INTEGRATION OF LEAN CONSTRUCTION CONSIDERATIONS INTO DESIGN PROCESS OF CONSTRUCTION PROJECTS

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The design phase in the life cycle of a construction project contributes significantly to the performance of a project. The poor outcomes from the design phase in the construction project development process are considered as the major contributors to project delay, poor performance, and budget overrun. All of these affect the overall project performance. It is the aim of this study to innovate a design process model to improve the performance of design process where conventional design processes would not be effectively or efficiently applied. The adaptation of lean principles with the identification of wastes in design process and identification of enablers in design process are evaluated. The innovative design process model presented in this paper is developed based on the core enabler that can be used to eliminate the identified waste. There are 15 wastes identified and the set-based concurrent engineering (SBCE) is considered in the core enabler of the design process model.

Keywords: design process, enablers, lean consideration, project life cycle.

INTRODUCTION

The design phase in the construction project life cycle is considered as a significant contributor to the project performance. Many researchers have considered this phenomenon as being dependent on the project success which comprises of quality, cost, time and sustainability. Nowadays, most of the construction projects must be delivered through the fast track, therefore it is difficult to co-ordinate between the specialists and personnel as there is no accepted platform of good practice in managing the design process (Bibby, 2003). Although some technologies have been developed and applied in construction projects, the performance of the construction industry is still considered low (Sacks and Goldin, 2007). Aziz and Hafez (2013) argue that the current technologies can only improve the management of the construction process, but, however, in improving quality of the projects effectively, it does not reduce cost and time of design and construction. This is referred to as the traditional method that is still in place and currently being practiced in the industry.

The objective of this study is to develop the innovative design process in building construction projects where 'lean thinking (LT)' is being considered for design process improvements. The proposed design process model integrates LT into the traditional design process with activities which are able to eliminate wastes in the design process. The model is based on the set-based concurrent engineering (SBCE) concept that has been identified in the literature review of this study.

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METHODOLOGY

A comprehensive literature review has been carried out to establish the definition of wastes in the design process for building designs, which forms a part of the LT principle where wastes are required to be eliminated in a process. As such, identification of waste is established. After establishments of the definition and identification of wastes, the lean enablers have been studied and identified, which the available tools and methods of lean implementation are considered. Evaluation of the core enablers is the main focus in this study as these core enablers are used to drive the process and to support the innovation of the design process. Subsequently, a design process framework model which adopts LT is proposed which includes waste identification, lean enablers, waste elimination and recommended design process activities.

LITERATURE REVIEW

Design Process

The construction process can be usually divided into three phases, i.e., project conception, project design, and project construction (Chan and Kumaraswamy, 1997). This can be described as a linear project delivery as modelled by Emmitt (2002). Project conception which involves clients and designers is identified as the inception phase where feasibility of the ideas and intention are being analysed. The project design involves two phases of project conception and design where designers and detailers work together to produce a concept design and convert it to a detailed design. Subsequently, the project construction is identified in the third phase as assembly where builders materialise the client's requirements. This construction process is also referred to as the design and production process which have been practiced in different countries such as USA, the UK, Australia and Canada. Lam *et al* (2012) elaborate the design process as being a process where an architect often prepares study drawings, documents, or other media that illustrate the concept of design for client’s review during the schematic design.

The guideline set above was made easily to follow and understand. However, in reality and on its practical point of view, it is very complicated as referred by Freire and Alarcón (2000) who state that the architectural design process itself possesses complicated management problems. They explained that the problems in design involve thousands of decisions which may take over a period of years to be resolved. However, all of the guidelines for the process above are still valid and practiced regardless of the problems encountered by the practitioners.

Although the construction process have been established in these countries, there is a lack in details on how these phases should be carried out (Orihuela *et al*., 2011). It has been suggested by the institutions that this is only a guideline for the practitioners, but it still however lacks details in activities which need to take place. Therefore, it is necessary to develop a design process framework in which shows details of activities that need to be considered. At the same time, such a design process framework is required to eliminate wastes and enhance building project performance.

Waste in Design Process

The design factors that affects quality of building projects studied by Oyedele *et al*. (2001), do not create value. This is related to the definition made by (Huovila *et al*., 1997; Koskela, 1997; Mossman, 2009), which states those factors that do not

contribute to the task completion and value generation can be considered as waste. Subsequently Koskela *et al* (2013) state that there are different definitions and perspectives when addressing the wastes in design such as iterations which can be a waste to the client but generates value to the project design, latency will lead to delay in a project but will provide time for solution development in design, and reciprocal interdependencies which can be a waste in the process but not in design that relies on the maturity of the design solution. The differences in waste perspectives that lead to the logic seven sources of wastes from the production perspectives as stated by Ohno (1978), may not be directly applied. Instead, it should act as a guideline to understand the waste in the design process.

It would be worthwhile to understand the knowledge gained by manufacturing industries in order to understand the meaning of waste beyond the surplus of materials. Taiichi Ohno's book (Ohno, 1988) lists seven wastes that can be identified in the production of cars. Such wastes are then cited in Koskela *et al*. (2013) which include overproduction, time on hand, transportation, processing itself, stock on hand, movement, and making defective products (listed in that order). The perspective of waste describes that waste can be divided into two categories, i.e., process and operation. Process is the conversion of input such as raw materials into the desired product while operation can be described as an activity that performs the conversion. Based on the identified wastes and definition of waste in manufacturing industry, they can be understood as the seven wastes that can be categorized in one of the two categories (Koskela *et al*., 2013). Waste as cited by Ohno (1988) is applicable to other industries such as service, health care, construction industry etc. However some of evidences suggest that several wastes in Ohno's list can be omitted as they are either not applicable or have little contribution in certain industries (Abila, 2010; Bicheno and Holweg, 2009). It is clear that the factors affecting the design performance does not contribute towards the tasks completion and value generation. Therefore, in this study, it is decided to consider factors that affect the quality of building projects in the design phase are in actual fact, and to identify the wastes in design process of construction projects.

Waste in construction projects can be defined as minimizing what is unnecessary for task completion and value generation (Koskela and Huovila, 1997). Similarly, Formoso *et al* (2002) consider the waste as the loss of any resources including materials, time and capital, which can be generated by activities either direct or indirectly caused and that do not add value to the final product for the client. Whereas, Pinch (2005) identified seven types of waste in construction projects: (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 is mostly relevant to the activities during the construction phase, but not at the planning and design phases. It is the intention of this study to elaborate on the waste that is related to the design activities. It is believed that the factors that affect the performance of the project have contributed to the waste within the design process (Alarcon and Ashley, 1996). According to Oyedele (2001), there are limitations in terms of literature with regard to the design factors that affects the quality of construction projects. If so, then it is a waste to the construction project to have these factors within the design activities. These factors are believed to be non-adding value to the client as well as the project itself. Most of the wastes in design can be associated with the contributing factors of low performance of the construction project. There is

no consensus and general agreement as to the set and categories of waste in the design process. On the basis of existing literatures, fifteen wastes in the design process of the construction projects can be identified as shown in Table 1, which can be eliminated by using the proposed design process. These identified wastes are the outcomes of the literature review carried out by the researchers where key words have been used to filter the research papers.

Table 1: An example of setting out a table with column headings

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

Lean Enabler

Lean enablers act to create value and eliminate wastes in the architectural design process. Subsequently, the method of identifying the lean enablers is based on the review of literatures purposely chosen from the International Group for Lean Construction (IGLC). The reason is because this organisation actively conducts conferences related to the development of new principles and methods for design and construction management, which is exclusive to the construction industry with reference to the lean principles that are developed in manufacturing industries (Etges *et al*., 2012).

On the basis of the collection of research papers presented in the IGLC's publications, there have been 85 research papers published which are relevant to the design process. However, 40 papers are concerned design processes referred to different design processes of structural, mechanical, and infrastructure engineering which are not of an architectural design in nature. 45 papers which are relevant to building projects with a focus on architectural design phase are being considered. There are six approaches that appeared in this review which are Concurrent Engineering, Target Value, Simulation, Collaboration, Coordination and Set-Based. Apart from these,

The lean enablers in other industries such as car manufacturing, electronics production, domestic appliances, and car accessories have been explored in this study. This research adopts the enablers studied by Khan (2012) for comparison and to find

enablers in construction project design. Khan (2012) states that the 'changeless core' was initially found as a main factor in the product development success of Toyota Motor Co. The cores of, such as value, knowledge, and improvement, are believed to be the foundation of product development that is later known as SBCE (Khan *et al*., 2011). Some of researchers state that SBCE is considered as the main enabler for lean production development (Ward, 2007). This enabler is a system of the design process which comprises other enablers and is supported by other enablers (Sobek *et al*., 1999). Therefore, in this research, the principle of SBCE is used to develop a construction design process framework so that it can be aligned with the conventional design process in building construction processes.

A Review of Set-based Concurrent Engineering

In the manufacturing industry, there are sufficient evidences for the use of scientific product development approaches (Ward *et al*. 1995). The study on the use of 'set-based design' in the Toyota production development provides the procedures on how the Toyota designers produce sets of design alternatives and gradually narrow the set until they come to a final solution. However, in some perspectives, this system of product development process is an inefficient system. Apparently Ward *et al* (1995) does not present a detailed process or methodology for the system, which just states the three central elements that the Toyota focuses on, namely: value, knowledge (or learning) and improvement. With this phenomena, researchers turn to study the system in detail. According to Khan *et al* (2011), the elements presented above enabled Toyota to achieve customer needs through the optimal designs, minimise design rework, and achieve high profit levels and named the process as SBCE.

In the construction industry, SBCE approaches have been applied to the construction phase such as site layout, construction engineering, engineering design and construction technology. There is limited literature that addresses the adaptation of SBCE in the construction project design process. Therefore, some of the procedures cannot be adopted entirely into the construction project design process. Nonetheless, the lesson learned can be considered as guidance where communication is very important in order to evaluate the set of design effectively.

A comparison between the traditional design method and the proposed design method in the process of design is conducted in this study. The traditional method can be called as point-based method, while the proposed method can be called as set-based method. Point-based method evolves the development of one problem solution which is further developed into the conceptual design as early as possible. This causes the iteration of design due to the knowledge gained throughout the process. Furthermore, this may also cause costly rework and some resources may not be available at the rework stage. The set-based method of SBCE provides various sets of design and the selection of the design is delayed as the design set is gradually narrowed based on the knowledge available to support decision making, and finally, the final design is then committed which will reduce or eliminate the re-work. The advantage of using set-based method is that the waste in the design process is eliminated by every activity embedded in the design phases. Therefore, by eliminating waste the value can be maximized.

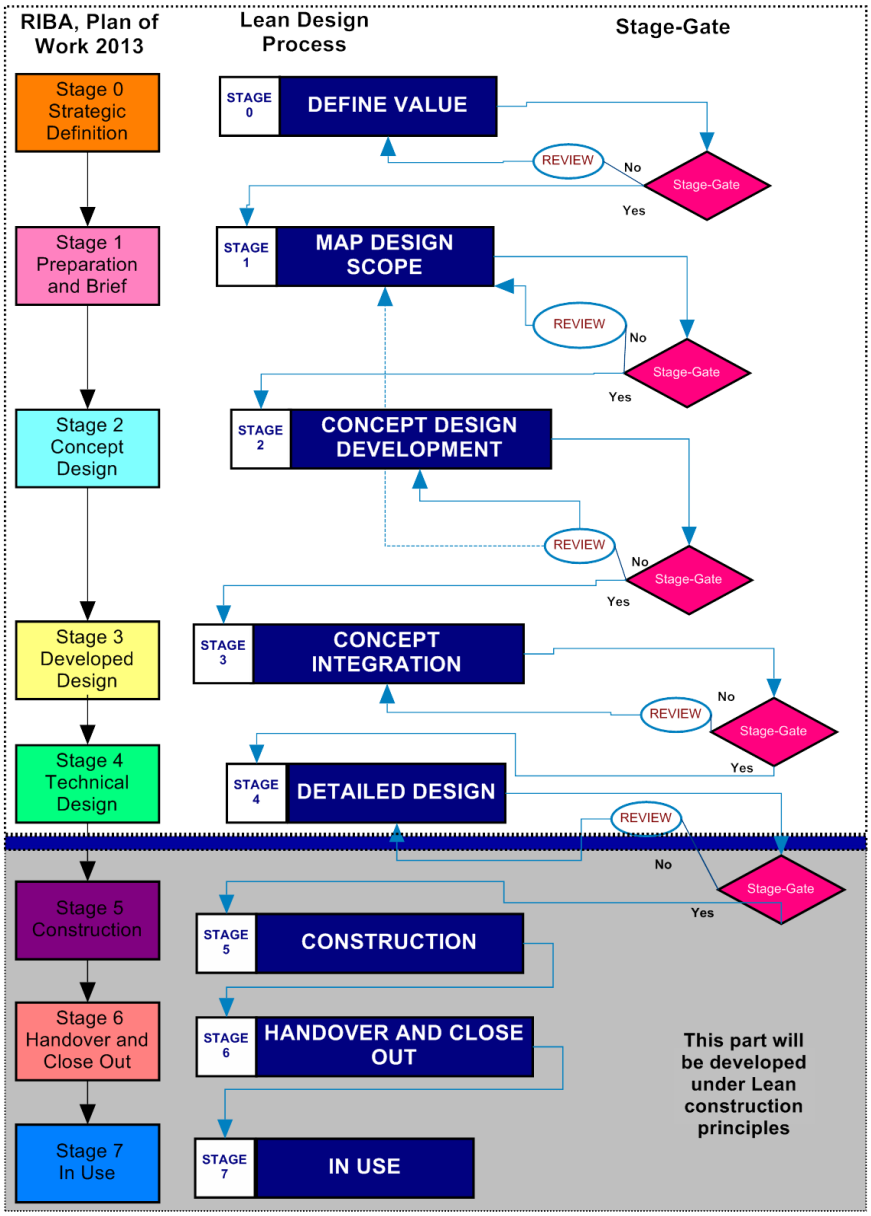

Figure 1: Design flow with embodied 'Lean Principles'

CONCEPTUAL DESIGN PROCESS MODEL

The design process improvement is initiated by implementing lean design based on the SBCE concept. The followings are the descriptions of each stage and activities with the elaborations of method to accomplish them. The stages in this model as shown in Figure 1 are aligned with the project stages presented by RIBA, Plan of Work 2013.

Stage 0: Define Value - the initial concept definition is developed based on strategic goals, client requirements, and any other factors that need to be considered.
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 the case that it impacts subsequent engineering activities. This is relevant in the context of sustainability development, when a refurbishment or

extension, or indeed a rationalised space plan, may be more appropriate than a new project.

0-2 Explore client value: Client 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.

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.

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.

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 available to all the parties involved in the design and any confidentiality should be treated accordingly.

Stage 1: Map Design Scope - designers define the scope of the design work required as well as feasible design options/regions.
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.

1-2 Decide on level of innovation to 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.

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

1-4 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 available to all the parties involved in the design and any confidentiality should be treated accordingly.

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

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 for a particular sub-project may be only 2 options, while a component that is not being changed would not require a set; Alternatives within a set may comprise of differences in fundamental concepts, components, arrangements, properties or geometry.

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

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

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.

2-6 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 available to all the parties involved in the design and any confidentiality should be treated accordingly.

Stage 3: Integrate Concept - sub-design intersections are explored and integrated designs are tested; based on the knowledge produced in this phase the weak design alternatives will be removed allowing a final optimum product design solution to progress into Stage 4.
3-1 Determine concept design intersections: sub design solution that progress into phase 5 can be considered for project integration. The intersection of feasible sets will be reviewed, considering compatibility and interdependencies between sub design solution and components.

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

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

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

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.

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 finalized.

3-7 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 available to all the parties involved in the design and any confidentiality should be treated accordingly.

The lean design model provides a process for conceptual design up until design freeze and the initiation of detailed design. There are some activities that have however been included as recommendations for detailed design that will be described briefly below.

Stage 4: Produce Detailed Design- the final specification is released, Architects, Engineers and Consultants provide tolerances and the process continues with detailed design activities.
4-1 Release final specification: The final specifications will be released once the final project concept is concluded; this is important because by communicating that the

specification will be released after all of the activities in phases 1 to 4, it will be more likely that the specification and commitment will be delayed.

4-2 Define construction tolerances: Construction will negotiate part tolerances with design teams; this is another aspect of delaying commitment in design.

4-3 Full project definition: Further detailed design work will follow; it is assumed that companies may continue with their detailed design processes for assurance and qualification of design solutions which is normally industry and product-specific.

4-4 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 available to all the parties involved in the design and any confidentiality should be treated accordingly.

CONCLUSIONS AND RECOMMENDATIONS

The design process framework presented in this paper provides an overview of implementation of LT in the design process of construction projects. The dominance tool of set-based concurrent engineering has been developed and acts as an enabler to adopt LT as well as lean construction. The framework focuses on the performance improvement in the design process in order to eliminate waste in the project design process. The proposed design framework by adopting LT will be able to achieve optimal designs, minimize design rework, and ease constructability. The presented design framework also addresses the challenges identified such as rework, sub-optimal design, knowledge crisis, lack of innovation, and high unit costs. The stages defined in the proposed model can be embodied into state-of-the-art design development of civil works while maintaining the traditional design process with the implementation of LT. Further research work will be conducted by case study to validate the framework in order to get an empirical result of the study.

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