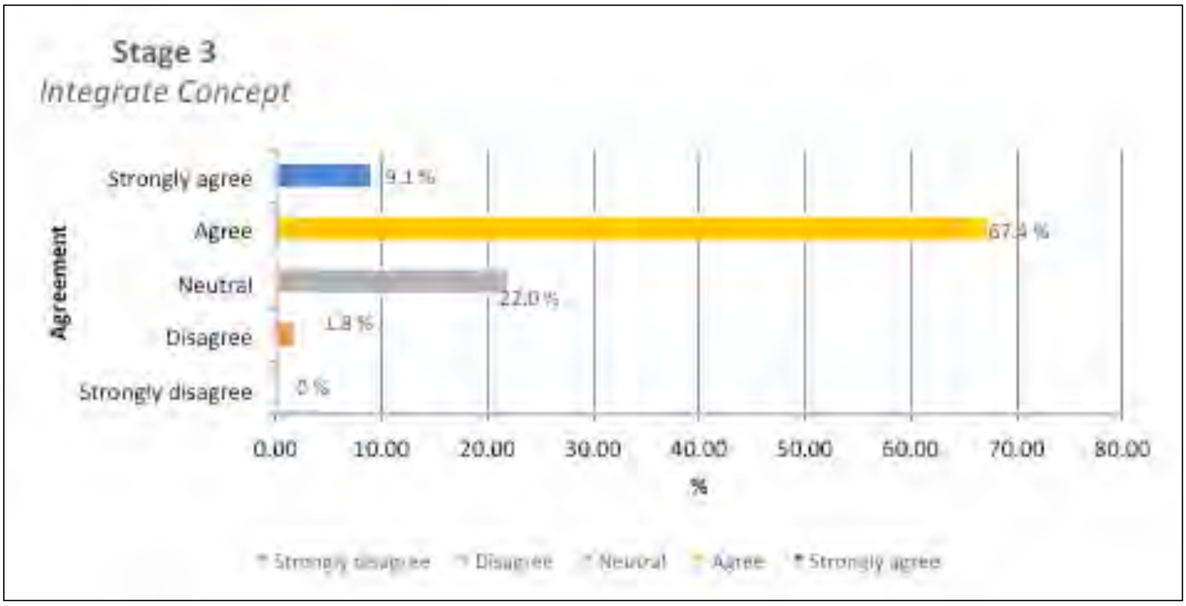
Figure 4.4 The Evaluation of Stage 2



Stage 3

The results shown in Figure 4.5 indicate that between 67.4 % to 72.7 % of the respondents consider this stage is able to resolve some issues in the design process. More than half of the respondents seem to relate to the problem of constructability of the design once it has commenced construction. Design changes are inevitable as client's requirements needs to be balanced out with other constraints that may be present in the design phase and in construction. The 'integration of final concept design' activity in Stage 3 encourages designers to communicate with other project teams or areas of expertise. This may result in the improvement of the constructability of the design and the opportunity to engage other professionals in the design phase of a project.

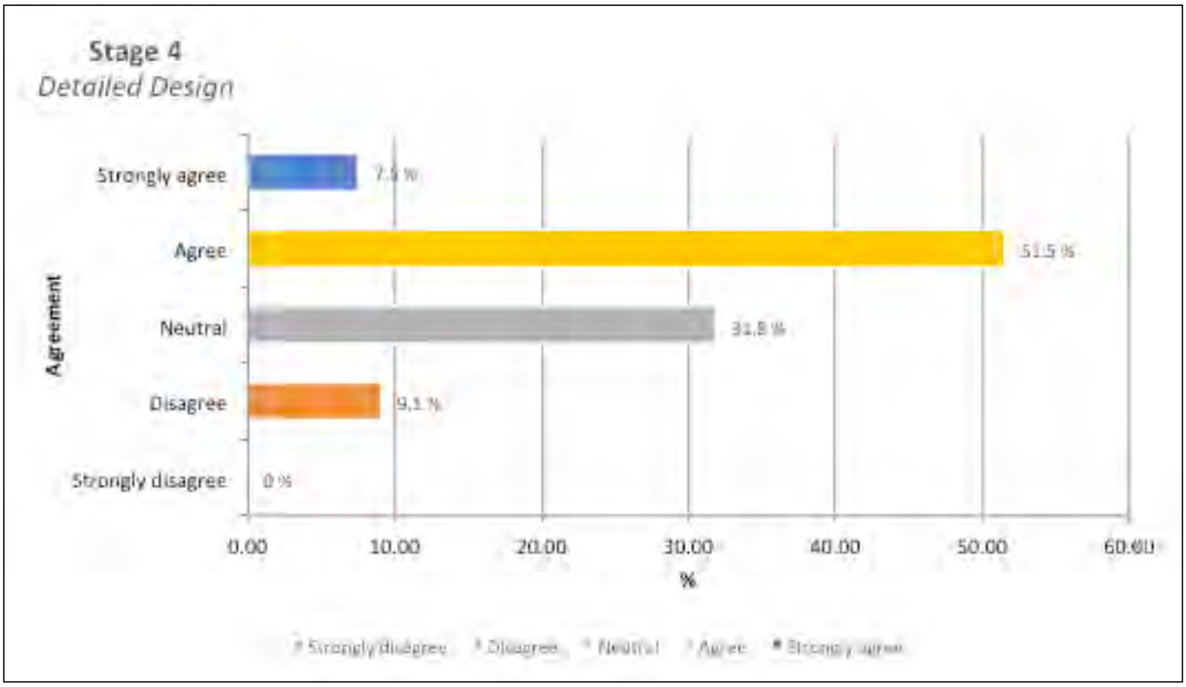
Figure 4.5 The Evaluation of Stage 3



Stage 4

This stage is relevant to the effectiveness of release of the final design and specifications to proceed with the detailed design activities. Results showed 51.5 % in agreement, as this stage is similar to the RIBA plan of work (Figure 4.6).

Figure 4.6 The Evaluation of Stage 4



Part 2: The Agreement of Elimination of Waste by the Proposed Design Process Activities

In this part, analyses and results from the elimination of the listed wastes by the design process activities are presented in Table 4.6 Frequency Distribution of Elimination of Waste Through Design Process Activities. The respondents were asked to give their agreement or disagreement on each of the activities.

Table 4.6 Frequency Distribution of Elimination of Waste Through Design Process Activities

Stage	Activity		Strongly Disagree	Disagree	Neutral	Agree	Strongly agree	Total	Mean	St.D
0	S0.1	**Frequency**	-	-	4	13	5	22	4.0	8
		Percentage	-	-	18.2	59.1	22.7	100		
	S0.2	**Frequency**	-	-	4	12	5	22	4.0	8
		Percentage	-	-	18.2	59.1	22.7	100		

	S0.3	**Frequency**	**-**	**-**	**7**	**13**	**2**	**22**	**3.8**	**9**
		Percentage	**-**	**-**	**31.8**	**59.1**	**9.1**	**100**		
	S0.4	**Frequency**	**-**	**-**	**9**	**10**	**3**	**22**	**3.7**	**8**
		Percentage	**-**	**-**	**40.9**	**45.5**	**13.6**	**100**		
1	**S1.1**	**Frequency**	**-**	**-**	**7**	**12**	**3**	**22**	**3.8**	**8**
		Percentage	**-**	**-**	**31.8**	**54.5**	**13.6**	**100**		
	S1.2	**Frequency**	**-**	**2**	**6**	**12**	**2**	**22**	**3.6**	**9**
		Percentage	**-**	**9.1**	**27.3**	**54.5**	**9.1**	**100**		
	S1.3	**Frequency**	**-**	**1**	**3**	**13**	**5**	**22**	**4.0**	**9**
		Percentage	**-**	**4.5**	**13.6**	**59.1**	**22.7**	**100**		
2	**S2.1**	**Frequency**	**-**	**2**	**5**	**11**	**4**	**22**	**3.8**	**8**
		Percentage	**-**	**9.1**	**22.7**	**50.0**	**18.2**	**100**		
	S2.2	**Frequency**	**-**	**-**	**8**	**14**	**-**	**22**	**3.6**	**7**
		Percentage	**-**	**-**	**36.4**	**63.6**	**-**	**100**		
	S2.3	**Frequency**	**-**	**-**	**4**	**16**	**2**	**22**	**3.9**	**10**
		Percentage	**-**	**-**	**18.2**	**72.7**	**9.1**	**100**		
	S2.4	**Frequency**	**-**	**-**	**8**	**12**	**2**	**22**	**3.7**	**8**
		Percentage	**-**	**-**	**36.4**	**54.5**	**9.1**	**100**		
	S2.5	**Frequency**	**-**	**-**	**6**	**14**	**2**	**22**	**3.8**	**9**
		Percentage	**-**	**-**	**27.3**	**63.6**	**9.1**	**100**		
3	**S3.1**	**Frequency**	**-**	**-**	**5**	**15**	**2**	**22**	**3.9**	**9**
		Percentage	**-**	**-**	**22.7**	**68.2**	**9.1**	**100**		
	S3.2	**Frequency**	**-**	**-**	**7**	**15**	**-**	**22**	**3.7**	**8**
		Percentage	**-**	**-**	**31.8**	**68.2**	**-**	**100**		
	S3.3	**Frequency**	**-**	**-**	**5**	**13**	**4**	**22**	**4.0**	**8**
		Percentage	**-**	**-**	**22.7**	**59.1**	**18.2**	**100**		
	S3.4	**Frequency**	**-**	**-**	**5**	**16**	**1**	**22**	**3.8**	**10**
		Percentage	**-**	**-**	**22.7**	**72.7**	**4.5**	**100**		
	S3.5	**Frequency**	**-**	**2**	**3**	**14**	**3**	**22**	**3.8**	**9**
		Percentage	**-**	**9.1**	**13.6**	**63.6**	**13.6**	**100**		
	S3.6	**Frequency**	**-**	**-**	**4**	**16**	**2**	**22**	**3.9**	**10**
		Percentage	**-**	**-**	**18.2**	**72.7**	**9.1**	**100**		

4	**S4.1**	**Frequency**	**-**	**2**	**5**	**12**	**3**	**22**	**3.7**	**9**
		Percentage	**-**	**9.1**	**22.7**	**54.5**	**13.6**	**100**		
	S4.2	**Frequency**	**-**	**-**	**8**	**13**	**1**	**22**	**3.7**	**9**
		Percentage	**-**	**-**	**36.4**	**59.1**	**4.5**	**100**		
	S4.3	**Frequency**	**-**	**4**	**8**	**9**	**1**	**22**	**3.3**	**9**
		Percentage	**-**	**18.2**	**36.4**	**40.9**	**4.5**	**100**		
Internal Review										
0-3	**SA LL**	**Frequency**	**-**	**2**	**5**	**7**	**8**	**22**	**4.0**	**1.00**
		Percentage	**-**	**9.1**	**22.7**	**31.8**	**36.4**	**100**		

After analysing the results from the respondents on the elimination of waste in design process by the activities, overall agreement is seen from the respondents about the elimination of wastes by the proposed design process activities. The activities in ‘Stage 0’ are appropriate for the ‘define value stage’ in the design process. This indicates that the activities proposed are capable of creating value to the client and eliminate waste. The averages of the agreement from the respondents came within the range of 3.7 to 4.0. This shows that the activities for this stage are necessary in order to achieve performance improvements in construction design projects.

The highest ratings were obtained from the activities of ‘classify project’ and ‘explore client value’ with an average rating of 4.0 for both. This rating may be due to the respondents’ familiarity with the activities and that the ‘define value’ stage is similar to client’s briefings in the traditional design process. However, the other activities were rated just below ‘neutral’, possibly because the respondents had very little experience or practice in that activity.

The activities in ‘Stage 1’ are developed to identify the scope of the design. This is where architects and designers decide on how the design should be developed. Results show that the type of activity under ‘define feasible regions of design scope’ received the highest rating compared with other activities at this stage. This could be a result of vast knowledge and experience acquired by the respondents throughout their career, where the decision-making is essential at the early stage. Conversely, the two other activities in this stage received a slightly above-neutral rating, which could be explained by the respondents having never put this activity into practice, despite its contribution to the performance improvement of projects.

In Stage 2, the respondents agreed that all the activities were able to eliminate wastes of ‘design changes’. The respondents may have personal knowledge that any design changes made at this stage may cost less, compared with changes made at a later stage. The activities at this stage are also able to capture knowledge that can be referred back, either as the record of design development, or as design data that can be used for other projects. These activities were given 63.6% and 54.3% of respondents’ agreement respectively. The involvement of other team members in design development such as quantity surveyor, contractor or sub-contractors engineers and safety officers might contribute to the constructability of the design which can influence the respondents’ perception on elimination of design changes.

In Stage 3, the majority of the respondents agreed that these activities are capable of eliminating the selected waste. The respondents were aware of the benefits of the proposed stage, with one of the interviewees commenting that by providing a number of different designs for a project, the client will have more options to compare. With options to compare, clients will have informed decisions that will assist them in reaching their final designs. Therefore, this should result in a reduction in the number of design changes.

Stage 4 acts, as a checklist to ensure that what is required for the next stage of the construction project is properly prepared. The respondents agreed with the need for elimination of the wastes by the proposed activities in this stage. All of the activities were able to eliminate design changes at the design stage of construction projects.

Internal Review

An internal review activity was incorporated in every stage of the proposed design process. This activity has the highest number of waste eliminations. Analysis of the rating of respondents' agreement on these activities showed an average of 4.0. One of the interviewees stated that the design review should be made as often as possible and it should be done during the process of designing a building project. This reflects a view that the respondents are agreeable to the elimination of the wastes identified in this research. The internal review also enhances communication amongst the design team and other professionals involved in the project. Therefore, it is apparent that internal review is an essential activity in the design process.

Section 4: The Evaluation of Proposed Framework

The evaluation of the proposed framework for this research was acquired through questionnaires, which asked respondents about their agreement or disagreement on statements which have been provided. Subsequently, the respondents were given an opportunity to suggest and comment on the proposed framework in the final section of the questionnaire.

As presented Table 4.7, the average rating values for the evaluation of the framework for this research came in the range of 3.8 to 3.6. Almost half of the respondents rated under “agree” and “strongly agree” categories. This indicates that the respondents are generally in overall agreement with this section of the questionnaire. However, some have rated neutral, which may reflect the limited exposure they have to new developments in the construction industry. As mentioned in the interview section of this research, most of the participants are not aware of LT and lean principles. This is reflected in the limited knowledge they have on the paradigm of design process and new developments of the principles.

The first evaluation of the proposed framework was to find out the respondents' opinions on the target of the framework development for this research, which is coded as "S1-Framework meets expectation". A total of 54.5% agreed that the proposed framework had the potential to eliminate waste. In this context, the elimination of waste means that the design process will be able to improve the performance of the project at the design stage. Such improvement is not limited to the overall performance, but the proposed design process also aims to improve the performance at every stage of the design process by having an internal review. Therefore, this kind of performance check will be able to control the design process, and poor performance can be detected where possible at an early stage.

In statement "S2-Framework is informative", the proposed design process has considered and incorporated the issue of information flow in activities where communication is enhanced. Translation of the information into the design can be difficult for some respondents, but with the available techniques and tools categorised as enablers for this research, the design process and the design itself will be enriched. This statement was agreed by 68.1% of the respondents.

The subsequent evaluation includes details of the process and activities of the proposed framework coded "S3-Framework provides sufficient details". This evaluation received 68.1% agreement from the respondents. The activities proposed in this research incorporates LT principles and clearly elaborates the steps and actions that need to be taken to ensure the design produced creates value for the client. Thus, the description of the activities would provide the respondents with a clear idea of what is the intended outcome of the proposed stage.

In statement “S4-Framework is easy to understand”, the development of the framework is based on the RIBA plan of work. Some respondents are already aware of the components of the plan of work that they have practised on projects. This has therefore made it is easy for the respondents to understand and follow the proposed design process.

In statement “S5-Framework is consistent with other design process”, the consistency of the stages helps the design process to be readable and to be easily understood and this might ease its implementation in practice. This statement received agreements of 59.1% and 54.5% respectively.

The compatibility of the framework and potential of the framework to be used by the respondents were assessed in the evaluations coded “S6-Framework is compatible with current design practices” and “S7-Framework has the potential to be employed” respectively. Less than half of the respondents agreed with these statements. Respondents may understand that the framework proposed may not be compatible due to differences in their current work practices. In order to adopt the proposed framework with the respondents’ current practices, some changes may be required. The changes will not only include the way they design, but also in the way they think. Only 45.12% of the respondents agreed to statement S6 therefore. Respondents may also have felt that it may be difficult for the proposed framework to be employed in their current work routine, as changes would be required. 45.5% agreed with this statement.

In statement “S8-Framework is feasible”, 50% of the respondents agreed with this statement. The feasibility of the framework is based on the features which the design process possesses. The features are structured so that it is easy to follow and are the stages, activities and method of executing the activities that are included in the presented design process.

In statement “S9-Framework is recommended”, the respondents are in general agreement that the proposed framework can be recommended to improve the PP, as they understand the issues listed in the list of waste in this research need to be addressed. In addition, the characteristics of enabling, simple, flexible and not forced which possessed by the proposed design process might draw interest from the respondents to recommend it to be applied in their organisation. This statement received 59.1% of respondents’ agreement.

In the final part of the questionnaire, “S10”, the respondents were asked as to whether they wish to participate in further research. 54.5% of the respondents agreed to be contacted for further development of the framework. This interest may be due to a realisation that they may have to cross some hurdles and make changes to be able to apply a new system into their routine. In doing so, time may need to be sacrificed and training may need to be undergone, which may take a toll on their work momentum. Change may not be particularly interesting to those who are content with their current work practices.

Table 4.7 The Evaluation of the Proposed Framework

Statement		Strongly Disagree	Disagree	Neutral	Agree	Strongly agree	Total	Mean	St.D
S1	**Frequency**	-	-	**10**	**9**	**3**	**22**	**3.7**	**5**
	Percentage	-	-	**45.5**	**40.9**	**13.6**	**100**		
S2	**Frequency**	-	-	**7**	**12**	**3**	**22**	**3.8**	**5**
	Percentage	-	-	**31.8**	**54.5**	**13.6**	**100**		
S3	**Frequency**	-	-	**7**	**13**	**2**	**22**	**3.8**	**6**
	Percentage	-	-	**31.8**	**59.1**	**9.1**	**100**		
S4	**Frequency**	-	-	**9**	**8**	**5**	**22**	**3.8**	**4**
	Percentage	-	-	**40.9**	**36.4**	**22.7**	**100**		
S5	**Frequency**	-	-	**10**	**9**	**3**	**22**	**3.7**	**5**
	Percentage	-	-	**45.5**	**40.9**	**13.6**	**100**		
S6	**Frequency**	-	-	**12**	**7**	**3**	**22**	**3.6**	**5**
	Percentage	-	-	**54.5**	**31.8**	**13.6**	**100**		
S7	**Frequency**	-	-	**12**	**8**	**2**	**22**	**3.5**	**5**
	Percentage	-	-	**54.5**	**36.4**	**9.1**	**100**		
S8	**Frequency**	-	-	**11**	**9**	**2**	**22**	**3.6**	**5**
	Percentage	-	-	**50.0**	**40.9**	**9.1**	**100**		
S9	**Frequency**	-	-	**9**	**11**	**2**	**22**	**3.7**	**5**
	Percentage	-	-	**40.9**	**50.0**	**9.1**	**100**		
S10	**Frequency**	-	-	**10**	**9**	**3**	**22**	**3.7**	**5**
	Percentage	-	-	**45.45**	**40.9**	**13.6**	**100**		

4.5. Summary of Findings

The results from this survey have been incorporated in the case study and the proposed framework. Any fine changes will then be considered and the final proposed framework will be used to conduct the case study.

The final version of the proposed design process in the design phase of a building construction project for this research, has taken significant input from the respondents which has had a great effect on the development of the proposed design process. The result from the interview and questionnaire survey have been supported by a continuous review of current literature and project report to develop a practical model that can be utilised in the context of construction design projects. Furthermore, the final results that have had a positive impact on the development of the proposed design process in Brunei can be concluded and summarised as follows:

- There are various factors which are required to be considered in design process in order to create value for clients.
- The design process possesses the four characteristics of: enabling, simple, flexible, and not forced. It can also be considered a guide for practitioners.
- Tools and techniques need to be incorporated into the design process to achieve optimum design.
- Standard practices or procedures should be established within the organisations for handling issues such as inadequate client briefs and analysing the costs and time constraints of a project.
- The application of BIM technology and methodologies has been proven to increase value for clients and minimise wastes in terms of time, materials and financing.
- A systematic approach to the assessment of a project will enhance the PP.
- There is no formal evaluation of PP in building design projects, either during the design phase, or at the completion stage.

- There are lots of variables to consider, which complicates the measurement of design performance.
- There is little evidence that continuous improvement is being practised.
- The results of the interviews and questionnaires have shown high agreement with the components proposed in the design process and their usefulness for the successful adaptation of an innovative design process. However, the results highlighted the desire to have a design process that can be easily understood and followed.
- The interviews have indicated that the details and descriptions of the proposed design process, which help to simplify its understanding and adaptation, should be a priority.
- The design review is essential for the design process in order to control the performance of the activities. However, the method is underdeveloped, especially in the design phase of construction projects.

4.6. Summary

In this chapter, analysis of the stages for the proposed design process and waste elimination by the proposed activities in have been analysed, based on data collected using semi-structured interviews and survey questionnaires. The reliability of the questionnaire is tested using the Cronbach's Alpha scale prior to the data collection. The results of interviews and questionnaires were analysed and discussed in this chapter. An in-depth study of the design process of Brunei's construction industry was also analysed. The waste elimination by the proposed design process activities was also analysed in order to achieve the practitioners' agreement. The proposed design process can be refined with the findings from this chapter and moved forward with confidence into the case studies. The following chapter would be the development of the proposed design process and its performance measurement.

5. DEVELOPMENT OF THE INNOVATIVE DESIGN PROCESS AND PERFORMANCE MEASUREMENT

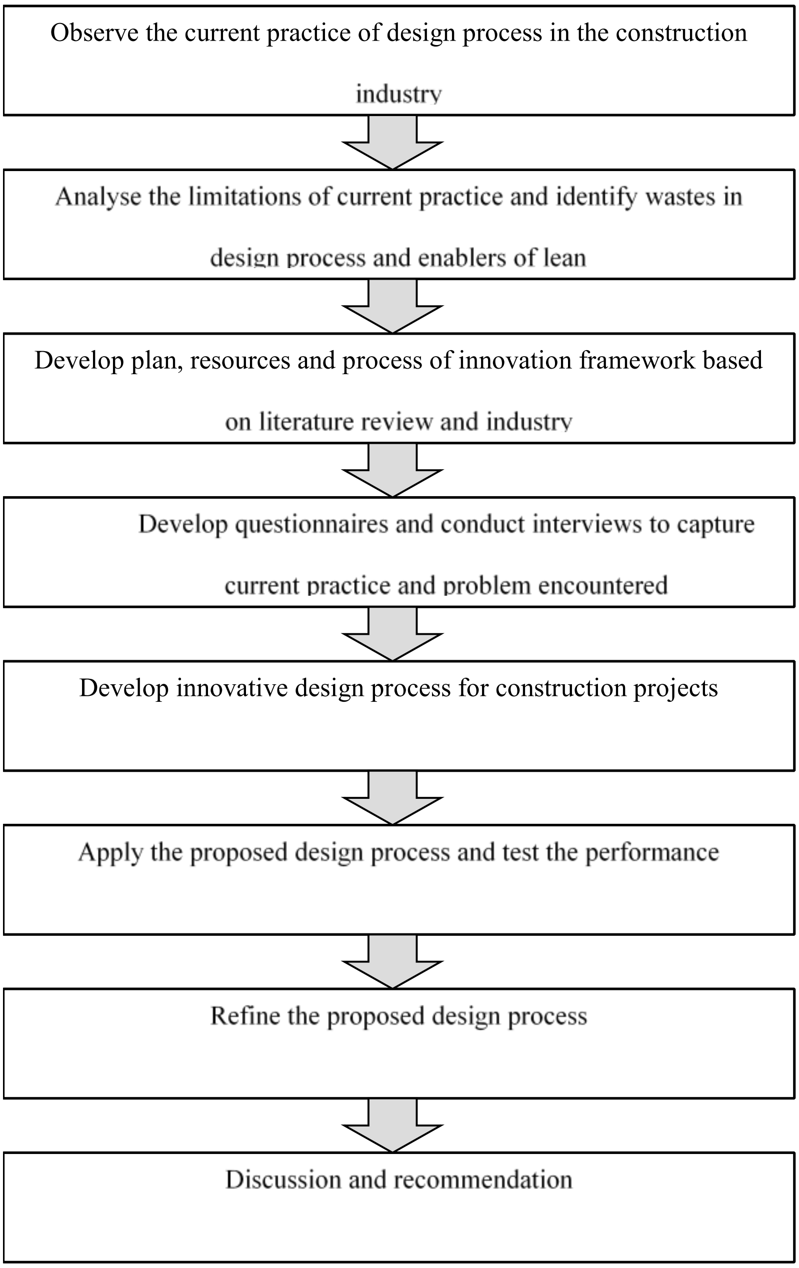
5.1. Introduction

As describe in this thesis, the results from literature review, the questionnaire survey and interview indicate that the current project development process has potential problems of uncertainty and complexity in processing information, value creation, elimination of identified waste, and measuring performance in construction projects. Therefore it is essential to develop an innovative design process to manage the performance of the construction project at the early stage effectively and efficiently.

The design process and its components, the results from the questionnaire survey and interviews, the identified waste and elimination, the tools and techniques, the performance measurement in this research as discussed in the previous chapters can be adopted in the development of an innovative design process for the industry in order to enhance the project performance. However, parts of the proposed design process, including the stages proposed such as the 'concept design development' and 'concept integration', may require some customisation according to the type of project which will consume considerable time, cost and effort. The proposed design process framework can be used to innovate the management of information, identify the waste and eliminate, and measure the performance.

Although many literatures resources may help to provide frameworks for innovation of design process, there is still a need to developed structured methods and customisation for design process implementation and application to each construction project (Gravina et al., 2013). Such customisation can be achieved through various elements. In this research, what makes the proposed design process unique is the customisation of the activities of each stages and its method of implementation. The sequence of the development of the proposed design process in order to customise the activities and implementation to generate innovation can be seen in Figure 5.1.

Figure 5.1 Stages of Development for the Proposed Design Process and Performance Measurement



5.2. A Framework for Innovation of Lean Design Process

The development of lean design process needs a definition in order to achieve the research objectives, which will be elaborated in this section. The approach adopted was first to formulate a knowledge domain. Domains provide a learning environment that can be understood by those who want information in depth, both for new knowledge, and also to test previous knowledge in order to make improvements (Biton & Howell, 2013). This will lead to the innovation in the research area. Therefore, it is important that the knowledge domains presented in the literature review are to be considered for the development of the framework. The seven domains that have been described by the researchers in their article have been analysed. The principles, methods, tools and techniques, which are based on the design in building construction projects that were mentioned in multiple publications, have been prioritised. Some of these were merged due to the overlapping of the research theme.

The linkage of the seven domains that becomes the components of Innovation of the lean design process is depicted in Figure 5.2. The main components for the innovation is the design process itself which is the main focus of this research. Therefore, these components received more attention and included in the development of a design process that can support LT principles and LC principles in order to improve the PP.

The seven components for the framework are:

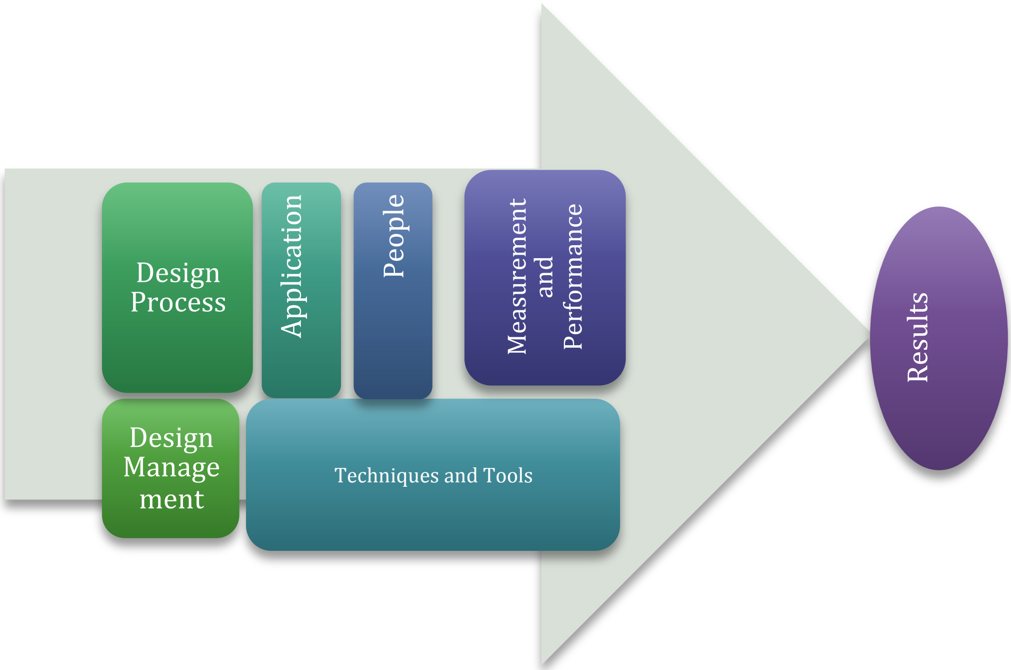
1. Application: those that use the principles and applied them in projects and development of framework. The application of the framework

2. Design Management: those that focus on the improvement of the project in design phase
3. Design process: those that focus on the specific stages in design phase
4. People: that that concern with the improvement in relation to the interaction amongst client, architect, stakeholders and other practitioners in the design phase.
5. Information flow: that that concern with the utilisation of information in projects.
6. Measurement and Performance: those that concern and focus on the performance of projects and developing the performance measurement of projects.
7. Techniques and Tools: those that focus on the development of techniques and tools for innovation in design phase of projects.

Design management will be the support of the design process, so that the management aspects in the architectural design are properly addressed in the design process. The component of techniques and tools will be for the support of application, people and performance measurement, allowing the application to be implemented in the design process. The user of the techniques and tools will be benefited in achieving their goals and objectives of accomplishing tasks in efficient and effective way. In performance measurement the techniques and tools will be developed to achieve the research objectives.

With all of these components flowing in the same direction, it is predicted to achieve the research objectives.

Figure 5.2 Framework for Innovation in Design Process



5.2.1. Components of Framework for Design Process Innovation

The framework presented in this chapter outlines the main components of design process innovation to facilitate the understanding and to show the relationships between the input, process and output of design.

Project management

A project is defined as a temporary event that creates unique product, services or result (PMI website: accessed 27 March 2017). In a building construction project, it is always a temporary organisation where the various levels of expertise are involved. Depending on the project description, such as building, school, hospital etc., it is the speciality of the team or individuals that makes the project particularly complex, with different clients, customers, users and stakeholders.

Therefore, effective project management is essential to integrate the knowledge of expertise and skills of solving problems and issues with the help of the tools and techniques available. All of these applications have one intention, which is to meet the project requirement from the client. This is where the project management process is utilised, where the important task is identifying the

project requirement. This also involves the planning and designs for the project where defining clear and achievable objective is acquired.

Then the project itself requires a balance of project scope, cost, quality and time. This is where the design process needs to look at the whole life cycle of the project in order to balance the competing demands. All of these demands are also simultaneously adapting the concerns and expectations of the stakeholders. Therefore, project management is important in this framework as this is an integral part of the design process that supports other constituents and it also interlinks with them.

Design process

The design process is the main focal point of the innovation in this research. Improvement of PP will be achieved through the integration of LT, and LC as the target. The development of lean design process has gone through several steps in a process of Conception, Formation, Integration and Representation.

(1) Conception

The initial step for the lean development is to categorise the action, which is the purpose of the framework, the user of the framework and the scope. With these categories the framework can be clearly defined.

The purpose of the development of the framework is to ensure it is based on lean design principles, which provide innovation in design process for the designer to incorporate lean type thinking for the PP improvement at the early stage. The intended target implementers were the architect and the designer, who are involved in the planning and design of building construction projects. The unique features of the framework would be: providing clear procedure to follow in a systemised method; providing a support in adopting available tools; PP measurement at the early stage of a project.

(2) Formation

The formation stage is influenced by in-depth studies of the design process, which was discussed in the literature review section. After the analysis of literature, it was commonly stated that the SBCE is widely applicable to the lean design (Knotten et al., 2014; Lee et al., 2012; Levandowski et al., 2014; Pasquire, 2012; Wesz et al., 2013). However, the SBCE's components and activities need to be modified and aligned with construction methods and activities in design process. This approach was incorporated in the planning and design stages of the RIBA, Plan of Work 2013, which is to acquire similarity in the project stages. The numbering of the stages in the plan of work also remains in the proposed design framework. The strategy of this approach is to keep the familiarity of the user on the known stages of design process to the proposed framework.

(3) Integration

This stage is the integration of the contents of the framework. The flow between the stages was made consistent with the guidance of activities within each stage and the method to accomplish the activities is also provided.

(4) Representation

The final step is to seek the most appropriate illustration of the framework that is user-friendly. It was decided that the lean design process can best be represented by illustrating the design flow and the activities and methods in a tabulated form (Table 5.7)

Application

The application for the framework in this research is given to the enabler of the process to achieve its goal and objectives. From the literature analysis of LE in the design process, the SBCE was found to be the most appropriate method. Other applications are also to be considered and incorporated into the framework development.

Techniques and Tools: Application, People and Performance measurement

The techniques and tools will be the support of the three other components: Application; people; and Measurement Performance. The purpose of this component is to enable the efficient and effective application principles to be adopted and for the user of the techniques and tools to have efficient results. This is in contrast with Performance Measurement, where the tools and technique for the proposed design process will be developed. This is due to the limited availability of suitable performance measurement, as based on the literature review.

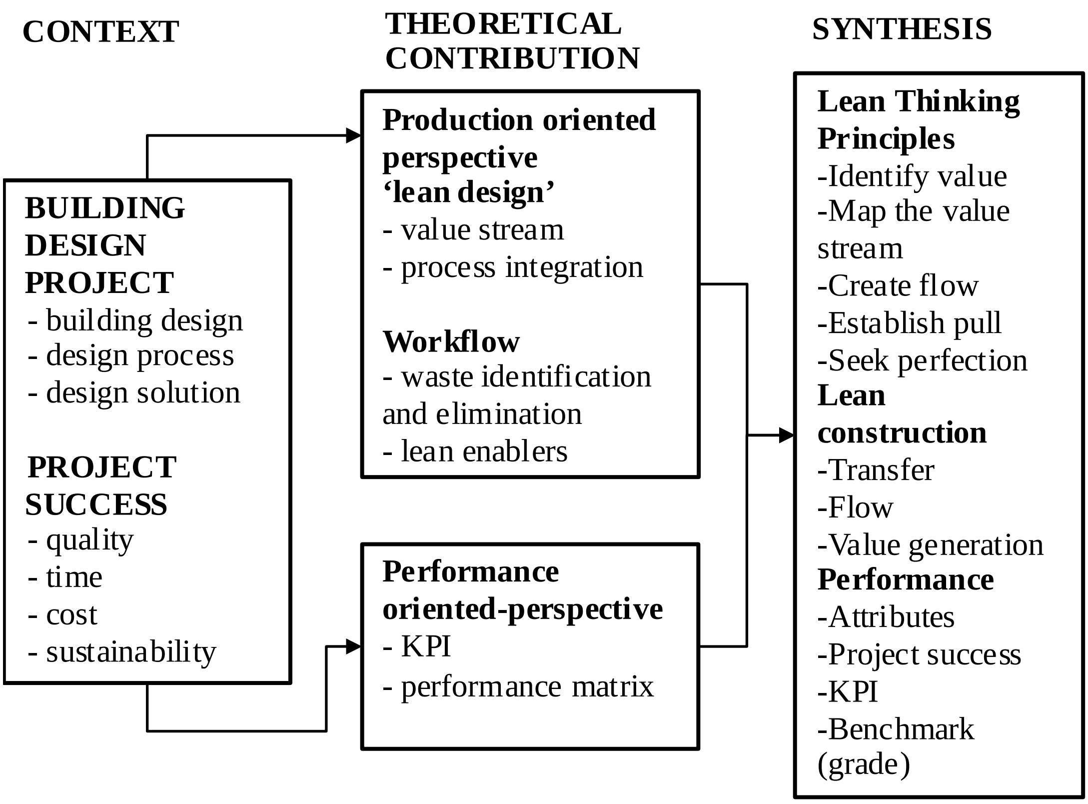
With this framework in place, the path to develop proposed design process now can be determined. The development of the proposed design process is further described in the following section which is based on the framework for innovation in design presented here.

5.3. The Approach of Proposed Design Process

In order to integrate the lean principles in construction project, the general approach of design process should be evaluate. This proposed design process will clarify the results and benefits of using the innovation of design process in project management. The approach is based on the integration model developed by Kestle et al. (2011) and is composed of three steps as shown in Figure 5.3.

The characteristics were referred to the perimeters of design project and project success. Then the practice of design and literature were reviewed in terms of production factors and performance factors which falls under the theoretical contribution. The four factors and plausible drivers were attained by contextualising the projects' lifecycle, identifying the contribution made by production and performance-oriented perspectives and producing a synthesis for the theoretical of proposed design process.

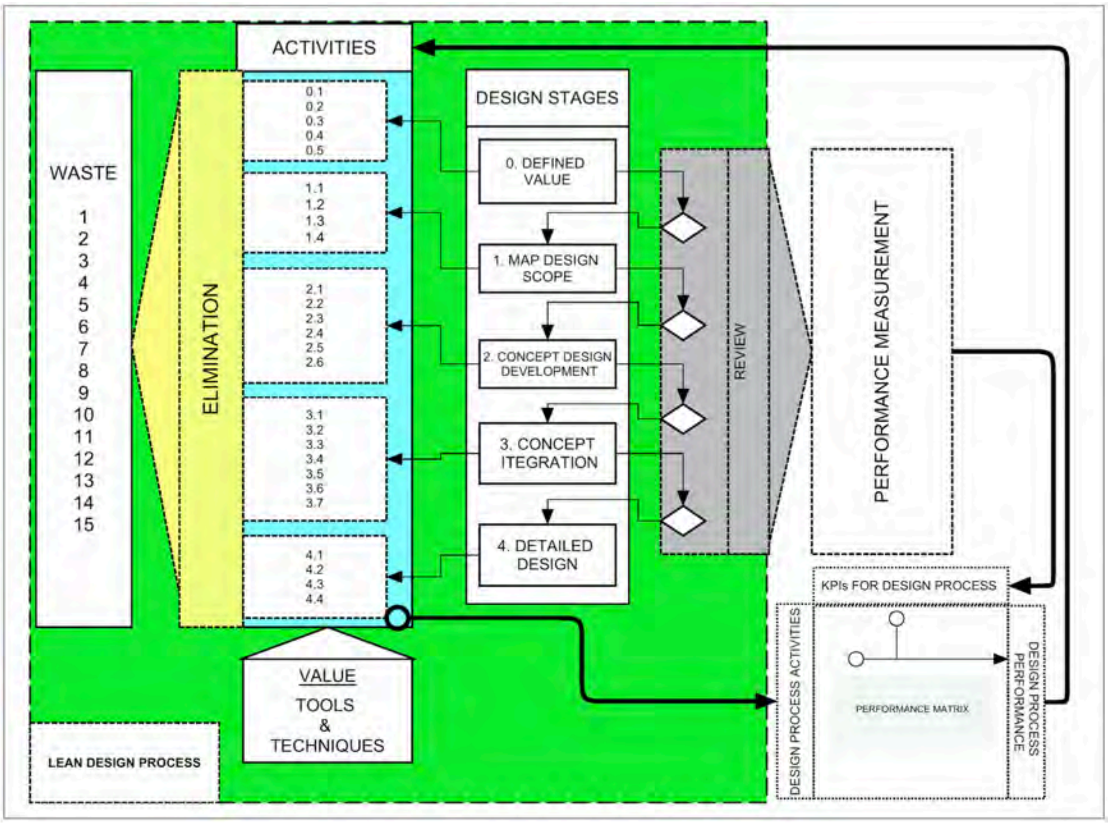
Figure 5.3 The Integration of Lean Principles in Construction Projects with Performance Measurement



5.4. Framework for the Propose Lean Design Process

After the considerations of innovation in design process and the integration approach have been discussed. This section will discuss the whole process of proposed design process as shown in Figure 5.4. The integration starts with the design stage as the main focus in this process. Then follows by activities that will eliminate the wastes which were identified in the traditional design process. Details of each component will be discussed in the following sub-section

Figure 5.4 Conceptual Design Process



5.4.1. Waste Identification and Elimination in Design Value Enhancement

The review of literature for the waste identification and elimination in this section is part of the conference paper presented by the author of this thesis published by ARCOM. At this stage of this research, 15 wastes have been identified in the design process and these are reproduced in the design process (Table 5.1).

The wastes in design process have been identified from the literature review, using keywords to filter the research papers. Based on an analysis of the design factors that affecting the quality of building projects these items were assessed as not creating value (Oyedele et al., 2001). This is related to the definition that anything that is not contributing to the task completion and value generation can be considered as waste (Huovila et al., 1997); (Koskela, 1997); (Mossman, 2009).

There are also different definitions and perspectives when addressing waste in design, such as iteration that can be a waste to the client but value generation to the project design (Koskela et al. (2013); there is also latency, that will lead to delay in a project, but provide time for solution development in design, and there are reciprocal interdependencies that can be a waste in the process, but not in the design that is relying on the maturity of the design solution.

It is also beneficial to explore knowledge gained by the manufacturing industry to understand waste beyond simply the surplus of materials. In the car manufacturing industry, Taiichi Ohno's book listed seven wastes that can be identified in the production of cars. Ohno (1988:18) listed the waste, as cited in Koskela, (2013), which included: overproduction; time on hand; transportation; processing itself; stock on hand; movement; and making defective products (listed in that order).

In a deeper perspective of waste by Shingo (1985:5), also cited in Koskela et al. (2013), waste can be divided into two categories of process and operation. Process waste is the conversion of input such as raw materials into the desired product; operation waste can be described as activity that performs the conversion. The list and definition of waste in manufacturing can be used to categorised the seven wastes into one of two categories (Koskela et al., 2013).

The waste approach of Ohno is applicable to other industries such as service industries, healthcare, construction etc., although some evidence suggests that several wastes in the Ohno's list can be omitted as they are not applicable or contribute little in certain industries (Bicheno and Holweg, 2009); (Abila, 2010).

From the literature reviews above clear shows that the definition of the wastes in design is subjective that depends on the context of the operation such as product design, design process, construction and manufacturing. The definitions can have different interpretation depending on the industry. Waste in building construction projects can be defined as either minimising what is unnecessary for task completion and value generation (Koskela and Huovila, 1997), or the loss of resources, including materials, time and capital, that is generated by activities, either direct or indirectly, that do not add value to the final product for the client (Formoso et al., 2002).

For building construction projects, seven types of waste have been identified (Pinch, 2005): (1) waste from defects, (2) waste from delays, (3) waste from over-production, (4) waste from over-processing, (5) waste from maintaining excess inventory, (6) waste from unnecessary transport, and (7) waste from unnecessary movement of people and equipment. This waste is mostly relevant to the activities during construction phase, rather than at the planning and design phases (Yusof et al., 2015).

The factors that affect the performance of the project contribute to the waste within the design process (Alarcon and Ashley, 1992). There are limitations in terms of literature evidence in relation to the design factors that affect the quality of building construction projects (Oyedele, 2001). According to Yusof et al. (2015), factors that affecting the poor performance of a project are believed to be non-value-adding to the client as well as the project itself and they can be considered as wastes in design phase of building construction projects.

Table 5.1 Identified Wastes in Design Process of Building Projects

Sources: *(Yusof et al., 2015)*

Code	Waste in Design Process
W1	**Poor client briefing**
W2	**Inadequate pre-design project meetings**
W3	**Lack of project definition**
W4	**Design defects**
W5	**Inadequate technical knowledge**
W6	**Poor specification**
W7	**Design changes**
W8	**Insufficient and unrealistic constraints of project cost**
W9	**Insufficient and unrealistic constraints of project time**
W10	**Inadequate involvement of other professionals and teamwork during the design stage**
W11	**Lack of constructability review of design**
W12	**Poor communication among design team**
W13	**Making design decisions on cost and not value of work**
W14	**Poor level of commitment to quality improvement among design professionals**
W15	**Effect of design code and standards on quality**

5.4.2. Lean Enablers with Supporting Techniques and Tools

The method of identifying LE is based on the review of the literature, purposely chosen from the IGLC conference paper. This organisation is actively organising conferences that are related to lean principles and to LC that includes construction phase and design. The IGLC's first publication was started in 1993. There is no categorisation of the research topics or areas at that time.

IGLC is focusing on the construction project, which involves architecture, engineering and construction. Therefore, it is believed that to consider the lean design process development from this organisation's publications such as journal and conference is strongly appropriate for this research. However this is not the only solution to find the lean design development. Therefore, some other construction industry journals were also being considered. Thus database such as Elsevier, Emeralds, Siboleth, Compendixs and web science were also being used.

The objectives of this review are to find the lean approach that has been used in architectural design process. It is believed that the architectural design process has tendency of doing building project as this research's scope is focusing on the building projects. It is worth mentioning that some of the IGLCs conference papers are also found in other journals. Therefore the researcher only considered the IGLCs conference paper for this review if there is double entry.

From the collection of research papers presented in the IGLC's publications, there are 85 relevant to the design process and the listing is presented in Appendix A (Yusof et al., 2015). These are relevant to building projects and focus on the design phases is being considered. Some papers were not suitable, as noted below (Yusof et al., 2015):

- Some referred to different design process than just the architectural design matters
- Seven research papers were not relevant to building projects, as the research area is in the manufacturing sector.
- Two papers concentrated on the whole project cycle, rather than focusing on the design phase of the projects.

- Others focused on the business perspective.

To analyse the papers further, the number of similar approach in these papers was recorded. Any approach that is found in more than 2 papers was considered a major enabler. Based on this classification, 43 papers are categorised as major enablers of design process and are presented in Table 5.2. The description of the listed enablers is presented in Table 5.3.

Table 5.2 Identified Lean Enablers in Design Process through Systematic Literature Review

No.	Domain	Research Paper	Incidence
1	**BIM**	**(AHarris & Lves, 2013)(Breit, Vogel, Häubi, Märki, & Raps, 2008)** **(Baldauf, Miron, & Formoso, 2013)** **(Bhatla & Leite, 2004)** **(Hamdi & Leite, 2012)** **(Oskouie, Gerber, Alves, & Becerik-gerber, 2012)** **(Tommelein & Gholami, 2012)**	**7**
2	**In**	**(Gil, Tommelein, Kirkendall, & Ballard, 2000)(Hammond, Choo, Austin, & Tommelein, 2000)(Tzortzopoulos, Formoso, & Betts, 2001)(Codinhoto, Tzortzopoulos, Rooke, Kagioglou, & Koskela, 2008)(Bhatla & Leite, 2004)(Xu & Tsao, 2007)**	**6**
3	**DSM**	**(Rosas, 2013)** **(Tuholski & Tommelein, 2008)** **(Ballard, 2000)** **(Koskela, Ballard, & Tanhuanpää, 1997)** **(Xu & Tsao, 2007)**	**5**
4	**LPS**	**(Wesz et al., 2013)** **(Rosas, 2013)** **(Koskela et al., 1997)** **(Bhatla & Leite, 2004)**	**4**
5	**QFD**	**(Björnfot & Bakken, 2013)** **(Gargione, 1999)** **(L. P. Lima, Formoso, & Echeveste, 2008)** **(Luis F Alarcón & Mardones, 1998)**	**4**

6	**CE**	**(Fabricio, Melhado, & Baía, 1999)** **(Melhado, 1998)** **(Codinhoto et al., 2008)**	**3**
7	**TV**	**(Oliva & Granja, 2013) (Kim & Lee, 2010) (Rybkowski, Munankami, Gottipati, & Lavy, 2011)**	**3**
8	**Sim**	**(Liu & Wang, 1999) (Gil, Tommelein, & Kirkendall, 2001)(M. A. Hossain & Chua, 2009)**	**3**
9	**Coll**	**(Fabricio et al., 1999)(Gil et al., 2000)(Jara, Alarcón, & Mourgues, 2009)**	**3**
10	**CoO**	**(Fabricio et al., 1999)(Gil et al., 2000)(Riley & Horman, 2001)**	**3**
11	**SB**	**(Parrish, Wong, & Tommelein, 2007)(Parrish, Wong, Tommelein, & Stojadinovic, 2008a)(Parrish, Wong, Tommelein, & Stojadinovic, 2008b)**	**3**
12	**VD**	**(Venkatachalam et al., 2009)(Luis Fernando Alarcón, Mandujano, & Mourgues, 2013)**	**2**
13	**DI**	**(Chua & Tyagi, 2003)(Venkatachalam et al., 2009)**	**2**
14	**MultiDM**	**(Hickethier, Tommelein, & Gehbauer, 2012)**	**1**
15	**CbA**	**(Haymaker, Chau, & Xie, 2013)(Parrish & Tommelein, 2009)(Abraham, Lepech, & Haymaker, 2013)**	**3**
16	**SNA**	**(Alarc, Alarc, & Alarc, 2013) (Hickethier, Tommelein, & Lostuvali, 2013)**	**2**
17	**MS**	**(Jensen, Hamon, & Olofsson, 2009)(Mohamad, Gehbauer, & Haghsheno, 2014)**	**2**
18	**EEI**	**(Chua & Hossain, 1998)**	**1**
19	**Dec**	**(Rossi, 1998)**	**1**
20	**DL**	**(Bogus, Songer, & Diekmann, 2000)**	
21	**TC**	**(Ballard, 2006)**	**1**
22	**WS**	**(Milberg, 2007)**	**1**
23	**PT**	**(Lawlor-wright, Tzortzopoulos, Codinhoto, & Koskela, 2008)**	**1**
24	**TFV**	**(Lawlor-wright et al., 2008)**	**1**
25	**Pull**	**(Ballard, 1999)(Tiwari & Sarathy, 2012)**	**2**
26	**DRS**	**(Whelton, Ballard, & Tommelein, 2011)**	**1**
27	**VE**	**(Miles & Ballard, 2001)**	**1**
28	**VG**	**(Sfandyarifard & Tzortzopoulos, 2011)(Caixeta, Bross, Fabricio, & Tzortzopoulos, 2013)**	**2**
29	**LP**	**(Jensen, Larsson, Simonsson, & Olofsson, 2013)**	**1**
30	**Cons**	**(M. M. X. Lima & Ruschel, 2013)**	**1**

Table 5.3 Descriptions of the Identified Lean Enablers as Design Tools and Techniques

No.	Code	Tool and Technique	Description/use
1	**BIM**	**Building Information Model**	**Utilising building design data information from previous building projects to visualise, and clash-detection of design**
2	**Int**	**Integration**	**This can be the involvement of contractor in the early design or merging the other model and theory in order to create innovation**
3	**DSM**	**Design Structured Matrix**	**DSM is oriented to achieve the best possible design sequence to reduce all possible changes. To plan information flow and to optimise the sequence of design tasks.**
4	**LPS**	**Last Planner System**	**This is a controlled production environment with continuous improvement promoting a teamwork environment.**
5	**QFD**	**Quality Function Deployment**	**This technique is collecting/translating customer needs and satisfying customer needs.**
6	**CE**	**Concurrent Engineering**	**The integration process refers to the identification of incompatibilities and conflicting requirements (trade-offs), which are solved through an integrated decision making process**
7	**TV**	**Target Value**	**TVD is a management method to keep design and cost aligned while delivering customer value by doing —design-to-cost.**
8	**Sim**	**Simulation**	**Simulation is a method of making a real situation being done in a safe environment such as using conceptual model to do the design.**
9	**Coll**	**Collaboration**	**Collaboration is the teamwork that has been establish between two or more parties to do the design in projects.**
10	**CoO**	**Coordination**	**Coordination is by having a centre in doing the design.**
11	**SB**	**Set-Based**	**Set-based design is by doing alternative design at the same time to seek possible solution**
12	**VD**	**Visual Display**	**Visual display is a process of utilizing data base information and apply them in design. Then the outcome of the process is display in a drawing either manually or computerised**
13	**DI**	**Design Interface**	**Design interface is a method to identify the problems created in the overlapping of design and construction phases and minimize the problem.**
14	**MultiDM**	**Multi Domain Matrix**	**To make actual information flow in a design organisation transparent and to ease identification of root causes for differences between actual and planned information flow.**

15	**CBA**	**Choosing By Advantage**	**This technique is to formalise the decision process and eliminate waste in this critical step of delivering customer value**
16	**SNA**	**Social Network Analysis**	**SNA examines the structure of social relationships in a group in order to be able to detect the real connections between people, including informal connections** **Such as collaboration is breaking down, where talent and expertise could be better leveraged, where decisions are getting bogged down, and where opportunities for diffusion and innovation are being lost**
17	**MS**	**Modularisation and standardisation**	**Modularise and standardisation is a method of making the design the same throughout the project**
18	**EEI**	**Early Estimated information**	**Estimation might be done from design results of similar project, past experience, or any other base line data.**
19	**Dec**	**Decoding**	**Creation of design language where the coding of design elements is created so that they can be understood for every design and construction team**
20	**DL**	**Design-Led**	**Design-led lean facilitates lean construction by considering constructability in the design in order to improve flow at the job site**
21	**TC**	**Target costing**	**Target costing is a management practice that seeks to make cost a driver of design, thereby reducing waste and increasing value**
22	**WS**	**Work Structuring**	**Work structuring is the breakdown of both product and process into chunks, sequences and assignments to make work flow smoother and with less variability, in turn reducing waste and increasing value.**
23	**PT**	**Performance Target**	**This is a process of quantifying initiatives that have taken a prominent role in the efficiency and effectiveness of a project. Project successes are set at the beginning in order to determine the performance**
24	**TFV**	**Transform, Flow and Value**	**This technique focusing on the conversion of information to design by transforming, looking at the process and consideration of value.**
25	**Pull**	**Pull Planning**	**This method is one of the lean principles where the design is based on the construction requirements and capability.**
26	**DRS**	**Design Rational System**	**This is the relationships between a designed artifact, its purpose, the designer's conceptualisation and the contextual constraints on realizing the purpose**
27	**VE**	**Value Engineering**	**This technique is used to solve problems, identify and eliminate unwanted costs, while improving function and quality.**
28	**VG**	**Value Generation**	**Participatory design approaches are suggested as the means to enable better identification of needs, supporting value generation. Understand what the user needs and preferences are, and respond with design solutions which meet those**

			preferences in the best possible manner.
29	**LP**	**Lean Platform**	**This is using platform thinking that offers insights not only of what a designer is offering to clients, but also production information about how these offerings (products) should be designed, produced and delivered. There are two phases: a design phase and a construction phase.**
30	**Cons**	**Constructivist**	**Analyses of problems and solution based on the experience of the stakeholders and clents.**

The top LEs are BIM, followed by Integration which appeared seven and six times in the papers respectively. DSM appeared five times in this process. Although LPS has been tested and is considered as applicable in design process, in this review only four incidences were found, the same as QFD. Six approaches appeared four times: Concurrent Engineering, Target Value, Simulation, Collaboration, Coordination and Set-Based (Yusof et al., 2015).

From this analysis, while some approaches were based on LC principles, this review found it was not a common approach. The reason being that the approach such as LPS and LPDS for instance are developed at almost the same time as the research area on the design process. Thus the researchers who were looking at the design process research area tended to adopt some of the approaches that have been established in the manufacturing industry. In the case of BIM, as the top enabler, this approach has been proven in the design process which is enable to support the performance of building construction projects. Therefore this enabler acquired high attention to the researchers in the last 3 years.

This analysis indicates that BIM is quite relevant to design process and its impact is significant in the improvement of design process. However, BIM is only the tool that will reduce the waste in design process; it does not have a system of design process and is considered as one of the tools that can improve and manage the information data in the design and building construction projects.

A comprehensive study in Khan (2012) which cited by Yusof et al. (2015) the research made in other industries such as car manufacturing, electronics production, domestic appliances, and car accessories, states the number of 'changeless cores' is the main factor for the product development success of the Toyota Motor Company. These changeless cores are: value; knowledge; and improvement. These are believed to be the foundation of Toyota product development that has latterly been known as SBCE (Khan et al., 2011).

Some researchers state that SBCE is considered the main enabler for lean production development (Ward, 2007). SBCE is a system of design process which comprises other enablers and is supported by other enablers (Sobek et al., 1999). Therefore this research will be beneficial to review the features that provided by SBCE as a basis to the proposed design process. The suitability of the SBCE for this research will be elaborated in the following section and will recommend the adaptation of the principles and integration in the development of the proposed design process.

According to Khan et al. (2011) the enablers for lean usually originated from the tools and techniques that will enhance the performance of a process. Therefore in this research the enablers will be the tools and techniques in design process where their function is to enhance the performance of proposed design process. The collection of the supporting tools and techniques for the proposed design process in this research is presented in Table 5.4. These tools and techniques were extracted from the comprehensive literature review where they have been applied, developed or used within a construction project and mostly at the design phase. However, their effectiveness and efficiency have not been tested. Therefore these tools and techniques were also included in the aim of the case study in this research to test their suitability with the proposed design process.

Table 5.4 Supporting Tools and Techniques for the Proposed Design Process

		Activities																					
No.	**Tools**	**0.1 Classify project**	**0.2 Explore client value**	**0.3 Align with company strategy**	**0.4 Translate value to designers**	**0.1 Internal review**	**1.1 Identify sub-design solution targets**	**1.2 Decide on level of innovation to the sub-design solution**	**1.3 Define feasible regions of design scope**	**1.4 Internal review**	**2.1 Extract design concepts**	**2.2 Create concept design for sub-design solution**	**2.3 Explore the concept design for sub-design solution**	**2.4 Capture knowledge and evaluate**	**2.5 Communicate concept designs to others**	**2.6 Internal Review**	**3.1 Determine concept design intersections**	**3.2 Explore possible designs**	**3.3 Seek conceptual robustness**	**3.4 Evaluate concept design for lean construction**	**3.5 Begin process planning for construction**	**3.6 Integrate the final concept design of sub design solution**	**3.7 Internal review**
1	**BIM**	■	■								■			■				■			■		
2	**Int**			■			■						■		■							■	
3	**DSM**	■	■																				
4	**LPS**					■				■						■							■
5	**QFD**		■		■						■												
6	**CE**											■	■										
7	**TV**		■		■																		
8	**Sim**																■	■	■		■	■	
9	**Coll**											■	■		■			■		■	■	■	
10	**CoO**													■	■						■		
11	**SB**										■	■	■										
12	**VD**		■		■								■		■		■		■		■		
13	**DI**																				■		
14	**Multi DM**		■																		■		
15	**CBA**				■							■	■				■						
16	**SNA**												■		■						■		
17	**MS**						■																
18	**EEI**								■												■		

19	**Dec**																						
20	**DL**																						
21	**TC**																						
22	**WS**																						
23	**PT**																						
24	**TFV**																						
25	**Pull**																						
26	**DRS**																						
27	**VE**																						
28	**VG**																						
29	**LP**																						
30	**Cons**																						

5.4.3. The Development of Proposed Design Process

The development of the proposed design process in this research is entirely based on the literature review, industrial field study through interviews and questionnaires. The findings and recommendations are presented in the previous chapters. As stated in the previous section that SBCE has potential to adopt lean principles in design for construction industry. Therefore, it is important to considered publication regarding SBCE which produced by Sobek et al. (1999). They presented a framework that features the principles of SBCE in design process. The followings are the structured set of principles based on their case study in Toyota product design system:

1. Map the design space

a. Define feasible regions

b. Explore trade-offs by designing multiple alternatives

c. Communicate sets of possibilities

2. Integrate by intersection

a. Look for intersections of feasible sets

b. Impose minimum constraint

c. Seek conceptual robustness

3. Establish feasibility before commitment

a. Narrow sets gradually while increasing detail

b. Stay within sets once committed

c. Control by managing uncertainty at process gates

Based on these principles Khan et al. (2011) extended the principles into five categories which accommodate the strategic value research and alignment, and create and explore multiple concept in parallel as shown in Table 5.5. These extended principles is claimed to be suitable in other industries as well, such as electronics, aerospace and marine manufacturing industry.

However, these principles have limitation in construction industry mainly in planning and architectural design. This is primarily due to the nature of construction project as one-off project. Therefore in this research, some alignments have been made and have been evaluated through the interviews with the practitioners and industrial field study.

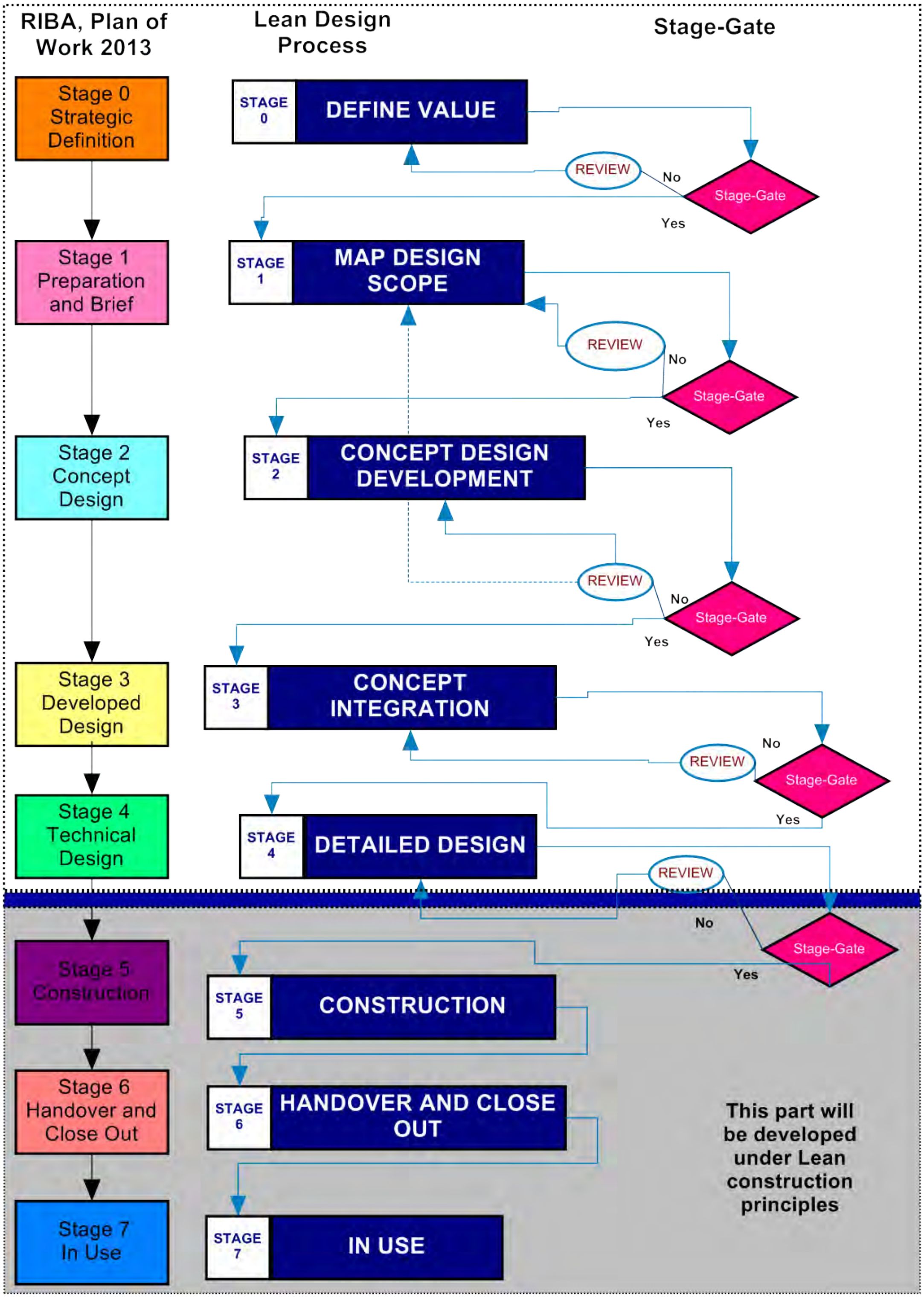
Table 5.5 Categorisation of SBCE Principles

Source: Khan et al. (2011)

Category	Principle
1. Strategic value research and alignment	• Classify projects into a project portfolio • Explore customer value for project X • Align each project with the company value strategy • Translate customer value (construction project vision) to designers (via concept paper)
2. Map the design Scope	• Break the system down into subsystems • Identify essential characteristics for the system [6] • Decide on what subsystems/components improvements should be made and to what level (selective innovation) • Define feasible regions based on knowledge, past experience and the Chief engineer, and consider the different perspectives/functional groups
3. Create and explore multiple concepts in parallel	• Pull innovative concepts from R&D departments • Explore trade-offs by designing multiple alternatives for subsystems/components • Schedule time for innovation and problem solving while the set of alternatives is broad • Ensure many possible subsystem combinations to reduce the risk of failure • Extensive prototyping (physical and parametrical) of alternatives to test for cost, quality, and performance • Perform aggressive evaluation of design alternatives to increase knowledge and rule out weak alternatives • Information goes into a trade-off knowledge base that guides the design • Communicate sets of possibilities
4. Integrate by intersection	• Look for intersections of feasible sets, including compatibility and interdependencies between components • Impose minimum constraints: deliberate use of ranges in specification and initial dimensions should be nominal without tolerances unless necessary • Seek conceptual robustness against physical and design variations • Concurrent consideration of lean product design and lean construction
5. Establish feasibility before commitment	• Narrow sets gradually while increasing detail: functions narrow their respective sets based on knowledge gained from analysis • Delay decisions so that they are not made too early or with insufficient knowledge • Design decisions should be valid for the different sets and should not be effected by other subsystems • Stay within sets once committed and avoid changes that expand the set [5] • Control by managing uncertainty at process gates • Contractor evaluates the final sets and dictates part tolerances • Contractor begins process planning before a final concepts has been chosen and thus act on incomplete information • Delay releasing the final hard specification to major suppliers until late in the design process

In this research, the alignment is presented in Figure 5.5. The principles of SBCE process are aligned with the RIBA, Plan of work 2013. This alignment is a significant contribution for a number of reasons. Firstly, it combines the design principles for construction industry with SBCE principles for focusing on value for client which link with architectural value. Secondly, the exploration of solution set in architectural design has been incorporated in the SBCE process. The third contribution is the lean design concept, which is integrated in the architectural design.

Figure 5.5 Stages for the Proposed Design Process



The conceptual design process, where the stages are similar to the RIBA's plan of work 2013, have design activities and description of methods for accomplishment. The stages were determined based on the key conceptual decisions that create architectural design. These decisions were based on the Osborne-Parnes' creative problem solving' process (Table 5.6). This process comprises of four stages and six steps. Each steps uses divergent and convergent thinking. Where divergent thinking refers to the generation of lots of ideas and options and convergent thinking refers to the evaluation of ideas and options, and making decisions. These definitions are suitable for the elements of SBCE and architectural design elements.

Table 5.6 Creative Problem Solving Model (Creative Education Foundation, 2015)

Stage	Step	Purpose
Clarify	**Explore the vision**	**Identify the Goal, wish, or challenge**
	Gather Data	**Describe and generate data to enable a clear understanding of the challenge**
	Formulate Challenges	**Sharpen awareness of the challenge and create challenge questions that invite solutions**
Ideate	**Explore Ideas**	**Generate ideas that answer the challenge questions**
Develop	**Formulate Solutions**	**To move from ideas to solutions. Evaluate, strengthen, and select solutions for best 'fit'**
Implement	**Formulate a Plan**	**Explore acceptance and identify resources and actions that will support implementation of the selected solution(s)**

On these basis questions were developed to present the key decisions that have to be made during the proposed design process.

1. What is the challenge? (this comprises of fact finding, problem statement, specification, aim, objective etc.)
2. What solutions are suitable for the conceptual design options? (this includes creating options/ideas)
3. Which conceptual design options can be considered? (this includes evaluating ideas based on the knowledge gained through design activities)
4. Which conceptual design options will be considered for the concept integration?
5. What is the optimum conceptual design solution identified? (this includes evaluating the conceptual design)

Subsequently these key decisions were extrapolated into five stages of proposed design process which aligned with RIBA, Plan of Work 2013:

0. Define value: the initial concept definition is developed based on strategic goals, client requirements, and any other factors that need to be considered;

1. Map design scope: designers define the scope of the design work required as well as feasible design options/regions;

2. Concept design development: each designer develops and tests a set of possible conceptual design solutions. This will enable designers to eliminate weak alternatives based on the knowledge produced in this phase;

3. Concept integration: Integrate the sub-design components and explore any intersections that might create optimum design solution. The weak design alternatives will be removed or modified and the good design will be analysed and used as final design solution to progress into stage 4;

4. Detailed design: Release the final specification, approval from the Architects, Engineers and Consultants required and the detail design activities carried out.

5.4.4. Lean Design Process Activities and Methods

The proposed design process is further broken down into activities that taking into account the steps proposed by the creative problem-solving model above. These activities also embodied the lean principles as in the SBCE and at the same time incorporate the lean construction principles as shown in Table 5.7. The method of accomplishment will be described step-by-step in this section.

Table 5.7 Proposed Design Process: Activities

RIBA Plan of Work 2013	Stage 0 Strategic Definition	Stage 1 Preparation and Brief	Stage 2 Concept Design	Stage 3 Developed Design	Stage 4 Technical Design	Stage 5 Construction	Stage 6 Handover and Close Out	Stage 7 In Use
Conceptual design process	**Define Value**	**Map Design Scope**	**Develop Concept Design**	**Integrate Concept**	**Produce Detail Design**			
	0-1: Classify project	**1-1: Identify sub-design solution targets**	**2-1: Extract design concepts**	**3-1: Determine concept design intersections**	**4-1: Release final specification**			
	0-2: Explore client	**1-2: Decide on level of innovation**	**2-2: Create concept design for**	**3-2: Explore possible**	**4-2: Define construction**			

Design Activities	**value**	**to the sub-design solution**	**sub-design solution**	**designs**	**tolerances**	**Construction Phase**
	0-3: Align with company strategy	**1-3: Define feasible regions of design scope**	**2-3: Explore the concept design for sub-design solution**	**3-3: Seek conceptual robustness**	**4-3: Full project definition**	
	0-4: Translate value to designers	**1-4: Internal review**	**2-4: Capture knowledge and evaluate**	**3-4: Evaluate concept design for lean constructi on**	**4-4: Internal review**	
	0-5: Internal review		**2-5: Communi cate concept designs to others**	**3-5: Begin process planning for constructi on**		
			2-6: Internal review	**3-6: Integrate the final concept design of sub design solution**		
				3-7: Internal review		

The development of the activities and methods has been gone through a series of review meetings with the practitioners in order to refine the process. The sequence of the activities under each stage may be interchangeable as the process is served as guidance for the designer to adopt innovative design process. In order to control the performance of the project, the activity for 'internal review' is included in every stage. This will enable the designer or architect to detect the performance of design process. The details of the measurement of the performance measurement will be described in the following section. The activities and method of accomplishment for each stage are described as follows:

Stage 0: Define Value

0-1 Classify project: Each project should be classified in order to forecast the time and cost commitment. The expected level of innovation at both the project and sub-project level should be clarified in addition to other relevant parameters. The intended market should also be clarified in case it impacts upon subsequent engineering activities. This is relevant in the context of sustainable development, when a refurbishment or extension, or indeed a rationalised space plan, may be more appropriate than a new project.

	Methodology for activity 0.1:
1	Create project classification matrix using a table or spreadsheet
2	Create project name and schedule
3	Determine client(s) requirements and need
4	Classify the level of innovation by indicating the system design architecture and identify level of innovation required in each sub-design solution.
5	Estimate project costs

	Methodology for activity 0.1:
6	Input additional parameter information

0-2 Explore client value: Client's needs and desires should be thoroughly understood in order to determine design targets and ensure the necessary provision of client value. The extent of this activity will depend on the level of innovation; design criteria will be determined based on client value, amongst other factors, to support the evaluation of alternatives of product designs.

	Methodology for activity 0.2:
1	Client value (needs and desires) should be internalised by Architect, Engineer Consultant and Contractor representatives using client request documentation, requirements, market research methods, and meetings with client representatives
2	Client value should be decomposed into attributes and structured/represented by creating a product value model
3	Building system targets (requirements) should be defined in order to clarify how the value attributes will be achieved; Special emphasis may be directed towards how the design will meet clients requirements.

0-3 Align with company strategy: Each project should be aligned with the company design strategy, in order to take strategic advantages from projects. This will prevent value (/benefits) gained through projects from being wasted and ensure the enhancement of the design process.

	Methodology for activity 0.3:
1	Identify strategic design goals from company documentation (company strategy, engineering strategy, and R&D strategy documents)
2	Create a matrix through which strategic goals may be structured and the impact of current projects may be analysed: goals vs. projects

	Methodology for activity 0.3:
3	Analyse current projects against strategic design goals to determine the strategic impact of each project on design and populate this data via the matrix created
4	Evaluate each future project against strategic design goals using the same matrix and determine new goals where appropriate

0-4 Translate value to designers: The information developed in this phase should be compiled in a document referred to as the building concept definition: both the strategic objectives and the understanding of client value will be translated to the designers that are involved in the project via this document.

	Methodology for activity 0.4
1	A building concept definition template can be used by internal personnel to translate client value to designers; client value may be represented visually using videos, photographs, sketches, diagrams etc. in addition to the necessary requirements, text and math - this can be achieved using additional web-based techniques if necessary; the template should cater for different departments/functional groups as they will develop their sub-design solution based primarily on this document
2	The building concept definition template combines the knowledge created in 0.1 in a single document; it may be that multiple versions are created for different audiences (e.g. senior managers) from the same information

0-5 Internal review: the internal review should be made after all the methods have been completed. This is acting as the gate stage to avoid any rework at the later stage. Reference should be made to all the parties involved in the design and any confidentiality should be treated accordingly.

Stage 1: Map Design Scope

1-1 Identify sub-design solution targets: Each sub design solution team should decide, based on the project concept definition, which components to improve and to what level of innovation; this will help to prevent over-design, while encouraging the necessary innovation and enhancements.

	Methodology for activity 1.1
1	The building concept definition should be used by sub design solution teams to understand the strategic objectives, design targets, and the level of innovation required for their particular sub design solution.
2	Based on the product concept definition subsystem participants/teams can further classify the level of innovation required for each component or sub- subsystem; using a subsystem architecture template that depicts the modular breakdown of the subsystem architecture the level of innovation for the different product components or sub-subsystem may be labeled

1-2 Decide on the level of innovation for the sub-design solution: Each sub-design solution or component team will analyse their design and identify their own lower-level targets (lower level requirements) based on the project design concept definition.

	Methodology for activity 1.2
1	Building system targets will be analysed in order to determine modifications to components that could help to achieve them
2	Based on the building design concept definition and innovation classification diagrams, lower-level targets (requirements) will be identified for sub design solution and components
3	Building subsystem targets will be reviewed by the design leader at the building system level in order to ensure the correct flow down of building system targets

1-3 Define feasible regions of design scope: Appropriate design possibilities should be defined based on knowledge and previous experience, while considering the views/constraints of the different functional groups.

	Methodology for activity 1.3:
1	Each sub design solution team should identify and document design constraints on their subsystem: what can/cannot/should not be done. This information can be extracted from lessons learnt logs, design standards, best practice guides and checklists
2	Each sub design solution team should identify ("map-out") possible options for their sub design solution, and components. Feasible regions may include different fundamental concepts, components, arrangements, properties or geometry; R&D departments should be engaged in order to understand state- of-the-art technologies
3	Representatives for the other sub design solution may be referred to at this stage to develop a pre-emptive understanding of interdependencies
4	Contractor/builder should be consulted to understand their current/future production capabilities and constraints before developing any of the potential options. Contractor/builder can be requested to provide the relevant information in a simple visual format to aid the designers (checklists, diagrams etc.)
5	sub design solution design constraints, manufacturing constraints and capabilities, interdependencies with other sub design solution, possible options and related information should all be documented in the sub design solution concept definition template which is used as the basis for the development of sub design solution concept sets

1-4 Internal review: the internal review should be made after all the methods have been completed. As 0-5 above, this is again acting as the gate stage to avoid any rework at the later stage and made available to all the parties involved in the design and any confidentiality treated accordingly.

Stage 2: Concept Design Development

2-1 Extract design concepts: Concepts should be drawn from previous projects, R&D departments, and competitor products (benchmarking).

	Methodology for activity 2.1:
1	sub design solution criteria should be defined based on value attributes, building system targets, constraints etc.
2	Alternative sub design solution and component design documentation/files should be extracted from previous projects, R&D departments, and competitor products based on the sub design solution concept definition
3	Building Information Model (BIM) (or product data/lifecycle management software) can be used as a central database from which information concerning previous projects and competitor products is captured and reviewed

	Methodology for activity 2.1:
4	Alternative options may be mapped against sub design solution criteria using matrices in order to filter some of the alternatives

2-2 Create concept design for sub-design solution: This time is scheduled specifically for design teams to brainstorm and innovate, so that a set of possible design solutions is proposed. The set of solutions for a particular sub-project may be only two options, while a component that is not being changed would not require a set. Alternatives within a set may comprise differences in fundamental concepts, components, arrangements, properties or geometry.

	Methodology for activity 2.2:
1	Based on the sub design solution concept definitions, design teams can compose initial sets of design solutions for each of the sub design solution which will include the extracted design concepts from activity 3.1
2	Idea generation techniques (e.g. brainstorming) and innovation frameworks (e.g. TRIZ) can be used in order to provoke creativity and facilitate innovation
3	Conceptual solutions can initially be sketched with minimum constraints: the deliberate use of ranges in specification, and initial dimensions should be nominal without tolerances unless necessary
4	Where feasible, CAD software may be used to represent the conceptual ideas

2-3 Explore the concept design for sub-design solution: alternative solutions are simulated, prototyped, and tested for lifecycle cost, quality, and performance.

	Methodology for activity 2.3:
1	A plan should be produced for testing each component alternative in order to ensure that the knowledge created through testing enables weak solutions to be exposed and increases confidence in the design; the plan can focus on rapid and low-cost techniques if necessary
2	The plan referred to here as ‘sub design solution knowledge creation plan’ should be translated into a document template which defines the test outputs and representations that would support the comparison of sets and other decision making

	Methodology for activity 2.3:
3	The different options should be explored and analysed through simulation, rapid- prototyping, mathematical modeling etc. to determine their feasibility, benefits, and potential costs and the results should be incorporated in the same template

2-4 Capture knowledge and evaluate: Knowledge that has been created is captured either quantitative or qualitative in order to evaluate the sets.

	Methodology for activity 2.4
1	The knowledge created through testing should be represented in the relevant graphical formats: limit curves for representing breaking points (and safe zones) for a single design option, and trade-off curves to compare the set of alternative components against sub design solution design criteria(e.g. cost and expected performance)
2	A SWOT analysis may also be conducted for the evaluation of options

2-5 Communicate concept designs to others: Each sub-project or component team will present their set to the other teams at an event (e.g. meeting) in order to get feedback and understand constraints.

	Methodology for activity 2.5
1	Conceptual solutions may be represented using an A3 template or MS PowerPoint presentation. The presentation should include the background, current condition, proposal, sketch/CAD drawing, and SWOT analysis
2	A ‘design set (integration) event' can be used as a milestone, where design teams come together to present their sets to each other
3	The set will also be presented using comparative tools such as trade-off curves, and function means analysis
4	Design teams will evaluate sets based on their constraints and will provide recommendations to each other; ideally, any subsystem design decision after this point should neither affect other subsystems nor be affected by other subsystems
5	Based on the evaluation, some of the alternative options may be discarded from the sets

2-6 Internal review: the internal review should be made after all the methods have been completed.

Stage 3: Concept Integration

3-1 Determine concept design intersections: sub design solutions that progress into stage 4 can be considered for project integration. The intersection of feasible sets will be reviewed, considering compatibility and interdependencies between sub design solution and components.

	Methodology for activity 3.1:
1	Populate a design concepts matrix with component sets in order to illustrate the possibilities for intersection/integration of the various sets into systems
2	Identify any dependencies
3	Determine which system combinations are possible and/or feasible using the concept intersection matrix
4	Analyse the effect of subsystem or component selection on the building system targets
5	Discount building system combinations that are infeasible based on knowledge from previous projects, dependencies, and potential/expected conflicts

3-2 Explore possible designs: Potential systems can be simulated/prototyped (parametric and physical) and tested for cost, quality, and performance.

	Methodology for activity 3.2:
1	A plan should be produced to test system combinations in order to ensure that the knowledge created enables weak system alternatives to be exposed and increases confidence in the design; The plan can focus on rapid and low-cost techniques, and check sheets can be used to track the tests
2	The plan referred to here as the ‘system knowledge creation plan’ should be translated into a document template which includes recommended representations for test results that would support the comparison of sets and other decision making
3	The different options should be explored and analysed through simulation, rapid- prototyping, mathematical modelling etc. to determine their feasibility, benefits, and potential costs and the results should be incorporated in the same template

	Methodology for activity 3.2:
4	The knowledge created should be represented in the relevant graphical formats: limit curves for representing breaking points (and safe zones) for a single design option, and trade-off curves to compare the set of alternative subsystems/components against design criteria (e.g. cost and expected performance)

3-3 Seek conceptual robustness: Conceptual robustness will be sought against physical, market and design variations to reduce risk and improve quality.

	Methodology for activity 3.3:
1	Identify adverse impacts that may arise from physical variation and noise factors such as manufacturing tolerances, aging, usage patterns, environmental conditions, etc.
2	Brainstorm potential market influences and client requirements/specification changes which may impact the final design solution
3	Consider the effects of potential market influences and client requirements/specification changes to the final design solution
4	Brainstorm potential effects that may result from any unexpected changes
5	Analyse the effect of the potential changes to the final design solution using a matrix
6	Analyse the system combinations and rank each solution based on the analysis

3-4 Evaluate concept design for LC: Once the potential sets have been explored, they will be evaluated for LC to assess the costs, efficiency, and problems etc.

	Methodology for activity 3.4:
1	Engineers and consultants may determine criteria with which building system alternatives may be evaluated for constructability/buildability.
2	Lean construction criteria should be developed so that building system alternatives can be evaluated to determine the effect of the different system combinations on wastes in construction
3	A 'lean construction event' or workshop may be held to evaluate system combinations for constructability and lean construction with both design teams and engineers present
4	Criteria can be weighted, and design options may be evaluated by means of a matrix; check sheets can be used to focus the evaluation

3-5 Begin process planning for construction: Once the potential sets have been evaluated, construction planning will be considered. The effects on cost, time, quality, efficiency, potential problems etc. will also be considered.

	Methodology for activity 3.5:
1	Identify design criteria which are related to the construction process (including criteria from design for constructability)
2	Develop construction process webs
3	Filter process alternatives based on design criteria, filtered design alternatives, etc.
4	Identify knowledge required to evaluate construction process
5	Explore and evaluate candidate of construction process against cost, time and quality parameters
6	Use a decision matrix to rank/compare alternative construction process chains

3-6 Integrate the final concept design of sub design solution: Based on the evaluations and knowledge captured, sub-optimal project designs will be eliminated and the proven optimal design from the project alternatives will be finalised.

	Methodology for activity 3.6:
1	Individual building system design solutions may be presented using an A3 template of MS PowerPoint presentation. The presentation should include the background, current condition, proposal, sketch/CAD drawing, and SWOT analysis
2	Potential building systems will be presented for comparison using trade-off curves, and decision matrices
3	A design concepts matrix can be used in order to assess the fulfillment of building system targets
4	The construction processes for potential systems can be evaluated with the designs in order to discount infeasible options, or options that are not cost effective before commitment
5	After narrowing the options based on the knowledge gained from analysis, a final system will be converged upon; the final building system combination will not be changed except in unavoidable circumstances and will be finalised at a 'design freeze (integration) event' where the final design will be presented/discussed

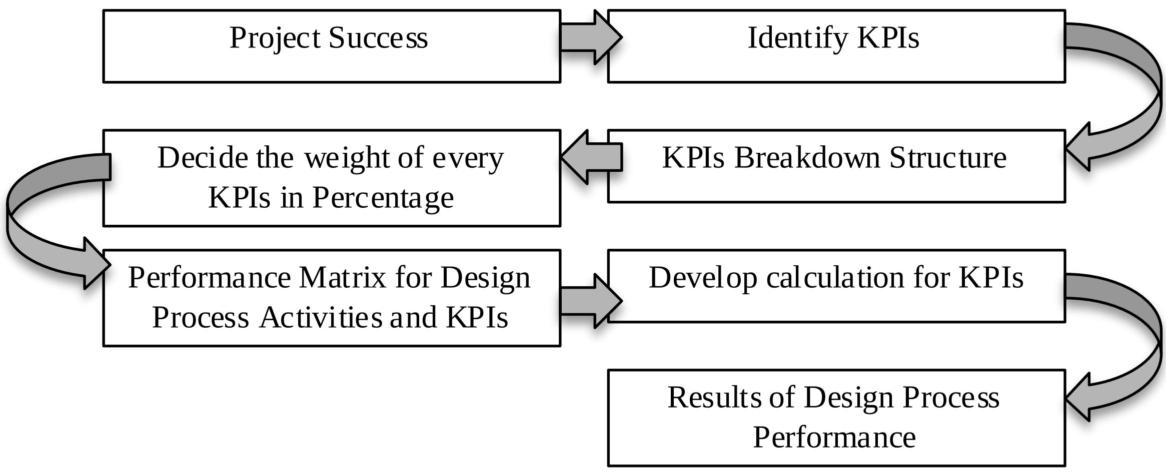
3-7 Internal review: the internal review should be made after all the methods have been completed.

The proposed lean design process model provides the stages and process until the optimum design is achieved and ready for the initiation of Stage 4 which is the preparation of detail design.

5.5. Framework for the Performance Measurement of the Proposed Design Process

The framework for measuring performance of proposed design process is developed based on the conclusions made by Chan & Chan (2004) that the project success can be used as key performance indicators for construction project (Figure 5.6). Their study uses project success as a direction of developing KPIs in construction and further develop a performance measurement. However, the set of KPIs suggested are not suitable for this research due to the method of quantification of the KPIs cannot be applied in design process. Therefore adjustments should be made in order to have similar performance measurement as suggested. Conversely, Beatham et al. (2004) develop performance measurement based on the KPIs proposed by various body of institutions that involve in construction industry. Their collection of KPIs covers every aspects of construction industry such as planning, design, construction, organisation and business. They categorised the KPIs as business, operation and diagnose. From their study on KPIs for operation, the performance measurement system they developed is focusing on the process where other element of project success that is deemed to contribute the project success is included. Based on this, different aspects of project success is being explored in this research and revealed that the sustainability aspects would give significant contribution. According to Sullivan (2012), that the sustainable development has been a major role in construction industry due to the changes in building regulations. Therefore in this research, it was decided to consider the project success for the performance measurement comprises of quality, cost, time and sustainability.

Figure 5.6 Framework for Performance Measurement of the Proposed Design Process



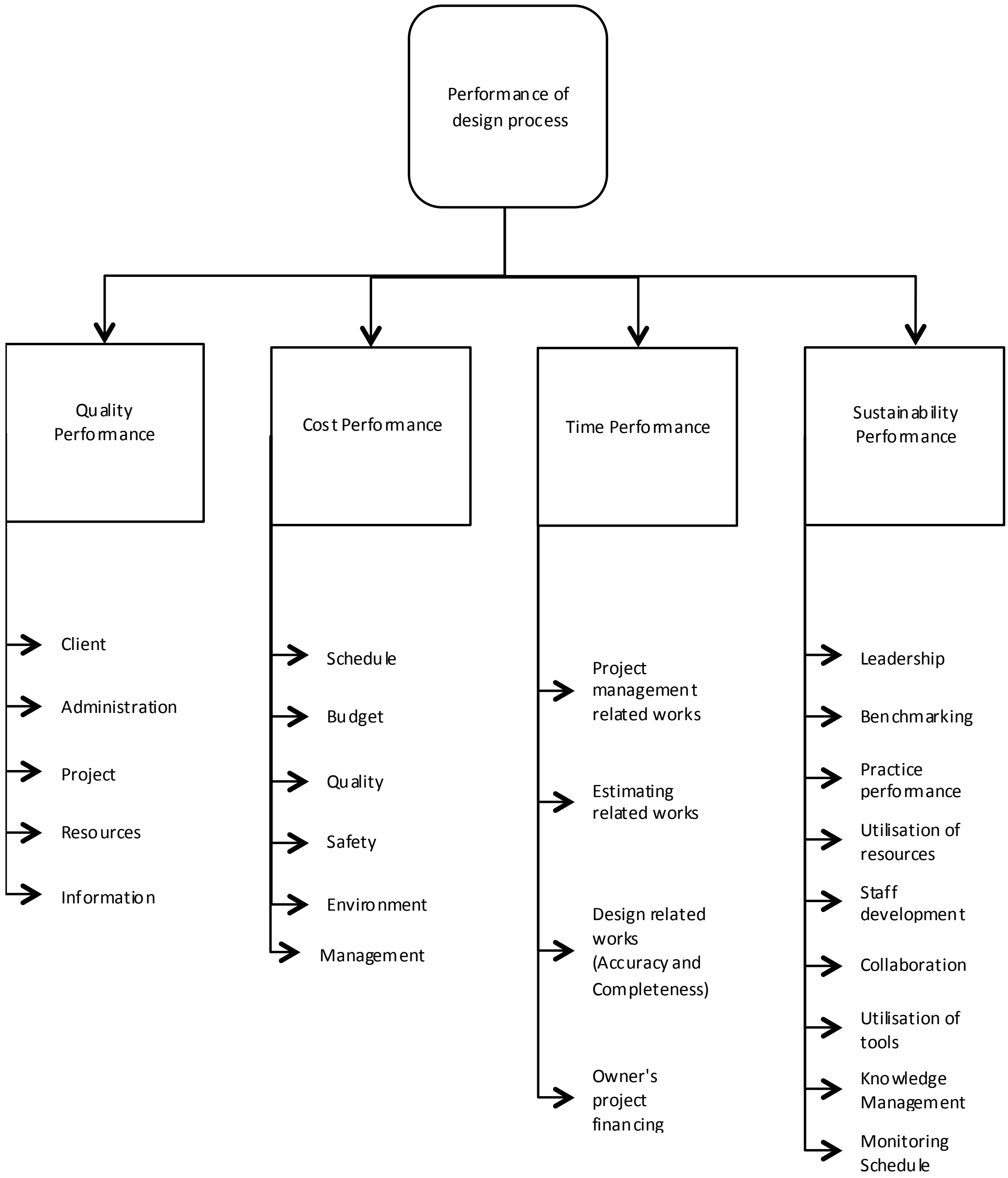
KPIs Identification

The members of the expert group are required to review the project success and identify KPIs and the success attributes. The project success can be related to the company values, policy and standard practice. However, all of these have to be discussed and agreed by all members of the group.

KPIs Breakdown Structure

The breakdown structure of KPIs, as depicted in Figure 5.7, was developed through brainstorming with practitioners. They are required to provide information on the project goals and discuss the attributes of the project success. For clear illustration hierarchy form was used to illustrate the relationships of each components. The hierarchy of performance is decomposed into the project success and further decomposed into the KPIs.

Figure 5.7 Hierarchy for the KPIs of Design Process Performance



Weightage of KPIs

The performance measurement with KPIs certainly requires some contribution weightage on each of them. However, the distribution of the weightage can be varies. Therefore in this research it was suggested that the practitioners to use their judgement in putting the weightage on each KPIs. The performance target can be measured based on the unit such as days, percentage and number of times as shown in **Error! Reference source not found.** (full table is in Appendix E).

Table 5.8 Target and Contribution of Weightage of KPIs

	KPIs	Unit	Description	Target	Weight (%)
Quality	Client	No.	Number of meeting with client per month	1	3
	Admin	day	Time taken to response to the queries	5	2
	Project	%	Meeting the project goals	60	6
	Resources	%	Increase in design progress from previous one	20	3
	Information	No.	Number of meeting with stakeholders per month	1	12
[redacted]					
Cost	Schedule	%	Delays	10	4.26
	Budget	%	Over budget	10	10.09
	Quality	%	Design changes	15	8.63
	Safety	No.	Number of safety elements included in the design	2	1.56
	Environment	No.	Number of constructability innovations	2	0.69
	Management	No.	Number of design iteration	5	3.75
[redacted]					

Time	Project Management related work	%	Delays in design progress	10	4.83
	Estimating related work	%	Delays in documents delivery	10	0.96
	Design related work	No.	Number of iterations	5	4.7
	Owner's project financing	Days	Advance project fund	15	14.51
Sustainability	Leadership	No.	Number of meeting with subordinates per month	2	1.68
	Benchmarking	No.	Number of design review on sustainability of project at each stage	2	0.97
	Practice Performance	No.	Number of review on methodologies at each stage	2	3.20
	Utilisation of existing resources	No.	Number of review on the utilisation of resources at each stage	2	0.96
	Staff development	No.	Number of training for staff per year	2	3.38
	Collaboration	No.	Number of discussion on design	2	4.95
	Utilisation of tools	No.	Number of tools used in design	3	0.8
	Knowledge management	No.	Number of new knowledge recorded	3	0.82
	Monitoring Schedule	No.	Number of review on design process at each stage	2	8.25

Calculation of the KPIs

The calculation of KPIs would be based on the comparison of the 'Actual' and 'Target'. The 'actual' would be the result of the action based on the activities of the proposed design process that have been performed (Table 5.9 and full table is in Appendix F). Whereas the 'target' would be the set value of the activities that is going to be performed. There are two types of performance that can be observed. The first one is the 'higher the better' type of performance where the higher the number achieved means the value is beyond the expected result and higher number will give positive impact. The example can be, the number of meeting with client, if it is higher value, this will indicates that the frequency of the meeting has been conducted beyond the target number. While the equal value achieved means the value of the KPIs achieved the target.

The second type of performance would be the 'lower the better' where the lower number means the number achieved means the value is beyond the expected result and the higher number will give positive impact. The example can be, the percentage of the delay of delivering or producing design that need to be reduced.

Table 5.9 Sample of Weight and Calculation of KPIs

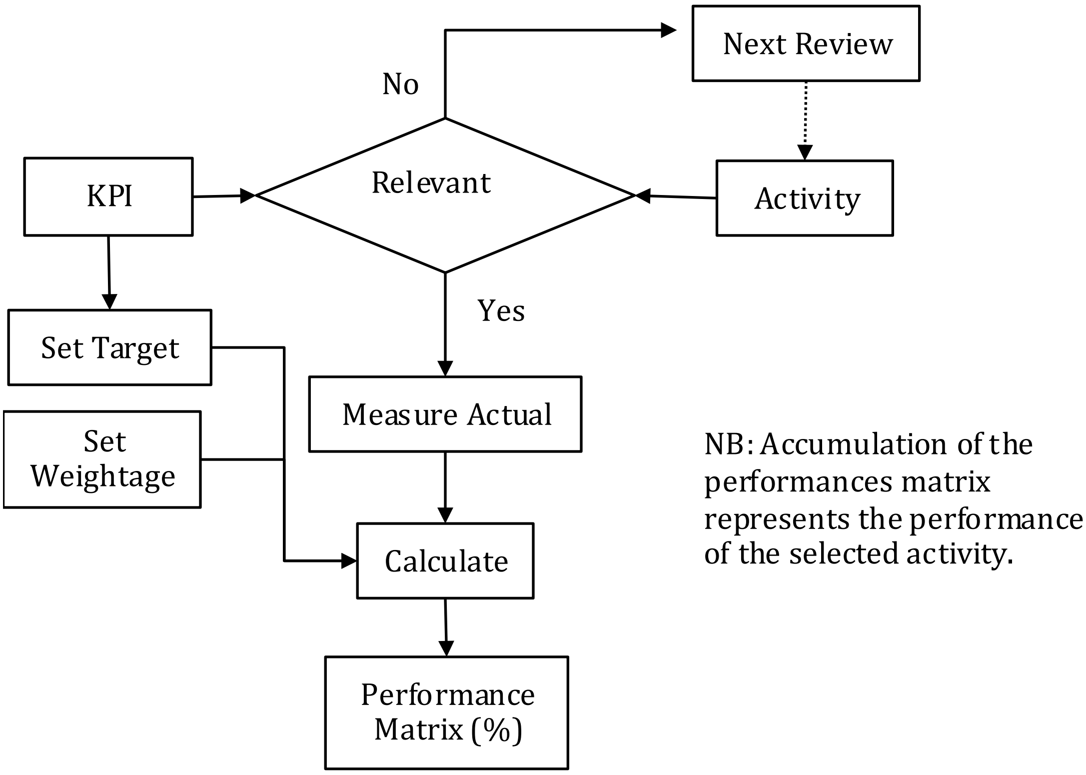
	KPIs	Unit	Description	Target	Weight (%)	Calculation for KPIs
Quality	Client	No.	Number of meeting with client per month	1	3	Higher the better $100\% + \left[\frac{Actual - Target}{Target} \times 100\%\right]$
	Admin	day	Time taken to response to the queries	5	2	Lower the better

						$\mathbf{100\%} + \left[\frac{\boldsymbol{Target - Actual}}{\boldsymbol{Target}}\right] \times \mathbf{100\%}$
	Project	**%**	**Meeting the project goals**	**60**	**6**	Higher the better $\mathbf{100\%} + \left[\frac{\boldsymbol{Actual - Target}}{\boldsymbol{Target}}\right] \times \mathbf{100\%}$
	Resources	**%**	**Increase in design progress from previous one**	**20**	**3**	Higher the better $\mathbf{100\%} + \left[\frac{\boldsymbol{Actual - Target}}{\boldsymbol{Target}}\right] \times \mathbf{100\%}$
	Information	**No.**	**Number of meeting with stakeholders per month**	**1**	**12**	Higher the better $\mathbf{100\%} + \left[\frac{\boldsymbol{Actual - Target}}{\boldsymbol{Target}}\right] \times \mathbf{100\%}$

5.5.1. Performance Matrix and Results

Performance matric is developed to seek the relevancy of the activities in the proposed design process with the KPIs set in this research. Therefore the flow of the performance measurement is presented in Figure 5.8. This flow chart is assuming that the target, weightage and calculation formulae are already set as in the Table 5.9. The first step would be selecting the activity to be measured and compare to the each KPI. If the activity has relevancy with the KPI, then the ‘actual’ number performed is measured and calculated. The result from this calculation would be the performance matrix of the selected activity with the relevant KPI (Appendix G). There will be several KPIs under the selected activity have relevancy. Therefore the accumulation of the performance matrix would be the overall performance of the selected activity. The grade of the performance would be the total performance matrix of all the activities under the ‘Stage’. This will be discussed in the following sub-section.

Figure 5.8 Flow Chart of the Design Process Performance Measurement



5.5.2. Experts to evaluate the KPIs in activities

The evaluation of the grade is divided into five divisions: 0%-49% means need improvement; 50%-59% is average; 60%-69% is good; 70%-79% id very good; above 80 is excellent. It is suggested that the organisation should set the grade boundaries, as they know what to be achieved and aligned with their company's policies. In this research it's the participants who decide the range of the grade boundaries as shown in Table 5.10.

Table 5.10 Performance Grade

Range (%)	Grade
> 80	**Excellent**
70 - 79	**Very Good**
60 - 69	**Good**
50 - 59	**Average**
0 - 49	**Need Improvement**

5.6. Implementation Process

The implementation process in this research is to provide a clear procedure to follow while conducting the activities of the research and this also identified as the case study protocol in this research. This step-by-step procedure can be considered as a stepping-stone of a plan for execution of case study research. Due to the limited resource projects for the case study in this research, a single case study was conducted.

In addition, the protocol will also provide reliability of the case study research. It will provide a tracking of the procedure. This case study protocol follows the guideline stated by Maimbo & Pervan, (2005). The bespoke protocol is presented in Table 5.11, which is suitable for this research.

The intention of this protocol is to develop a guideline in conducting the case study within this research. The aim is to validate the proposed design process and performance on its applicability, suitability, and adaptability.

The guideline activities also presented in this process and the expected outcome is listed as well.

Table 5.11 Case Study Process

Resource: (developed in this research)

Step 1	Understand Requirement	Document
Activities	**Hold preliminary Meeting to represent the proposed design process**	**Conceptual Design Process**
	Outline the potential advantages	**Benefit of the proposed design process** **Waste elimination** **Value creation** **PP**
	Get Top management agreement	**Ethic** **Confidentiality**
	Stakeholders agreement	**Research ethic** **Commitment**
	Identify suitable case study	**Criteria:** **-the project can be at any stage of design process** **-local** **-**
	Perform gap analysis	**interview**
	Perform internal benchmarking	**From the gap analysis the performance of the existing design process will be identified.**
	Evaluate by using historic case	**Use the proposed project control**
Outcome	**Develop the requirement**	**Propose action to enhance PP**
Step 2	**Design the New Approach**	
Activities	**Case study has been selected**	**Get the background of the project** **Type, budget, cost of design, duration, special requirement, complexity etc.**
	Develop a recommendation of implementation for the proposed design process	**Set target for the performance enhancement of the design process**
	Match the requirement with the new approach	**Develop a matrix: requirement vs new approach (tools)**
	Conduct a workshop to refine the customised proposed design process	**Give briefing on the new approach, benefits, advantages and disadvantages.**
Outcome	**Develop an implementation plan for the case study**	**Proposed design process**
Step 3	**Implement the New Approach**	
Activities	**Identify and form design**	**Design team from the participating organisation**

	team to implementation the proposed design process	
	Train the team for implementation on the activities and supporting tools	**Procedure of the implementation**
Outcome	**Implement the proposed design process on the cases study project**	**Interview questions**
Step 4	**Evaluation**	
Activities	**Performance**	**Semi-structured interview**
	Benefit	**Semi-structured interview**
	User friendly model	**Semi-structured interview**
	Flow	**Semi-structured interview**
	Collaboration	**Semi-structured interview**
Outcome	**Report**	**Thesis**

The main unit of analysis in this case study is the implementation of the proposed design process with performance measurement system. The data collection procedure will follow the implementation process of the case study for this research and it is elaborated in this section. The enquiry for this case study is based on 'How' and 'Why'. The analysis of the data acquired is using the method described in the following list.

Linking Data to Propositions

The 'pattern matching' is one of the useful approaches in analysing case study data (Table 5.12).

Table 5.12 Pattern Matching

Resource: (developed in this research)

No.	Pattern	Rival Pattern
1	**There exist no documented systematic design process**	**A documented systematic design process**
2	**There is no documented systematic project control in design process**	**A documented systematic project control**
3	**A systematic design process perform well and has more chances of acceptance in industry**	**Acceptance of design process does not perform well; rather it is overshadowed by other factors such as company procedures and policies, client constraints, design constraints etc.**
4	**The project control in design process has an effect to the overall PP at the early stage**	**The project control is misunderstood as design control**
5	**The proposed project control aids in evaluation of the design process**	**The proposed project control is considered as individual checklist of design performance.**

5.7. Summary

In this chapter, the development of the proposed design process was presented and described. The lean design process enablers were extracted from the literature review were prioritised and structured into a framework.

There were three elements identified to merge the theory and practice in research for the development of lean design process: concept, principles and methodologies. Therefore this research is following a chronological order of merging. The concept starts with the development of framework for design process innovation, where the elements were acquired from the research literature review, and these were then converted to form components of the framework. There are seven components of framework; Application, Design Management; Design process; People; Information flow; Measurement and performance; and Techniques and tools.

A proposed lean design process is based on the framework and enablers, where the core enabler is SBCE. This enabler has capability to convert existing design process become lean. This has been elaborated in the findings of literature review and the questionnaire. The proposed design process was divided into five stages, which are identical to the RIBA, Plan of Work 2013. This design process also incorporates performance measurement, which is the review of each stage of the process. This review becomes the project control that measures the performance of the design process that contributes to the PP at the design stage. Further development was made on the PP measurement which has three phases; Preliminary phase; Computation phase; and Measurement of performance.

The supporting tools and techniques were also presented based on the review made during the interview with the practitioners. Then the implementation process is developed for the case study. The development considers the case study protocol and unit of analysis.

The next chapter describes the application of the proposed design process by using case studies. The chapter reports the test of the proposed design process in the construction industry.

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6. CASE STUDY

6.1. Introduction

In this chapter, the proposed design process and performance measurement are tested in the context of the construction industry in Brunei. The researcher contacted all the 22 questionnaire survey respondents companies and received five replies who are willing to participate in the case study research. However, due to the business commitments and time limit of the research, three companies were eliminated. The proposed design process and the performance measurement is applied to a design project in each of the selected companies and analysed. Finally the applicability of the proposed design process and the performance measurement are discussed.

6.2. Objectives

The case study aims to investigate the proposed design process application in the building construction project and evaluate the proposed design process in terms of its suitability, usefulness and applicability in building construction projects in general. In addition, the case study aims to demonstrate the impact of the proposed design process at the early stage of the projects. The details of the case study are further elaborated upon within this chapter.

6.3. Action Research Overview

The case study implements the proposed design process with the architectural firms, which are addressed as “consultant” firm in this thesis. The implementation was held in different stages, as shown in the Table 6.1. This is due to the time constraint on implementing the proposed design process with only one design project, as any such project will take between six and eighteen months to complete. Furthermore, the unpredictability of the design activities in design projects was difficult to plan and manage. Subsequently, the availability of the participants in allocating their time to commit to this case study became a contributing factor placing time constraints on the case study.

Companies were sought that have one or more projects that meet the criteria of the case study in planning and design phase of a project. The criteria for the company was set as one that is registered with the government of Brunei; this type of company will have experience of handling large projects for the government and, to be registered with government, the company has to meet certain the criteria, including the principal architect or designer having a licence to practice. This will prescribe the level of professionalism in providing information and cooperation during the case study of this research.

Although the representatives of the architectural firm showed their interest in applying the proposed design process, they also expressed their concern about the adaptability of the proposed design process. This is important, as the goal of the implementation of the proposed design process is going to be applied onto a live design project, which requires strong support from the firms involved. Their mind-set needs to be in such that the impact of the proposed design process can be seen after the implementation. The approach of action research ideally suggests that there should be a facilitator to lead the case study. Therefore, this thesis' author would have to be the facilitator for the case study.

Table 6.1 Involvement of Consultants at Every Stage

Stage	Consultancy	Project Type
0	**A**	**Residential house**
1	**A**	**Residential house**
2	**B**	**Residential house (component of a house)**
3	**B**	**Residential house (component of a house)**
4	**No implementation**	**-**

The action research follows the case study process described in Chapter 5. Step 1 is to understand the requirement of the processes that need to be improved. A preliminary meeting was held with a representative of the architectural firm to present the proposed design process and discuss the advantages of adopting the proposed design process. As identified in this research, this leadership aspect is one of the factors influencing successful implementation. Therefore, agreement from the top management is acquired through the activity in step 1, which comprises assuring the representatives on matters of confidentiality of information during this research. The confidentiality assurance is extended to the stakeholders that are relevant to the projects being studied.

Subsequently, during the preliminary meeting, a suitable project for the case study was discussed and identified. The selection of the case study was challenging due to factors including project timescales, relevancy of the case, and the stages where the project was currently are. Once the project was identified and selected, gap analysis was conducted to identify and compare between the companies' actual design process and the proposed design process. Historic case analysis is used to capture the actual design process based on previous projects of the firms. The questions for the historical case analysis were set according to the recommendations made by Khan (2012). At the end of step 1, proposed action to make bespoke changes to the design process for the particular project was developed.

In step 2, the details of the selected projects for case study were collected and recommendations developed based on the target performance enhancement of the project. The case study requirements from step 1 were matched to develop a bespoke design process. The second meeting was conducted to present the bespoke design process and implementation process for the selected project.

Step 3 was conducted either at the same time as in step 2, or on another date. The design team can be a group of designers or an individual designer acting on one project. They need to be trained on the implementation procedure through the cascading of information and the use of the techniques and supporting tools proposed.

While still in contact with the firm's representative, step 4 was conducted for evaluation of the proposed design process and the performance measurement. This is to catch the immediate response of the user of the proposed design process.

In this chapter there are four case studies presented according to the proposed design process stages. The sequence of the case study presented in this chapter is as follows: description of the case study; case study development; and the result of case study. Some of the details have been deliberately omitted to meet the confidentiality requirement.

6.4. Case Study 1: Stage 0- Residential House

6.4.1. Case Study Description

There are a limited number of design projects available at any one time. The only project that was found to be relevant to the requirement to the case study is that of a proposed private residential house. It was considered suitable for the case study as it was only within the preliminary stage of the project. According to the proposed design process it is in stage 0 (Define Value).

6.4.2. Case Study Development

The initial communication with Consultant A was initiated through a telephone conversation where the key contact person (Principal Architect) gave his consent to be involved in this study. During this stage the principal architect was briefed on the study topic area and some detailed documents were sent by email to ensure the participant had a general background on the study and known what was to be expected during the case study. These matters included the number of appointments and the outcome of the study.

The participant agreed to the plan and as the participants were the principal architect and the owner of the firm, top management agreement has been achieved. Therefore the information gathered was a true representation of the firm's case study materials. Based on the objective of the case study the participants agreed to use one of its design projects which was at the stage 0 of the proposed design process.

Upon meeting with the participants, gap analysis of the existing process was conducted through a semi-structured interview; this was guided by the activities of the various stages and the questions were related to the activities, summarised in Table 6.2. The gap analysis was conducted by using analysis of a historic case, where the activities in the design stage were discussed and the gap is identified based on the participant's answer.

Table 6.2 Historic Case Study Questionnaire: Stage 0

Source: *(developed in this research base on M. S. Khan, 2012)*

Lean PD Activity	Question	Answer	Analysis
0.1 Classify project	**How was the project classified and when did this classification take place?**	**No formal classification of the project**	**E**
0.2 Explore client value	**How was the voice of the client represented to the design team? How do you ensure/measure that the design meets customer expectations?**	**The client's requirements were extracted through series of meetings.** **Iteration is being practiced in order to get information from client.**	**y**
0.3 Align with company strategy	**How was the project aligned with the company strategy? Was the project used to improve design process?**	**SOP-standard Operation Procedure (JKR)** **Confirmation in meetings** **MoM-Minutes of Meeting being recorded for future reference and confirmation** **Paper work**	**E**
0.4 Translate value to designers	**How was the design concept communicated to designers?**	**Cost , Time, Quality-considerations**	**x**
Key:	**E-Expedient methodology already in place** **x- Gap identified but not addressed** **y- Gap identified and addressed** **N- Not considered for implementation**		

With this information, the participants were presented with the gap analysis and the proposed solution. The design stage is at the 'Stage 0' where the activities 0.1, 0,2, and 0.3 are already in place. In activity 0.1, the client had already specified the classification of the project and the expected completion time, with the allocation of budget already set. Therefore, there was no further recommendation needed for this activity.

In activity 0.2 **Explore client value**, the gap was identified where there was no proper method of transferring the client value to the design team. Although the participants use the meeting so as to understand the client value, this method of interpretation of the client's value is only by the tacit knowledge of the participant.

In activity 0.3, **Align with the company strategy**, the participant used 'Standard Operating Procedure'. Therefore there is no further recommendation needed for this activity.

In activity 0.4, **Translate value to the design**, there is a gap identified and not yet addressed. Therefore, further recommendations were needed for this activity.

6.4.3. Case Study Results

The structure of this section is based on the proposed design process in this research. The description of the result will follow accordingly.

Stage 0- Define Value

Activity 0.1 - Classify project

Although project records were used, classification was according to the organisation’s filing record only. The details are only relevant to the organising the company’s project files. It is not used for the design process. Therefore this method of classification cannot be considered as part of the design process as insufficient level of detail has been provided for the design to be completed.

Therefore, a project classification has been developed where all the constraints were taken into consideration that might be used in the later design process. Table 6.3 shows some of the detailed considerations for the design project.

Table 6.3 Project Classification Information

Project ID	Start	Duration	Completion	Level of constraints	Level of complexity	Level of innovation	Special Request
H01	**March 2016**	**6 months Design + 18 months Construction**	**2018**	**Low (1)**	**Low (2)**	**Medium**	**Quality room with specific orientation view**
Key:	**Level**		**Constraint/Complexity**				
	Low (1)		**Can be solved by the designer**				
	Low (2)		**Can be solved the team of designer**				
	Medium		**Required minimum external resources**				
	High (4)		**Require medium external resources**				
	High (5)		**Require specialist**				

The level of constraint is considered as low (1), as the client has already specified in the requirement and, based upon the series of meeting, it was made clear that the finance of the project is already confirmed and the land area was suitable for the residential building. The level of complexity was considered higher than the constraint, as the rooms and other facilities needed to be properly matched with the orientation of the required views. This might require design team members to give different perspectives and ideas. The level of innovation is considered medium, as the design was a totally new building concept and there were no project examples that could be used that would be similar to this design.

Activity 0.2 Explore client value

As the design was being developed by the architect and design team, the client's requirements were collected over a period of 2 weeks. These included discussion between the architect and designer and the client. Sometimes the discussion was followed up with phone conversations or formal discussions. Therefore some of the information that passed between the parties could not be recorded, as the ideas came spontaneously from the client. The only recorded outcome of the informal discussion was the ideas which the architect or designer thought would change the concept of the design.

In this activity, the client value was recorded, interpreted and then presented back to the client to make sure that the ideas were captured and agreed. Since this historical practice has been used over a period of time by the architect and engineer, then to adopt a new system of capturing the ideas and turning it into customer value will take time to adopt. However, this activity did highlight the importance of recording and having a systematic value interpretation so that the agreement can be reached. Then other activities can be proceed.

Activity 0.3 Align with company strategy

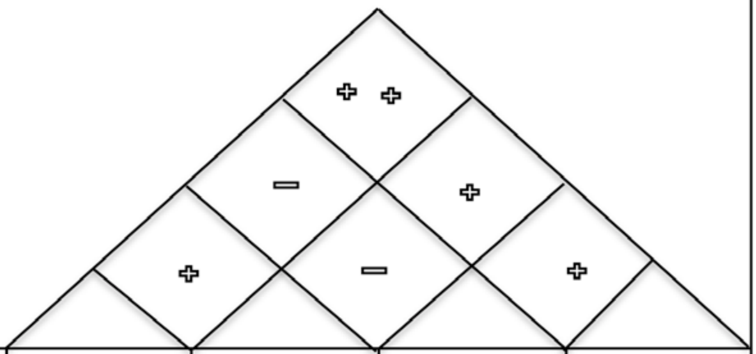
The objective of referring to the strategy of the company and aligning it with the client's requirements and design was something new to the participants, who had not considered such matters were relevant to the design. Furthermore, the participants were not able to co-relate the significance of this stage to the design planning. Therefore this activity was omitted.

Activity 0.4 Translate value to designers

From the gap analysis conducted, the participants only mentioned factors that needed to be considered to translate the value to the designer. There is evidence that the method used to achieve this activity is through a series of discussions. Iterated concept of design that satisfies the client requirement was recorded in the form of sketches and sample designs from previous projects and from relevant literature, such as magazines and books. Thus the design iteration becomes frequent, as there is no proper system in place.

For this research the tools available to accomplish this activity were discussed and it was proposed to use ‘Quality Function Deployment’ (QFD) to translate value to the designer. First, the benefit and effectiveness of QFD was briefed out to the participants. Then the procedure of using this tool was explained. Once the participants understood the concept and procedure, then the actual use of the tool could be started. The QFD for this case study was presented in Figure 6.1 below. Once the participant tried out the tool, then the interpretation of the results was explained. This was where the evaluation of the information gathered in this QFD was examined.

Figure 6.1 Use of Quality Function Deployment for Value Translation



Client Requirement	Rate	Height	Space	Exterior Lighting	Cost
Direction of Improvement		▲	▲	▲	▼
Bed Rooms	5		●	△	
Living Room	5	○	●	●	
Dining Room	3.5		●	○	
Surau	2	△		○	●
Storage Facility	5		●		○
Quality Room	3	△		●	○
Evaluation		20	166.5	93.5	42
%		6.2	51.7	29	13
Priority		4	1	2	3

The QFD was used to analyse the interaction between the client's requirements and the key functions of the design. Figure 6.1 shows that space is the focus of the design and the suitable lighting for the rooms would make a great contribution to client value. The correlation between space and exterior lighting indicate weak correlation.

The outcomes of Stage 1 were compiled to develop the design concept and presented to the designer. At this stage, free-hand sketches were used to communicate the information extracted.

Finally, the Stage 0 review was conducted, where other designers in the organisation were invited to participate. Concept definition and plan for future activities were discussed in the review.

The Principal Architect felt challenged with the proposed design process in this stage, as it required a lot of thinking and decision making. However, he felt that if this was continuously done, it would become the organisation's culture and there would be more innovation created.

6.5. Case Study 2: Stage 1-Residential House

6.5.1. Case Study Description

Stage 1 of the proposed design process was to 'map design scope' where the level of improvement and innovation in design needs to be decided based on cost and time constraints. Hence design concept definition is essential in deciding the target level. The project from the previous stage (Stage 0, Section 6.4) was used for this stage (Stage 1). The following section describes the details of the case study.

6.5.2. Case Study Development

A meeting was set for this stage to utilise information acquired from the previous stage. This is important for this case study, where continuity of information can be utilised so that the proposed design process can be evaluated. The same consultant was still involved in this stage, and already had experienced and understanding of the concept of the proposed design process. This made the case study process easier to conduct, since the representative and the researcher have built a rapport.

The interview questions and gap analysis are presented in Table 6.4. Activities 1.1 and 1.3 have gaps that are not addressed in their design process. For activity 1.2, there is a similar activity within the design process. However, it would be better if the system was in place for applying design tools.

Table 6.4 Historic Case Study Questionnaire: Stage 1

Source: *(developed in this research base on M. S. Khan, 2012)*

Lean PD Activity	Question	Answer	Analysis
1.1 Identify sub-design solution targets	**Did subsystem participants identify lower-level system targets (e.g. reduce weight by x%)?**		**x**
1.2 Decide on level of innovation to the sub-design solution	**How did you control the amount of innovation that was designed into sub-assemblies/components?**	**Architect will propose a design based on the clients requirement and then present it.**	**y**
1.3 Define feasible regions of design scope	**How did you ensure that designers/engineers designed within the constraints of construction, buildability and client's finance and other functions (without inhibiting innovation)?**	**Only by referring to the client requirement and agreement.**	**x**
Key:	**E-Expedient methodology already in place** **x- Gap identified but not addressed** **y- Gap identified and addressed** **N- Not considered for implementation**		

6.5.3. Case Study Results

Activity 1.1 Identify sub-design solution targets

The objective of this activity was to determine a challenging design and innovation for the project based on the available technology. However, due to time constraint of this research, the sub-design solution target was not defined. The sub-design may be the selection of floor material, wall tiles, wardrobe, floor level etc.

Activity 1.2 Decide on level of innovation to the sub-design solution

With the information gathered in stage 0 through the QFD technique, the functional requirements that need to be focused upon are space and exterior lighting. Space has correlation with height, where by adding some height can add more headroom in order to extend the space of the room. Exterior light has correlation with cost, where for example adding extra windows can increase the cost of the construction. Furthermore the height and cost has double correlation with cost as the construction cost will increase by adding height to the walls. Therefore cost should be considered in every design proposal.

This activity provided a clear indication that space and exterior light should be given higher innovation and design effort as shown in Table 6.5.

Table 6.5 Level of Innovation

Component	Space	Exterior Lighting
Bed Rooms	**High**	**Low**
Living Room	**High**	**High**
Dining Room	**High**	**Medium**
Surau (prayer room)	**Low**	**Medium**
Storage Facility	**High**	**Low**
Quality Room	**Low**	**High**

Activity 1.3 Define feasible regions of design scope

The architect reviewed various options and the design possibilities were discussed and brainstormed with other designers. Constraints were considered based on the previous projects and company standards. Although there is some information available from the previous projects, the feasibility of the design was only limited by the budget allocation.

6.6. Case Study 3: Stage 2-Staircase

6.6.1. Case Study Description

This case study focused on the components of a building for design. After some discussions with the architect, agreement was made to focus the design on the staircase of a house. This was believed to be appropriate for this research given the time constraints faced.

6.6.2. Case Study Development

Consultant B was contacted before the case study started. The first meeting was set to discuss the activities for the case study (Table 6.6). The case study process was used to guide the research in conducting the case study. Selecting a project for the case study proved to be difficult. Most of the projects were either at the early stage, or almost complete. Hence the design of building components was decided to be appropriate for use with the proposed design process.

Table 6.6 Historic Case Study Questionnaire: Stage 2

Source: *(developed in this research base on M. S. Khan, 2012)*

Lean PD Activity	Question	Answer	Rating
2.1 Extract design concepts	**Were previous projects, R&D projects, and other building design considered? How did you ensure that designers considered a range of options?**	**The design process started with the Client Design Brief then applied with the Designer's expertise and experience. Similar typographies are also reviewed and good points considered.**	**E**
2.2 Create concept design for sub-design solution	**How were the initial sub-design alternatives represented?**	**Design Proposals come in multiple options. Those presented to the Client have already been short-listed by the Design Team based on compliance to Client requirements, budget and time.**	**y**
2.3 Explore the concept design for sub-design solution	**What methods did you use to test concept design alternatives? Do you have a test strategy?** **Eg. lifecycle cost, quality, and performance.**	**No specific testing done. Designs are measured against known standards (both international and local) and any other specialist requirements.**	**x**
2.4 Capture knowledge and evaluate	**In order to compare alternative sub-designs what are the most critical characteristics that should be analysed? What methods did you use to compare design alternatives?**	**Quality. Cost. Time.**	**y**
2.5 Communicate concept designs to others	**What information is required by different project teams in order to provide feedback and constraints regarding possible design alternatives?**	**The Design Team is informed of the Concept Design and continuously updated thru the Design Development while coordinating with the Client and Local Authorities. A Base Plan is constantly updated for the Team's information.**	**E**
Key:	**E-Expedient methodology already in place** **x- Gap identified but not addressed** **y- Gap identified and addressed** **N- Not considered for implementation**		

From the gap analysis in Table 6.9, it was found that the activity 2.1 is already being practiced within the existing design process. Activity 2.2 has a gap that needs to be addressed. Activity 2.3 addressed the optimisation of information from the briefing and incorporated in the design. Then a comparison was made of the proposed alternative designs. For activity 2.4, the knowledge captured by documenting the discussions and decisions made identified a gap but it was already being addressed.

6.6.3. Case Study Results

Activity 2.1 Extract design concepts

The establishment of the design for a staircase was first considered based on the type of staircases available in architecture. The architect considered six aspects (as in Figure 6.2) of staircase designs: available height for staircase; rise and step ratio; width allowance; inclination of the staircase; position and space available; suitable types of staircase; and choice of materials. The architect emphasised the space of the building available for the staircase and the height of the floor to ceiling of the building (Figure 6.3). This is a fundamental aspect of designing a staircase in which a stringent calculations need to be carried out to utilise space. At this stage, this information is essential to decide the type of the staircase. It was recommended to use functional requirements to incorporate the client requirement into the design. Unfortunately this design was already halfway through to completion. Also, there was no documentation on the functional requirements made earlier. The materials for the staircase are also part of the essential design component.

Figure 6.2 Design Considerations for Staircase

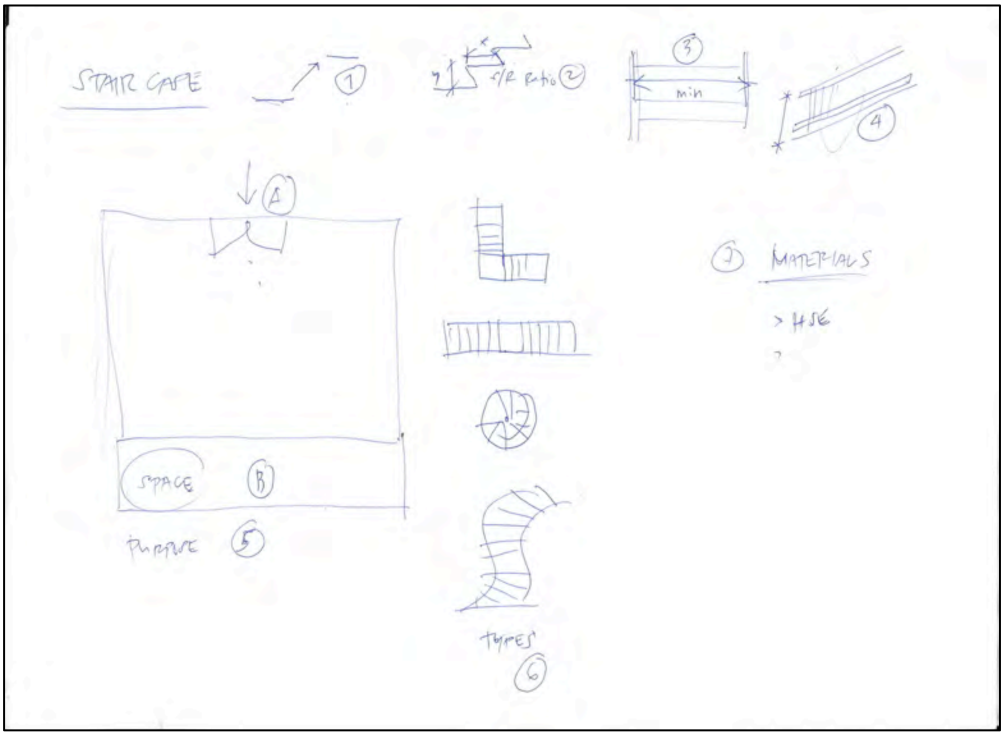
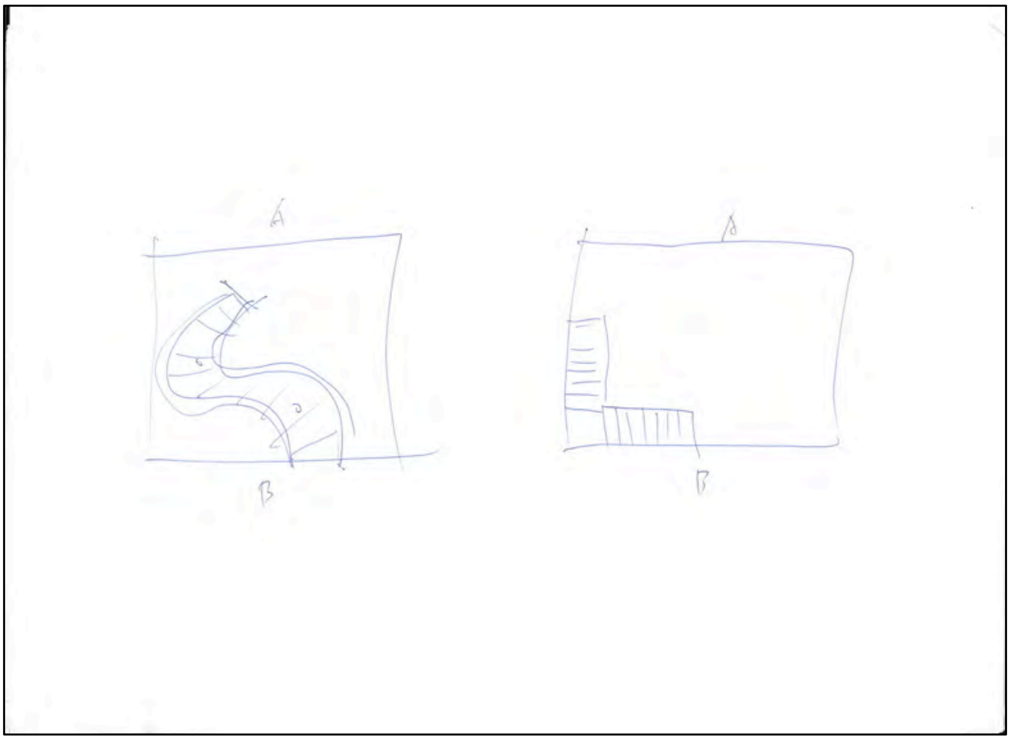


Figure 6.3 Simulating the Type of Staircase for Space Utilisation



Activity 2.2 Create concept design for sub-design solution and

With this information, the architect was able to list down the essential design components and match the design alternatives as shown in Table 6.7. However, the selection of the design had not yet been decided at this stage. Therefore, the architect needs to have meetings with structural engineer, quantity surveyor and safety engineer in order to gain some more information on the design.

Table 6.7 Design Alternatives for the Staircase

Design Component	Alternatives	Description
Space	**a1**	**Left Position**
	a2	**Middle position**
	a3	**Right position**
Height	**b1**	**One flight**
	b2	**2 flight with one landing**
	b3	**3 flight with 2 landings**
Design type	**c1**	**Curve**
	c2	**L shape**
	c3	**Dog leg**
Material	**d1**	**Wood**
	d2	**Concrete**
	d3	**Composite**
Safety	**e1**	**Handrail**
	e2	**Irregular steps**
	e3	**Headroom**

Activity 2.3 Explore the concept design for sub-design solution

Further brainstorming was conducted with other designers. There were some missing information in the master plan of the building where the architect had to contact the engineer. The architect consulted the engineer on the structural viability on the design, giving a different perspective. Table 6.7 was also discussed with engineers on the alternative designs that were available. The engineer raised the issues of buildability of the staircase, cost of the design, and safety aspects. All of the items discussed at this stage were recorded and minuted as required by the proposed design process in activity 2.4. In this case study, meetings with other consultants were set for a later date, which is outside the scope of this research timeframe. Also, while implementation of activity 2.5 was not formally done, there was some evidence of where the architect communicates the design with other designers and consultants in the project.

6.7. Case Study 4: Stage 3-Staircase

6.7.1. Case Study Description

This stage is the continuation of the previous stage where design of a staircase was used. Therefore, the results from the previous stage were absorbed into this stage. There was another meeting conducted for this stage and the information, documents and the details from the previous stage were brought to the design table.

6.7.2. Case Study Development

The historic case study presented in Table 6.8 is the continuation of the staircase design in stage 2 of the proposed design process. The consultant B from stage 2 of the proposed design process was still involved and the same staircase design was used for this stage.

Table 6.8 Historic Case Study Questionnaire: Stage 3

Source: *(developed in this research base on M. S. Khan, 2012)*

Lean PD Activity	Question	Answer	Key
3.1 Determine concept design intersections	**How can you determine whether or not components will intersect with each other and how difficult it will be?**		**x**
3.2 Explore possible designs	**What methods do you use to test design alternatives? Do you have a system test strategy? How did you evaluate the potential costs, quality, and performance of design concepts?**		**N**
3.3 Seek conceptual robustness	**How did you ensure that the design works, regardless of variations in usage, environment, or the construction process? How do you ensure the design will not be affected by making changes?**	**The Design is confirmed to work basically via review by the End Users and compliance to relevant standards. A certain degree of flexibility which is integral to any design is applied in order to accommodate changes in the future. Although there is a limit of feasible changes wherein the cost and time implications may be high.**	**N**
3.4 Evaluate concept design for lean construction	**How did you analyse the effects of a design on its construction process?**	**Monitoring the Construction and coordinating any technical issues with the Design Team and Contractors.**	**y**
3.5 Begin process planning for construction	**How and when did you begin process planning for construction?**	**Planning the construction starts from the very initial stages of design.**	**N**
3.6 Integrate the final concept design of sub design solution	**How did you decide/determine the final design?**	**Compliance to the Design Concept and Client Requirements.**	**x**
Key:	**E-Expedient methodology already in place** **x- Gap identified but not addressed** **y- Gap identified and addressed** **N- Not considered for implementation**		

The gap analysis presented identifies activities that were already in place in the organisation's design process. However, there is some room for improvement that can be suggested. In this case, study the researcher was trying to introduce techniques that are listed as supporting tools and techniques for this research. Activities 3.1, 3.4 and 3.6 were considered as not being practiced in the existing design process. Activities 3.3 and 3.5 were considered '*no implementation is needed*' as there are constraints on the available information of component such as cost, quality and performance.

6.7.3. Case Study Results

Activity 3.1 Determine concept design intersections

In determining the design intersection of the chosen staircase, options were as depicted in Table 6.9. The architect was able to identify the design constraints, not only within the issue of cost but also other components as well. Such other constraints included for example, the position where design c3 cannot be integrated, as the right position will block the access to the living room. Other possible combinations of design would be the materials available for the three options. These three types of staircase can be constructed by using these three materials suggested from the brainstorming earlier.

Design Component	Alternatives	Design Type		
		C1 (Curve)	**C2 (L Shape)**	**C3 (Dog Leg)**
Space	**a1**	**C**	**Y**	**C**
	a2	**Y**	**C**	**N**
	a3	**N**	**Y**	**C**
Height	**b1**	**C**	**N**	**N**
	b2	**N**	**C**	**N**
	b3	**N**	**N**	**C**
Material	**d1**	**Y**	**Y**	**Y**
	d2	**Y**	**Y**	**Y**
	d3	**Y**	**Y**	**Y**
Safety	**e1**	**Y**	**Y**	**Y**
	e2	**N**	**Y**	**Y**
	e3	**N**	**C**	**Y**
Key:	**Y-Easy to Integrate** **C-Some Conflicts** **N-Do not Integrate**			

Table 6.9 Design Intersections

Activity 3.2 Explore possible designs

The design of the staircase was evaluated based on the data presented in Table 6.13. The architect decided to consider type C2. This type of staircase provides easy integration with the functional requirements. The summary of the selection is presented in Table 6.10.

Table 6.10 Result of Design Intersections

Design Component	Alternatives	Description
Space	**a1**	**Left Position**
	a2	**Middle position**
	-	**-**
Height	**-**	**-**
	b2	**2 flight with one landing**
	-	**-**
Design type	**-**	**-**
	c2	**L shape**
	-	**-**
Material	**d1**	**Wood**
	d2	**Concrete**
	d3	**Composite**
Safety	**e1**	**Handrail**
	e2	**Irregular steps**
	e3	**Headroom**

Activity 3.4 Evaluate concept design for LC

This activity recommends collaborations with other design teams, engineers and other consultants. From the observation in this case study, the designers do not have formal meetings with other design teams and consultants, information exchange occurred through telephone contacts and discussions and correspondence through emails, which can be considered as valid collaborations in acquiring information.

This case study recommends design-led in order to gain interactive collaborative process to create life cycle flow. Therefore the contractor is required to directly involve in the design phase. Furthermore, the contractors can be the leading designer. However, due to the lack of preparedness and resources from Consultant B, the Design-led process cannot be implemented during this case study. Instead, Consultant B was recommended to identify the possible variabilities at the construction site that might affect the construction performance. After some discussions and brainstorming inadequate design information, availability of the specified materials, and incomplete prerequisite work are considered as the common variability that needs to be considered during the design stage.

Activity 3.6 Integrate the final concept design of sub design solution

The final design concept is determined by the outcome of the design intersection. However, some consultations with other design teams is necessary to gain different perspective and consensus. As presented in activity 3.2, the design C2 is the final selection of staircase design. This was brought forward for further analysis and discussion. There were some enquiries made by the design team on the type of design selected, such as the budget and criteria for the living room design. For the budget issue, there was no further discussion made as the architect would refer to the estimator and client on the allocation budget for this component. There was a need of design integration for the staircase and living room as the staircase will be the focal point of the living room. Therefore the design team needed to consider these aspects. However in this case study the integration could not be included, due to the time constraint.

6.8. Performance Measurement Results

Each case study in this research was evaluated by using the developed performance measurement in this research. The architects as the participant for this research were given the table for the measurement of the performance. The actual values in the table were determined. The results are presented in Table 6.11.

The results of the performance measurement matrix is elaborated based on the proposed design stages. From the result acquired, the performance of ‘Stage 0’ is recommended to be very good as the activities scored 72% of the target performance. ‘Stage 1’ gives a result of 51%, which is considered as average result and there is a potential to be improved. ‘Stage 2’ provides 39% of target performance which recommended to be improved and re-reviewed. 'Stage 3' gives 53% of the target performance, which is average performance.

By knowing this performance, the participants tend to discuss the activities that they have done. They also review the activities that they have missed. They make speculation on the proposed activities such as if they have done the missed activities that will improve the performance rather than increase the actual value of the activities. Another prediction made by the participants was the target of performance increase, which will increase the commitment of the participants to do the proposed activities in the design process. This will encourage the participants to strive the score up to the target or beyond the target.

Table 6.11 Case Study: Performance Grade

Stage	Performance (%)	Grade
0	**72**	**Very Good**
1	**51**	**Average**
2	**39**	**Need Improvement**
3	**53**	**Average**

6.9. Evaluation of the Proposed Design Process and Performance Measurement

The representatives of both Consultants were asked to review the proposed design process and performance measurement system that have been implemented for their project design. The evaluation was conducted by using a semi-structured interview. The interview used open-ended questions and the findings are summarised as follows:

- Applying the proposed design process can provide an opportunity for the architects and designers to identify and keep track of their activities, as the proposed design process requires documentation of the activities. The documentation is not just a record for future reference, but it also provides some degree of measurement.
- The proposed design process can be used to quantify the activities in design and be used to benchmark other design projects. With this feature, design can be scheduled and finished on time as prediction of the finish time would be quantified.
- The activities recorded and documented can be collected for archiving and used to develop a database for BIM. With the BIM database the tools used in design activities that are unique for any one project can be evaluated for use in similar designs. The criteria for using specific tools can be set so that the usage of the tools would be efficient.
- The performance measurement used is useful to predict the PP at the early stage.

- The flexibility of the design process and the PP measurement enables the users to customise their requirements according to the capacity of the project team. In small organisations, the activities can be suitable as there is a large choice of tools to be made. In the larger organisation, the activities can be added according to the organisational policy, where design teams provide different design options on a project. Therefore with the proposed design process there is alignment of the organisational requirements.

6.10. Summary

In this chapter case studies have been presented in which the proposed design process was applied with performance measurement system on two different projects.

Two building construction projects were selected, based on the availability of on-going projects, and with two architectural consultants. Consultant A was designing a proposed residential house with six bedrooms. Consultant B was designing a building project which focused on one component of the building, the staircase. The gap analysis was performed in order to identify any design process improvement needed between the historic case and method proposed for the proposed design process. This allowed the customisation of the implementation of the proposed design process for each stage. The result of the application of the activities in each stage have been described separately.

7. DISCUSSIONS ON THE FINDINGS

7.1. Introduction

This chapter summarises the findings from this research and discusses application of the proposed lean design process and its performance measurement. The findings from the literature review, questionnaire surveys, interview, case studies and achievement of the research objectives are also presented in this chapter.

7.2. Findings and discussions on the Literature Reviews Analysis

The literature review indicated that the design phase has a major influence on PP. The upstream planning and development of a project has great impact on the downstream performance of it. The cost of design improvements at the early stages of the project will be much lower compared with improvements and late changes made at the construction stage.

However, the literature review found that research on project improvements at the construction stage is more dominant than at the design stage and as a result, research at the design stage has had a lack of advancement in terms of theory development as well as implementation. This gap in advancement was a principal driver for this research, adopting a combination of theory development from construction and design research areas for the development of a lean design framework.

The literature review also identified that to make a process lean, a review of lean thinking principles is a fundamental prerequisite. It was decided to use this approach as the basis for design process transformation, which is in essence the elimination of waste and creation of value.

In terms of waste in the design process, this research identified 15 sources of waste for construction projects. There were some differences when considering waste in the construction design process, compared with the seven waste categories suggested by the TPD system. Such differences include waste in transportation. The literature suggests this is not applicable to the design process, although some papers try to fit it into this category, as there will be the delivery of a set of drawings to other design teams or transporting the information to others.

In this research, such issues have been considered as part of the flow of information within the design process. Therefore, this research does not to follow the seven categories of waste which are traditionally used. Instead, the waste identified in this research is treated as individual waste items that are relevant to the design process.

There is limited information in the literature on the methods or mechanisms to eliminate design waste in construction projects. Most papers refer to methods and techniques that are already established in the manufacturing design environment, where the product design can be perfected through continuous improvement. However, this has limited relevance in construction, where most buildings and other structures are bespoke designs, each being its own “prototype”. Also, their effectiveness on waste elimination in the design stage is unknown.

Therefore the method of waste elimination in this research was through modifying the activities in the design process. These activities are able to resolve the issues that arise from the wastes that were identified in this research. The effectiveness of waste elimination, suitability of the method, and efficiency of the proposed activities were found to be simply verified through questionnaire, interviews and case study.

Enablers of the lean design process were also extracted from the literature, with 32 enablers identified. These enablers were clustered, based on the stages of design process proposed in this research. Their suitability in each stage was based either on recommendation from other research and whether or not they have been applied in these case studies or have been the subject and application of the research study.

The literature also showed that the TPD system has been using the SBCE as its design process system and identified as lean design. SBCE was analysed and modified to allow application of the principles to the architectural design process. This enhanced the conversion of traditional design process into the lean design process.

Generally the design process used in the construction industry is relatively similar from organisation to organisation. They have client briefing at the early stage of the design process and comes with planning. However, in this research the element that makes it different is the activities with then process. These activities will make the process unique. In this research the activities will determine the performance of the design process. Activities cannot be developed without considering the nature of the process. In this research the nature of the process is the problem solving. Therefore the problem solving flow of action is the backbone of the proposed design process in this research.

With the findings of activities that will lead to the performance of the design process, performance measurement is essential in order to determine the achievement of the design process. Without this measurement it is difficult to know the process is progressing or regressing. Therefore this performance measurement should be part of the design process as this will provide the monitoring system of the proposed design process.

Another finding of the developed performance measurement in this research is the possibility of performance measurement with non-financial related element. This will enable the design activities in the proposed process to be quantified and interpret the result as a performance result.

Following the systematic review of the literature, relevant to the design in construction projects, 32 themes were identified, which were divided into seven categories. These categories were identified as knowledge domains for the development of a framework for the lean design process in this research. These domains also provide essential elements for project improvement. Therefore, integration of these knowledge domains serves as basis for the development of the proposed design process in this research.

The literature also identifies that performance measurement in the design process is relevant to the PP and can be developed from the project goals and project success. Subsequently, the complexity of construction projects leads to the use of KPI to measure performance. Therefore, this research considers four project goals as determinants of primary project success: Quality, Time, Cost and Sustainability. The attributes under these goals are based on the relevancy of design process. Then the hierarchy was developed to illustrate the links of goals and attributes.

Multi-dimensional performance measurement concept was adopted for this research, to develop performance measurement of the design process. After analysing the available approaches in literature, the facilitator-led approach was considered most suitable in the design process environment for construction project measurement. During case studies, the design team was given a full control of the decision making, while the facilitator gave only guidance and resources of information to do the performance measurement.

After reviewing the literature on the lean design process for building construction projects and its' performance, innovation for design process improvement for this research was based on the seven knowledge domains, which act as essential project improvement elements.

7.3. Findings and discussions on the Questionnaire and Interviews Research Analysis

The structure of the questionnaire comprised of four sections. Section one asked for details of the respondent, including demographics. All of the respondents had a building design background. Almost all possess architectural academic qualifications and some were members of architectural institutions. Their experience was relevant to the study area and the length of experience can be considered as knowledgeable in building design process. With this demographic established, the respondents of the questionnaire can be considered as practitioners who possess relevant experience and knowledge in design process.

In section two of the questionnaire the respondents were asked to give their agreement as to the list of waste that can be found in the architectural design process, based on the wastes identified from the literature. Most of the respondents agreed with the list of wastes in the design process. There were some suggestions of other wastes, based on the respondents' experience, but following analysis, most of these new suggestions were already incorporated in the existing list. Therefore the list of waste extracted from the literature review was used as the final list of waste.

From the analyses, the results from this questionnaire survey have achieved the aim of the survey for this section. The aim was to have consensus from the practitioners on the wastes that can be found in the design process. From the overall results above, the respondents agreed with the list of wastes from W1 to W14. However, the result for waste W15 (Effect of design code and standards on quality) shows the respondents were unsure as to whether the standard could be included and was a relevant contributor to poor PP, as the respondents' ratings were more neutral. The design code and standards were considered to be guidance to their design. This also important, as the design code and standards are an obligatory issue that every designer has to follow. In this research all of the wastes were considered as waste in the design process, and therefore, the wastes need to be eliminated or minimised in order to achieve high PP.

The analyses also demonstrated the top five wastes from the list were 1) poor client briefing, 2) inadequate technical knowledge, 3) Poor specification, 4) design changes and, 5) making design decision on cost not value of work. These top five wastes also mentioned during the interviews. Therefore it can be concluded that the top five wastes have significant impact on the design process performance. In the performance measurement, the target performance for KPIs have to be relevant to the top five wastes. In the case study the set target for poor briefing was based on the frequent meeting with the client. By doing this, the wastes have been eliminated and subsequently enhance the performance. This demonstrate that there is a correlation between the each proposed design activities and the set KPIs in this research.

From the list of waste, the waste of 'making decision on cost not value' received the highest mean. This indicates that with the design cannot be based on the budget of the project. It is important to consider value as well where the client requirement might affect the design quality of a building and this might avoid the design changes during the construction.

In section three, the questionnaire presented the proposed design process and activities. This was to give the respondents an understanding of the development of the design process and the significance of having a design process in order to improve PP. Then the respondents were asked for their agreement on the elimination of waste by having the proposed activities in each stage of the proposed design process.

The final results of the interviews and questionnaires provide significant impact on the development of the proposed design process. Subsequently these will encourage more refinement of the proposed design process towards expected results. The final results that have positive impact on the development of the proposed design process can be summarised as follows.

The results show high agreement as to the components proposed in the proposed design process and their usefulness for successful adaptation of innovative design process. However, the results also highlight a desire to have a design process that can be easily understood and followed. As a priority, it is important to provide accurate and straightforward details and descriptions of the proposed design process to help simplify its understanding and adaptation. It has been found that the design review of every stage is over emphasised and this can be developed based on the performance measurement system.

These findings are incorporated in the further development of the framework and design process. The final version of the proposed design process, after the fine tuning based on the above results, should then be implemented, considering also that the development of the proposed design process is in the Brunei construction industry's context.

7.4. Findings and discussions on the Case Studies Analysis

In the case studies conducted as part of this research, there were two separate design projects with different stages in the design process.

The first design project was the design of a proposed residential building, which was at the beginning of the design stage, defined in this research as stage 0 and stage 1.

The second design project was a staircase for a residential building, which was at stage 2 and 3 of this research.

These design projects were selected based on the availability of suitable projects with the firms of participating Consultants (A & B) over the period of this research.

The implementation of the proposed design process in real case studies provided an opportunity to test the efficiency and effectiveness of the design process components within the industry. Therefore, a protocol of implementation process was prepared to ensure the desired results were achieved. From the feedback from the case studies, most of the activities proposed in the design process were assessed as easy to follow and understand. However, some of the techniques and tools suggested were unfamiliar to the practitioners. As a result, the implementation process was found to take longer than anticipated.

The evidence from applying the proposed lean design process in the case studies provides an opportunity for the architects and designers to practice transparency on the tasks. This required the design teams to document and keep track of their activities and record information in order to capture knowledge. The documentation is not just a record for future reference, but it also provides some degree of measurement. The transparency practice is part of the lean design principles.

The results from the analyses of this case study show that the proposed design process can be used both to quantify the activities in design and to benchmark other design projects. With this feature, design can be scheduled and be finished on time as prediction of the finish time would be quantified.

The activities recorded and documented can be collected and be used to develop a database for BIM. With an available database in BIM, the tools used in design activities that are unique for any one project can be evaluated and used for other similar designs later. The criteria of using specific tools can be set so that the section of the tools would be efficient.

The project briefing was documented and was assessed as being easy to refer to. More systematic filing was created for the project and this made the filing system easy to extract for future reference, which can also be a support to the BIM initiative.

The architect was also able to focus on the priorities of the functions of the design after using the QFD tool. The architect decided to use the tools and develop more functions analysis in the future project.

The performance measurement system developed in this model acted as a process review and was useful to predict performance at an early stage of building construction project. The flow of performance measurement was clear and easy to follow by the practitioner. This performance measurement process also agreed with the findings in the literature review.

The flexibility of the proposed lean design process and the PP measurement enabled the users to customise their requirements as according to the capacity of the project team. In small organisations, the activities can be suitable as the available selection of tools is large. In larger organisations, the activities can be added according to the organisational policy, such as where design teams should provide different design options on a project. Therefore, with the proposed design process there is an alignment with organisational requirements.

7.5. Findings and discussions on the Achievements of Research Objectives

As discussed in the introduction chapter, the primary aim of this research was set out to develop an innovative design process for building construction projects. This aim has been achieved, as this research has successfully proposed a design process for construction, which has then been tested within two architectural firms as part of the case studies. These case studies proved that the proposed design process can be implemented not only in construction projects in Brunei. It is likely that the proposed design process will also have application in other developing countries, provided that the external environment conditions are similar; these include the political, economic, social, technological, environmental, and legal situations.

The first objective of this research was achieved through extensive review of literature in order to understand the research area. Then a systematic literature review approach was adopted to identify the current state of literature on the principles, theory, trend, barrier, wastes and enablers. The development of a framework, proposed design process and measurement system was based on the outcomes of the literature review. These incorporations lead to the innovation of design process in building construction projects which will improve the performance at an early stage.

The development of design process by using “Set-based Design” and “Set Based-Concurrent Engineering” have brought lean thinking into the design process. The design process provides several design solutions at the same time and keeping the decision at the last possible moment. While the lean construction process provides the method of processing information that satisfies the design process.

The design process model developed by Khan which adopting the SBCE gives the manufacturing industries benefits of adopting lean thinking. His work has proved that the activities developed can reduce the number of iterations. However, the design process does not address the elimination of waste in design and provide monitoring system for project improvement. Furthermore, his work only proven to be suitable in the manufacturing industry where continuous life cycle of the design and manufacturing is in place.

The proposed design process of this research is focusing on the construction projects where the activities proposed are suitable with the type of one-off projects. The context of one-off project in this research can be referred to the design team from different organisations. Therefore this proposed design process could be adopted in any type of building projects. Moreover the methods of implementation of the activities will give provide guidance to the design team.

This research proposed a design process with performance measurement system. This shows a fulfilment of the objective to develop a design process with performance measurement in the context of design phase of building construction projects in Brunei. The fulfilment of this objective is also confirmed by the implementation of the proposed lean design process through case studies conducted with architectural firms in Brunei. From analyses of the results from the case study, it has been shown that the practitioners agreed that the proposed design process is suitable for the construction industry in Brunei.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1. Introduction

This chapter builds on the case study findings from the research reported earlier to develop conclusions and recommendations for implementing lean design processes within architectural firms, targeting construction in Brunei and developing countries.

8.2. Conclusions from the Research

The following conclusions are drawn from the work presented in this thesis:

- The importance of innovation in construction design process has been expressed by academics. However, there is a shortage of research.
- The presented research shows that the principles of SBCE give enabling factors to adopt lean thinking principles in architectural design process.
- The approach of integrating ‘problem solving’ theory with SBCE principles supports the development of activities for the proposed design process.
- The definition of waste in construction process cannot be adopted in design process. Hence, the list of wastes identified in this research is developed.
- There are seven knowledge domains identified from the literature review that support the innovation of design process in construction industry. This innovation design process was able eliminated the wastes in design process.
- The proposed design process suggests a ‘Stage review’ on every stages of design process. KPIs performance measurement approach is adopted for the review. The integration of activities and the KPIs in this research to measure the performance give positive indication of the design process.

The research makes the following contributions: (1) identification of wastes and enablers in design process, (2) the innovation on the design process enabled the architect to eliminate the identified wastes in the design process, (3) The case studies confirmed that the proposed lean design process is applicable to be used in the construction industry. (4) The performance measurement developed in this research can be utilised as a tool for performance indicator.

8.3. Recommendations and Improvements

This section recommends relevant research areas where the research value can be further enhanced. Several recommendations for future work to extend the parameters of design process development and performance measurement system were formed based on the issues and problems encountered throughout the progression of this research. The followings are the recommendations and improvement needed for this research:

- In-depth study of each of the stages in the proposed design process, to enhance the integration of lean thinking principles in every stage and activity.
- Further development of the project improvement framework based on specific segments of the construction industry. This will help align the fragmentation of the design and construction phases of projects.
- The selection of techniques and tools requires more comprehensive methods to ensure their effectiveness in specific contexts.
- Extensive studies are needed to explore the performance measurement system, to achieve complete project control of the whole building construction projects.

- The integration of lean thinking methods and proposed design process development should be extended to the construction phase, so that the whole project cycle can be covered and continuous improvement implemented.
- It is recommended that the proposed design process be tested over the whole life cycle of a construction project, rather than just the parts of it explored in this research. The proposed lean design process can be expected to create other benefits for the project.
- The performance measurement developed in this research can be refined through action research. In this manner, benchmarks for PP can be established and best practice for the process can be identified.
- The implementation of the proposed design process in this research requires the participation of industry. In this research, the researcher was considered to be an outsider by the architectural firm, and in such an environment, it proved to be difficult to motivate designers and engineers and other consultants. Communication between the designers and the other consultants and company leadership, with regard to proper implementation of the lean design process activities, are areas that also need to be explored.
- This research provides a platform for further development and refinement of lean design process so that the proposed lean design process can be calibrated accordingly based on the research context, allowing the objectives and aspirations of Egan (1998) to be recognised.

8.4. Limitations and Need for Further Research

This research focuses on the design process and performance measurement at the early stages of building construction projects, based in Brunei. The proposed design process does not consider construction projects in other countries. The fact that the implementation of the proposed design process is offered by an outsider to the architectural firm, creates some restrictions on the access to data required for research analysis. Therefore it proved to be difficult to convince the architectural firm to commit fully to the implementation procedure, and this may have possibly given a different emphasis with regard to the expected results.

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APPENDIX A RESEARCH THEMES AND CATEGORIES

No.	Category	Theme	Reference	Total
1	Application	Adaptation	(Yusof et al.2015) (Low & Show, 2008)	21
		Buildability/ Constructability	(Tiwari & Sarathy, 2012)	
		Concurrent	(M. a. Hossain & Chua, 2014)	
		Contract	(Darrington, 2011)	
		Decision Making	(Baba, 2013) (Parrish & Tommelein, 2009)	
		Framework	(Brady et al. 2013) (Raspall, 2015) (Blizzard & Klotz, 2012)	
		Integration	(H. W. Lee et al. 2010) (Codinhoto et al. 2008) (Alvarez, 2015)	
		Interface	(Li et al., 2008)	

			(Jørgensen & Emmitt, 2009) (Mossman et al. 2010)	
		Research	(Rocha et al. 2012)	
		Simulation	(Negendahl, 2015) (M. A. Hossain & Chua, 2009)	
		Waste	(Mossman, 2009a)	
		Model	(Sarker et al. 2012)	
2	Design Management	Briefing	(El.Reifi et al. 2013) (El.Reifi et al. 2014)	13
		Collaboration	(Jara et al. 2009)	
		Definition	(El. Reifi & Emmitt, 2013)	
		Integration	(Knotten et al. 2014) (Kestle et al. 2011)	
		Lean	(Emmitt, 2011)	
		Lean Techniques	(Deshpande et al.	

			2012)	
		Performance	(Martins & Cachadinha, 2013)	
		Sustainable Building	(Rekola et al. 2012)	
		Tool	(Venkatachalam et al. 2009) (Orihuela et al. 2011)	
		Tool		
		Waste and Elimination	(Munthe-kaas et al. 2015)	
3	Design Process	BIM (POE)	(Hua, 2015)	27
		Collaboration	(Oliva & Granja, 2013) (Kim & Lee, 2010)	
		Complexity	(Lima et al. 2011)	
		Computation	(Serag et al. 2008)	
		Coordination	(Riley & Horman, 2001)	
		Decision making	(Whelton et al. 2011)	

		DSM	(Tuholski & Tommelein, 2008)	
		Innovation	(Panuwatwanich & Stewart, 2012)	
		Lean Principles	(Ko & Chung, 2014a) (Ko & Chung, 2014b) (Jensenet al. 2009)	
		LPS	(Wesz et al. 2013)	
		Management of Waste	(Kpamma & Adjei-Kumi, 2011)	
		Model	(M. M. X. Lima & Ruschel, 2013)	
		Organisation	(Aquere et al. 2013)	
		Performance	(Haponava & Al-Jibouri, 2010) (Chalupnik et al. 2008)	
		Performance Measurement	(Kristensen et al. 2013)	
		Project loop	(Hua, 2015)	

		(POE)		
		Quality	(Koziołek & Derlukiewicz, 2012)	
		Rework	(Hickethier et al. 2012)	
		Set-Based	(Parrish et al. 2008)	
		Simulation	(Marvel & Standridge, 2009)	
		Tools and Techniques	(Lutters et al. 2014)	
		Uncertainty	(Chalupnik, Wynn, Eckert, & Clarkson, 2008)	
		Waste	(Furtmeier & Tommelein, 2010)	
4	People	Collaboration	(Lawlor-wright et al. 2008) (H. W. Lee et al., 2010)	8
		BIM	(Elmualim & Gilder, 2014)	

		Competencies	(Ahadzie et al. 2014)	
		Early Involvement	(Saleh et al. 2011) (Franz et al. 2013) (Sfandyarifard & Tzortzopoulos, 2011) (Caixeta et al. 2013)	
5	Information Flow	Information	(Cai, Peng, & You, 2009)	3
		Analysis	(Hickethier et al. 2013)	
		Design Quality	(Lockert & Berard, 2014)	
6	Measurement and Performance	Analysis	(Lee et al. 2012)	14
		Assessment	(Eastman et al. 2009)	
		Design process	(Marzouk et al. 2012)	
		Design Quality	(HARPUTLUGİL et al. 2014)	

		Design Problems	(Flageret al. 2014)	
		Information flow	(Tribelsky & Sacks, 2010)	
		Performance	(Söderholm & Johnsson, 2009)	
		Quality	(Ek & Çıkış, 2013)	
		Project Quality	(Dodoo et al.2010)	
		Measurement	(Flageret al. 2014)	
		Information flow	(Tribelsky & Sacks, 2010)	
		Performance	(Söderholm & Johnsson, 2009)	
		Quality	(Ek & Çıkış, 2013)	
		Early Involvement	(Caixeta et al. 2013)	
7	Technique and Tools	Design Techniques	(Mohamad et al. 2013)	6
		Implementation	(Hamzeh, 2009)	
		Tool	(Hamzeh, 2009)	
		Design Error	(Mryyian & Tzortzopoulos,	

			2013)	
		Innovation	(Murphy et al. 2008)	
		Maintainability	(Ismail & Mohamad, 2015)	

APPENDIX B DESCRIPTION AND RATIONALE OF SEMI-STRUCTURED QUESTIONS

Semi Structured Interview Schedule (2)

Full title of the project:

Research title:

Researcher's introduction:

The aim of this interview is to gain further understanding of the design process and the performance improvement for the design process in the design phase of construction projects. This interview particularly aimed at awareness of the architect on the design process and performance in improving the PP in the construction projects through the experience of the architects.

The participants are welcomed to make any points(s), as s/he thinks relevant, without limiting the questions stated here. You participation in this study is appreciated.

PART 1: Design practice and performance

SECTION I- Profile of the Participants and Organisation

Researcher to complete

Participant	Name of interviewee	
	Job title	
	Expertise/specialisation	
	Age category?	
	Education/ qualification background	
	How many years in the construction industry?	
	How many years in the current organisation?	
	Date of interview	
Organisation	**Name of organisation**	
	Nature of Business	
	Private /Public	
	Size of organization (employee)	
	No of year established	

Section II-Understanding of the Design Process.

a) Do you have formal visual representation of design process?

Yes No

b) Can you describe the design process that you/your oraganisation currently practice?

c) What elements are critical in design process? And which aspect of the design process do you think needs to be improved

d) Are you familiar with other design process but you did not consider practicing it? Please describe/list/name them.

e) Who else is involved in the design process?

f) Are you familiar with 'Lean Thinking' concept?

Section III – Awareness of performance improvement in design process

a) How satisfied are you with the performance of construction project (s) that you have recently been involved in? (in terms of delivering project on time, cost and quality standards)

b) How effective is your design process?

c) What element that makes it effective?

d) Does your current design process helps improve PP?

e) How do you improve your design process in order to improve the design performance?

f) What are the common causes of poor overall performance in the construction project based on your experience that build up from pre-construction phases?

Section IV - Element of performance improvement in design process

a) What is the contribution of design phase towards the construction phase?

b) Do you experience that design is the contributing factor to the overall project failure? List the issues.

c) List the elements of design activities that is essential to improve the design performance based on your current project.

d) List the elements of design activities that should be practice to improve the design performance based on your knowledge.

Section V – Performance improvement measurement.

a) What are the elements of performance improvement that should be included in order to measure the performance of design process?

b) State your agreement on the percentage of the performance grade presented below:

PART 2. The evaluation of the proposed design process model

Lean PD Activity	Question	Answer	Model Answer
0.1 Classify project	How was the project classified and when did this classification take place?		No formal classification
0.2 Explore client value	How was the voice of the client represented to the design team? How do you ensure/measure that the design meets customer expectations?		Hardware/software requirements documents; (the) design team designs according to the specifications; once the designed part is available it is measured against requirements
0.3 Align with company strategy	How was the project aligned with the company strategy? Was the project used to improve design process?		Strategy alignment is assured by architecture group which defines the design architecture; (the) project is not used to improve PD
0.4 Translate value to designers	How was the design concept communicated to designers?		By giving architectural representations of the system
0.5 Internal review			
1.1 Identify sub-design solution targets	Did subsystem participants identify lower-level system targets (e.g. reduce weight by x%)?		Not controlled
1.2 Decide on level of innovation to the sub-design solution	How did you control the amount of innovation that was designed into sub-assemblies/components?		Since this is just a sub-system component in itself, we usually have overall target (e.g. cost) and this is difficult to sub-divide due to interaction and impact between components
1.3 Define feasible regions of design scope	How did you ensure that designers/engineers designed within the constraints of manufacturing and other functions (without inhibiting innovation)?		We have design rules for all disciplines for manufacturing; we also keep manufacturing plant involved
1.4 Internal review			
2.1 Extract design concepts	Were previous projects, R&D projects, and other building design considered? How did you ensure that designers considered a range of options?		Yes, both previous projects and competitor products considered; there is no process to ensure that designer considered range of options
2.2 Create concept design for sub-design solution	How were the initial sub-design alternatives represented?		In the form of different block diagrams
2.3 Explore the	What methods did you use to test concept design		They are not tested until

Appendices

PART 3. Waste in design process and their elimination

Phase	Activity	Type of Waste														
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Stage 0 Define Value	0.1 Classify projects															
	0.2 Explore client value															
	0.3 Align project with company strategy															
	0.4 Translate value to designers															
	0.5 Internal review															
Stage 1 Map	1.1 Identify sub-design solution targets															
	1.2 Decide on level of innovation to sub-design solution															
	1.3 Define feasible regions of design scope															

Design Scope	1.4 Internal review															
Stage 2 Concept Design Development	2.1 Extract design concepts															
	2.2 Create concept design for sub-design solution															
	2.3 Explore the concept design for sub-design solution															
	2.4 Capture knowledge and evaluate															
	2.5 Communicate concept designs to others															
	2.6 Internal review															
Stage 3	3.1 Determine concept design intersections															
	3.2 Explore possible designs															

Concept Integration	3.3 Seek conceptual robustness															
	3.4 Evaluate concept design for lean construction															
	3.5 Begin process planning for construction															
	3.6 Integrate the final concept design of sub design solution															
	3.7 Internal review															
Stage 4 Detailed Design	4.1 Release final specification															
	4.2 Define construction tolerances															
	4.3 Full project definition															
	4.4 Internal review															
Total																

Key:

W1=Poor client briefing

W2=Inadequate pre-design project meetings

W3=Lack of project definition

W4=Design defects

W5=Inadequate technical knowledge

W6=Poor specification

W7=Design changes

W8=Insufficient and unrealistic constraints of project cost

W9= Insufficient and unrealistic constraints of project time

W10=Inadequate involvement of other professionals and teamwork during the design stage

W11= Lack of constructability review of design

W12=Poor communication among design team

W13=Making design decisions on cost and not value of work

W14=Poor level of commitment to quality improvement among design professionals

W15=Effect of design code and standards on quality

APPENDIX C WASTES IN DESIGN PROCESS AND THEIR ELIMINATION (RESULT)

Phase	Activity	Type of Waste														
		W1	**W2**	**W3**	**W4**	**W5**	**W6**	**W7**	**W8**	**W9**	**W10**	**W11**	**W12**	**W13**	**W14**	**W15**
Stage 0 Define Value	**0.1 Classify projects**	√		√												
	0.2 Explore client value	√		√										√		
	0.3 Align project with company strategy			√											√	
	0.4 Translate value to designers	√		√	√									√		
	0.5 Internal review		√					√			√		√		√	
Stage 1 Map Design Scope	**1.1 Identify sub-design solution targets**				√											
	1.2 Decide on level of innovation to sub-design solution				√											
	1.3 Define feasible regions of design scope				√				√	√						
	1.4 Internal review		√					√			√		√		√	
Stage 2 Concept Design Development	**2.1 Extract design concepts**							√							√	
	2.2 Create concept design for sub-design solution							√								
	2.3 Explore the concept design for sub-design solution							√			√					
	2.4 Capture knowledge and evaluate					√	√	√								
	2.5 Communicate concept designs to others		√				√	√								
	2.6 Internal review		√					√			√		√		√	

Stage 3 Concept Integration	**3.1 Determine concept design intersections**						√	√								
	3.2 Explore possible designs						√	√								
	3.3 Seek conceptual robustness											√				√
	3.4 Evaluate concept design for lean construction							√								
	3.5 Begin process planning for construction						√	√				√				
	3.6 Integrate the final concept design of sub design solution							√			√	√				
	3.7 Internal review		√					√			√		√		√	
Stage 4 Detailed Design	**4.1 Release final specification**						√	√								
	4.2 Define construction tolerances						√	√				√				
	4.3 Full project definition						√	√								
	4.4 Internal review		√					√			√		√		√	
Total		**3**	**6**	**4**	**4**	**1**	**8**	**18**	**1**	**1**	**7**	**4**	**5**	**2**	**7**	**1**

Key:

W1=Poor client briefing

W2=Inadequate pre-design project meetings

W3=Lack of project definition

W4=Design defects

W5=Inadequate technical knowledge

W6=Poor specification

W7=Design changes

W8=Insufficient and unrealistic constraints of project cost

W9= Insufficient and unrealistic constraints of project time

W10=Inadequate involvement of other professionals and teamwork during the design stage

W11= Lack of constructability review of design

W12=Poor communication among design team

W13=Making design decisions on cost and not value of work

W14=Poor level of commitment to quality improvement among design professionals

W15=Effect of design code and standards on quality

APPENDIX D QUESTIONNAIRE SAMPLE

Lean Design Process

I am delighted to invite you to participate in this questionnaire and support the research on the improvement performance for design process in construction projects. This research is undertaken as part of a PhD study at the University of Birmingham, UK, which I am currently undergoing,
The aim of the current research is to develop a design process framework in construction projects. The objective of the questionnaire is to get the awareness level of practitioners on the wastes(elements that might affect the performance of design) in design process project performance. If these wastes can be eliminated, it is believed that the project performance will be enhanced. The proposed framework developed is based on the RIBA, Plan of Work 2013 with consideration of lean thinking for the design process. The principles of 'set-based concurrent engineering' (SBCE) which originated from the Toyota Production System (TPS) is adopted in the design process.
The questionnaire is divided into four sections which will take you approximately 15 minutes to complete.
Participation in this research is entirely voluntarily and there is no penalty if you do not participate. There is no risk associated with filling in the questionnaire since the researcher guarantees anonymity of the answers as well as its participants.

Thank you very much
Best wishes
Ismawi Yusof
PhD Candidate
University of Birmingham, UK
School of Civil Engineering

Please refer to the proposed framework for question 10 and 11.

* Required

Section 1. Participant's Background

1. **Q1. The title of my current job position is** *

   ____

2. **Q2. I have been involved in the construction field for:** *
   Mark only one oval.

   - ◯ less than 2 years
   - ◯ 3-5 years
   - ◯ 6-9 years
   - ◯ more than 10 years

3. **Q3. My company's scope of operations** *
(please specify country of operation in 'other') you may choose more than one answer
Check all that apply.

- [ ] World wide
- [ ] Nation wide
- [ ] Specific region in the nation wide
- [ ] Other: ____________

4. **Q4. My company's size in terms of the number of employees** *
Mark only one oval.

- ◯ less than 20
- ◯ 21-50
- ◯ 51-100
- ◯ more than 101

5. **Q5. The main clients from my last project involved** *
Mark only one oval.

- ◯ Government
- ◯ Private
- ◯ Both
- ◯ Other: ____________

6. **Q6. The type of project from my last completed task was** *
Mark only one oval.

- ◯ housing/building
- ◯ civil engineering works
- ◯ industrial construction
- ◯ Other: ____________

Section 2. Waste in Design Process

7. **Q7. In your opinion, what are the causes of poor project performance?** *
List five only.

____
____
____
____
____

8. **Q8. What aspect(s) of the design process do you think needs to be improved in order to enhance project performance? List five only** *
(such as quality, cost and time)

....

....

....

....

....

9. **Q9.Please rate how strongly you agree or disagree on the list of waste factors below based on your knowledge and experience .** *
The following are the list of waste factors that affect design performance. These factors are considered as waste in design process.
Mark only one oval per row.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
W1. Poor Client Briefing	⬭	⬭	⬭	⬭	⬭
W2. Inadequate Pre-design Project Meetings	⬭	⬭	⬭	⬭	⬭
W3. Lack of Project Definition	⬭	⬭	⬭	⬭	⬭
W4. Design Defects	⬭	⬭	⬭	⬭	⬭
W5. Inadequate Technical Knowledge	⬭	⬭	⬭	⬭	⬭
W6. Poor Specification	⬭	⬭	⬭	⬭	⬭
W7. Design Changes	⬭	⬭	⬭	⬭	⬭
W8. Insufficient and Unrealistic Constraints of Project Cost	⬭	⬭	⬭	⬭	⬭
W9. Insufficient and Unrealistic Constraints of Project Time	⬭	⬭	⬭	⬭	⬭
W10. Inadequate Involvement of Other Professionals and Teamwork During the Design Stage	⬭	⬭	⬭	⬭	⬭
W11. Lack of Constructability Review of Design	⬭	⬭	⬭	⬭	⬭
W12. Poor Communication Among design Team	⬭	⬭	⬭	⬭	⬭
W13. Decisions on Cost Rather than on Value of Work	⬭	⬭	⬭	⬭	⬭
W14. Poor level of commitment to quality improvement among design professionals	⬭	⬭	⬭	⬭	⬭
W15. Effect of Design Code and Standards on Project Performance	⬭	⬭	⬭	⬭	⬭

10. **Please state other waste factors not included in the list which you consider as a waste in the design process.**

....

....

....

....

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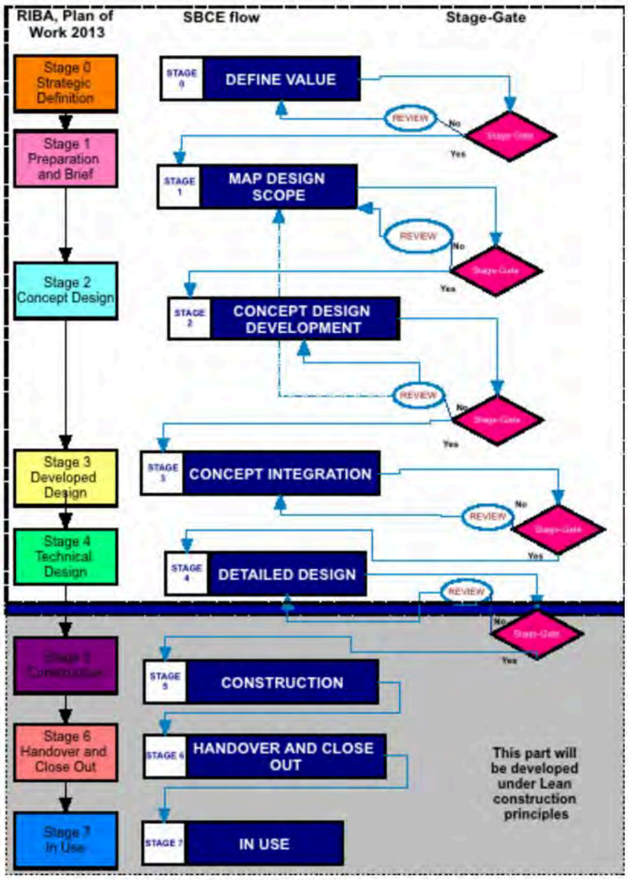
Proposed Framework



Section 3. Design Process

The following are the list of design elements that should be included in the design process. The design element will be able to eliminate the waste factors in section 2 and improve design performance.Please refer to the proposed framework for better understanding of the design process. This framework will eliminate wastes that is listed in question 9 above.

11. **Q10. Please rate how strongly you agree or disagree on the ability of design element to eliminate waste factors in design.**
Mark only one oval.

( )

12. **Stage 0: Define Value** *
Mark only one oval per row.

	Strongly Disagree	Disagree	Neutral	Agree	Strongly agree
Stg 0.1 Classify project eliminates poor client briefing and lack of project definition	( )	( )	( )	( )	( )
Stg 0.2 Explore client value eliminates Poor Client Briefing, Lack of project definition and Making design decisions on cost and not value of work	( )	( )	( )	( )	( )
Stg 0.3 Align with company strategy eliminates Lack of project definition and Poor level of commitment to quality improvement among design professionals	( )	( )	( )	( )	( )
Stg 0.4 Translate value to designers eliminates Poor Client Briefing, Lack of project definition, Design defects and Making design decisions on cost and not value of work	( )	( )	( )	( )	( )

13. **Stage 1: Map Design Scope** *
Mark only one oval per row.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Stg 1.1 Identify sub design solution targets eliminates design defects	( )	( )	( )	( )	( )
Stg 1.2 Decide on level of innovation to sub-design solution eliminates design defects	( )	( )	( )	( )	( )
Stg 1.3 Define feasible regions of design scope eliminates design defects,insufficient and unrealistic constraints of project cost, Insufficient and unrealistic constraints of project time, Lack of constructability review of design and making design decisions on cost and not value of work	( )	( )	( )	( )	( )

14. **Stage 2: Concept Design Development** *
Mark only one oval per row.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Stg 2.1 Extract design concepts eliminates design changes and poor level of commitment to quality improvement among design professionals	⬭	⬭	⬭	⬭	⬭
Stg 2.2 Create concept designs for sub design solution eliminates design changes	⬭	⬭	⬭	⬭	⬭
Stg 2.3 Explore the concepts for sub design solution eliminates design changes and Inadequate technical knowledge	⬭	⬭	⬭	⬭	⬭
Stg 2.4 Capture knowledge and evaluate eliminates inadequate technical knowledge, poor specification and design changes	⬭	⬭	⬭	⬭	⬭
Stg 2.5 Communicate concept designs to others eliminates inadequate pre-design project meetings, poor specification and design changes	⬭	⬭	⬭	⬭	⬭

15. **Stage 3: Concept Integration** *

Mark only one oval per row.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Stg 3.1 Determine concept design intersections eliminates design changes and poor specification	⬭	⬭	⬭	⬭	⬭
Sgt 3.2 Explore building's concept design eliminates design changes and poor specification	⬭	⬭	⬭	⬭	⬭
Sgt 3.3 Seek conceptual robustness eliminates lack of constructibility review of design and effect of design code and standards on quality	⬭	⬭	⬭	⬭	⬭
Stg 3.4 Evaluate concept design for lean construction eliminates design changes	⬭	⬭	⬭	⬭	⬭
Stg 3.5 Begin process planning for construction eliminates poor specification, design changes and lack of constructibility review of design	⬭	⬭	⬭	⬭	⬭
Stg 3.6 Integrate the final concept design of sub design solution eliminates design changes, inadequate involvement of other professionals, teamwork during the design stage, lack of constructibility review of design and poor communication among design team	⬭	⬭	⬭	⬭	⬭

16. **Stage 4: Detailed Design** *

Mark only one oval per row.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Stg 4.1 Release final specification eliminates design changes and poor specification	⬭	⬭	⬭	⬭	⬭
Stg 4.2 Define construction tolerances eliminates design changes, poor specification and lack of constructability review of design	⬭	⬭	⬭	⬭	⬭
Stg 4.3 Full building system definition eliminates design changes and poor specification	⬭	⬭	⬭	⬭	⬭

17. **All Stages: Internal Reviews** *

In every design stage (please refer to the proposed framework)

Mark only one oval per row.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
Internal Review eliminates design changes, inadequate pre-design project meetings, inadequate involvement of other professionals and teamwork during the design stage, poor communication among design team and poor level of commitment to quality improvement among design professionals	⬭	⬭	⬭	⬭	⬭

Section 4. The Proposed Framework

The following are the statements pertaining to the proposed framework. Please refer to the proposed framework for better understanding of the design process.

18. **Q11. Please rate how strongly you agree or disagree on the statements below.** *

Mark only one oval per row.

	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
S1. Framework meets expectation (eg. Eliminate waste in design process)	⬭	⬭	⬭	⬭	⬭
S2. Framework is informative	⬭	⬭	⬭	⬭	⬭
S2. Framework is informative	⬭	⬭	⬭	⬭	⬭
S4. Framework is easy to understand	⬭	⬭	⬭	⬭	⬭
S5. Framework is consistent with other design processes (eg. RIBA)	⬭	⬭	⬭	⬭	⬭
S6. Framework is compatible with current design practices	⬭	⬭	⬭	⬭	⬭
S7. Framework has the potential to be employed	⬭	⬭	⬭	⬭	⬭
S8. Framework is feasible	⬭	⬭	⬭	⬭	⬭
S9. Framework is recommended	⬭	⬭	⬭	⬭	⬭
S10. Participant's willingness to participate in further development of the framework	⬭	⬭	⬭	⬭	⬭

19. **Please provide any comments in this study and suggestions in the development of design process framework.**

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APPENDIX E TARGET AND CONTRIBUTION OF WEIGHTAGE OF KPIS

	KPIs	Unit	Description	Target	Weight (%)
Quality	Client	No.	Number of meeting with client per month	1	3
	Admin	day	Time taken to response to the queries	5	2
	Project	%	Meeting the project goals	60	6
	Resources	%	Increase in design progress from previous one	20	3
	Information	No.	Number of meeting with stakeholders per month	1	12
Cost	Schedule	%	Delays	10	4.26
	Budget	%	Over budget	10	10.09
	Quality	%	Design changes	15	8.63
	Safety	No.	Number of safety elements included in the design	2	1.56
	Environment	No.	Number of constructability innovations	2	0.69
	Management	No.	Number of design iteration	5	3.75
Time	Project Management related work	%	Delays in design progress	10	4.83
	Estimating related work	%	Delays in documents delivery	10	0.96
	Design related work	No.	Number of iterations	5	4.7
	Owner's project financing	Days	Advance project fund	15	14.51
Sustainability	Leadership	No.	Number of meeting with subordinates per month	2	1.68
	Benchmarking	No.	Number of design review on sustainability of	2	0.97

			project at each stage		
	Practice Performance	**No.**	**Number of review on methodologies at each stage**	**2**	**3.20**
	Utilisation of existing resources	**No.**	**Number of review on the utilisation of resources at each stage**	**2**	**0.96**
	Staff development	**No.**	**Number of training for staff per year**	**2**	**3.38**
	Collaboration	**No.**	**Number of discussion on design**	**2**	**4.95**
	Utilisation of tools	**No.**	**Number of tools used in design**	**3**	**0.8**
	Knowledge management	**No.**	**Number of new knowledge recorded**	**3**	**0.82**
	Monitoring Schedule	**No.**	**Number of review on design process at each stage**	**2**	**8.25**

APPENDIX F DESCRIPTION, TARGET, WEIGHTAGE AND FORMULAE FOR KPIS

	KPIs	Unit	Description	Target	Weight (%)	Calculation for KPIs
Quality	**Client**	**No.**	**Number of meeting with client per month**	**1**	**3**	Higher the better $100\% + \left[\frac{Actual - Target}{Target}\right] \times 100\%$
	Admin	**day**	**Time taken to response to the queries**	**5**	**2**	Lower the better $100\% + \left[\frac{Target - Actual}{Target}\right] \times 100\%$
	Project	**%**	**Meeting the project goals**	**60**	**6**	Higher the better $100\% + \left[\frac{Actual - Target}{Target}\right] \times 100\%$
	Resources	**%**	**Increase in design progress from previous one**	**20**	**3**	Higher the better $100\% + \left[\frac{Actual - Target}{Target}\right] \times 100\%$
	Information	**No.**	**Number of meeting with stakeholders per month**	**1**	**12**	Higher the better $100\% + \left[\frac{Actual - Target}{Target}\right] \times 100\%$
[redacted]						

Cost	**Schedule**	**%**	**Delays**	**10**	**4.26**	Lower the better $100\% + \left[\frac{Target - Actual}{Target}\right] \times 100\%$
	Budget	**%**	**Over budget**	**10**	**10.09**	Lower the better $100\% + \left[\frac{Target - Actual}{Target}\right] \times 100\%$
	Quality	**%**	**Design changes**	**15**	**8.63**	Lower the better $100\% + \left[\frac{Target - Actual}{Target}\right] \times 100\%$
	Safety	**No.**	**Number of safety elements included in the design**	**2**	**1.56**	Higher the better $100\% + \left[\frac{Actual - Target}{Target}\right] \times 100\%$
	Environment	**No.**	**Number of constructability innovations**	**2**	**0.69**	Higher the better $100\% + \left[\frac{Actual - Target}{Target}\right] \times 100\%$
	Management	**No.**	**Number of design iteration**	**5**	**3.75**	Lower the better $100\% + \left[\frac{Target - Actual}{Target}\right] \times 100\%$

Time	**Project Management related work**	**%**	**Delays in design progress**	**10**	**4.83**	Lower the better $$100\% + \left[\frac{Target - Actual}{Target}\right] \times 100\%$$
	Estimating related work	**%**	**Delays in documents delivery**	**10**	**0.96**	Lower the better $$100\% + \left[\frac{Target - Actual}{Target}\right] \times 100\%$$
	Design related work	**No.**	**Number of iterations**	**5**	**4.7**	Lower the better $$100\% + \left[\frac{Target - Actual}{Target}\right] \times 100\%$$
	Owner's project financing	**Days**	**Advance project fund**	**15**	**14.51**	Lower the better $$100\% + \left[\frac{Target - Actual}{Target}\right] \times 100\%$$
[redacted]						
Sustainability	**Leadership**	**No.**	**Number of meeting with subordinates per month**	**2**	**1.68**	Higher the better $$100\% + \left[\frac{Actual - Target}{Target}\right] \times 100\%$$
	Benchmarking	**No.**	**Number of design review on sustainability of project at each stage**	**2**	**0.97**	Higher the better $$100\% + \left[\frac{Actual - Target}{Target}\right] \times 100\%$$

	Practice Performance	**No.**	**Number of review on methodologies at each stage**	**2**	**3.20**	Higher the better $\mathbf{100\%} + \left[\frac{\boldsymbol{Actual - Target}}{\boldsymbol{Target}}\right] \times \mathbf{100\%}$
	Utilisation of existing resources	**No.**	**Number of review on the utilisation of resources at each stage**	**2**	**0.96**	Higher the better $\mathbf{100\%} + \left[\frac{\boldsymbol{Actual - Target}}{\boldsymbol{Target}}\right] \times \mathbf{100\%}$
	Staff development	**No.**	**Number of training for staff per year**	**2**	**3.38**	Higher the better $\mathbf{100\%} + \left[\frac{\boldsymbol{Actual - Target}}{\boldsymbol{Target}}\right] \times \mathbf{100\%}$
	Collaboration	**No.**	**Number of discussion on design**	**2**	**4.95**	Higher the better $\mathbf{100\%} + \left[\frac{\boldsymbol{Actual - Target}}{\boldsymbol{Target}}\right] \times \mathbf{100\%}$
	Utilisation of tools	**No.**	**Number of tools used in design**	**3**	**0.8**	Higher the better $\mathbf{100\%} + \left[\frac{\boldsymbol{Actual - Target}}{\boldsymbol{Target}}\right] \times \mathbf{100\%}$
	Knowledge management	**No.**	**Number of new knowledge recorded**	**3**	**0.82**	Higher the better $\mathbf{100\%} + \left[\frac{\boldsymbol{Actual - Target}}{\boldsymbol{Target}}\right] \times \mathbf{100\%}$

	Monitoring Schedule	**No.**	**Number of review on design process at each stage**	**2**	**8.25**	Higher the better $\mathbf{100}\% + \left[\frac{\boldsymbol{Actual - Target}}{\boldsymbol{Target}}\right] \times \mathbf{100}\%$

APPENDIX G PERFORMANCE MATRIX (COMPLETE EVALUATION)

			RESULT	Quality (0.25)					ost (0.25)						Time (0.25)				Sustainability (0.25)									
Stage	Process	Code	Activities	Client	Administration	Project	Resources	Information	Schedule	Budget	Quality	Safety	Environment	Management	PM	Estimating	Design	Financing	Leadership	Benchmarking	Performance	Existing Resources	Staff Development	Collaboration	Tools	Knowledge Management	Schedule	
			Weightage	0.03	0.02	0.06	0.03	0.11	0.03	0.09	0.08	0.01	0.01	0.03	0.05	0.01	0.04	0.15	0.02	0.01	0.02	0.01	0.03	0.05	0.01	0.01	0.09	100
		0-1	Classify project	3	0	5	0	0	0	0	0	0	0.5	0	0	1.5	0	20	0	0	0	0.5	0	0	0	0	0	30.5
		0-2	Explore client value	3	0	6.5	0	22	0	4.5	9.6	0	0	0	5	1	7.2	0	0	1	2	0	0	5	0	0	0	66.8
0	Define Value	0-3	Align with company strategy	3	0	6.5	0.75	22	3	9	0	0	1	3.6	4	0.5	4	20	4	1.5	5	1	0	2.5	0	0	4.5	95.9
		0-4	Translate value to designers	4.5	0	1.2	0.9	22	0	9	13.3	0	1.5	0	0	0	0	25	2	1	0	1.5	4.5	0	1.33	0	9	96.8
		0-5	Internal review																									
		1-1	Identify sub-design solution targets	4.5	-2	0.4	0	22	0	-4.5	13.3	0	1.5	3.6	0	0.5	0	0	2	1	2	0	4.5	7.5	1	0.67	0	58
1	Map Design Scope	1-2	Decide on level of innovation to the sub-design solution	0	0	6.5	0.75	22	0	0	8	1	1	3	5	0.4	2.4	18	2	0	2	1	4.5	7.5	1	1	0	87.1
		1-3	Define feasible regions of design scope	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0.67	1	0	6.67
		1-4	Internal review																									
		2-1	Extract design concepts	0	0	3	1.2	44	-0.6	-4.5	0	1	0	0	0	-0.2	-1.6	0	0	0	0	1	1.5	7.5	1.33	0.67	9	63.3
		2-2	Create concept design for sub-design solution	0	0	0	0	22	0	0	0	0	0	0	0	0	-4	0	0	0	0	0	0	0	0.67	1	0	19.7
2	Concept Design Development	2-3	Explore the concept design for sub-design solution	0	0	6	3	0	0	0	6.4	0	0	0	0	0	-4	0	0	0	0	0	0	0	1	0.67	0	13.1
		2-4	Capture knowledge and evaluate	0	0	0	0	33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	34
		2-5	Communicate concept designs to others:	3	0	6	2.25	33	-1.5	-5.4	5.33	0	0	0	0	0	0	15	0	0	0	0.5	0	5	0	0.67	0	63.9
		2-6	Internal review																									
		3-1	Determine concept design intersections	3	0	2	3	22	0	9	8	1	0	0	0	0	4	15	0	1.5	3	1	0	10	1.33	0	0	83.8
		3-2	Explore possible designs	0	0	6.5	3	22	0	0	6.4	0.5	0	0	0	0	4	14	0	0	0	0.5	0	2.5	0	0.33	0	59.7
		3-3	Seek conceptual robustness	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	Concept Integration	3-4	Evaluate concept design for lean construction	3	0	6.5	3.75	11	3	0	0	0	0	3	-2.5	0	0	0	2	0	0	0	0	5	0.67	0	0	35.4
		3-5	Begin process planning for construction	4.5	0	6	3.75	44	3	0	0	1	0	1.8	5	-0.5	0	15	2	0	2	1.5	4.5	7.5	1	0	9	111
		3-6	Integrate the final concept design of sub design solution	4.5	0	6	0	0	0	0	7.47	1	0	0	0	0	1.6	0	0	0	0	0.5	0	7.5	1.33	0	0	29.9
		3-7	Internal review																									
		4-1	Release final specification	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	Detailed Design	4-2	Define construction tolerances	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		4-3	Full project definition	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		4-4	Internal review																									

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