APPLICATION OF LEAN PRINCIPLES TO DESIGN PROCESSES IN CONSTRUCTION CONSULTANCY FIRMS

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ABSTRACT

Simulation modelling and Lean principles have both been applied in the construction industry to improve work processes. The outcomes from their implementation are outstanding and have motivated construction researchers to seek means by which other aspects of construction production could benefit from this development. Therefore the aim of this research is to use computer simulation as a tool for assessing the impact of applying Lean principles to design processes in construction consultancy firms to aid in decision making at early stages of construction projects. A comprehensive model for the design process was built before the principles of Lean construction were depicted in the model. Through a detailed case study, it was concluded that applying Lean construction principles to the design process significantly helped to improve process efficiency, in terms of reduced process durations and increased resource utilisation.

KEYWORDS: Lean principles, construction consultancy firms, design phase, computer simulation.

INTRODUCTION

The results and benefits of applying Lean production principles have been proven worthy whenever implied correctly. Consequently, it has always been a goal for other fields to modify the tools and techniques of Lean production to be able to start applying Lean principles in other fields. In the early 1990s, the term ‘Lean Construction’ appeared. It was an effort of researchers trying to introduce Lean production principles to the construction industry. Generally speaking two main hurdles stood in the way of transferring Lean production principles to the construction industry. The first hurdle was the difference between production and construction fields. Howell (1999) mentioned that the construction industry has rejected many ideas from manufacturing because of the belief that construction is different. Manufacturers make parts that go into products, but the design and construction of unique and complex projects in highly uncertain environments, which are carried out under great time and cost pressure, is fundamentally different from typical production. This difference made some researchers start comparing construction to production and listing the differences, others took some Lean production techniques and tools and started modifying them to be applicable in the construction field, while some started from the Lean production principles and tried to develop new techniques and tools for the construction field.

The second hurdle was the fact that the construction industry is famous for rejecting change and resisting alterations. This industry is known for having a strong tendency to follow the same well known procedures and steps throughout every project course. This second hurdle highlights the importance of relying on simulation whenever experimenting with newly suggested tools or techniques in the construction industry, as simulation enables building models for existing processes and experimenting and reviewing results and outputs of different scenarios before committing resources to modify an existing process. These two hurdles clearly point out the importance of using simulation whenever attempting to change the construction industry through applying Lean principles and techniques.

For many, Lean thinking and simulation are very closely linked or even identical. Processes can be efficiently modelled and analyzed from a practical perspective using simulation. Therefore, the concepts of Lean construction can be validated using simulation as means of testing Lean concepts prior to actual implementation (Halpin and Kueckmann, 2002). Many researchers utilised simulation to thoroughly assess the impact of applying Lean principles to construction related processes. However, examining the existing literature revealed that most researches were attracted to applying Lean principles to on-site processes where waste is more tangible and visible (Agbulos & AbouRizk, 2004, Al-Sudairi, Diekmann, & Songer, 1999, Velarde, Saloni, Dyk, & Gyuonta 2009). The design process is a complicated process with many interdependent complex processes. It is also applied differently by each firm. Moreover, it differs within each firm according to the types of projects currently at hand. A major step towards the success of this research was to manage to build a simplified model that can correctly depict the interconnectivity of processes and activities forming the design process. As many earlier trials addressed the application of Lean principles to the construction field. This research addresses using simulation to assess applying Lean principles to the design process.

The design phase is generally identified as the phase where the customer's ideas and speculations are conceptualized into a physical model by defining his needs and requirements into procedures, drawings, and technical specifications (Freire and Alarcón, 2002). Applying Lean principles to the design process was introduced by several researchers (Koskela, Ballard, & Tanhuanpaa, 1997; Chua and Tyagi, 2001; Melhado, 1998). However, such efforts are required to be broader to encompass more Lean principles. The main objective of this research is to build a computer simulation model to represent the design process in engineering consultancy firms handling different types of projects. The proposed model can be used to assess the benefits of applying Lean construction principles to the design process. Choosing the development of a simulation model for managing the design process brings a number of benefits for design organisations (Laguna & Marklund, 2005), such as:

1. The fact that a stable, consensual and explicit model of the design process exists, makes it easier to identify the necessary improvements e.g. simplification of the information flow, reduction of the number of steps etc.

2. All actors involved in the process are able to understand the process as a whole, their roles and responsibilities. This increases the process transparency and tends to improve communication between them.

3. It is possible to increase the effectiveness of the information flow, since the necessary information for performing each activity is formally established, as well as information

which must be produced by each activity. This tends to improve both the quality of design and creates the possibility of reducing the duration of the design stage.

4. It becomes easier to devise and implement tools for measuring and controlling product and process performance.

5. An effective feedback to the process is facilitated, since the design tasks are monitored and registered in a systematic form, including those design related tasks which are performed during the production and building operations stages. The data collected during those two stages can be used for feedback and knowledge management of future projects and the firm's strategic planning process.

RESEARCH METHODOLOGY

Simulation and process modelling are key tools for optimizing the performance of any process. The steps of developing the proposed simulation model are:

- Determining the goals of the model: The goals of the model were defined as producing an accurate representation of how the design process is carried out in a consultancy firm. This model will be used for introducing certain modifications to assess the benefits of applying Lean principles to the design process.

- Understanding the process to be modeled through the use of basic analysis and design tools, such as flowcharting: The process modeled was fully analyzed by obtaining detailed charts showing how the design process is carried out at a consultancy firm. These charts were used to develop the flowcharts which reflected how the design process flows, and how its activities are sequenced.

- Building a block diagram using appropriate tools from available libraries in simulation software to present each element of the model accurately. The model was built using software called ‘Extend V.6’, which is a tool applied to model design and analyze business processes. It can also be used to model and simulate discrete events or continuous systems in a wide variety of settings ranging from production processes to population growth models.

- Specifying appropriate parameter values for each block: The appropriate parameters were reasonably estimated to logically complete the model. However exact numbers will be needed for each firm according its unique size and pattern to personalize the model to match the firm’s exact behavior, as done in the case study to follow.

- Defining the logic of the model and the appropriate connections between blocks: The logic of the model and the appropriate connections between blocks were determined according to the logic of the design process and the flowcharts developed earlier.

- Validating the model: Validating the model was performed through a case study included with its results and analysis.

- Analyzing the output data and drawing conclusions: The output of the model was obtained using output and plotting blocks included in the 'Extend' simulation software, and the data was analyzed as will be explained later.

This simulation model was the second of the two main tools used in this research; the first tool was the flowchart, which represents graphically the design process, including the division of the process into sub-processes, making explicit precedence relationships. There is a general flowchart representing the different design phases and how phases are sequenced in relation to each other. Then a separate more detailed flowchart is developed to demonstrate the activities included in this phase and the inter-relationships between these activities for each phase as described in the section below. This form of representation gives a broad view of the design process, making it possible to plan the design process at a relatively fine level of detail.

CLASSES AND PHASES OF DESIGN PROCESS

When trying to build a comprehensive simulation model that can be used to model any design process as accurately as possible, it was necessary to look at the process differently. It was found impractical to unify all types of projects under one path that they all follow in the same way throughout the design process; a classification was needed to differentiate between types of projects and how each of them is handled within the design department. Projects were divided into three main classes namely *Public*, *Industrial*, and *Residential* projects. *Public* projects are big scale projects that are designed to serve a large population. These projects usually consist of more than just a building, they are essentially a group of buildings and the needed infrastructure to serve these buildings. Typical public projects are universities, clubs, compounds, small towns and large scale infrastructure facilities. *Industrial* projects comprise factories, warehouses and other industrial facilities. These types of projects usually have greater focus on the functionality of the buildings, rather than how it looks. It typically requires buildings with bigger spans, higher roofs and special electro-mechanical requirements. Finally, *residential* projects are the most common type of projects which are built for housing purposes. They range from studios and small apartments, to villas, few story buildings, high rise buildings and small compounds. They are of smaller scale than public projects, and they do not usually have the complications of industrial projects. The best practices of design processes in Egypt have been followed to produce the holistic flowchart that captures the design process. It was taken into consideration that the model comprises all possible aspects of the completed design process. The three phases are project initiation, core design and finalising and closing of the project.

Project Initiation Phase

The simulation model begins with the project initiation phase, during which the client places an order by expressing his/her requirements and setting the guidelines for the design to start. Then, the design divisions start producing the preliminary project design forming different alternatives for the client. Later, one of these alternatives is approved, this forms a draft that different divisions will base their design upon to guarantee the project will remain within the client's expectations till the end. The modelling of project initiation cycle is illustrated in Figure 1. This phase begins with an *Import* block, resembling the launch of the project. The *Import* block produces items based on the time interval between arrivals of items; its menu contains many time distributions to represent different behaviours. For the target of presenting a realistic model, a uniform distribution was selected. In this distribution, all the integers between the minimum and maximum are equally likely to occur. The next block is the *Merge* block which receives items from up to three sources and merges them into a single stream.

The items remain individual and unique: they are not joined or batched together to form a single item that are just funneled from multiple flows into one flow. The block following the *Merge* block is the *Stack* block which takes in items and holds them until they are requested by other blocks in the model. This block is needed before each operation block, because items might arrive at a faster rate than the rate at which they pass through the operation itself, so they need to be stored somewhere. The *Operation* block comes next and is used to represent an activity, process, action, delay, transformation and so on, within a model.

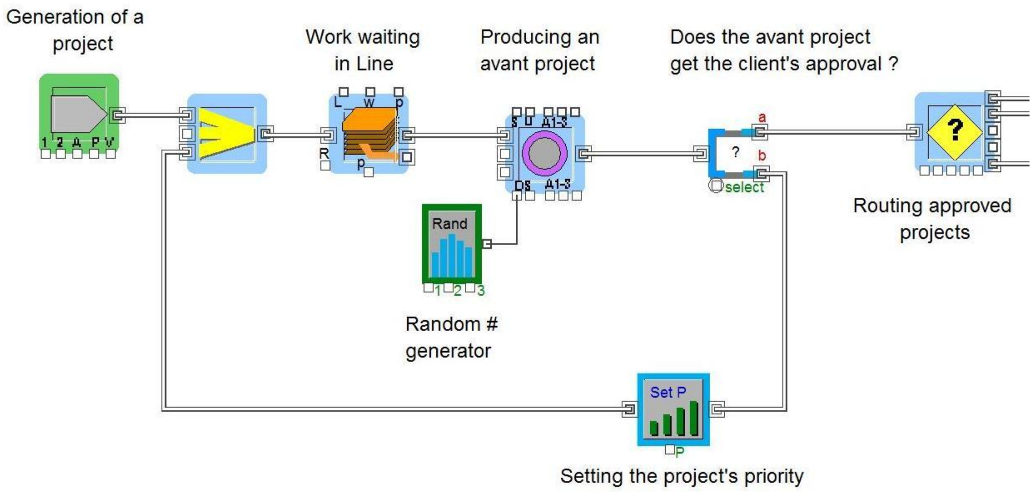

Figure 1: Modelling the project initiation phase using 'Extend V.6'

The operation block takes 'N' items from up to three input streams, holds them for a specified period of time and releases only one output item. This block represents the production of the Avant project, and departments presenting a primary report. To set the processing time, an input random number block is needed. It generates random integers or real numbers based on the selected distribution. It allows using the dialog or the three inputs, one, two and three to specify arguments for the distributions. The distribution used is the 'Real and Uniform' distribution. After the Avant project is ready, it is presented for the client for his approval. This step is modelled using a *Select DE Output* block. This block selects the input item to be the output at one of two output connectors based on a decision. This is done by having one out of every specified number of items go to the top connector or a random probability for each item to go to the top connector. This probability should be set according to what usually happens for each type of project, for each organisation. The projects that get approval are forwarded to the *Decision* block, which routes each type of project to one of the three design paths according to its type, as a different path is built for each type of project. The projects that do not get approval are sent to the *Set Priority* block, which assigns a priority to items that pass through. The priority of the items is increased, so that when they return to the design process they are processed first and do not have to wait in queue.

Core Design Phase

This phase starts after the preliminary project design gets the client's approval to proceed. This is the part of the design process where the project is delegated to different divisions where each division works on developing a full design package for the project. The duration of the design tasks differs according to the type of project. This is why the design phase has three different paths according to the three types of projects identified earlier. The first path is for the public projects type. In public projects, the architectural design begins first, and when it reaches 60% completion, the rest of the divisions begin their designs simultaneously while the architectural division completes its design. The modelling of core design phase cycle is illustrated in Figure 2. In industrial projects, which have the structural division involved during the whole duration, the electromechanical (HVAC) and architectural divisions work for shorter times. All divisions usually work simultaneously. In residential projects type, like the industrial projects type, all divisions work consecutively. The architectural division is the main performer, and the structural and electromechanical divisions need less time to complete their design packages.

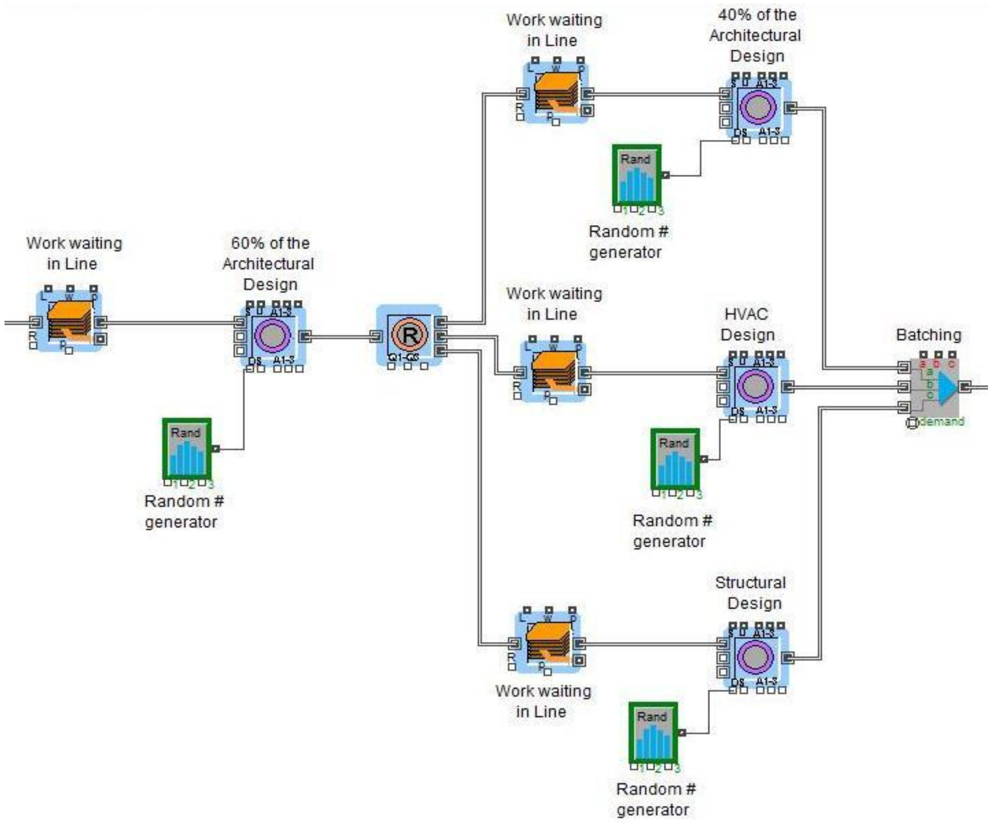

Figure 2: Modelling the core design phase using 'Extend V.6'

The part of the model representing the core design phase described above starts with a *Reverse Operation* block which sends three copies of the project to the main design divisions. Each of the main divisions is modelled by a *Stack* block and followed by an *Operation* block representing the *Stack* actual design of the three main divisions (architectural, structural and electromechanical), and a *Random Number Generator* block to set the processing time for the *operation* block. For the three main design divisions the processing time has been set using real, uniform distributions. After all the departments are through with their designs, they meet again at the *Batching* block, which is used to allow items from several sources to be joined as a single item, representing a complete design package for a certain project. This block ensures all divisions have finished their design package before the project moves to the next phase.

Finalising and Closing Phase

The final and remaining phase of the design process is the *Finalising and Closing* phase of the project. This phase starts when all divisions complete their designs for the project. This phase comprises the coordination, where different design packages are gathered from different divisions and revised mutually and checked for any conflicts or divergence. When the design packages from different divisions are found to be finally compatible, the project documents are produced. This documentation is the final activity of the final phase of the design process. The modelling of project finalisation and closing phase cycle is illustrated in Figure 3. The part of the model representing the finalisation phase begins with a *Merge* block, to merge projects coming from different streams into a single stream. Then the projects pass through to coordination, where all drawings for a certain project are revised together to assess whether there is any conflict or divergence between different drawings. The coordination activity is modelled by an *Operation* block preceded by a *Stack* block, and connected to a *Random Number Generator* to set the needed coordination time.

The *Select DE Output* block is used to model whether the coordination activity finds all drawings having conflicts or they are compatible. This block bases a decision on probabilistic distribution. In case conflict is found between drawings they pass to a different route, where their priority is increased using a *Set Priority* block, then they are routed to their design division according to the project type using a *Decision 5E* block. When they return to the design phase, they are processed directly without having to wait in queue as their priority is now increased, and then they re-enter the coordination phase again. If all drawings are found to be in conformance with each other, they pass to the documentation activity which is modelled using also an *Operation* block preceded by a *Stack* block, and connected to a *Random Number Generator* to set the needed documentation time, which is set to use real, uniform distributions ranging from one to two weeks. After the documentation, the projects are exported to an *Export* block as a complete documented design package.

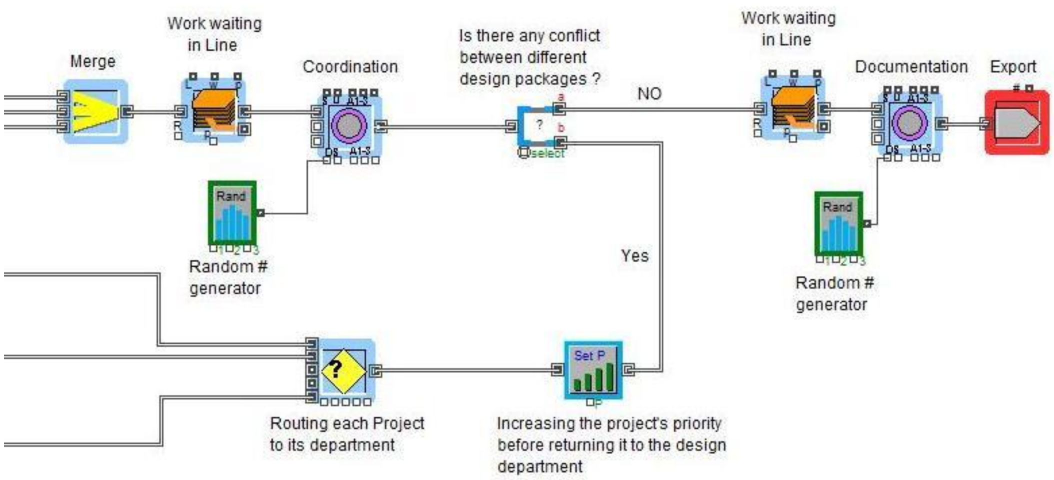

Figure 3: Modelling the finalisation and closing phase using 'Extend V.6'

USING SIMULATION TO MODEL LEAN IN DESIGN PROCESS

Through using the built simulation model, the five Lean principles are applied in the design process to eliminate all sources of waste. The five Lean principles are: specifying value, identifying value stream, achieving flow, achieving pull, and achieving perfection. Each of these five principles are studied one at a time throughout the three phases of the design process (project initiation, core design, and finalisation and closing) to assess the effect of applying Lean principles.

Specifying Value

Lean thinking consequently starts with a conscious attempt to precisely define value in terms of specific products with specific capabilities offered at specific prices through a dialogue with specific customers. Clearly the delivery team members (Architects, Engineers and Contractors) have values as well, but they are concerned with delivering the best value to their client, otherwise the client will look elsewhere. For converting the value identification and generation into practical actions to be integrated into the design process, Emmit, Sander, & Christoffersen (2005) suggested a four stage workshop procedure, which helps to identify value for a project and is shown in Figure 4.

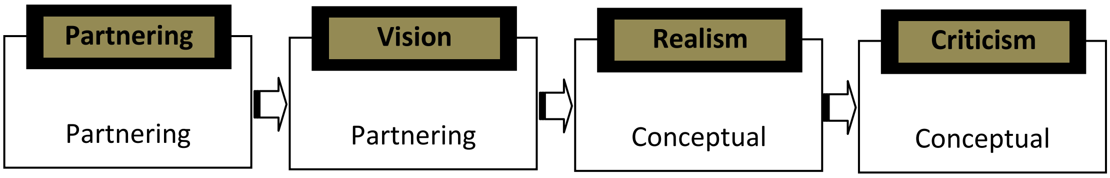

Figure 4: Value identification workshops

To assess the impact of holding these workshops at the beginning of the design process, these workshops needed to be represented in the built simulation model. An exploration into this application suggests a longer time needed for preparing the Avant project, as attending these workshops will take time, especially at the earlier trials. On the other side, a more accurate identification of value at such an early stage is bound to significantly shorten the chances of producing an Avant project that does not match the client's need. This is represented in the built model by adding an *Operation* block to represent the workshops duration and changing the design durations based on the improvements expected to accompany holding the suggested workshops, as the workshops help identify, communicate and deliver greater value from the client's perspective. Figure 5 shows the project initiation phase after adding the workshops stage.

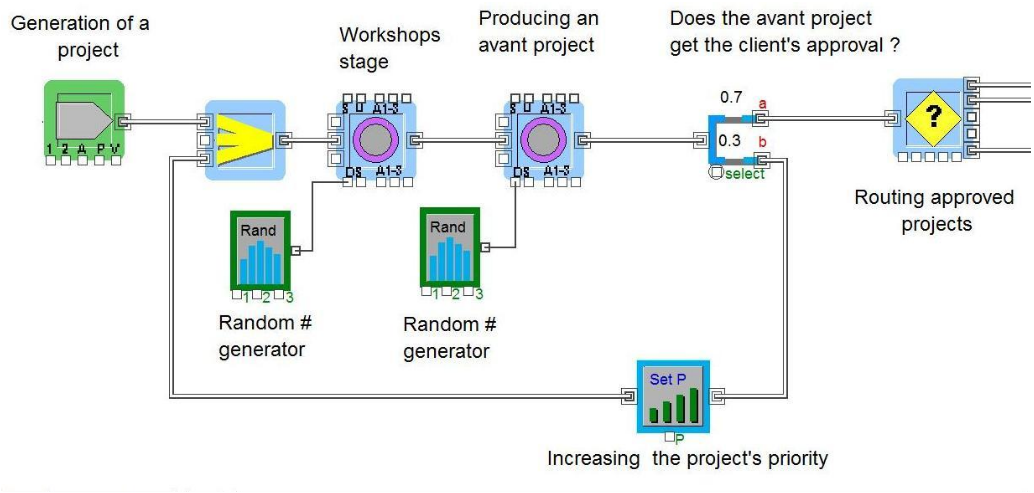

Figure 5: Project initiation including workshops

Identifying Value Stream

This is the second of the five Lean principles that needs to be applied to the design process. The value stream is the set of all specific actions that are required to bring a specific product or service to a client. Value stream analyses always show that three types of actions are occurring along the value stream (Womack and Jones 1996):

- Type 1: Many steps will be found to be clearly creating value.
- Type 2: Some other steps will be found to create no value, but to be unavoidable with current technologies and production knowledge.
- Type 3: Some additional steps will be found to create no value, and to be immediately avoidable.

After all activities in a process are classified according to the three classes listed above, the third action is removed to clear the way to work on the remaining non-value-adding steps through the use of the flow, pull and perfection techniques described later. This step is represented in the built simulation model by completely removing the *Operation* blocks representing the non-value adding activities, and making provisions for the accompanying changes. The activities involved in the design process are listed in Table 1 along with their respective classifications. It is clear that *Type 3* activities do not produce any value to the client but they are rather present according to the way the current design process exists. These are considered to be redundant to the value stream that produce value to the client.

Table 1: Types of design process activities

Type 1	• Receiving clients' requests and producing Avant project proposals • Actual design tasks for different divisions for different projects types • Documentation
Type 2	• Getting client's approval for proposed Avant project • Coordinating different divisions' design packages and checking for contradictions
Type 3	• Modifying proposals to match the clients' requests • Returning to design to resolve contradictions

Achieving Flow

After removing the non-value adding activities from the stream responsible for delivering value to the client, the remaining value adding activities are treated by making the value creation steps forming the value stream flow without interruption. For information and data handling activities, like in the design process (where physical material is not commonly exchanged or produced in considerable volumes), it is rare that there is a single type of flow, as it is the case in traditional production environment.

In the case of information, one of the critical elements in achieving 'flow' is certainly the development of an integrated information system infrastructure where data exchange occurs automatically and in real-time. It is also important to minimize the duplication of information, the volume of out-of-date or unnecessary information and the duplication of effort within the organisation, across departments, clients and suppliers. Hicks (2007) identified several barriers to data and information flow that influences design processes. Removing these barriers leads to smoother and faster flow, which consequently results in faster delivery of the correctly specified value to the client. The four main barriers to data and information flow are:

1. Information that cannot flow because it has not been generated, a process is broken, or a critical process is unavailable.
2. Information is unable to flow because it cannot be identified and flow activated or shared processes are incompatible.
3. Excessive information is generated and maintained or excessive information flows, and as a consequence, the most appropriate and accurate information cannot be easily identified.
4. Inaccurate information flows resulting in inappropriate downstream activities, corrective action or verification.

These four types of flow barriers can be eliminated by producing a detailed map of the design process that shows the value stream that delivers the value to the client. The value stream includes all value-adding activities, with their locations and sequence in the process, and how each of these activities is linked together along with their respective inputs and outputs. As such, eliminating excess data and producing only the necessary data are achieved (i.e. eliminating the *flow demand* and *flow excess*).

Applying Pull

The *Applying Pull* concept means that no activity should produce a good or a service until the next customer downstream asks for it. *Pushing* leads to spending money on material until they become semi-processed products, then you continue spending money for storing these semi-processed products until a downstream activity is ready to work on them. Clearly this should work the other way around. When it comes to applying *pull* to the design process, this is done by scheduling the whole process backwards, starting with the required delivery date as the end date. This will result in upstream activities being scheduled to release work only when downstream activities are ready, thus eliminating intermediate inventories. This is represented in the built simulation model by removing the *Stack* block before each *Operation* block. These blocks are presented in the model before each activity to temporarily hold any work that flows in while the activity block is already processing another job. As the main goal of *pull* is to remove intermediate inventory stations, these stack blocks are removed. Removing those *Stack* blocks allows work to flow downstream only when the next activity to follow is ready and not busy. The influence of removing the intermediate *Stack* blocks will move backwards, until the upstream activities are working only according to the succeeding downstream activities conditions, instead of continuously pushing work and forcing work into the intermediate *Stock* blocks.

Achieving Perfection

Organisations begin to accurately specify value, identify the entire value stream, make the specific steps for creating and delivering value flow continuously and let customers and clients pull the exact value they need only when they need it. However, it is an endless process for involved parties to reduce efforts, time, space, cost, mistakes and all sources of waste, while continuing to offer clients what they want exactly. It is realized that the four initial principles interact with each other continuously in a cycle. Enabling value to flow faster always reveals hidden waste in the value stream. This is attributed to the fact that more *pull* reveals more obstacles to flow so they can be removed. Teams in direct contact with the client are continuously discovering new ways to specify value more accurately. Moreover, although eliminating waste sometimes requires new process technologies and new product concepts, the technologies and concepts are usually surprisingly simple and ready for implementation. This makes it clear that making a process Lean is not a change that can be implemented in a certain period and then let the process continue running, it is rather a continues effort to keep pursuing a process that excludes waste of any form completely. It is argued that the most important drive to perfection is transparency, the fact that in a Lean organisation everyone can see everything, which makes it easy to discover better ways to create value. This perfection is pursued by continuously applying and reapplying the first four Lean principles (*specifying value*, *identifying value stream*, *achieving flow*, and *applying pull*), while keeping an open eye for new operating technologies that help take further steps towards becoming Lean. This principle of Lean cannot be represented in the model, but it can be a base for continuous refinement of the model.

CASE STUDY

The case study shows in detail how the built simulation model of the design process is used to evaluate the impact of applying Lean principles to the design process, by running it once to model the current process at a firm (a renowned engineering consultancy firm in Egypt) and measure its performance the way it is currently carried out, and then run it again after introducing the Lean principles to the model. By comparing the output of the two runs the changes brought by applying Lean principles is measured. This firm handles the bigger scale of all three types of projects (public, industrial and residential). A detailed description of the case can be found elsewhere (Bakry, 2010).

After entering the initial data to the model, it was run for 200 projects, which is long enough to guarantee that the model reaches a steady state. The 200 projects were completed over duration of 727.2 months. The output of the model indicated the total and average utilization of activities are 6.4939 and 0.4309, respectively. After entering lean data, the model is run for the same number of projects. The results are obtained and compared to the original run made earlier. This time the duration needed for completing the 200 projects was 676.9 months, and the total and average utilization of activities are 7.5158 and 0.5116, respectively.

The comparison of the two models reflects how using the simulation tool highlighted the higher performance of the Lean model, as it showed the Lean model had higher total and average activity utilization.

CONCLUSIONS

This paper showed how computer simulation can be used as a tool for assessing the impact of applying Lean principles to the design process in construction consultancy firms. The design process was divided into three main consecutive phases including project initiation, core design, and finalising and closing phase. A generic simulation model was designed to represent the design process, which can be utilised by consultancy firms with different sizes to closely represent their design process. Different blocks and various functions of the used software were utilised to depict the different components of the design process and their interconnectivity. Subsequently, the model was optimized to take into consideration Lean principles in the design process including: *specifying value*, *identifying value stream*, *achieving flow*, *applying pull* and *achieving perfection.* A comprehensive explanation of the impact of these principles on the design phase was presented. A case study was conducted to evaluate the impacts of applying Lean principles to the design process by running the model in two scenarios, which were the traditional design process and after introducing Lean principles). Further lean concepts including matching workload and process capacity, minimising input variations, and increasing transparency could be investigated in future research efforts.

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